UNIVERSITY OF
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Research and Design of an Embedded Controller and GUI for the Automation of the Armature Volt-Drop Test

Sunveer Matadin

2009

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Sunveer Matadin

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Abstract

In a rapidly evolving technological and industrialised society, automation is a current and growing trend. The concept is typically applied to uneconomical processes and extends from the automation of highly complex processes to those that are less complex. This dissertation discusses the automation of a previously mundane, manual, time-consuming and inefficient task using an embedded controller with dual enhanced microcontrollers as its core. Spoornet recognised the need to automate this and other processes hence a drive was initiated by Spoornet's Engineering and Technology department into the study of automation principles and techniques that can be used as a basis for the automation of workshops and test centers. This research stems from the above mentioned drive.

The Volt-Drop Test was the process that was used as a model to investigate the considerations, boundaries, design concepts and the hardware and software development that is inherent in the automation of a process. The design of the controller that facilitates the automation of the Volt-Drop Test was completed after research into embedded systems, embedded microcontrollers, programming languages and techniques, digital electronics, analogue electronics, digital system design concepts and techniques, analogue system design concepts and techniques, and the latest available electronic components.

A Graphic User Interface (GUI) was developed to interface with the controller to set up test parameters, display the present test status, perform calculations on the data received from the controller and display faults in the armature under test. Further, the GUI has the functionality to save all test data in a predefined and secure location to be retrieved and viewed as historical data or used for trending. A Remote Graphic User Interface (RGUI) was also developed. This interface is used solely to view test data (retrieved from the saved history files), from any geographic location provided that the user has been granted access to the secure location in which this data is saved.

In the testing phase, all tests were carried out using high quality, high accuracy and recently calibrated instrumentation. The test results obtained largely reflected what was expected from the system when compared to simulations that were carried out on the controller and the GUI during their development. With regard to the automation process, the system follows the procedure as it was designed with respect to correct switching sequences, response to system errors, timing of events and correct and efficient communication between the controller and the GUI. In terms of the data acquisition aspects the system captures, converts, calculates, analyses and logs data, within the expected input range with a level of accuracy that is considered to be high (a maximum percentage error of 0.75% - expressed as a percentage of the injected test supply) for this type of application when compared to the accuracy of present test methods.

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Chapter 1

Introduction

1.1 General Background

Automation [1], [6] in the industrial arena was the evolutionary step from mechanisation. Mechanisation sought to use machinery to accomplish physical tasks that were previously undertaken by humans or animals, through the use of mechanical engineering concepts in order to complete tasks in a shorter timeframe and with less effort. The machinery was still fully controlled by humans that were required to use their senses to monitor, their brain to compute progress, decisions, outcomes or assessments and their limbs (actuated by muscles), voice or physical actions to provide an appropriate output.

Automation involves the use of sensors/transducers, controllers and actuators to control a machine carrying out a task or a process consisting of multiple operating machines. Sensors [1], [7], [8] are used to sense the value/condition/progress/status of a parameter or task in the real world. They convert real world parameter values for temperature, pressure etc. to electrical signals. Controllers read these electrical signals and convert them to meaningful values that are used as variables in the controller logic to determine an appropriate output. If a physical output is required, the controller may itself or via the use of sub-controllers control actuators [1], [7], [8] that perform the real-world action required. Tasks within a process can be precisely controlled as there can be constant communication between controllers or process coordination via a master controller (master) to which individual task controllers (slaves) report.

From a controller perspective, the automation of industrial processes and machinery (leading into the realm of robotics) can be accomplished using the wealth of controllers and controller architectures available off the shelf, and by the design of embedded controllers which are used for dedicated or specialised applications. An automation project begins with the study of an existing process or machine. If the process or machine is not in existence then a theoretical or academic analysis of the process is undertaken to determine how the process can be best automated and what machinery is required to carry out the task or tasks. As part of the machine or process design the inputs to the system needs to be determined. This leads to the choice of the appropriate transducer to convert the real world parameter values to electrical signals e.g. distance, temperature, pressure, acceleration, speed, flow rate etc. Also part of the machine or process design is the identification of the required outputs from the system.

Actuators are chosen based on what the machine or process is required to physically control or output. Actuators convert the electrical signals from the control system to real world physical outputs. Audio, visual, data etc. may also be required as outputs. These are implemented using audio system, display units and communication modules/ports/buses. The automated machine may be a standalone device or part of a process or network. If the latter is true then communication between devices is critical. The communication protocol is dependant on the choice of the control device, i.e. PLC [1], [6], [8] embedded controller or industrialised mother board. Also to be determined is whether a human-machine interface (HMI) or graphic user interface (GUI) is required.

Some tasks or processes may require an output or end result with no need for human intervention. In this instance, all that is required from the controller is data or physical real world outputs. Where human intervention is required, a HMI or GUI will give the operator control of the machine or process when required. As important is the HMI or GUI which provides insight into the status of the tasks presently undertaken as well as graphically displaying required data. The choice of HMI or GUI is also dependant on the choice of controller. For example where PLCs are used, Supervisory Control and Data Acquisition (SCADA) [6] software (e.g. Wonderware) is most commonly used. In the case of embedded controllers and industrialised mother boards, HMIs or GUIs can be developed in Visual Basic [3], [4], C Sharp etc.

PLCs have proven to be the most popular controller choice for industrial automation. They are considered as a generic solution for automation tasks that do not require specialised processing and control. Single, standalone PLCs can be used for the control of a machine or multiple networked PLCs, distributed throughout a plant, can control multi-loop processes aided by communication over Ethernet and using protocols such as Modbus, Profibus etc. System architecture may vary from central control where a single PLC controls multiple remote Input/Output (I/O) modules, to a distributed system architecture where PLCs are networked and communicate with each other or via a master controller that coordinates tasks and the flow of data. In the first instance, the PLC is the core of the system and performs all the processing (logic and mathematical operations) and issuing of instructions. The PLC communicates with remote I/Os to acquire data or instruct an output. The processing capability of an I/O module is determined by the application. In the case of a distributed architecture each PLC is assigned the control of a task, machine, or component. Data is transmitted between PLCs or to a master PLC. The HMI resides on a host PC or microprocessor based display unit that communicates with the master PLC via the serial port, Ethernet etc. This system is defined as a SCADA system and its configuration is similar in functionality and architecture to a formally defined Distributed Control System (DCS) [6].

A DCS is typically a large control system that consists of a number of distributed microprocessor/microcontroller based controllers situated near or on the device it controls. I/O devices can be directly coupled to the controller or they can be located remotely and connected to the controller via the chosen industrial network. Also integral in a DCS are PCs or microprocessor based display units that run HMIs etc. All these subcomponents are supplied by single vendor that custom designs and configures a complete system for the process(s) to be controlled. This differs from a SCADA system where controllers, I/O devices, HMI software, display units etc. may all be off the shelf and originate from different vendors. In the past, SCADA systems were considered to be supervisory in nature with its primary function being data acquisition and display, and to provide the primary control system with calculated parameter values. DCS were considered as the primary control system. With the introduction of PLCs and the advanced communication technologies now used in SCADA systems, the line between DCS and SCADA systems have been blurred.

A PLC can be programmed in five programming languages as defined by IEC 61131-3. These are: Ladder Logic (LD) [8], Structured Text (ST), Instruction List (IL), Functional Block Diagram (FBD) and Sequential Function Chart (SFC). With the evolution of PLCs came the evolution of HMIs. SCADA software has proven to be the most popular. Tags or points are assigned to each input or output controlled by the PLC. The SCADA software interface addresses tags or points when data has to be read from an input or an output has to be controlled. Points are referred to either as “hard” or “soft” with “hard” referring to actual data and “soft” referring to values that are the result of mathematic or logic expressions using “hard” point values. All data can be displayed numerically or graphically using the SCADA HMI graphic building blocks to represent components, equipment or processes. Data can also be stored in a data base for historical trending or auditing. Alarms and warnings can be defined to alert the operator of undesirable or dangerous conditions so that the operator can take the appropriate action using the interface to control the outputs of the PLC.

Embedded controllers are designed for specialised needs that are dedicated to specific tasks where generic PLCs may offer inferior performance. Microcontrollers [9] or Digital Signal Processors are usually the core of an embedded system with interfacing circuitry comprising digital and analogue electronic subsystems that condition signals to the input of the core and provide outputs from the core to the outside world. In most instances the core is a self contained device comprising of all the modules that are found on a standard PC. Microcontrollers for example contain a central processing unit (CPU), input/outputs ports, onboard Flash memory, RAM and communication ports (serial, USB, Ethernet). On specialised microcontrollers, analogue to digital converters (ADCs), comparators, PWM generators etc. can be found. Microcontrollers are manufactured by a number of companies each with various families that range from 4-bit to 64-bit and are chosen based on the processing power required. Microcontrollers are programmed in Assembler, C etc. using development environments that are provided by the manufacturer of the device e.g. Atmel, Microchip etc. or by developers that specialise in developing embedded development tools e.g. Keil C, Acebus [2] etc. The code that resides on an embedded controller is referred to as firmware.

Embedded controllers may operate in isolation as in the case of a dedicated controller for a machine or component or as part of a DCS. In the case of DCSs, each embedded system is a dedicated controller and communication between controllers via Ethernet, serial port, CAN bus etc. can be accomplished using protocols such as Controller

Area Network (CAN) [13], [14], [15], [16], etc. Systems communicate with each other or via a master controller (master) with slave controllers (slaves) reporting to and taking instructions from the master. The degree of pre-processing and control by slaves vary based on the system needs. This will impact on the choice of slave processor. In the CAN architecture, CAN transceivers embedded on each controller are responsible for communication via the CAN bus. A CAN master controls the flow of data on the CAN bus as well as providing data to a host PC which interprets, processors, stores or displays the data on a HMI or GUI. The HMI resides on the PC and communication with the CAN master is via the serial port, Ethernet etc. Due to the flexibility inherent in the design of an embedded controller (cost factor aside) controllers can be designed for various operating conditions, tasks, inputs, outputs and processing requirements.

A step taken to make embedded controller design more accessible to programmers as opposed to specialised engineering disciplines was the introduction of the industrialised mother board. This motherboard is essentially a standard PC motherboard that has been designed to operate in harsh environments, i.e. extreme temperatures, EMI [5] conditions etc. Boards vary depending on the type of processor, memory, input/output ports etc. that are required. Processors only differ from standard PC processors with regard to temperature specification due to the environments in which they operate. Any standard operating system (OS) can be loaded onto these processors, however for efficiency and improved processing speeds embedded OSs such as Embedded Windows XP are used with only the drivers required for the incorporated peripherals installed. Touch screens and LCDs that display the HMI or GUI are easily incorporated. HMIs and GUI can be written in almost any language for execution on the controller. The industrialised motherboard controller interfaces with off the shelf I/Os, specialised designed I/Os and other controllers via the onboard communication ports, hence they can operate within a network or as a standalone controller.

Controllers are most widely used for the execution of predefined tasks and error handling procedures based on predefined conditions or events. This is accomplished by hard coding logical steps or mathematical algorithms that provide outputs based on the inputs received. Decisions are presented as a choice of possible hard coded outcomes. Using this methodology or approach, every possible outcome, event or occurrence must be known before coding can begin. This approach works very well when a complete system analysis has been carried out and every possibility or occurrence in the system is taken into account. In systems where every possible event or outcome is not known or where the system is expected to adapt or "learn" from basic building blocks in the decision making process, or make decisions that do not exist as hard coded instructions, Artificial Intelligence (AI) [10], [11], principals are introduced to bridge the divide. Concepts such as Fuzzy Logic [8], [10], [11], Neural Networks [10], [11], etc. are applied to make decisions based on inputs that are not discrete or expected or use past "experiences" that are based on human experience or historical data and outcomes acquired by the controller. In the realm of automation AI is most prevalent in robotics with AI concepts being applied to motion control, balance, sight based on image recognition and image processing etc. With the growth in processing power in most controllers, AI will become a more prevalent feature as knowledge and trust in the field grows.

1.2 Overview

Given the advancement of technology, the need be efficient in order to drive financial gains and the need to be competitive, Spoornet acknowledged the necessity to streamline their processes and methods of operation in order to improve their efficiency, reduce cost and increase profit. One way of achieving this is through the automation of processes that require skilled staff to perform simple and time consuming tasks. The objective of this research project was to design an embedded controller and GUI that will automate the Volt-Drop Test process.

The successful design principles, techniques and findings from this research and design process will be used to automate other such tests and processes in workshops and test centers. The reason for the design approach as opposed to the purchasing of controllers is based on Spoornet having a wealth of recourses in terms of equipment, facilities, funding and engineers, all of which have been used successfully to design, build and install embedded systems onboard locomotives. It was therefore a natural extension to use these resources to design controllers to automate processes in workshops and test centers.

This research and design was undertaken according to the mandate given by Spoornet to design an embedded controller and GUI for the automation of the Volt-Drop test. All software and firmware development is entirely the original work of the author. Where mathematic equations were encoded to form the computation algorithms for the GUI, the sources were quoted. The sources are purely mathematic books, which only provided equations, the coding of the equation as a function in the GUI was the work of the author. The circuit design is also entirely the original work of the author, except for the standard circuitry that is stipulated by the manufacturer for the setting up of the 555 Timer, the AT89S51, the MAX 701, the MAX 4622, the MAX 232 and the MAX 1166. This standard circuitry includes quartz crystals, capacitors and resistors that are stipulated by the component manufacturer in the component datasheet for the correct operation of the component.

In certain instances the suggested values were changed to suit the application for which the component was used. Other than the standard manufacturer component set-up circuitry, all designs, component choices and calculations were undertaken by the author. This includes all circuit designs, schematic designs, component choices, PCB layout and design, protection circuitry that was required, EMI protection and software and firmware development. This work is also based on the experience that the author has gained during the design of controllers which operate on locomotives, especially in highly electrically noisy environments. One such design was that of a Weak-field controller for a pneumatic Weak-field switch array on the 6E class of electric locomotives.

Given the mandate, the first phase of the research into embedded controllers and embedded system design involved research into microcontrollers. Once the basic principals were understood, more complex concepts such as Interrupts and Interrupt Service Routines, as well as Serial Communications were tackled, as these are key features that the controller would require for effective operation. The next phase in this project involved devising a practical concept for the automation of the Volt-Drop Test. From this phase, the author was able to decipher the number and types of transducers that would be required to monitor the system and provide the relevant feedback, as well as gauge the number and types of outputs that would be required by the Drives and Drivers of the associated actuators (off-the-shelf Drives are used for motor control and off-the-shelf Drivers are used for IGBT switching). With knowledge of the number of inputs and outputs that the embedded system would require, as well as the expected input and required output, electrical signals that would enter and leave the system, an interfacing Digital and Analogue System was designed. These networks form the interface between the signals being received from sensors and transmitted to Drives and Drivers, and the microcontroller core.

The digital system involves level shifting, signal conditioning and logic manipulations. Also part of the digital system is the Analogue to Digital Converter (ADC) [8]. The ADC is controlled by the Communications Microcontroller, which also reads the data made available on ADC's eight-bit parallel output bus. The ADC's analogue input is the last stage in an analogue network that is responsible for the rejection of any signals that are out of the ADC Analogue input range. Considerable time was also spent in researching components such as ADCs, instrumentation amplifiers, semiconductor based analogue switches, optical sensors, proximity switches, motor drives, IGBT drivers etc.

The development of the GUI was carried out in parallel to the design of the controller. For the GUI development, the principals and techniques of object orientated programming had to be understood before the interface was designed and coded. A critical aspect during this phase was the establishment of a serial communication link between the GUI and the controller. During development however, the controller was not available to test the GUI's response to prompts and data transmitted from the controller. It was for this reason that a simulation interface was designed to mimic data that was transmitted by the controller.

Using the simulator, the author was able to monitor the GUI's response to prompts and ascertain the accuracy of the calculations carried out by the GUI. The GUI was not only designed as an interface to the automated system. Along with data analysis, test results are automatically saved in files that bear the same name as the serial number of the armature under test in a predefined destination that is specified using the GUI. This is done in order to create a test history of each armature tested. At the end of a test, the user also has the option of printing an official test report that reflects the name of the user, the type of armature under test, the date of the test, armature winding faults that were logged during the test, as well as an undertaking, that has to be signed by the user, to remedy these faults.

Once the two entities, these being the controller and the GUI, were fully developed, additional features were integrated into the system before the testing phase of this project began. Two of these features ensure a greater level of accuracy during data acquisition and analysis. The first is the ability of the system to capture one hundred consecutive readings on a single pair of bars and record these readings on an Excel spreadsheet, which is also automatically saved along with the Fault Logged results. Presently, the average of the one hundred readings is used in calculations and is displayed on the GUI. However, any other filtering or statistical methods algorithm can replace the averaging algorithm in order to group the most relevant readings, and use an average of those grouped readings in the calculation algorithm.

The second feature is the addition of a calibration screen. At this point, the calibration screen is used by the administrator to capture readings and compare them to injected values, thus aiding the administrator to "tune" the controller in order to gain more accurate values. It is however envisaged that this calibration screen will in the near future be used to apply software calibration techniques in order to calibrate the system.

Tests were carried out on the controller to verify that the physical automation process operated as was required and designed to operate. Data accuracy and computation algorithms that formed the basis of the GUI were also tested.

The reader will be lead from the present Volt-Drop Test process to the overall design concept of the automated process and then to the more specific machine, software and electronic hardware design concepts. This finally leads to the discussion on the actual hardware, software and machine design that encompassed the specific considerations and factors that needed to be taken into account in order to implement the project practically. Each phase is discussed with reference to technical explanations, reasoning and decisions so that the reader may follow the entire design process from conceptualisation to testing.

This chapter illustrates the process to be automated. The theory of the Volt-Drop Test is briefly discussed along with the present test processes and the shortcomings thereof.

1.3 Background of the Volt-Drop test

The Volt-Drop test is carried out on armatures in order to test the integrity of the windings. This test is conducted on locomotive traction motors that have failed during operation and have been brought in for repairs. The Volt-Drop test is one of the first tests conducted after the motor has been stripped and cleaned. This test is also conducted prior to the armature being passed for assembly into the traction motor. The stator of the traction motor undergoes a different test and repair procedure.

The Volt-Drop test is a simple yet effective test. The effectiveness of the test however, depends on the accuracy of the test equipment. Very basically, the test entails the injection of a high current, via probes, to the commutator of the armature under test. The volt-drop across each pair of bars, hence across the winding that the bars are connected to, is measured and is compared to a reference value. The reference value is usually the volt-drop measured across the first pair of bars that were tested. If this comparison depicts a large percentage variation from the reference reading, the armature winding that is connected to that pair of bars, is either damaged, open circuited or short circuited.

The distinction between these three conditions is made evident by the value of the reading acquired for that pair of bars. Short circuited windings will be reflected by a potential difference reading that is very nearly zero volts whilst open circuited windings will be reflected as a potential difference reading that is equal to the potential of the supply test current (+15VDC maximum). Damaged windings will be reflected as a percentage variance from the reference reading. Typically any variance larger than 5% is considered by depot engineers as a reflection of a damaged winding. One should however note that if there are constant faults being recorded for each pair of bars after the pair on which the reference reading was taken, it is highly probable that the winding on the reference pair of bars itself was damaged. In this case, a new reference reading is recorded on a different pair of bars. More detail into the present test process follows in the section below.

1.4 Present test program and short-comings

Presently, a trained technician carries out the volt-drop test. The author has observed two different test techniques at two test bays situated in different parts of the country. The first technique that was observed is as follows: The armature under test is placed on rollers and a test current of 350Amps (max), is available to the commutator of the armature under test, via two current probes mounted roughly 30° apart, on a semi-circular frame. This current is applied to the commutator when a footswitch is pressed. At this point the technician holds two probes, one on each consecutive bar, and measures the potential difference or volt-drop between them. The variance from the reference reading, which is usually the first reading, if large, reflects a short circuit, open circuit or a damaged armature winding. The test instrument that measures the volt-drop variation is zeroed on the first pair of bars.

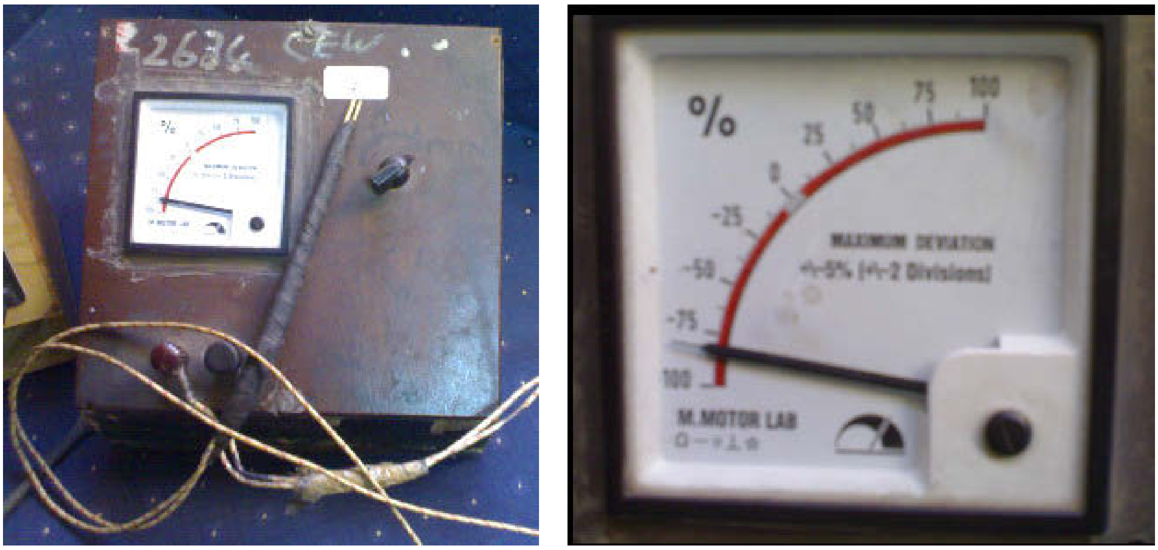


FIGURE 1-1: PRESENT TEST INSTRUMENT

This is now the reference value. On either side of the zero mark percentage variance markings are present. If the needle deflection on a pair of bars is within a chosen percentage variance, the pair is passed and the next pair is tested. If the needle deflection falls outside a chosen range that pair of bars is marked for further attention.

After the reading has been taken, the test current to the armature is switched of by releasing the footswitch, and the technician rotates the armature by hand to the next pair of consecutive bars. The process is then repeated until the voltage drops between all bars have been taken.

The second technique is similar to the first with the difference being that the test current probes are held onto an armature (also roughly 30° apart) by means of a weighted band. This is a non-conductive band that is 3cm wide with weights on either end. Once slung over the commutator the weights on the ends of the band allow for the current probes to be held firmly between the commutator and the band.

The current is switched on once and the readings are taken bar-to-bar using the same instrument mentioned above. The current is not switched off, the supply probes are simply moved from section to section until the entire commutator has been tested. This method is not recommended and is discouraged by company policies and safety regulations due to the possibility of electric shock if the supply current probes are not handled with care. The only reason the author can deduce for adopting this practice is that this method is considered easier to implement and is far less time consuming.

The figures that follow will give the reader a better understanding of the present test setup. Please note that the Commutator End Bearing and Front End Bearing are separate units which are fixed onto the armature shaft in order to enable rotation on the test stand. These bearings are not part of the armature and its motor assembly.

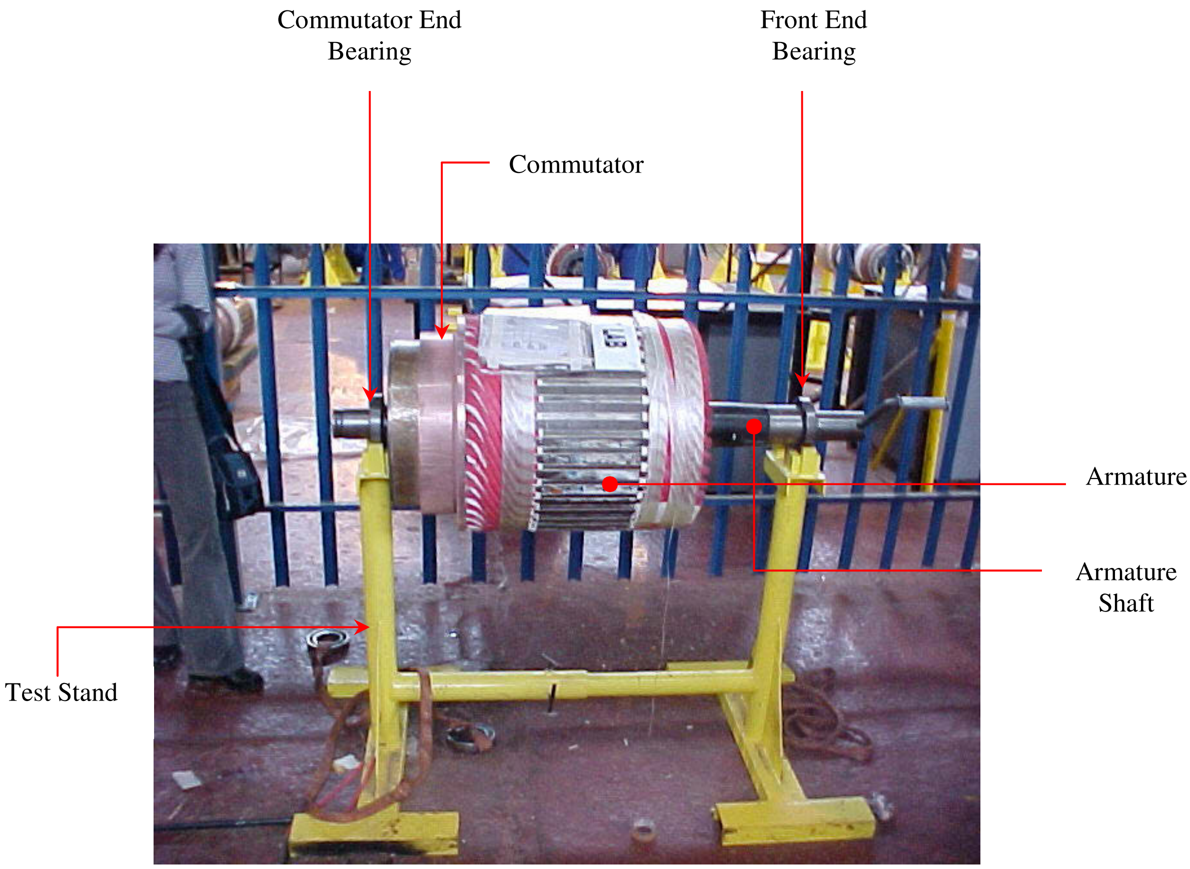


FIGURE 1-2: PRESENT TEST SET-UP

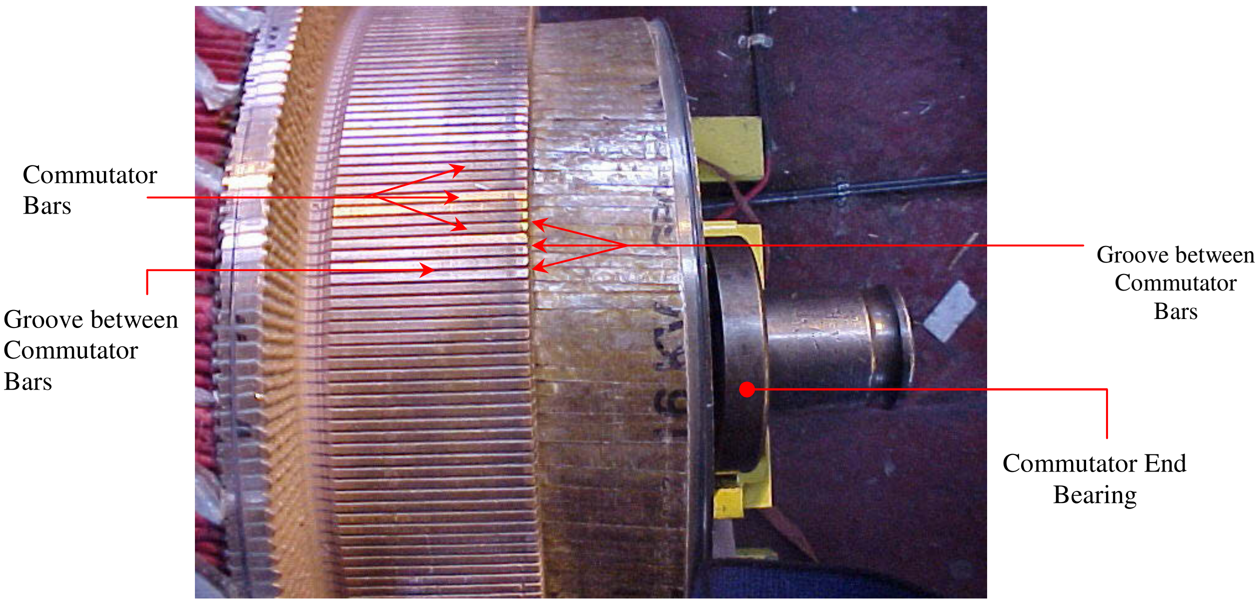


FIGURE 1-3: COMMUTATOR – TOP VIEW

In Figure 1-3, the reader will notice the distinct grooves between the commutator bars. This is due to a process called Undercutting. Not all commutators are undercut before the volt-drop test, some commutators are simply turned in a lathe leaving the Epoxy Resin between the commutator bars. This makes no difference to the actual test however it is an important issue that has to be considered when choosing a sensor to detect the bars.

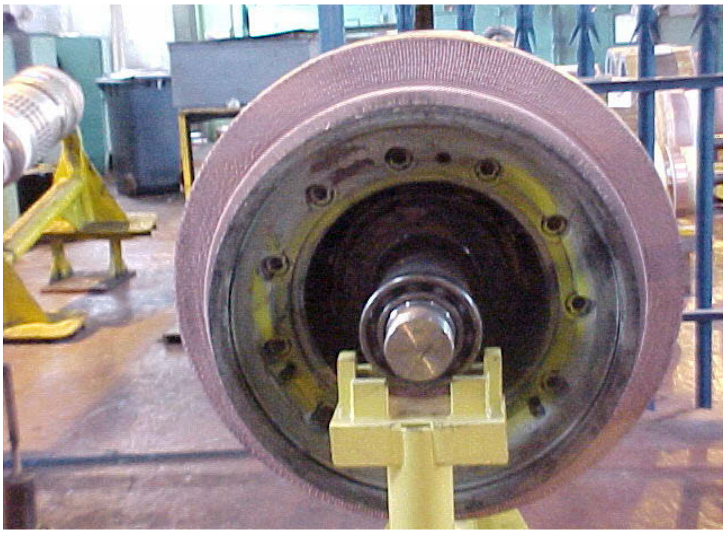


FIGURE 1-4: COMMUTATOR – FRONT VIEW

The shortcomings of these test methods become apparent when one considers the fact that some faults on the windings pass through undetected. There are two reasons for this. The first relating to the accuracy of the test instrument being used and the other is the manner in which the test is carried out by the technician. Due to a lack of test evidence, the tests are sometimes conducted in a haphazard manner. A further shortcoming of the present test is that there is no record created, soft or hard copy. A test history can therefore not be created. Further, this task is repetitive, uncomplicated, time consuming and leads to inefficient use of skilled staff.

Chapter 2

Project Concept and Overview

2.1 Design Objectives

The objective of the design of the controller for the Automated Volt-Drop Tester is twofold. The first aim is addressed by automating the test. This introduces cost effectiveness and reliability into the armature refurbishing process. The second aim is addressed through the capturing and storing of digital test data. Using this data, a history of an armature can be created and test technicians can be held accountable for overlooking the detected faults as the recorded test results, which reflects the name of the technician, serves as evidence. The overall accuracy of the system is also improved by the introduction of an electronic means of capturing volt-drop readings.

2.2 Project Scope

This project entailed the design of an Embedded Controller and a Graphic User Interface that controls the motion, inputs and outputs of a mechanical structure which enables the automation of a Volt-Drop Test as well as taking voltage readings that can be analysed, displayed and stored. The aforementioned controller consists of an embedded core i.e. a pair of microcontrollers, which analyse input data from the system and then prompts the appropriate output devices.

The interface between the system to be controlled and the embedded core is a digital system. This digital system was designed to condition signals before they are input to the microcontrollers. The digital system also provides the appropriate signals and voltage levels as inputs to drivers, drives and other output modules.
An analogue signal-conditioning module was also designed. The purpose of this module is to provide the input to the ADC with a volt-drop reading that is within its input range.
A Graphic User Interface (GUI) was designed to provide the controller with the required information, provide the user with a tool to monitor the system and test the

progress as well as a means to save data collected during tests. Visual Basic 6 was used to develop this GUI.

A Remote Graphic User Interface (RGUI) was also developed using Visual Basic 6. The RGUI is installed on the desktops and laptops of authorised persons based anywhere in the country with access to the network. The GUI updates and creates records on the network. The RGUI enables a remote user to view records from any network position at any time.

The aim of this project was not to “redesign the wheel”. Where components and modules are commercially available there is no need to design or develop them. These devices have been researched, designed, built and tested by leaders in the specific field. Their reliability has been proven in industry. It is therefore logical and cost-effective to incorporate these modules into the system as it will add to the reliability of the system and reduce cost as time and money would have to be invested in the research, design, building and testing of these modules.

The control of motors, in terms of speed and soft-starting, is not within the scope of this project and will be accomplished by drives that are readily available as off-the-shelf units. The design of drivers for IGBTs is also not within the scope of this project. IGBT drivers are commercially available and are recommended for, or matched with, specific IGBTs based on the device rating and application.

2.3 Design Concept

The design concept will be discussed under two more specific headings, namely, the Automation and Machine Design Concept and the Data Acquisition Concept.

2.3.1 Automation and Machine Design Concept

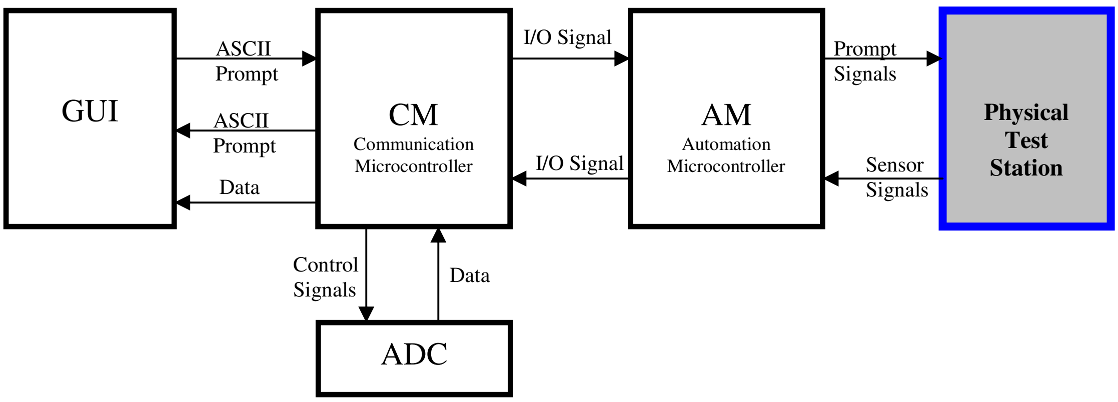


FIGURE 2-1: SYSTEM BLOCK DIAGRAM

In order to design an efficient machine and controller that carries out all the operations required to perform the test, time had to be spent in the test bay observing and conducting tests. It was noted that in terms of basic operation, the armature under test had to be rotated, the commutator bars had to be detected, the test probes had to be lowered and raised, the test current supply had to be switched and the reading analysed. For the design of the automated system, which includes the test machine (physical test station) and controller, each of these tasks had to be accomplished using transducers, actuators, electronic hardware systems or software.

In this system a PC or Laptop that interfaces with the controller runs software that provides a Graphic User Interface (GUI) to the system. The test and test machine can be controlled via the interface. The interface displays the test status, faults logged and system errors when they occur. The GUI also performs analysis and storage of data. Analysis and storage of data will be discussed under the heading Data Acquisition Concept. The figures that follow are aimed to aid the reader in the understanding of the mechanical design concept for the Physical Test Station. These figures do not reflect the final design as different, more economical and robust approaches were taken by the manufacturer, however, the concept remains the same. These are the original sketches that were presented to mechanical engineering companies in order to describe the system that was required.

The mechanical system is designed to operate as follows under the control of the embedded controller and GUI. A test has to be set-up by the test technician. The technician ensures that the armature to be tested is lowered into the correct position using an overhead crane. Once the armature is in position the test technician lowers the Test Current Probes onto the surface of the armature ensuring that the Test Current Probes are roughly 30° apart. See Figure 2-5 for a front view sketch of the Test Current Probes.

The Test Current Probes are the probes from which the Test Current is injected though the armature under test via an IGBT. The IGBT is used to switch the Test Current. The Test Current Probes are lowered onto the commutator and are fixed into place at the start of the test and are in no way attached to the Detection Unit. These probes are never raised off the surface of the commutator at any time during the test. Once the Test Current Probes are fixed into place, the technician must position the Detection Unit such that two consecutive bars are detected. See Figure 2-6C and Figure 2-6D. The detection of the bars on the commutator is accomplished through the use of an optical detection sensor unit.

The optical sensor operates on the principal of emission and reflection. A laser beam is emitted onto a surface by the unit and the reflection is detected by an optical sensor on the same unit. These optical sensors, together with the spring mounted test probes (see Figure 2-6A) form the Probe and Sensor Unit as shown in Figure 2-6B. The Detection Unit Head comprises of one fixed Probe and Sensor Unit and one sliding Probe and Sensor Unit as shown in Figure 2-6C. The Detection Unit is set up such that two consecutive bars are detected by lowering the unit to the surface of the bars, typically between 50mm and 70mm above the surface of the bars, and ensuring that the fixed Probe and Sensor Unit detects a bar. This is indicated by the green LED on the optical sensor switching on. This is a built-in feature on the optical unit. Once this occurs the sliding Probe and Sensor Unit is slid into position above the immediate next bar until the green LED on that optical sensor is also switched on. Once this has occurred the sliding Probe and Sensor Unit is fixed into position using the wing-nut as shown in Figure 2-6C and Figure 2-6D. The Detection Unit Head is then raised to its original position by the test technician.

Once the set-up has been completed the technician begins the test using the GUI. The armature under test is then rotated by the Armature Drive Motor via a gear drive system until the next pair of bars has been detected. See Figure 2-2. When a pair of bars has been detected, the Armature Drive Motor is stopped and the armature is locked into place using a solenoid in the gear drive unit. The signal to the solenoid driver that allows for the energising and de-energising of the solenoid is the same as the signal used to stop and start the Armature Drive Motor via the Armature Drive Motor drive. Note that this gear drive unit is to be designed by the mechanical engineering company that was awarded the tender to design the mechanical system.

Once the armature under test has been locked into place the test current is switched on via an IGBT and the Detection Unit Head is lowered onto the surface of the commutator bars via the Detection Unit Drive Motor and the Mechanical Linear Setup which incorporates a mechanical power thread/screw [13] system much like that used in a mechanical press as shown in Figure 2-3 and Figure 2-4. The Detection Unit Drive Motor rotates, lowering the Detection Unit Head until both the spring mounted Test Probes are on the surface of the bars with sufficient pressure. This is indicated by the mechanical switches that are “Made” when the test probes are on the bars. See Figure 2-6A. Once this is signaled, the Detection Unit Drive Motor is stopped and the Detection Unit Head is held in position by the mechanical power thread which is designed not to allow movement unless it is being rotated.

Test readings can now be taken on this pair of bars. Once the reading has been completed, as signaled by the GUI, the Detection Unit is raised by rotating the Detection Unit Drive Motor in the opposite direction. The Detection Unit is raised to its original position, which is signaled by the mechanical switches on the Mechanical Linear Setup as shown in Figure 2-3 and Figure 2-4, and the Test Current is switched off. This marks the end of one test cycle. To begin the next test cycle on the next pair of bars the controller waits for a prompt from the GUI. Upon receiving this prompt the solenoid in the gear drive unit is de-energised thus unlocking the armature under test and the armature is rotated by the Armature Drive Motor until the next pair of bars has been detected. This continues until the last pair of bars has been tested. Note that future references to the stopping of the Armature Drive Motor will imply both the signal to stop the Armature Drive Motor and the locking of the armature under test. Future references to the starting, prompting or rotating of the Armature Drive Motor will imply both the signal to start the Armature Drive Motor and the unlocking of the armature under test.

Initially mechanical switches were to be used on the Mechanical Linear Setup and on the spring mounted Test Probes to indicate position of the Detection Unit Head and the state of the Test Probes respectively. However, seeing as these applications entail a high number of repetitive on-off transitions when monitoring the position of the Test Probes and the initial position of the Detection Unit, the mechanical switches were replaced by non-contact inductive proximity switches. This was done because mechanical switches entail the physical "making" and "breaking" of metal alloy contacts and due to the high number of transitions, these contacts will wear after short periods thereby reducing the lifetime of the mechanical switch to much lower than that of non-contact switches. This is discussed further in Section 5.1.4 and Section 5.1.5. Due to the cost of the inductive proximity switches, one switch instead of the two depicted in Figure 2-3 is used to detect when the Detection Unit has returned to its initial position. Although the type of switch has been changed from those reflected in the sketches provided, the principle purpose and positioning of the switches remain the same.

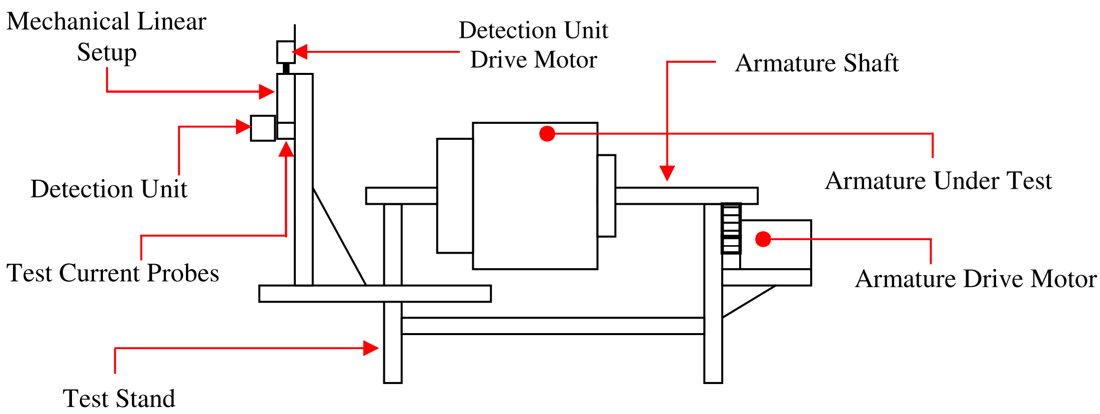


FIGURE 2-2: SKETCH OF TEST SETUP [LEFT VIEW]

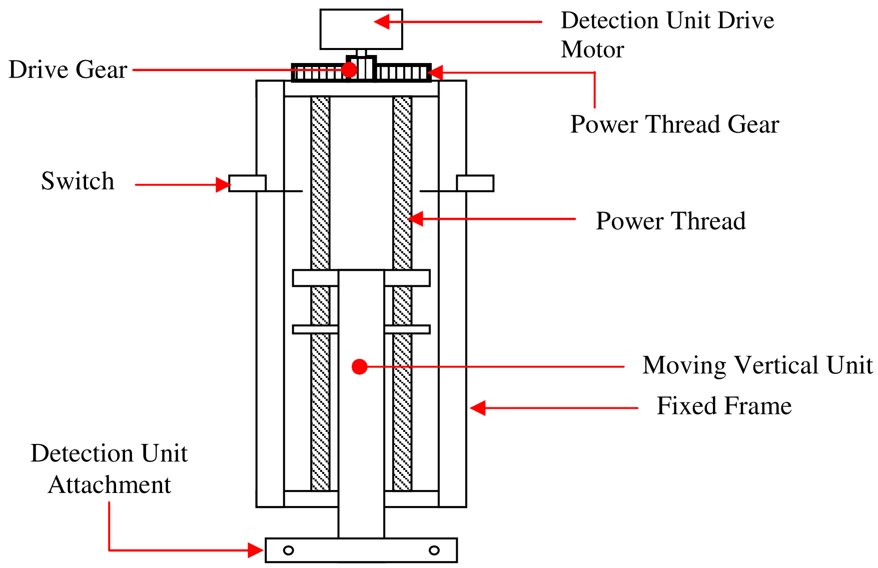


FIGURE 2-3: SKETCH OF MECHANICAL LINEAR SETUP [FRONT VIEW]

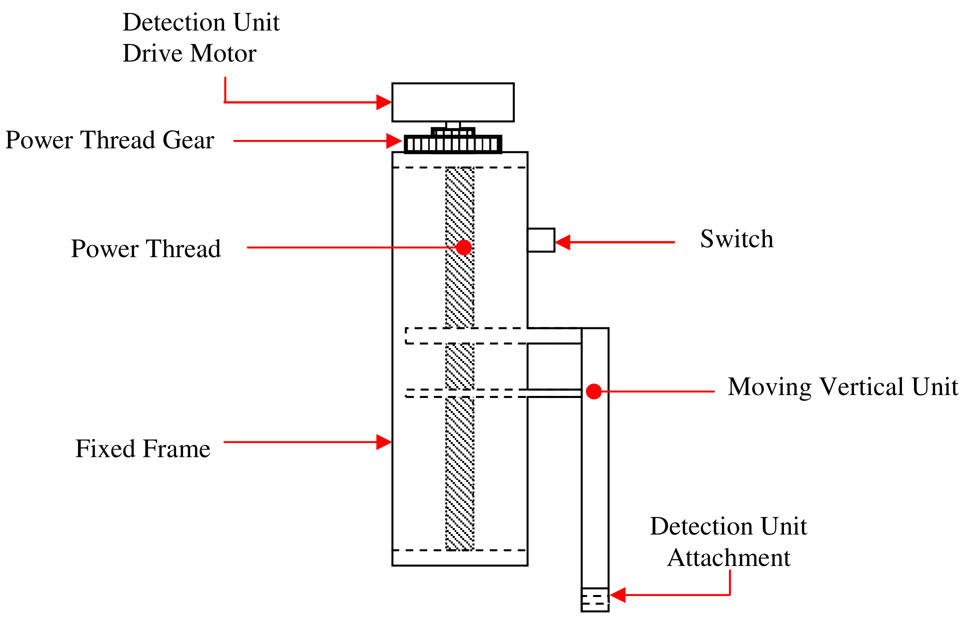


FIGURE 2-4: SKETCH OF MECHANICAL LINEAR SETUP [LEFT VIEW]

The switches shown in Figure 2-3 and Figure 2-4 indicate when the Detection Unit Head has been returned (is raised) to its original position. The switch shown in Figure 2-6A indicates when the Test Probes are resting on the pair of bars under test with adequate pressure as supplied by the compressed spring.

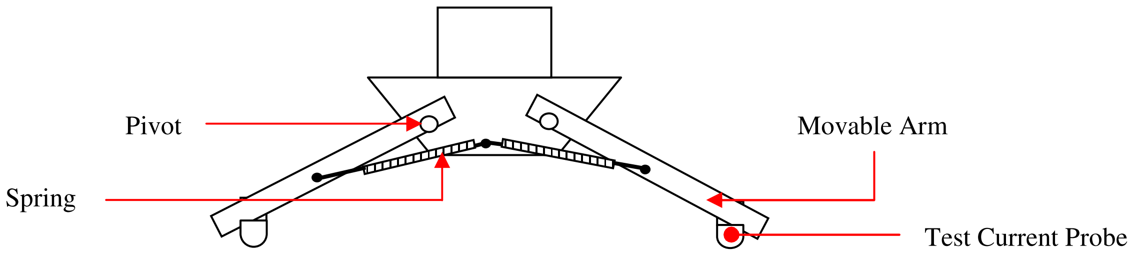


FIGURE 2-5: SKETCH OF TEST CURRENT PROBES [FRONT VIEW]

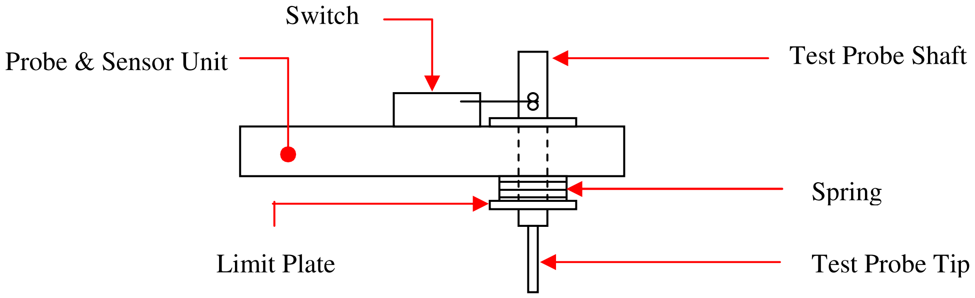


FIGURE 2-6A: SKETCH OF SPRING LOADED TEST PROBES [LEFT VIEW]

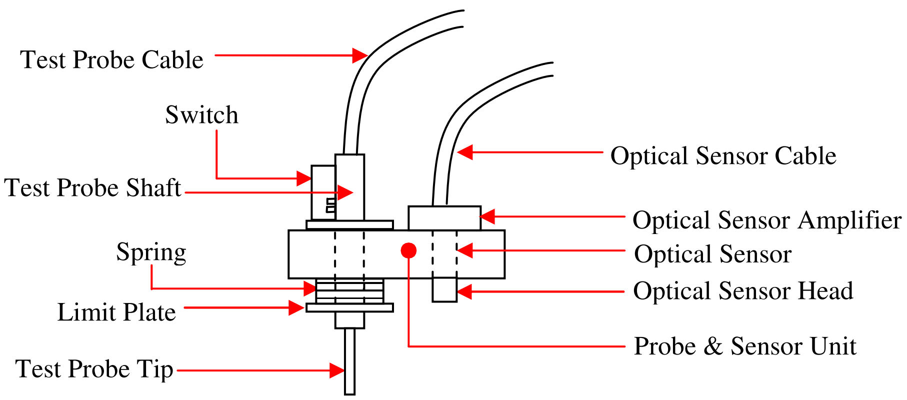


FIGURE 2-6B: SKETCH OF PROBE & SENSOR UNIT [FRONT VIEW]

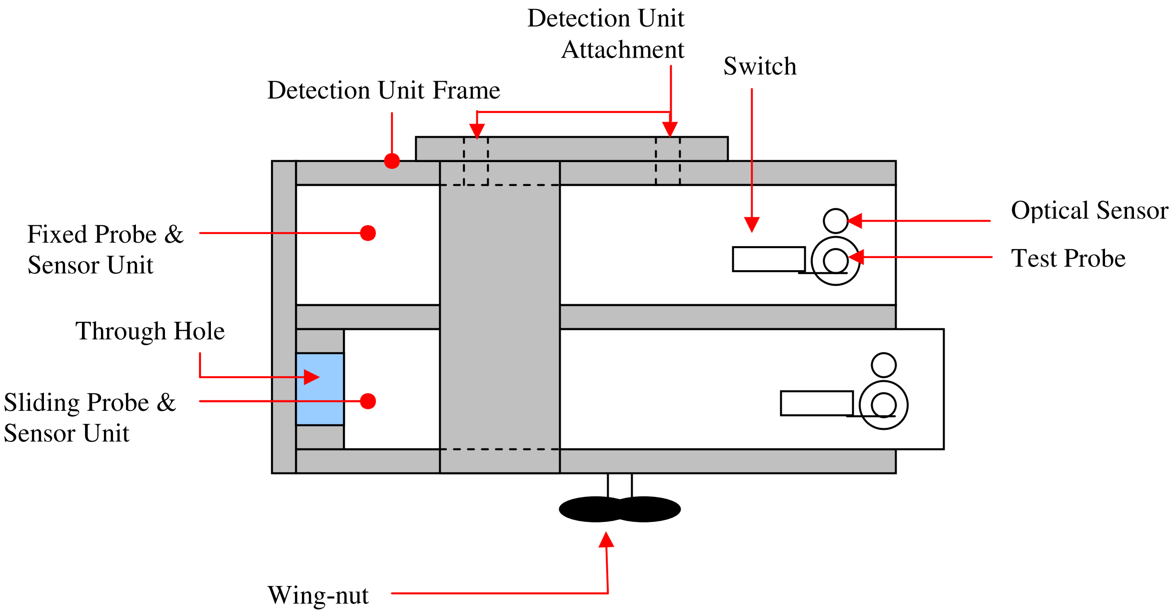


FIGURE 2-6C: SKETCH OF THE COMPLETE DETECTION UNIT HEAD [TOP VIEW]

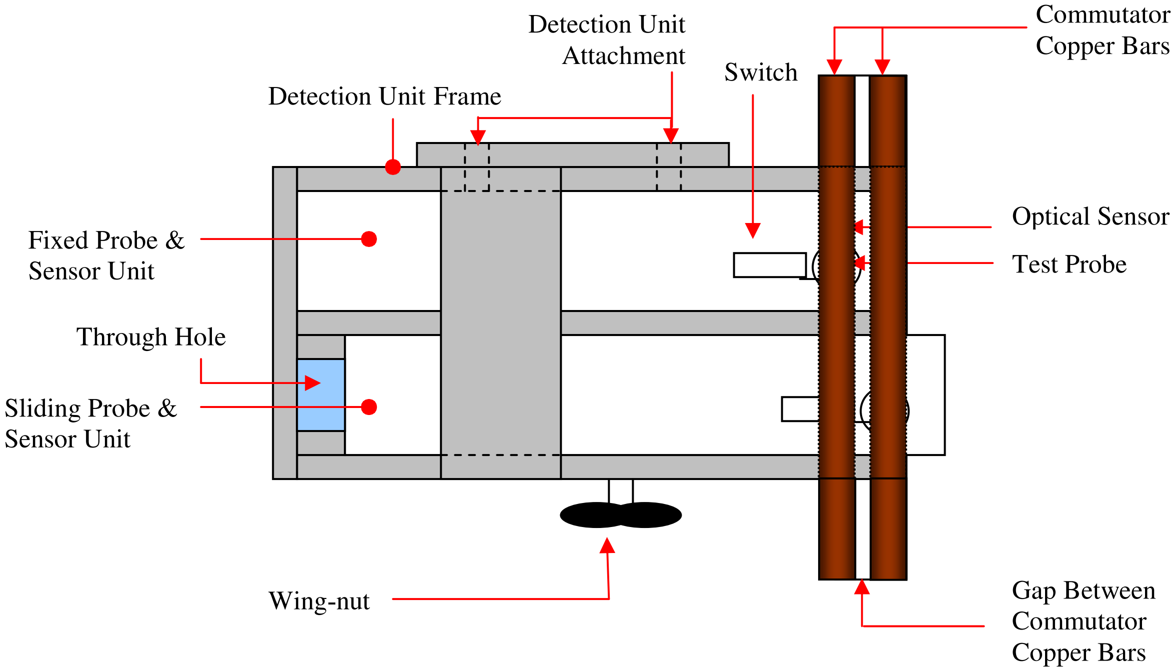


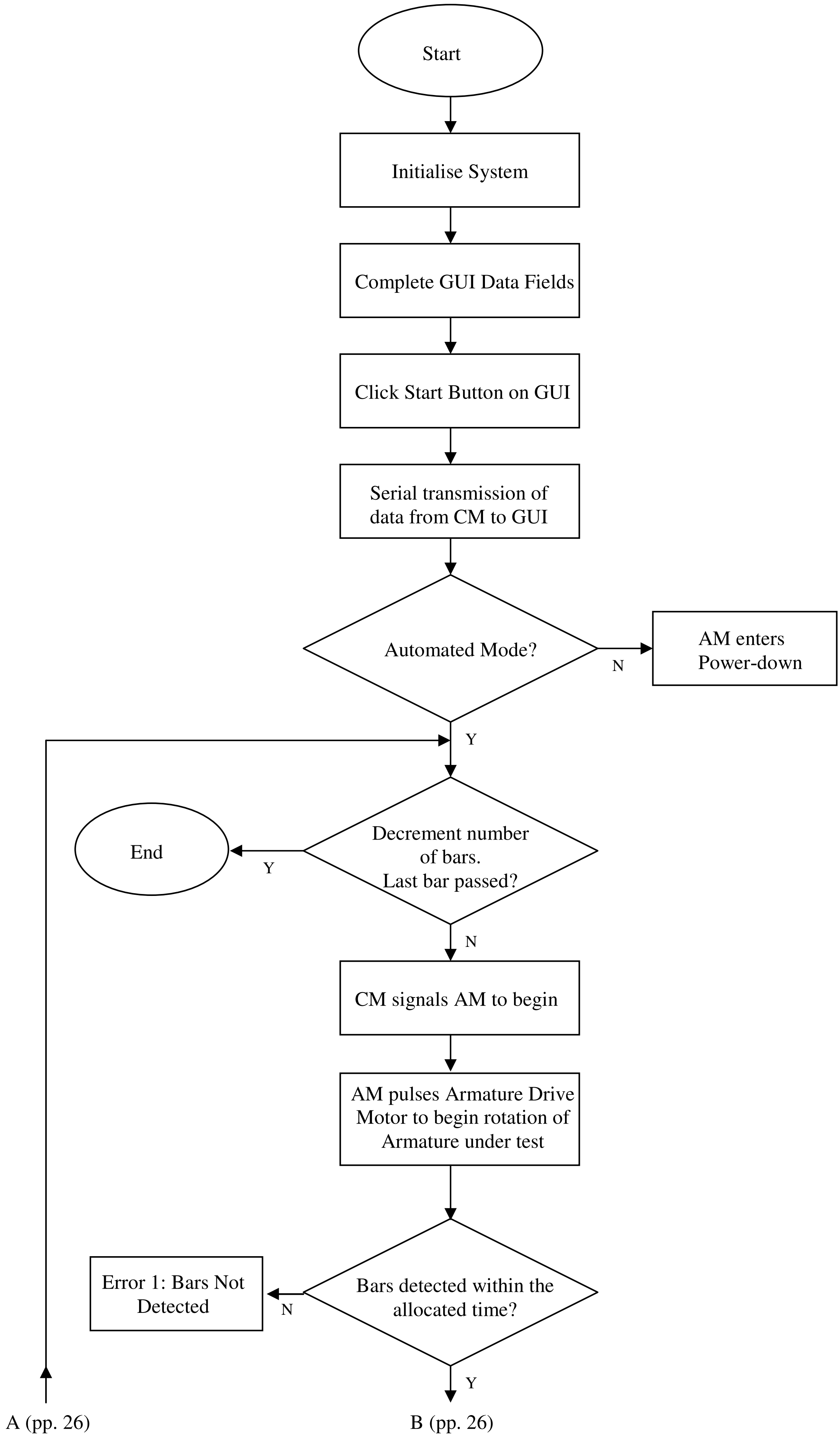
FIGURE 2-6D: SKETCH OF THE COMPLETE DETECTION UNIT HEAD (ABOVE A PAIR OF COPPER BARS) [TOP VIEW]

Given that this machine has to perform specific tasks at certain times, an algorithm was developed to facilitate smooth and accurate task execution. The said tasks are based on information received from three sources: the machine itself, the controller and the Graphic User Interface. In order to better understand the above-mentioned algorithm, the discussion that follows will describe the Graphic User Interface and controller and their roles in the system.

The controller core consists of a pair of embedded microcontrollers that interface with a digital system and an analogue system. Each of these two microcontrollers has a specific role. One microcontroller is tasked with the automation procedures and is aptly named the Automation Microcontroller (AM) whilst the other is tasked with data acquisition and communication with the GUI, and is called the Communications Microcontroller (CM). These two microcontrollers communicate with each other via a port-to-port parallel bus.

The CM communicates with the GUI via a serial link, where the UART of microcontroller is interfaced with the serial port of a PC or Laptop. The test technician completes the GUI data fields. Using this information, the GUI analyses the input data and calculates and displays the test status. The relevant information is then transmitted to the CM, which in turn communicates with the AM. Information is also transmitted in the opposite direction, from the AM to the CM to the GUI. The system is designed to operate in one of two modes: Automated or Manual.

In Automated mode, the mechanical system is controlled by the controller via the AM. In Manual mode, the automation functionality is disabled and the CM and GUI are used to capture, analyse and record readings. The operation of the GUI and the controller is discussed in detail in Chapters 3 and 4 respectively. Figure 2-7 presents the flow chart that describes the basic operation of the test machine.


Start
Initialise System
Complete GUI Data Fields
Click Start Button on GUI
Serial transmission of data from CM to GUI
Automated Mode?
N
AM enters Power-down
Y
End
Y
Decrement number of bars. Last bar passed?
N
CM signals AM to begin
AM pulses Armature Drive Motor to begin rotation of Armature under test
Error 1: Bars Not Detected
N
Bars detected within the allocated time?
Y
A (pp. 26)
B (pp. 26)

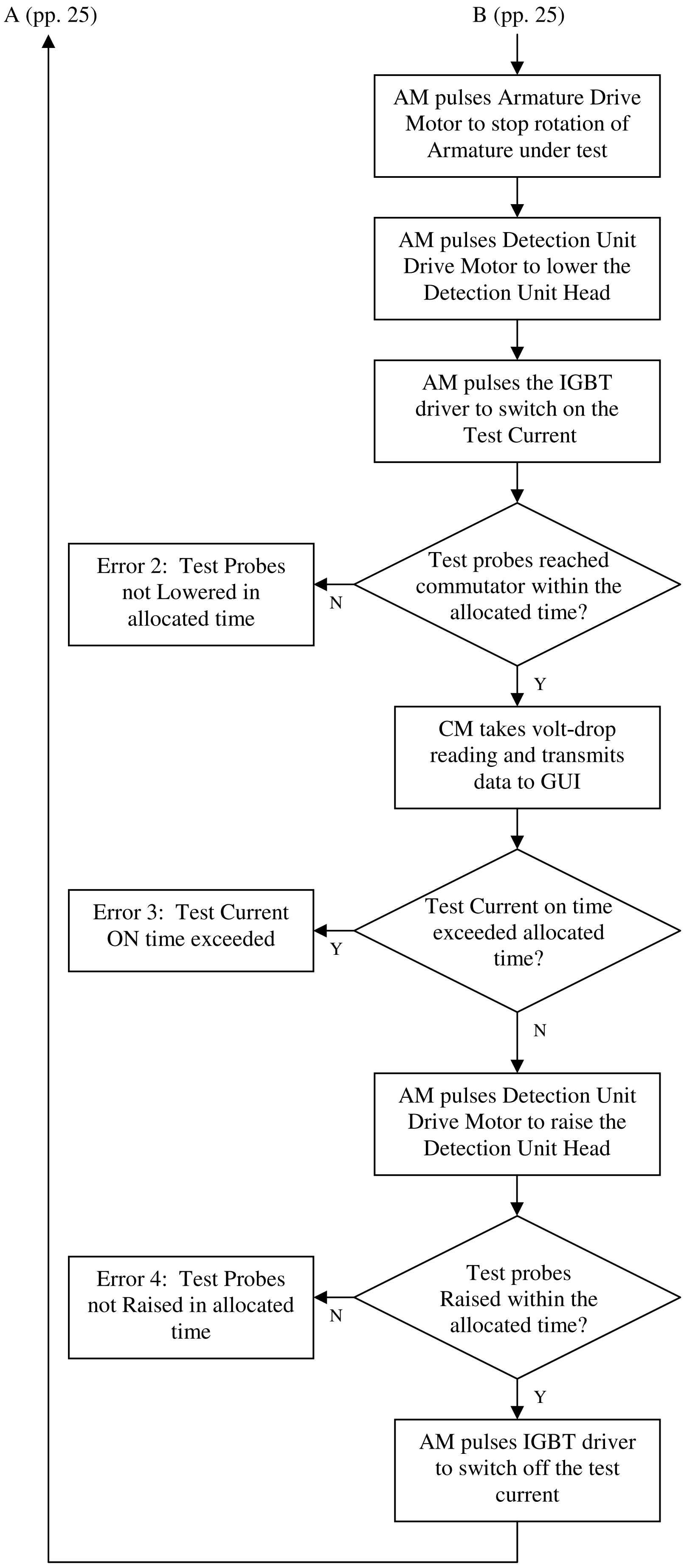


FIGURE 2-7: BASIC SYSTEM FLOW CHART

Errors 1, 2, 3 and 4 are the result of undesired events occurring in the system during operation. When any one of these errors occurs the AM enters the relevant subroutine and informs the CM which then also enters its relevant subroutine. The CM in turn informs the GUI of the error so that it is reflected on the interface.

Error1 occurs when a pair of bars is not detected by the optical sensors within a specified time. This time is calculated by recalling the time taken for the detection of the previous pair of bars and adding an additional twenty percent of this previously recorded time.

Error2 occurs when the test probes are not present on the surface of the commutator within a pre-selected default time. This occurs when the switches shown in Figure 2-6A and Figure 2-6B are not "made" within the default time.

Error3 occurs when the test current is not switched off before a pre-selected default time has expired. If the period of time measured from the instant that the microcontroller pulses the IGBT driver to switch on the Test Current, till the instant that the microcontroller pulses the IGBT driver to switch off the Test Current, is greater than the default time, Error3 will be signaled. This condition is monitored by the Test Current On-Time Timing Module which is discussed in Chapter 5.

Error4 occurs when the test probes are not raised to their original position within a specified time. This time is calculated by recalling the time taken to lower the test probes onto the surface of the commutator and adding an additional twenty percent of this previously recorded time. The switches shown in Figure 2-3 and Figure 2-4 indicate when the Detection Unit has returned (is raised) to its original position

2.3.2 Data Acquisition Concept

The input module that measures the volt-drop across each pair of bars is made up of three distinctive sub-modules. These are the Input Instrumentation Amplifier, Signal conditioning and the Analogue to Digital Conversion. The Analogue to Digital Converter that was chosen has a resolution of sixteen bits and an eight bit parallel output bus that interfaces with an eight bit input port on the CM. The sixteen-bit word is saved as two bytes (high byte and low byte) in allocated registers in the CM. These two bytes are then transmitted to the GUI where it is analysed. Analysis comprises the conversion of the received data into the correct data type and then using this value, the actual volt-drop reading is calculated. This calculated volt-drop reading is then compared to the reference value and if the variation is greater than the pre-selected percentage variance on the GUI, a fault is recorded. Based on the results of the analysis, the GUI either records the reading as a fault or signals the AM via the CM to continue to the next pair of bars. The GUI allows the user to set the following properties before a test can commence

- Select the type of armature to be tested
- The allowable percentage variance from the reference value and
- The destination on the hard drive, or network where the recorded data is to be saved.

The RGUI allows for authorised persons to view records from remote locations, provided that there is access to the network. The capturing of data and the analysis thereof is covered in detail in Chapters 3, 4 and 5.

2.4 System Advantages and Features

This system will address the problem of inaccurate readings and the lack of recorded data and armature test history. The fact that the system is automated allows for skilled staff to be deployed in critical areas while the tests are being conducted. Looking ahead, if multiple units are built and placed in test bays, more than one test can be carried out at the same time with one member of staff overseeing the entire process.

Below the reader will find a list of the system's main features.

- User name and password
- Administrator name and password
- Lockout
- Armature serial number (Job number)
- Time and date of test
- Duration of test
- Automated operation – Motion, bar detection, test current switching and data acquisition are governed by the controller
- Manual operation – Physical motion, bar detection and test current switching are controlled by the test technician. Data is acquired automatically when prompted by the test technician
- Error indication
- Printout of all recorded faults
- Addition of new armatures settings (only administrator)
- Addition of new percentage variance settings (only administrator)
- Set new destination for data files (only administrator)
- Emergency stop
- Test history for armatures (Save and View test files)
- Bar under test
- Number of bars remaining
- Number of faults logged
- Delete files (only administrator)
- Record reference value
- Data analysis and processing
- Fault display
- Test status
- Reference value reset
- Test status reset on reference value reset.
- Remote Graphic User Interface (RGUI) to view records from remote locations.
- Additional Features
  - The ability to automatically take repetitive readings on a single pair of bars

- Automatically record each reading and the average of all the readings for a pair of bars on an Excel Spreadsheet. Also automatically save Excel Spreadsheets at the end of tests.
- Calibration of the system using the GUI.
- Multiple, unique user names and passwords
- SuperUser name and password

Chapter 3

Graphic User Interface (GUI) Development

The GUI provides a means to control the automated machine as well as a means to capture, analyse and store data. See Appendix A for a screen capture of the GUI and Appendix C for the complete GUI source code. Also see Appendix P for a detailed discussion including flow diagrams and code extracts. In order to perform the above two functions, reliable communication between the GUI and the Controller is imperative. As previously mentioned, the GUI communicates directly with the Communication Microcontroller (CM) which then in turn communicates with the Automation Microcontroller (AM).

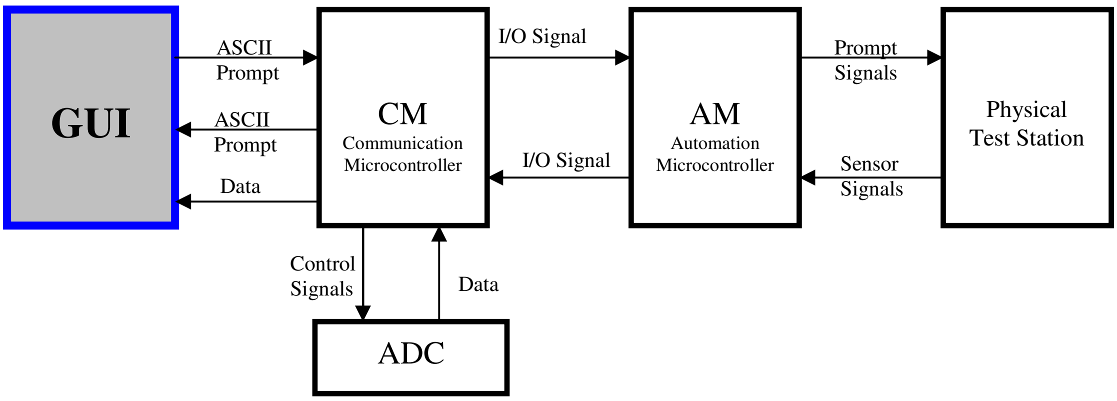


FIGURE 3-1: SYSTEM BLOCK DIAGRAM

In order to understand the function of the GUI, the communication between GUI and the CM has to first be discussed.

The GUI and the CM communicate serially using their respective serial ports which are setup to interact as required. In this chapter the author will discuss how data is processed from the point at which it is present in the GUI serial buffer and the prompts transmitted by the GUI to the controller, more specifically, the CM.

The interface between the GUI and the serial port (RS232) of a PC or Laptop using the Visual Basic 6 development environment is the MSComm component. Once enabled the properties of the MSComm component have to be set so that they mirror the settings for the CM serial port.

3.1 A walk through the GUI

The aim of this walk through is to lead the reader through the features, functions and code behind the Graphic User Interface. Screen captures will help the reader to understand how the GUI responds to user prompts and data that is received. See Appendix A for a true representation of the GUI and Appendix O for a GUI PowerPoint Presentation. The GUI is divided into two separate parts, one being the Test Setup Fields and the other being the Test In Progress Fields. Each of these will be discussed individually in the sections that follow.

3.1.1 Test Setup Fields

3.1.1.1 User Identification Frame

The input fields in this section are used to setup the system for the specific armature that is to be tested. The User Identification frame is the location in which the details of the staff member performing the test are entered.

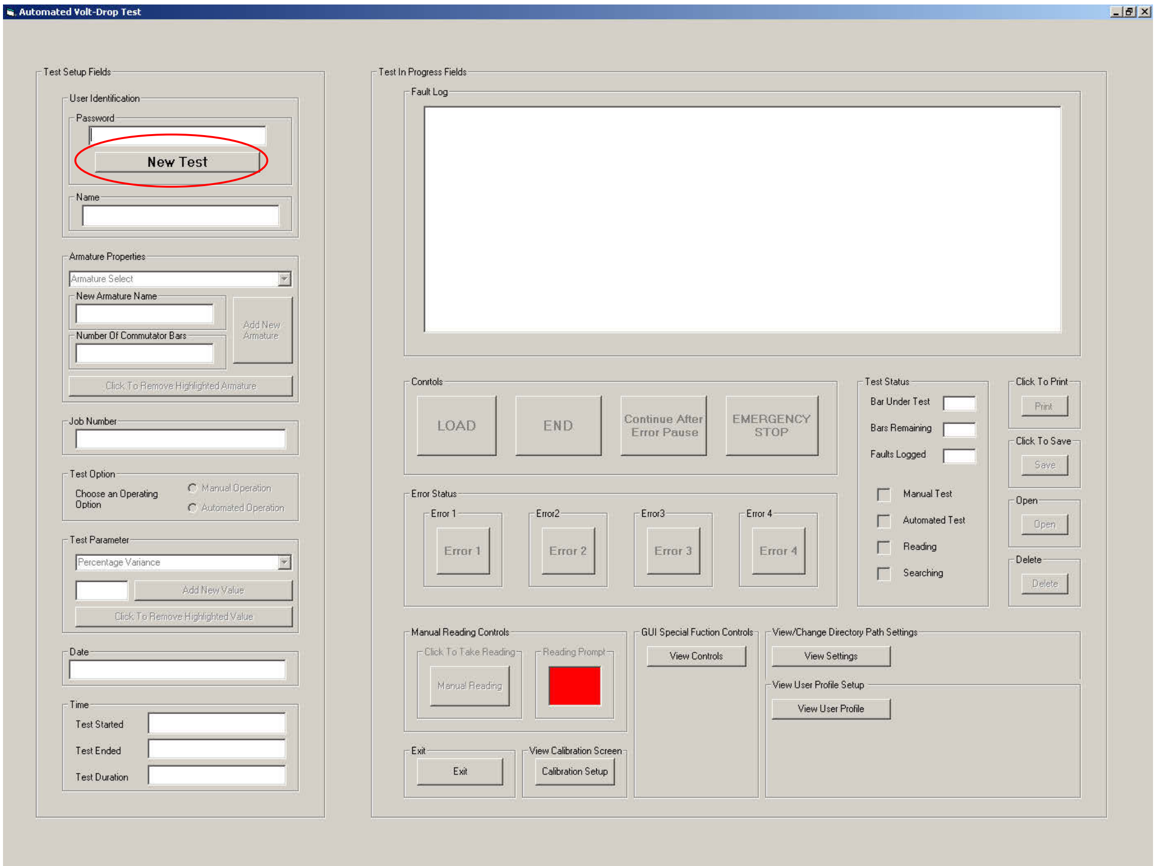


FIGURE 3-2: INITIAL TEST SCREEN

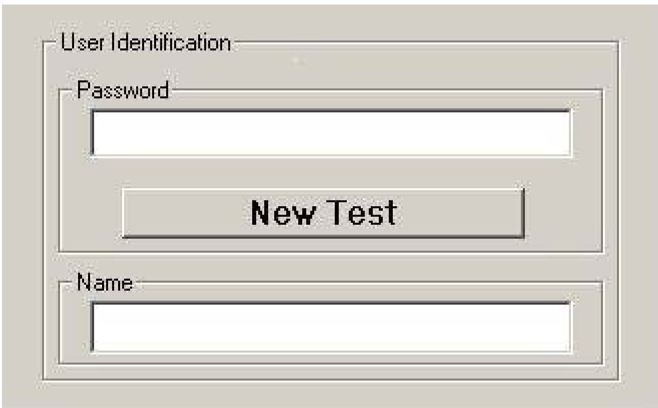


FIGURE 3-3: USER IDENTIFICATION FRAME ON THE INITIAL TEST SCREEN

Initially, except for the New Test button encircled in Figure 3-2, all the buttons and text input boxes are disabled. On clicking the New Test button in the Password frame the Enter button is enabled and replaces the New Test button. See Figure 3-4.

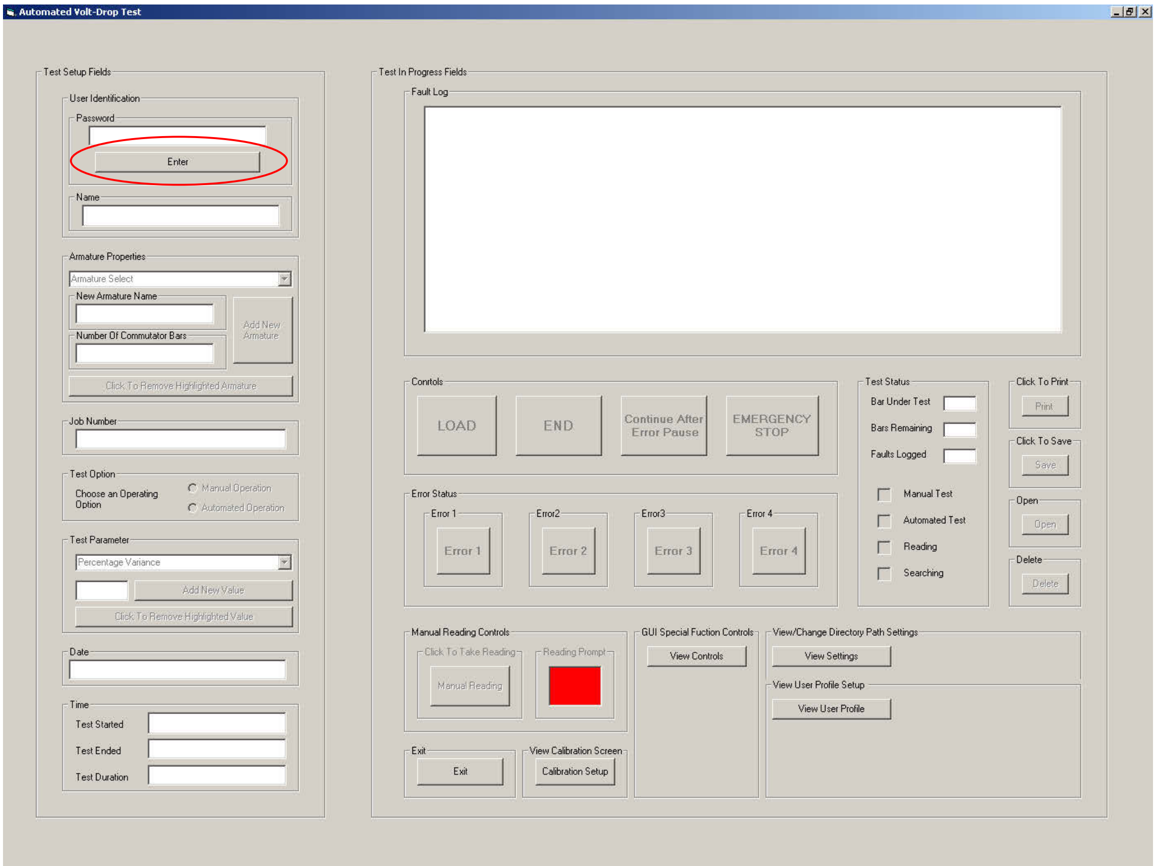


FIGURE 3-4: INITIATE TEST SCREEN

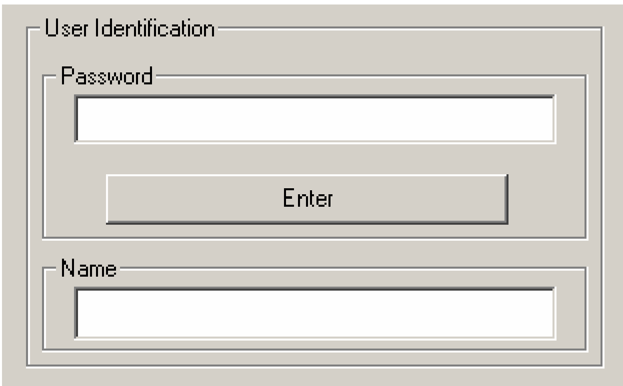


FIGURE 3-5: USER IDENTIFICATION FRAME ON THE INITIATE TEST SCREEN

At this stage, except for the Enter button, all other control buttons are disabled and except for the Password text input box all the text input boxes are still disabled. To enable the GUI the correct user password has to be entered. This password was originally a generic password that was assigned to the system. Any staff member that was assigned to use this system was to use this password. This has subsequently been changed such that each user has a unique username and password that is chosen by the individual. The username and password is stored in a file on the PC or laptop hard-drive and is accessed and/or edited via the GUI whenever need be.

The login system requires that the password is entered in order to use the system. If the password is one that exists in the Username and Password file, the username that is associated with the entered password is displayed in the Name text box. This method is used to ensure accountability as the username displayed in the Name text box is the name that is printed in the test report and saved in the test history file. The username and password feature is discussed in detail in Chapter 6 under the heading, Multiple User Names and Passwords.

On entering the incorrect password GUI informs the user that the password is incorrect as well as the number of attempts that remain. See Figure 3-6A and Figure 3-6B.

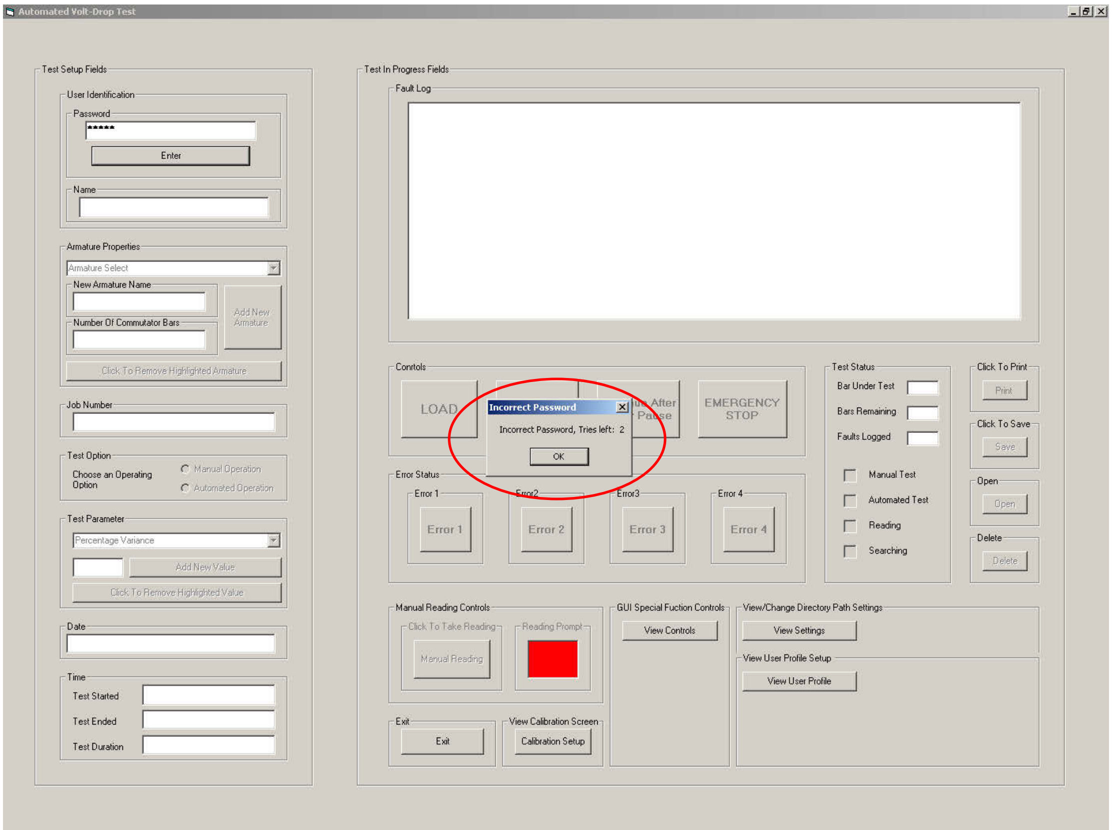


FIGURE 3-6A: GUI REPRESENTATION WHEN AN INCORRECT PASSWORD HAD BEEN ENTERED

FIGURE 3-6B: MESSAGE BOX INFORMING THE USER OF THE NUMBER OF TRIES THAT REMAIN

If, on the third attempt, an incorrect password is entered the message box depicted in Figure 3-7A appears informing the user that he/she is about to be locked out by the system.

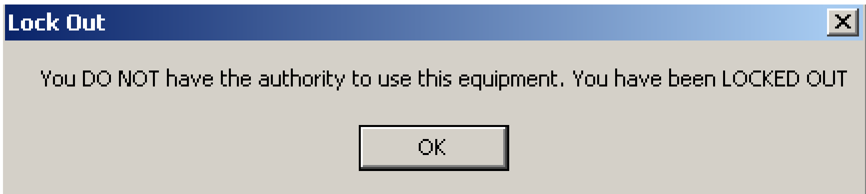


FIGURE 3-7A: MESSAGE BOX INFORMING THE USER THAT HE/SHE HAS BEEN LOCKED OUT

On acknowledgement of this message (by clicking on the OK button) the Lock Out frame is activated. The Lock Out frame hides every input and output function of the GUI, except for the Administrator Password functionality. See Figure 3-7B. The administrator password is used by a member of staff that is responsible for the supervision of the tests as well as the test technicians. This password allows the administrator to access and edit properties such as the Armature Properties, Test Parameters, Directory path and Unlocking. A user with a basic user password does not have the ability to edit these properties. Note that only the administrator can unlock the system once it has been locked.

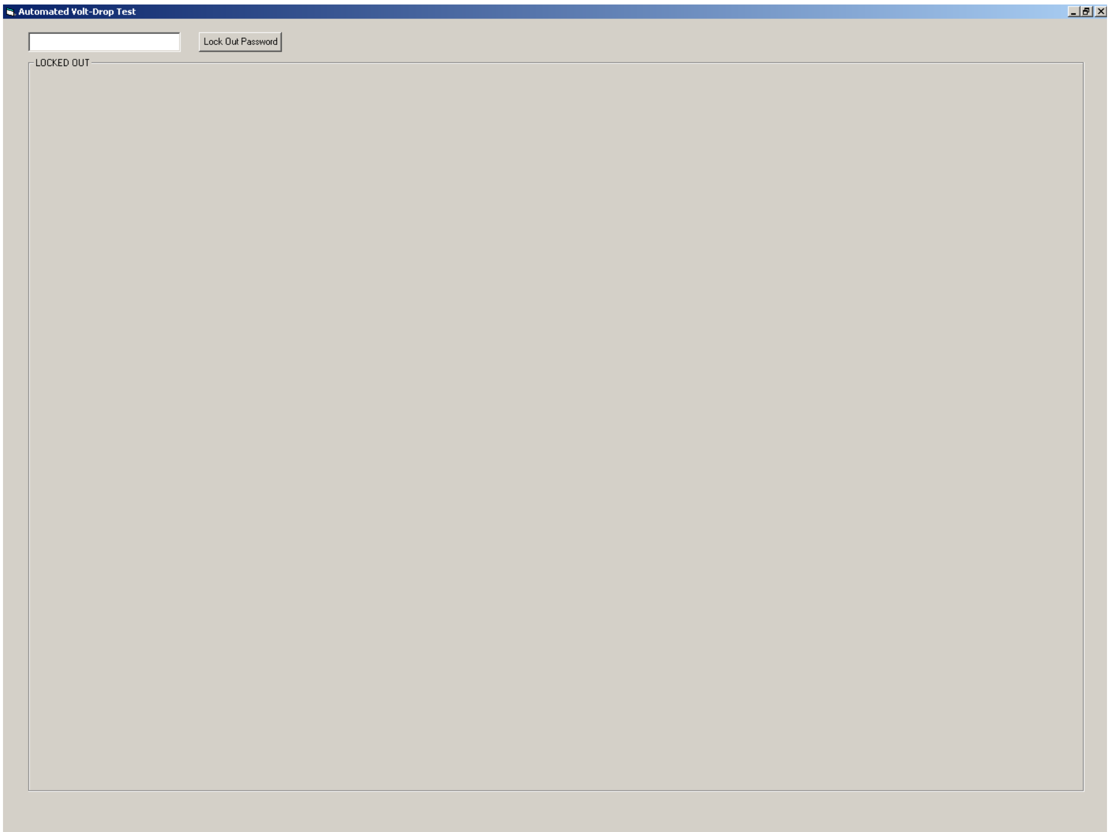


FIGURE 3-7B: LOCK OUT SCREEN

3.1.1.2 Armature Properties Frame

It is here that the user selects the armature type that is to be tested. See Figure 3-7C.

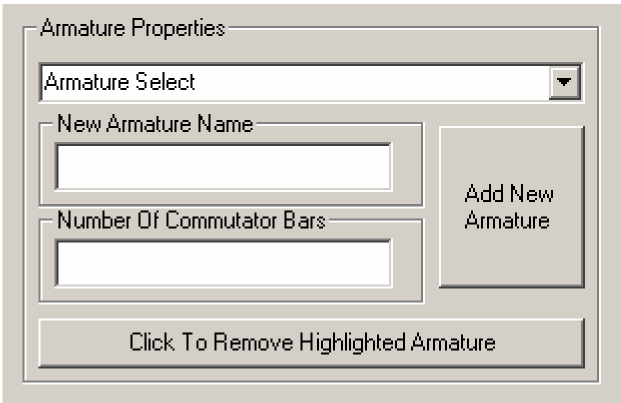


FIGURE 3-7C: ARMATURE PROPERTIES FRAME

The list of armatures is created by completing the New Armature Name and Number of Commutator Bars field and then clicking on the Add New Armature button. As mentioned previously, this functionality is only available to the administrator, therefore upon clicking the above mentioned button, the user is asked for the administrator password before the new armature is added, see Figure 3-8 and Figure 3-9. If an incorrect password is entered the new armature will not be added. For the removal of armatures from the list the Click To Remove Highlighted Armature functionality is used and is a functionality only available to the administrator. The reason for limiting access to these property fields is to exercise control over the test system. The user may only use the system and may not define any test limits and conditions other than those available to him/her.

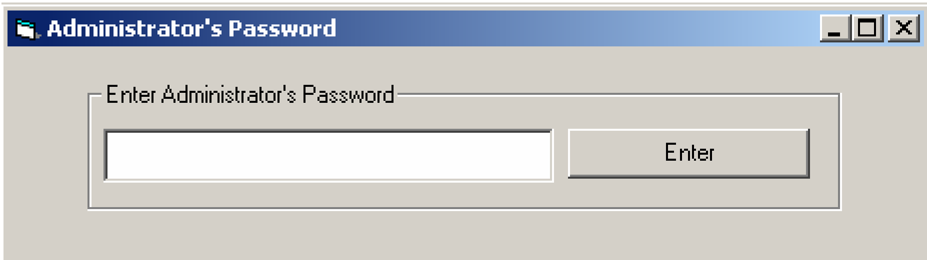


FIGURE 3-8: ADMINISTRATOR'S PASSWORD PROMPT

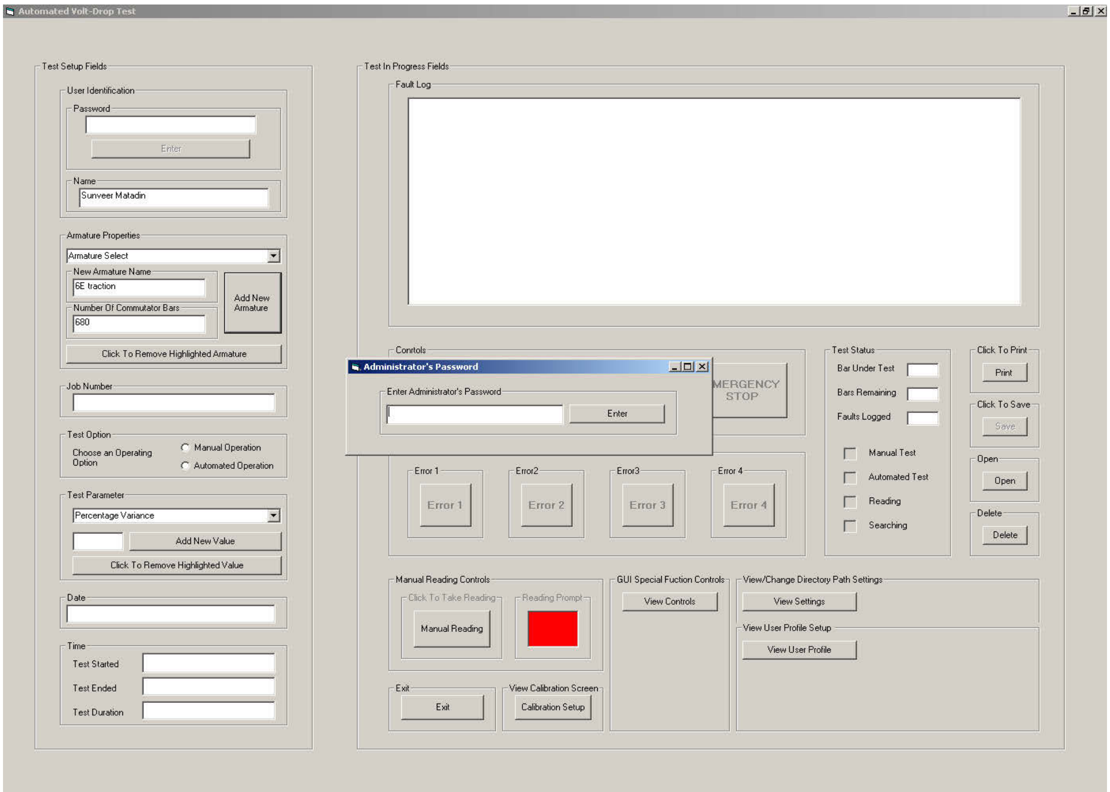


FIGURE 3-9: GUI DISPLAYING THE ADMINISTRATOR'S PASSWORD PROMPT

All armatures that appear on the list are stored in a sequential file. This sequential file is accessed and/or edited when creating the list of armatures that are to be tested, adding a new armature to an existing list or deleting an armature from the list.

The destination to which this file is saved is determined by **Default Path**. This path is specified in the Directory Path frame which will be discussed later in this chapter. The name of the file is Arm.

3.1.1.3 Job Number Property Frame

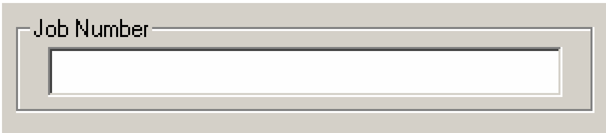


FIGURE 3-10: JOB NUMBER PROPERTY INPUT FRAME

It is in this input box that the armature serial number is entered. This serial number is reflected in the test report printout and it is also used as a file name under which the test results are saved. As will be discussed later in this chapter, tests are saved in files bearing the serial numbers of armatures as filenames in order to generate a test history for each armature. When a test is carried out on an armature with a file name (serial number) which does not appear in the file containing the list of armatures that were previously tested, that armature is added to the saved list, i.e. its serial number is added to a sequential file named '**Saved_List**'.

A sequential file bearing the name of the serial number of the armature is also created and it is here that the test results are saved. When saving a test for an armature with a serial number that already exists the content of the Job Number Property frame is compared with the list of serial numbers in the 'Saved_List' file. When a match is found that file is opened and the present test details are added to it. If no match is found then a new file is created and the name of the file is added to the 'Saved_List' file.

3.1.1.4 Test Option Property Frame

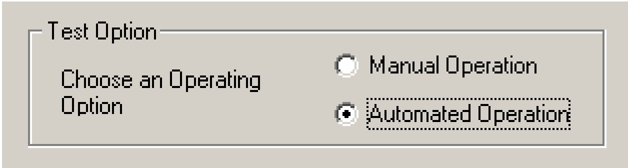


FIGURE 3-11: TEST OPTION PROPERTY FRAME

This property frame allows the user to choose between Automated and Manual modes by selecting the appropriate option. Once a selection is made it is reflected in the Test Status property frame, as show on Figure 3-12 below.

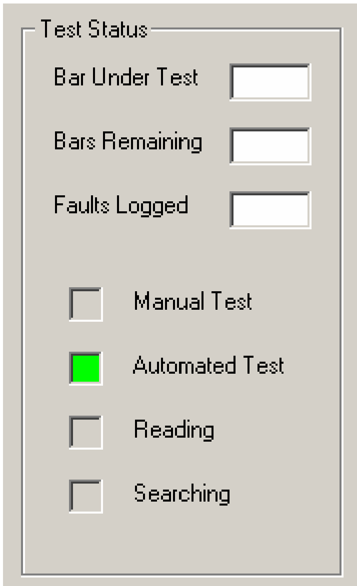


FIGURE 3-12: TEST STATUS PROPERTY FRAME

In Automated mode the entire system is enabled. This means that the controller, more specifically the Automation Microcontroller (AM), controls the mechanical system according to the commands from the GUI and the Communication Microcontroller (CM). In Manual mode, the automated control functionality of the system is disabled and the AM enters power-down mode. Only the data acquisition, analysis and storage functionalities of the system are available to the user. In this mode, the test technician is responsible for placing the test probes on the commutator bars and switching the test current using a footswitch.

3.1.1.5 Test Parameter Property Frame

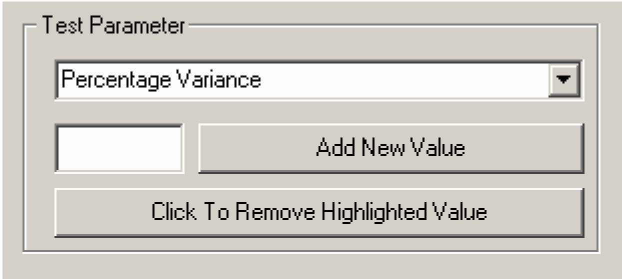


FIGURE 3-13: TEST PARAMETER PROPERTY FRAME

The Parameter Property Frame is where the user stipulates the allowable percentage variance (i.e. percentage difference) of present reading from the reference reading. This value is then stored in variable **Percentage** to be used in the Calculation subprogram. Different ranges can be added and removed from the available options by the administrator in exactly the same was way as the Armature Properties Frame. The operation of this frame is identical to that of Armature Properties Frame therefore the author will not enter into a discussion on the operation of this frame.

3.1.1.6 The Date and Time Frames

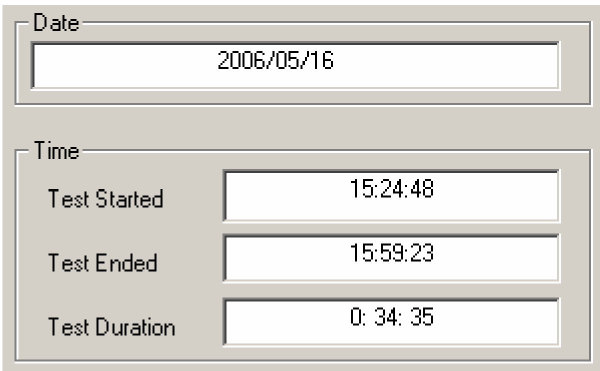


FIGURE 3-14: DATE AND TIME PROPERTY FRAME

These output fields reflect the date and duration of the test. On starting the test, by clicking the Start button, the date and the current time (Test Started) is uploaded from the PC’s internal clock.

When a test ends, either naturally (when all the bars have been tested) or unnaturally (when an emergency stop has been invoked), the end time of the test (Test Ended) is uploaded from the PC's internal clock.

3.1.2 Test In Progress Fields

3.1.2.1 Fault Log List

The Fault Log list is a list that displays each reading that falls outside the specified percentage variance range. It is also the screen that is used to display all relevant test information and test history that is retrieved from stored files.

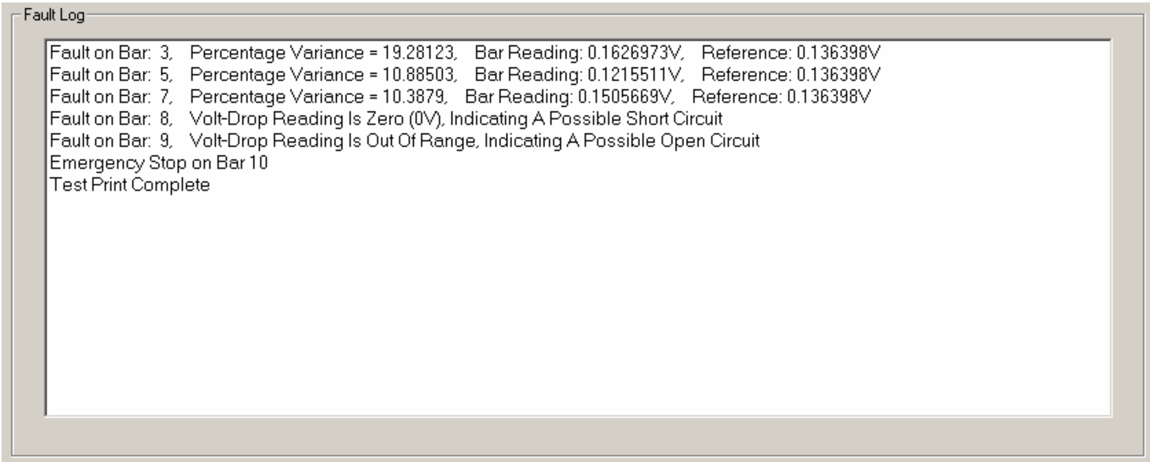


FIGURE 3-15A: THE FAULT LOG SCREEN DISPLAYING PRESENT TEST FAULTS

Figure 3-15A depicts a typical test fault log. This is what the user will see during the test as faults are recorded. Figure 3-15B illustrates the same test results that have been recalled from a stored file.

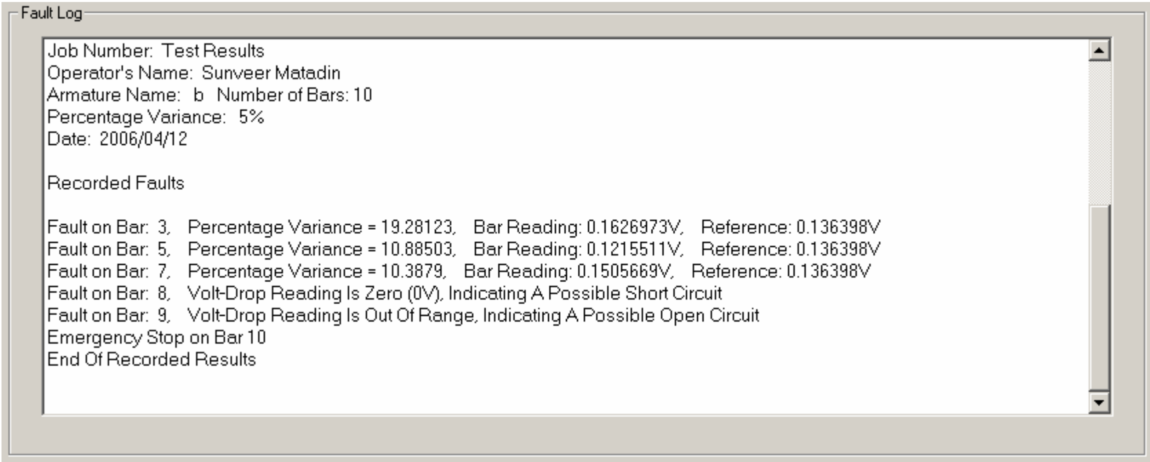


FIGURE 3-15B: THE FAULT LOG SCREEN DISPLAYING RETRIEVED FILE DATA

Figure 3-15B depicts a saved test that has been recalled in order to view the stored results. Critical information such as the job (serial) number, the operators name, the type of armature (the armature name and the number of bars on the commutator), the allowable percentage variance and the date of the test are displayed.

Under ‘Recorded Faults’, each fault is recorded with the following information: the number of the pair of bars on which the fault was recorded, the percentage variance from the reference reading, the actual volt-drop reading across the present two bars, the actual reference reading and, in the event of an emergency stop, the pair of bars on which such a stop was initiated.

3.1.3 The Control Commands

The control commands are used to prompt the controller, and where necessary the automated machine, to react to a user initiated event. There are three controls that may be used under normal test conditions when none of the system errors have occurred. These are the Load/Start, End and the Emergency Stop controls as shown in Figure 3-16.

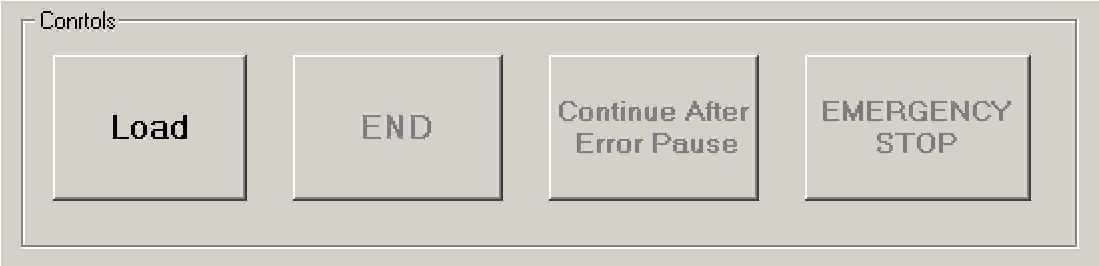


FIGURE 3-16: CONTROLS FOR NORMAL TEST CONDITIONS

In the event of an error, the two controls to be used are the Continue After Error Pause and the Manual Reading as shown in Figure 3-17A and Figure 3-17B. On an error that requires a manual reading to be taken, i.e. Error1 and Error2, the Manual Reading Control is enabled and the Reading Prompt turns green. A red Reading Prompt alerts the user that the system is not ready to take a manual reading whilst a green setting indicates to the user that the system has been prepared for a manual reading procedure. The user clicks on the Manual Reading button on the GUI when the reading is about to be taken. Thereafter the user presses a Manual Reading switch situated on the automated machine after the test current is switched on and the test probes are set in place. The volt-drop reading is then captured and processed.

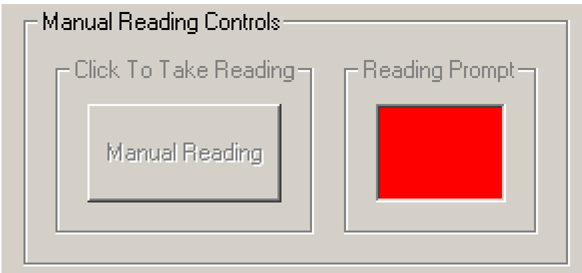


FIGURE 3-17A: DISABLED MANUAL READING CONTROL

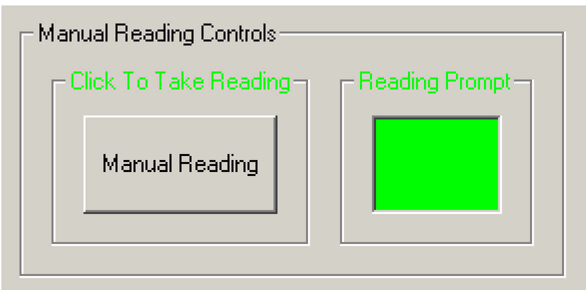


FIGURE 3-17B: ENABLED MANUAL READING CONTROL

Referring to Figure 3-16, the reader will notice that the first button in the Controls frame is the Load button and all other control buttons are disabled. This is to ensure that all the data required for a test has been entered correctly in the Test Setup Fields as discussed earlier.

Once all the data has been entered the Load button is clicked to upload the applicable information to the controller (more specifically the Communications Microcontroller). All the input data fields on the GUI are disabled when the Load button is clicked in order to ensure that the input setting can not be altered during a test. If any input data fields have not been completed when the Load button is clicked a message box or an input box appears prompting the user to enter the required data. See Appendix P the flow diagram relating to this process. Once the CM has received the information it acknowledges having done so by transmitting the ASCII code for the letter ‘d’ back to the GUI.

On receiving this, the Load button is replaced by the Start Button and the Emergency Stop Button is enabled as depicted in Figure 3-18B. When the user is ready to begin the test the Start button is clicked and ‘A’ is transmitted to the controller to begin. When the Start button is clicked it turns green, as shown in Figure 3-18C, and the mouse pointer changes to a pointer and hourglass signifying that the test is in progress.

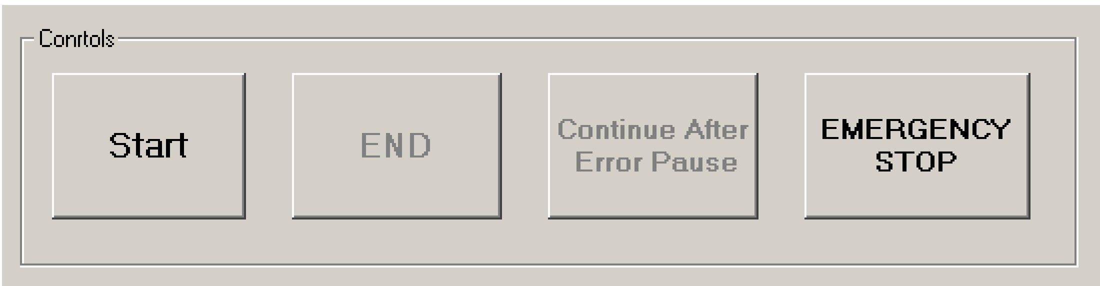


FIGURE 3-18B: START AND EMERGENCY STOP CONTROL ENABLED

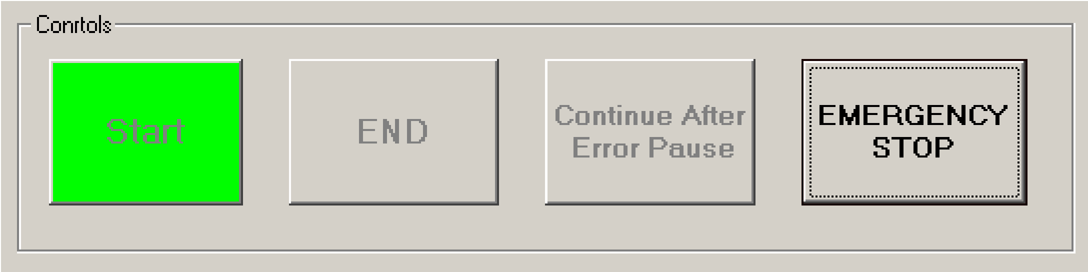


FIGURE 3-18C: START CONTROL BUTTON CLICKED TO BEGIN TEST

After the last pair of bars has been tested the End control button is highlighted in blue as shown in Figure 3-19A below. This alerts the user that the test is complete. The user must acknowledge this alert by clicking on the End button. The End control is also enabled and highlighted when an Emergency Stop is initiated. This is further discussed below.

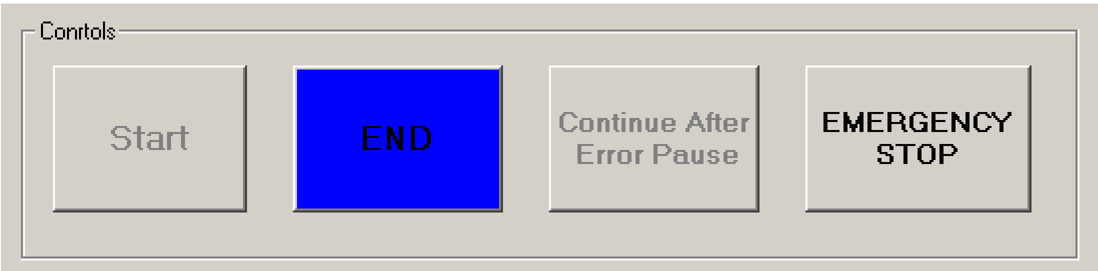


FIGURE 3-19A: END CONTROL HIGHLIGHTED BLUE TO ALERT USER

When the End control button is clicked, 'B' is transmitted to the controller and the End button is highlighted in green to signify the completion of the test. This signifies that the controller has entered powerdown mode and that the data is ready to be printed and saved or only saved. Referring to Figure 3-19B, the reader will notice that the Print and Save options are now enabled. All the output fields in the Test Status Frame and all the input fields in the Test Setup Frame are cleared. Further, all control and input buttons, except for the password Enter Button, are disabled. This allows the user to begin the next test once a valid password has been entered.

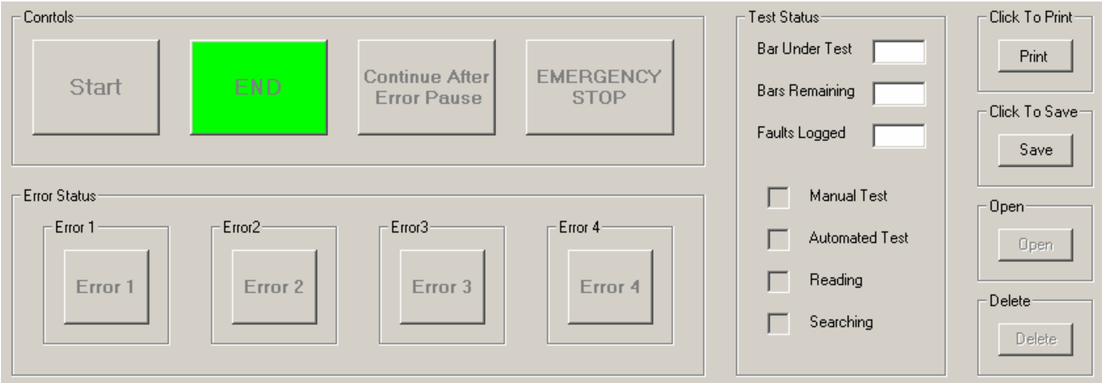


FIGURE 3-19B: END CONTROL HIGHLIGHTED GREEN AFTER ALERT IS ACKNOWLEDGED

When the detection unit, containing the test probes and optical sensor, is not raised to its initial position within the allocated time Error 4 is invoked and the Continue After Error Pause control, The Emergency Stop control as well as the Error 4 status display are enabled and highlighted as depicted in Figure 3-20.

The GUI is made aware of this error when the ASCII code for the letter ‘L’ is received. When this error occurs the user has to assess the problem and if the fault is not serious enough to abandon the test, the user will physically raise the unit to its initial position. Once this is done and the user is confident that the error was not due to an event that may be recurring, the user will click on the Continue After Error Pause control for the test to progress as usual. Once clicked all the control buttons and displays that were highlighted and enabled due to the error are disabled and are no longer highlighted. If the fault is deemed to be serious and possibly recurring in nature the user will then click on the highlighted Emergency Stop control to immediately stop the test.

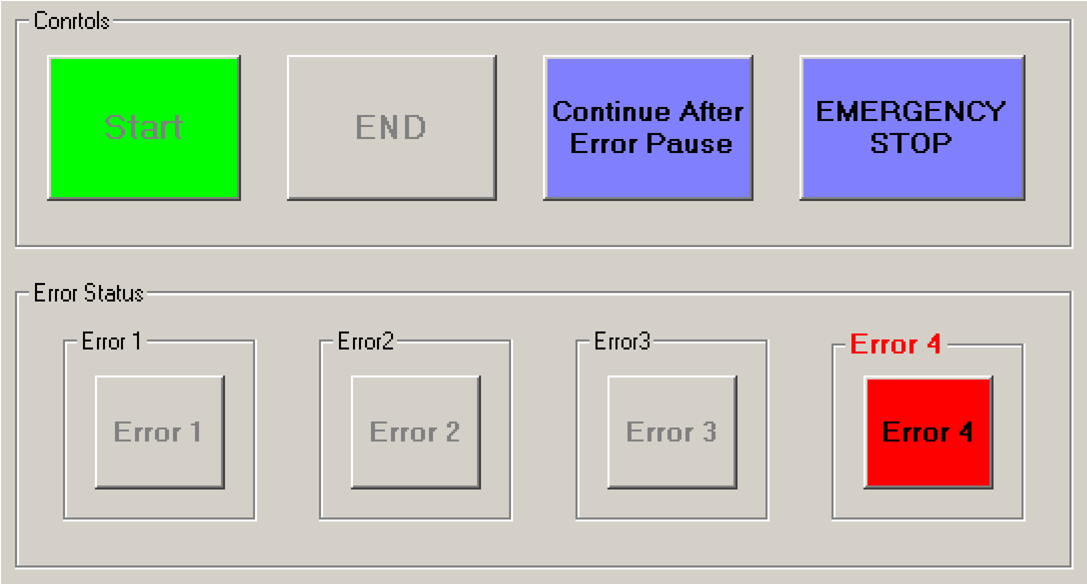


FIGURE 3-20: CONTINUE AFTER ERROR PAUSE CONTROL ENABLED FOR ERROR 4

The last control featured in the Controls frame is the Emergency Stop button. This functionality is enabled as soon as the test is started and remains enabled throughout the test. If at any point during the test, the user decides that it is unsafe to continue with the test, an emergency stop can be evoked by clicking on the Emergency Stop control button. When clicked, the Emergency Stop control is highlighted in red, the End button is enabled and the ASCII code for the Letter 'F' is transmitted from the GUI to the CM. The CM then Sets (1) P0.5, which is connected to the AM P1.5 and P3.2 (External Interrupt 0). When the AM is interrupted due to External Interrupt 0 being triggered and P1.5 is High (1), the AM immediately initiates an emergency stop. The AM immediately halts the task that was being carried out, switches off the Test Current by Clearing (0) P2.7 and safely shuts the system down before entering Powerdown mode. The GUI reflects the fact that an Emergency Stop was evoked in the Fault Log and waits for the user to click the End button in order to end the present test.

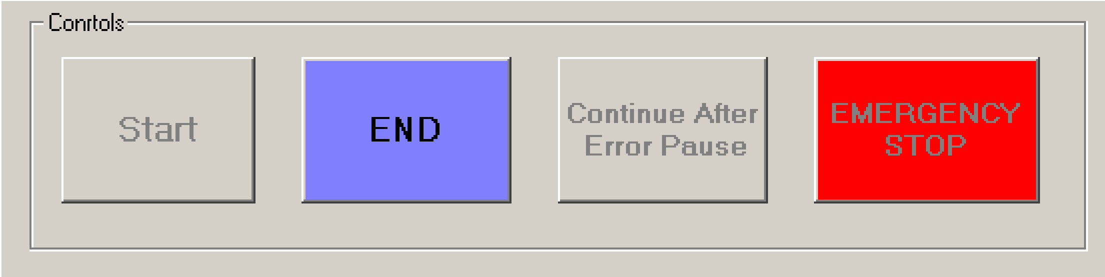


FIGURE 3-21: EMERGENCY STOP EVOKED

3.1.4 Error Status Frame

The Error Status Frame is where errors are reflected as or when they occur. When no errors have occurred, the frame looks like Figure 3-22, with each error status display being disabled.

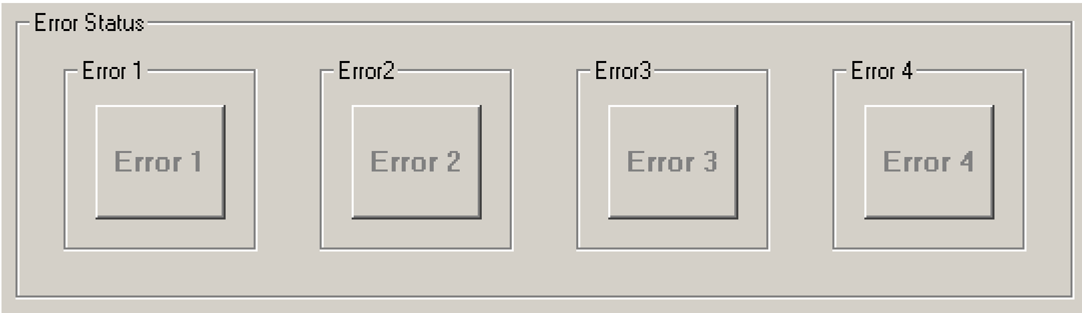


FIGURE 3-22: ERROR STATUS FRAME

When an error does occur the appropriate display is highlighted red and is enabled. Once the user clicks on the error a display message box pops up informing the user of the type of error, the cause and possible steps to follow. Only once the error has been corrected and the controller communicates this to the GUI, will the highlighted display be disabled. Each error and flow chart depicting the steps taken when they occur will be discussed in detail in Chapter 4 and Appendix Q. For the purposes of this discussion, the author will only concentrate on those events which trigger these errors and the manner in which the GUI reflects them.

Error 1 occurs when a pair of bars is not detected within an allocated time. The controller is responsible for the timing of this process and if the allocated time has elapsed before the next pair of bars are detected, the controller transmits the ASCII code for the letter 'J' to the GUI. When the GUI receives a 'J' it immediately enables and highlights the Error 1 display as well as the Manual reading control. As mentioned earlier, a detailed discussion concerning this and all the other errors will follow in Chapter 4. See Figure 3-23A for a representation of the Error 1 display. When the Error 1 display is clicked the following message appears in a message box:

"The next pair of bars has not been detected within the allowable period. A Manual Reading must now be taken"

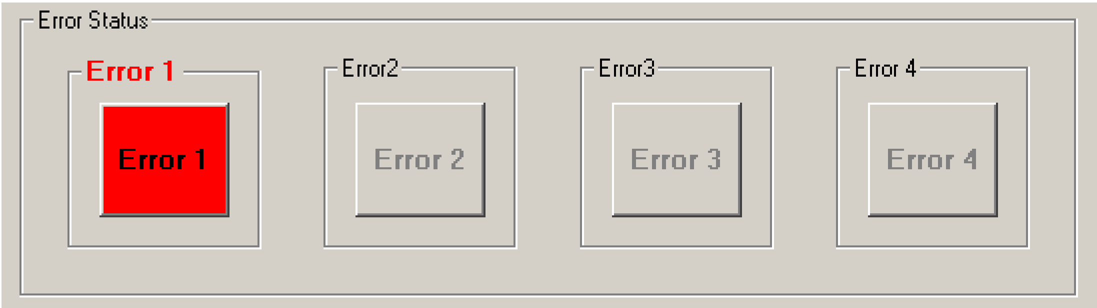


FIGURE 3-23A: ERROR 1 DISPLAY

Error 2 occurs when the detection unit has not been lowered onto the surface of the commutator within the allowable time. Here again the controller is responsible for the timing of this process and if the allocated time has elapsed before the detection unit has been lowered the controller transmits the ASCII code for the letter 'm' to the GUI. On receiving this character the GUI highlights Error 2 and enables the Manual reading control.

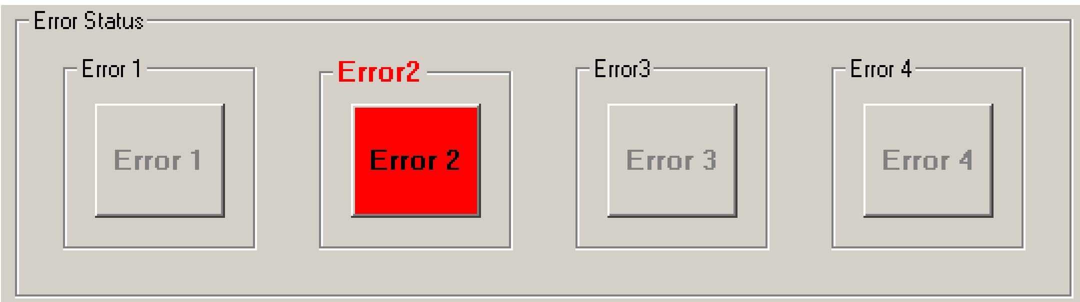


FIGURE 3-23B: ERROR 2 DISPLAY

When the Error 2 display is clicked the following message appears in a message box:

"The Test Probes have not been lowered within the allowable period. A Manual Reading must now be taken"

Error 3 occurs when the test current is switched on for a period longer than the predetermined allowable time. In this case the controller transmits the ASCII code for the letter 'L' to the GUI. Unlike the previous two errors, Error 3 initiates an immediate Emergency Stop (by transmitting the ASCII code for the letter 'F' to the controller) and enables the End control function. The GUI still however highlights Error 3 in order to inform the user that the Emergency Stop was initiated as a result of the occurrence of Error 3. On clicking the Error 3 display the following message appears in a message box:

"The Test Current has been switched on for too long, and as a safety measure an Emergency Stop has been invoked. Please Click End, check the device and Restart the Test"

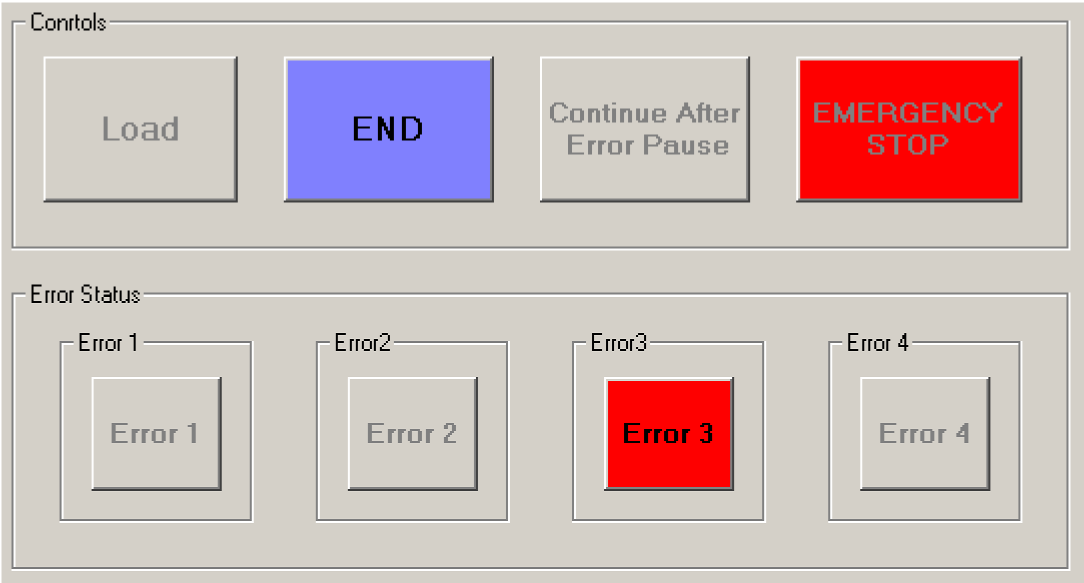


FIGURE 3-23C: ERROR 3 DISPLAY AND INVOKED EMERGENCY STOP

Error 4 was discussed in the explanation pertaining to the Continue After Error Pause Control, however for completeness it has been discussed briefly below.

Error 4 occurs when the detection unit has not been raised to its initial position within the allowable time. When this occurs the controller transmits the ASCII code for the letter 'Q' to the GUI. On receiving this the GUI highlights and enables the Error 4 display as well as the Continue After Error Pause and Emergency Stop controls as shown in Figure 3-20 and Figure 3-24. The user then assesses the fault and elects to either continue with the test by clicking on the Continue After Error Pause button or stopping the test by clicking on the Emergency Stop button.

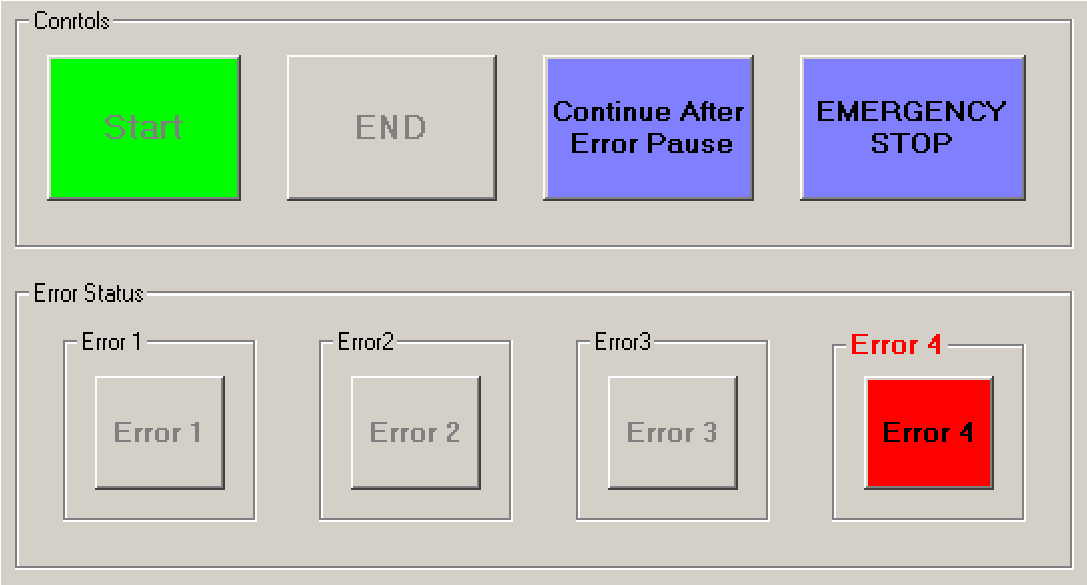


FIGURE 3-24: CONTINUE AFTER ERROR PAUSE CONTROL ENABLED FOR ERROR 4

3.1.5 Test Status Display

The Status Display is responsible for the summary of the present test at any point during the test. As can be seen from Figure 3-25, the information displayed includes the number of the pair of bars (i.e. first pair, second pair etc) that is currently under test, the number of pairs of bars that remains to be tested, the number of faults that were logged, the mode that the system is operating in (i.e. manual or automated) and the task that the system is presently performing (i.e. either searching for the next pair of bars or taking a reading).

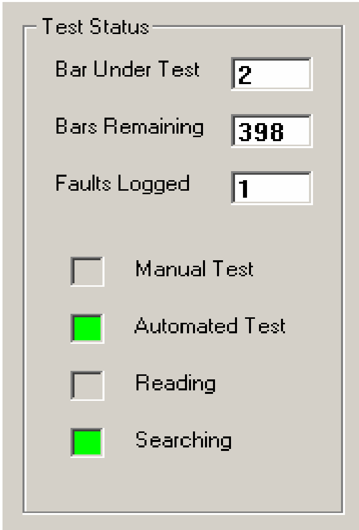
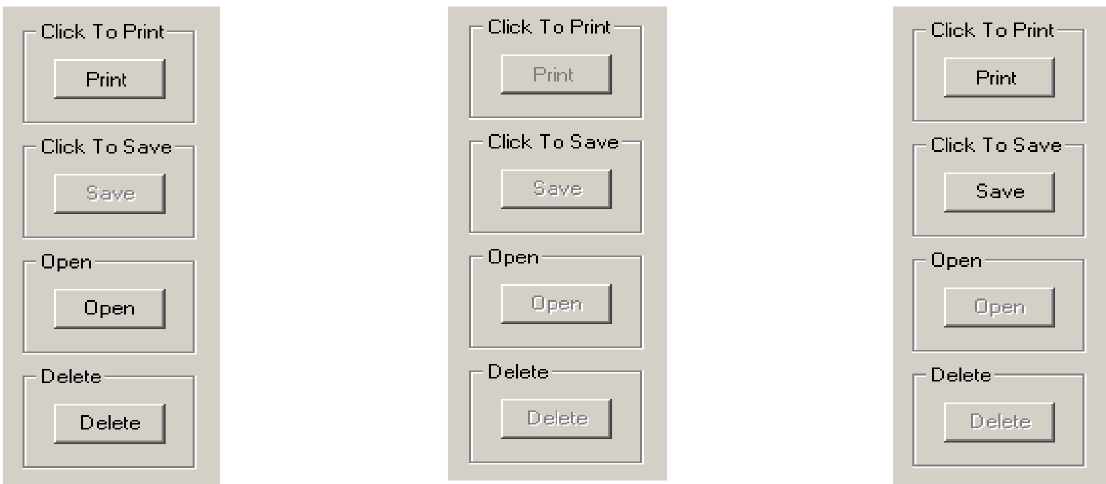


FIGURE 3-25: TEST STATUS DISPLAY

3.1.6 Recorded Test Data Option

The user has four options relating to the handling of recorded test data. These are the print, save, open and delete options. Each will be discussed individually in the subsections that follow. Below is a representation of the options available at different stages of the process.

Figure 3-26A depicts the options available after the correct password is entered but before a test has started. Figure 3-26B depicts the options available while a test is in progress and Figure 3-26C depicts the options available at the end of a test.



(A) (B) (C)

FIGURE 3-26: TEST DATA OPTIONS

3.1.6.1 Print Option

A printed test report is useful for three reasons. Firstly, a hard copy of a specific test or a test history of an individual armature can be made available. The second reason is that a written record travels with the armature after this test so that staff involved at the next stage of the process will have access to the results. The third use of a printed test report is that it aids in accountability, i.e. the technician that performs the test can be held accountable for the test and the results since his/her name appears on the test report as well as his/her signature acknowledging the faults.

The user may view and print saved test records by opening a specified file using the Open button. It is for this reason that the print option is made available to the user after the correct password is entered but before a test is started. When Print is clicked, all the data contained in the opened file is printed in the format shown in Appendix D. If a file was not opened, thus implying that no data is displayed when Print is clicked, the following message appears:

"No Data Available To Print"

Once a test is in progress the print option is disabled until the end of the test. Here, when Print is clicked, only the data recorded during the test which was just completed is printed in the format shown in Appendix E. One of the main features of this new system is the fact that test data can be printed and stored. It is for this reason that when the user prints the present test the data is also automatically saved in the appropriate file.

3.1.6.2 Save Option

As mentioned above, when a completed test is printed it is also automatically saved therefore there is no need to click on the Save button. The Save button is useful when the user wishes to only save the present test data without printing a copy.

A dual sequential file system is used to save a test record. The first sequential file is the one used to store the names or serial numbers of the armatures that have been tested and saved, in order to generate a list when required. This file is named

DefaultPath & "Saved_List.TXT". DefaultPath is the specified location of the file named Saved_List. The above-mentioned list is available when the user clicks on the Open or Delete buttons.

The second sequential file is the one in which the test data is saved. The file name is the serial number of the armature under test. Each record added to this file has the following fields: the serial number of the armature, the name of the test technician, the type of armature, the allowable percentage variance specified for the test, the date of the test and recorded faults (if any) read by incrementing the index number of the Fault Log list and the actual fault logged on that pair of bars. In other words, each fault recorded on the Fault Log list is saved in the file with the test parameters and identification data fields preceding it. A typical record in the file is found below,

"matadin","sun 04/05","Armature Name: f Number of Bars: 50","Percentage Variance: 20%","2005/05/04","Emergency Stop on Bar 0"

Once the last item from the Fault Log has been saved, a record containing ‘xxx’ in the user name, armature name and allowable percentage variance fields together with the serial number field is saved to indicate the end of a test record.

"End","xxx","xxx","xxx","2005/05/04","End Of Recorded Results"

3.1.6.3 Open option

This option is only available to the user once a valid password has been entered. By clicking on Open, the user may view any and all saved tests. When clicked an input box, as shown in Figure 3-27, appears prompting the user to enter the serial number of the armature for which the test data is to be viewed. When this number has been entered all the recorded tests for that serial number i.e. the armature test history, are displayed on the Fault Log display.

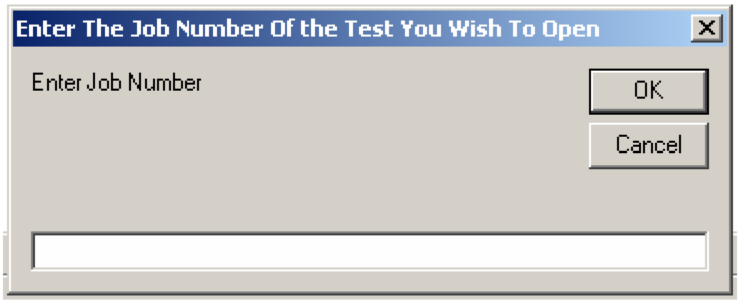


FIGURE 3-27: INPUT PROMPT WHEN 'OPEN' IS CLICKED

In order to refine the search, for example if a test on a specific date is required, the user enters 'Find' in the input box. A list of armature serial numbers appears as shown in Figure 3-28. This list is generated by reading the 'Save_List' file mentioned above.

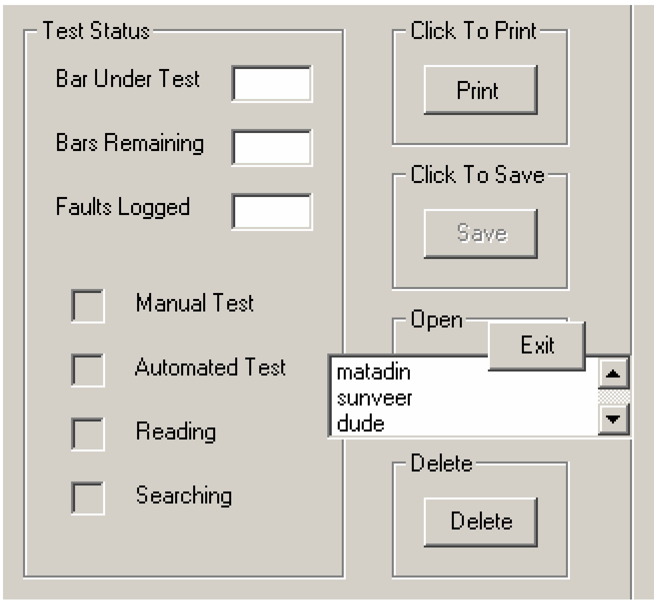


FIGURE 3-28: LIST OF SAVED SERIAL NUMBERS

By clicking on a serial number from this list a search is initiated. This search entails the opening of the file with the name matching the selected serial number, in this case matadin, reading through each record and displaying the dates on which tests were carried out on the selected armature. All these dates along with a 'View All' option are displayed in a list box as depicted in Figure 3-29.

By selecting a specific date, the user may view the data recorded during the test (or tests) carried out on that armature on the specified date. By clicking on the 'View All' option a test history containing all tests recorded and saved under the specified serial number is displayed. The user clicks on the Exit button provided to exit from the Open procedure at any time.

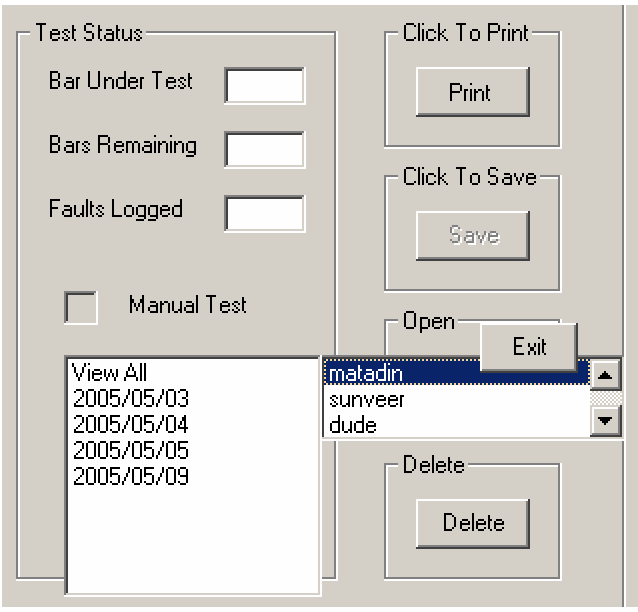


FIGURE 3-29: LIST OF TEST DATES FOR A SPECIFIED ARMATURE SERIAL NUMBER

3.1.6.4 Delete Option

The delete option allows a user with administrative rights to delete a file with a specified serial number. When an armature is discarded it may be decided that the history of that armature is no longer relevant however, the opposite may also be true. The relevance of the history of a discarded armature can only be decided by the workshop management and maintenance engineers.

The Delete option works in the same way as the Open option. All the records with the specified serial number are located when that serial number is entered into the input box prompt or a list containing all the saved serial numbers is generated when “Find” is entered into the input box as depicted in Figure 3-30. The difference is when the Delete button is clicked - the GUI requests the Administrator’s password. If the password is entered correctly and a serial number is selected the GUI will ensure that the user is sure of his decision by prompting a response using a pop up box as shown in Figure 3-31.

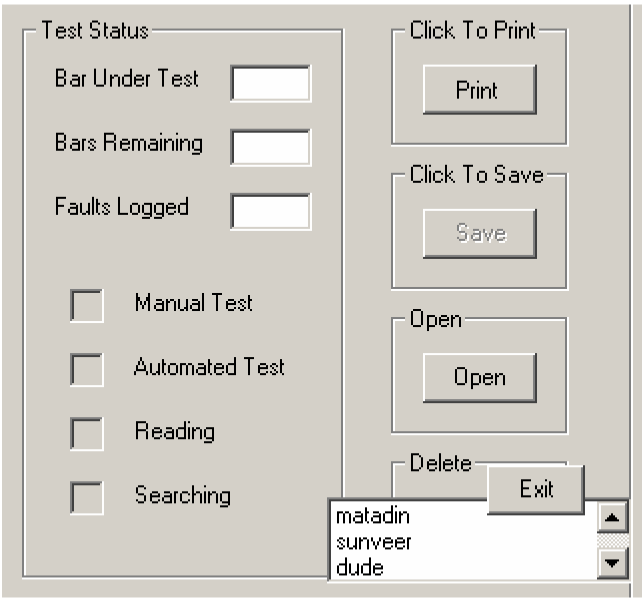


FIGURE 3-30: LIST OF SERIAL NUMBERS GENERATED ON THE DELETE CLICK EVENT

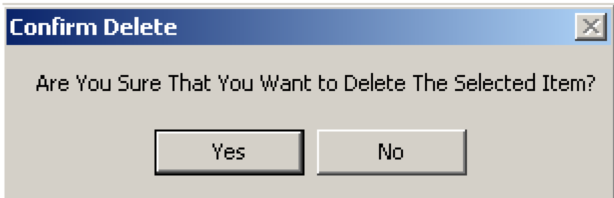


FIGURE 3-31: POP UP PROMPT ON SELECTING AN ITEM TO BE DELETED

If Yes is selected by the user the deletion process is initiated. This process entails the removal of the selected serial number from the sequential file that generates the list of saved serial numbers, i.e. **"Saved_List.TXT",** as well as removing the file that contains the test history saved under the name of the selected serial number. Removing the selected item from the **"Saved_List.TXT"** file is accomplished by reading this file and copying all items except the one selected into another file, in this case **"Saved_List_Del"**. At the end of this process, **"Saved_List.TXT"** is deleted and **"Saved_List_Del"** is renamed as **"Saved_List.TXT"**.

To delete the file containing the test history the following statement:

```
Kill (DefaultPath & Save_Test)
```

is used to remove the file with the name stored in **Save_Test** (which is the serial number of the selected item) using **DefaultPath** to locate it.

3.1.7 Directory Path Specification

The Directory Path specifies the location where all files generated and accessed by the GUI are saved. This location is copied into the variable **DefaultPath** which precedes the file name. Using **DefaultPath** files can be saved on the local hard drive, written to removable data storage devices or by mapping a network drive, files can be stored in allocated locations on the network.

The Directory Path settings can be viewed and reset via the Directory Path frame. The Directory Path frame is made visible by clicking on the View Setting button found on the View/Change Directory Path Settings Frame. The user can return to the View/Change Directory Path Settings Frame from the Directory Path Frame by clicking on the Exit Settings button. See Figure 3-32 and Figure 3-33.

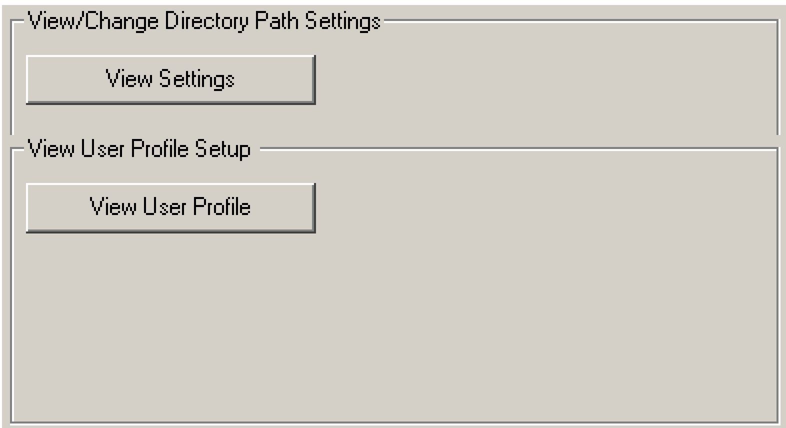


FIGURE 3-32: DIRECTORY PATH SPECIFICATION

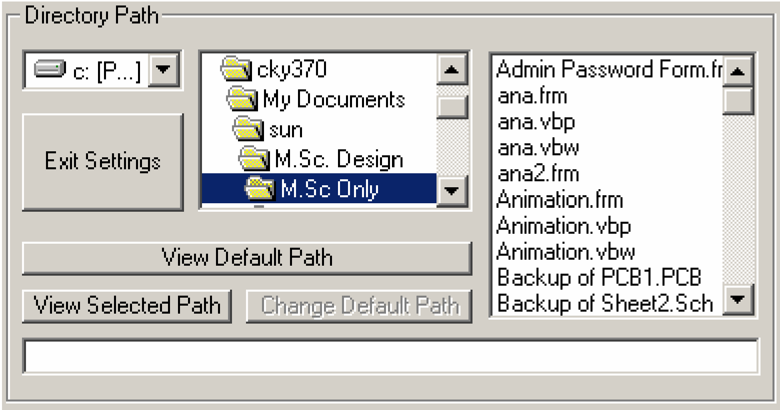


FIGURE 3-33: DIRECTORY PATH SPECIFICATION

The Default Path can only be set or changed by an administrator. A directory path is selected using the drive, directory and file input boxes. The administrator then clicks on 'View Selected Path' to verify that this is the correct selected destination. Once satisfied with the selected path, the administrator clicks on Change Default Path. An input box which prompts the administrator for the administrator's password appears and if the correct password is entered the selected path is saved as the new default directory path.

The default path can also be viewed by clicking on the 'View Default Path' button. The Default Path setting is dynamic (i.e. it can be changed when required and is not hard-coded) and points to the location in memory in which data can be saved. The Default Path itself also has to be saved in a file so that it can be referred to whenever the default path is required. The location of this file is static i.e. it is hard-coded and cannot be changed by the user or the administrator.

The name and location of this file is **SavePath** and **"C:\Program Files\SavePath"** respectively. When the GUI is loaded for use each time it is initiated, the Form_Load procedure opens the **SavePath** file and copies its contents into the Default Path variable. This is carried out on the onset of a test so that the Default Path variable can be accessed whenever the path is required instead of opening, reading and closing a sequential file each time it is required.

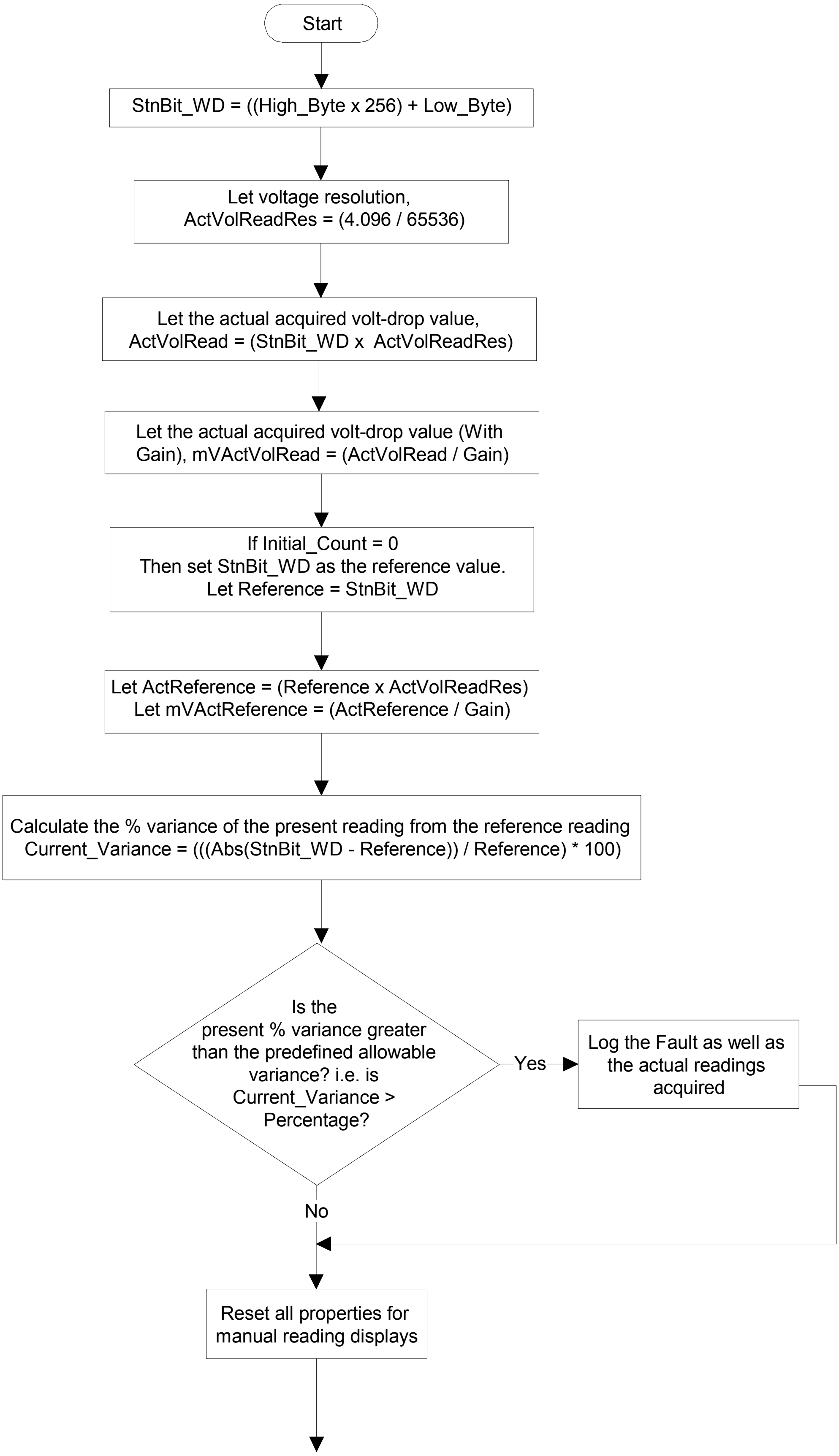
3.1.8 Exit Command

The exit command allows the user to exit from the GUI before a test is started or once the test has ended. The Exit functionality is disabled during a test.

FIGURE 3-34: EXIT COMMAND CLICK

3.2 Percentage Variance Calculation.

All the literature in this chapter thus far has concentrated on the activities of the GUI when being prompted by a user or the controller and the output commands or signals that are transmitted by the GUI to the controller based on the data received and calculations carried out by the GUI. One such calculation is carried out when the GUI receives the test data from the Analogue-to-Digital converter (ADC) via the CM. This is the calculation of the percentage variance of the present reading from the stored reference reading. This is arguably the most critical calculation as the need for the entire project has evolved around it.


Start
StnBit_WD = ((High_Byte x 256) + Low_Byte)
Let voltage resolution,
ActVolReadRes = (4.096 / 65536)
Let the actual acquired volt-drop value,
ActVolRead = (StnBit_WD x ActVolReadRes)
Let the actual acquired volt-drop value (With Gain), mVActVolRead = (ActVolRead / Gain)
If Initial_Count = 0
Then set StnBit_WD as the reference value.
Let Reference = StnBit_WD
Let ActReference = (Reference x ActVolReadRes)
Let mVActReference = (ActReference / Gain)
Calculate the % variance of the present reading from the reference reading
Current_Variance = (((Abs(StnBit_WD - Reference)) / Reference) * 100)
Is the present % variance greater than the predefined allowable variance? i.e. is Current_Variance > Percentage?
Yes
Log the Fault as well as the actual readings acquired
No
Reset all properties for manual reading displays

A (pp. 63)

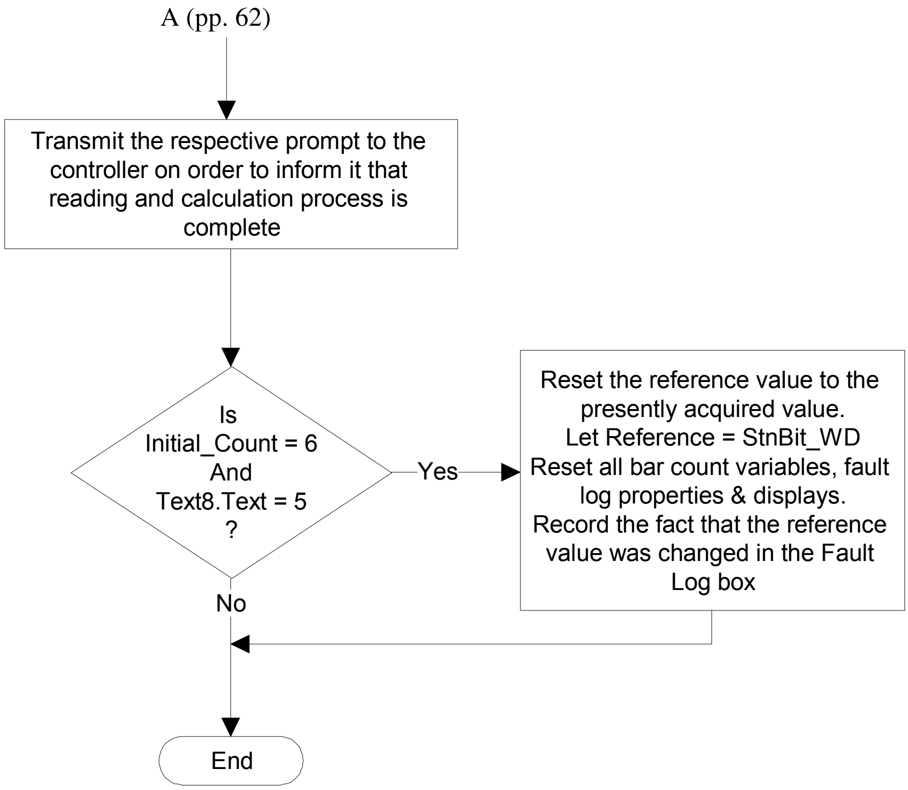


FIGURE 3-35: FLOW DIAGRAM FOR THE CALCULATION SUBPROGRAM

This subprogram has two objectives; the first is to calculate the percentage variance of a present reading from the reference reading whilst the second objective is centered on the reference reading itself. Consider this, what if the reference reading is in fact a fault reading, i.e. what if the reference reading is the reading across an open or short circuit or a damaged winding on the armature? The first step would be to check whether the first reading recorded is very close or equal to zero volts.

This would indicate a short circuit and this value will therefore not be stored as a reference value. A true open circuit would be indicated by a reading that is very close to or equal to the supply voltage. But the supply voltage and current is not the same for every type of armature tested due to the armature characteristics as well as the arc length between the test current supply probes on the commutator. Also considering that damaged and potentially problematic windings also have to be detected. There is no clear cut value that can be used to reject a reference reading (that is other than the reading for a short circuit). In order to detect that the reference value being used is indeed a value that was recorded on a fault winding; the GUI performs a check after the first five readings taken, subsequent to the reference reading.

This essentially means that this check is carried out on the sixth reading captured. Variable **Initial Count** keeps track of the number of readings taken and by recalling an earlier discussion regarding the Test Status display, the reader will remember that the number of faults recorded is displayed in a text box (Text8). Noting this, in the event that the value in **Initial Count** is six and the value of Text8 is five,

```
If (Initial_Count = 6) And (Val(Text8.Text) = 5) Then
```

this event will indicate that five (5) faults have been logged immediately after the reference value was set.

If such an event occurs, the GUI will conclude that based on the last five captured readings, the reference value was set on a fault or damaged winding reading. The reference value is then reset to that of the value recorded on the present bar (which will be the sixth bar). The values in the Test Status display as well as the variables that hold the values which reflect the number of bars that remain to be tested and the bar presently under test, are also adjusted appropriately to reflect this change. The test is reset on the sixth bar and continues as normal from that point forward.

For all of the above to occur the data transmitted from the controller has to be converted, manipulated and passed through mathematical formulae in order to obtain usable values that can be compared, displayed and stored. The following discussion will cover the manner in which this is done. Recall, that ASCII codes are transmitted by the controller. These ASCII codes are then converted into their associated numerical values in the OnComm procedure using the Visual Basic **Asc** function, as shown below,

```
Low_Byte = Asc(SerIn)
```

and,

```
High_Byte = Asc(SerIn)
```

When the calculation subprogram is called by the OnComm procedure, the Low_Byte and High_Byte variables already contain the required numerical values. The first step in the calculation subprogram is to convert these two bytes of data into the original sixteen (16) bit word that was present in the ADC register before its transmission as two separate bytes to the CM. This is accomplished using:

```
StnBit_WD = ((High_Byte * 256) + Low_Byte)
```

Once the sixteen-bit word has been realised, it is then necessary to calculate the actual voltage that this word represents. This is accomplished by dividing the ADC reference value (which is also the maximum input ADC voltage) by the sixteen-bit word when each bit is equal to 1 (i.e. 1111 1111 1111 1111 which equals 65536). By doing this, the voltage-per-bit value or the resolution in volts (stored in variable **ActVolReadRes**) is obtained. With an ADC internal V_{Ref} of 4.096V and sixteen bit resolution, the smallest voltage increment that the input signal can broken down into is:

$$\text{Resolution in Volts} = 4.096 / 65536 = 62.5\mu V$$

This value is then multiplied by the value of the sixteen-bit word that was captured (**StnBit_WD**) to produce the actual voltage associated with the sixteen bit word. This actual voltage is then stored in variable, **ActVolRead**. Furthermore, the actual voltage is divided by the analogue gain to obtain the true voltage reading that is present on the bars before the analogue gain. Note that the variable named “Gain” holds the value of the analogue gain as set using the Instrumentation Amplifiers external gain resistor R_G.

```
Let ActVolReadRes = (4.096 / 65536)
Let ActVolRead = (StnBit_WD * ActVolReadRes)
Let mVActVolRead = (ActVolRead / Gain)
```

For the calculation of the percentage variance however, these actual voltage values are not used. The percentage variance is calculated using the numerical value of the sixteen bit words that are stored in variable **StnBit_WD** (which holds the value of present reading) and that stored in variable **Reference** (which holds the value of the reference reading). This is done in order to use values as close to the original recorded values as possible and to decrease the probability of any errors that may arise by using values that have been rounded off. The equation below is responsible for the calculation of the percentage variance of the present reading from the reference reading.

```
Current Variance = (((Abs(StnBit_WD - Reference)) / Reference) * 100)
```

Abs is a Visual Basic function that produces the absolute value of a mathematical calculation. Here it is used to provide the absolute value for the difference between the present reading value (**StnBit_WD**) and the reference reading value (**Reference**) as either value may be greater than the other for any reading taken. This value is then divided by the reference value and multiplied by a hundred to obtain the percentage variance.

The next step is to compare the percentage variance value (**Current Variance**) to the allowable or pre-selected percentage variance that was selected by the user. Recall that this pre-selected percentage variance is stored in variable, **Percentage**.

```
If (Current_Variance > Percentage) Then
List1.AddItem "Fault on Bar:  " & Text6.Text & ",    Percentage Variance = " &
                 "Current_Variance & ",    Segment Reading: " & ActVolRead & "V" &
                 ",    Reference Reading: " & ActReference & "V"
Let Text8.Text = Val(Text8.Text) + 1
End If
```

The statements above show the comparison between the two values. In the instance where **Current Variance** is greater than **Percentage**, a fault will be recorded in the Fault Log display.

Another subprogram that is executed on every bar is the calculation of the number of bars that remain to be tested. The Bar_count subprogram decrements the number of bars that remain to be tested (stored in variable No_of_Bars) by one each time the controller transmits an increment prompt (ASCII code for the letter 'I'). This increment prompt is transmitted by the controller before the rotation of the armature under test is initiated hence the total number of bars is decremented before the very first rotation.

With this in mind, the reader will follow that when the increment signal is transmitted by the controller before the last pair of bars is tested, the decremented value in Bar_count will be zero. After the last pair of bars has been tested and when the controller next sends an 'I' the decremented value will be less than one. It is at this point that the GUI signals to the controller that the last bar has been tested and that the test must now end.

The prompt to the CM which signals that the last bar has been tested is the ASCII code for the letter 'P'. For every increment signal received by the GUI before the last one, the ASCII code for the letter 'p' is transmitted to the controller to indicate the last bar has not been tested and that rotation should be initiated.

3.3 The Remote Graphic User Interface (RGUI)

The Remote Graphic User Interface is used by authorised users in remote locations to view test records via the network, see Appendix F for a true representation of the RGUI and Appendix G for a printout of the associated code. The RGUI can only access information when the test station GUI stores data in a location on the network by mapping the network as a drive. The Default Path that is set on the RGUI must be the same as that of the GUI on the workshop floor. The RGUI only allows users to read and print information from saved files. Note that the format in which test data is displayed is exactly the same as the format in which the GUI displays retrieved file data as shown in Figure 3-37A and Figure 3-37B.

The user cannot edit, replace or delete files from a remote location. The RGUI contains three fields, namely the Search Information field, Data Display field and Directory path field. The inputs and button prompts are much the same as those on the test station GUI. They carry out the same functions and operate in the exact same way. The only variation from the test station GUI is the File Names and Refined Search – Dates display lists. The File Names list and contents is the same as the list that appears on the test station GUI when the Open button is clicked. In the RGUI this list box is permanently displayed.

The Refined Search – Dates list and contents is the same as the list that appears when a serial number is clicked on in the serial number list on the GUI. Here as well, the difference is that this list box is permanently displayed on the RGUI. As in the GUI, when Open is clicked, an input box appears prompting the user to enter a serial number. If a valid serial number is entered all test results for that serial number will be displayed in the Data Display screen. If ‘Find’ is entered into the input box the serial numbers of all tested armatures are displayed on the RGUI in the File Names list.

Upon selecting an item from this list, all dates on which tests were carried out on the selected armature as well as a ‘View All’ option appears in the Refined Search – Dates list. By selecting a specific date the results of test(s) carried out on that date will be displayed in the Data Display screen. If ‘View All’ is selected, results of all tests carried out on the selected armature are displayed. All other functionalities that are available on the RGUI operate in the same manner as those on the GUI.

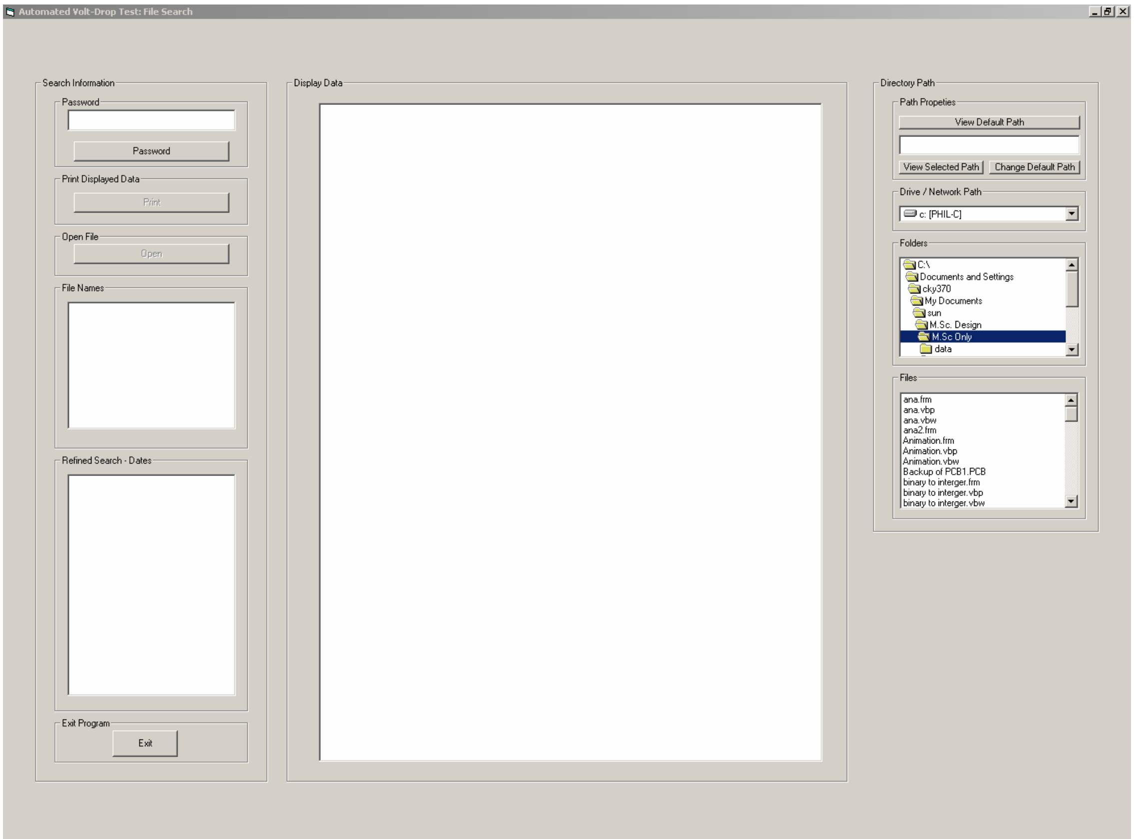


FIGURE 3-36: REMOTE GRAPHIC USER INTERFACE (RGUI)

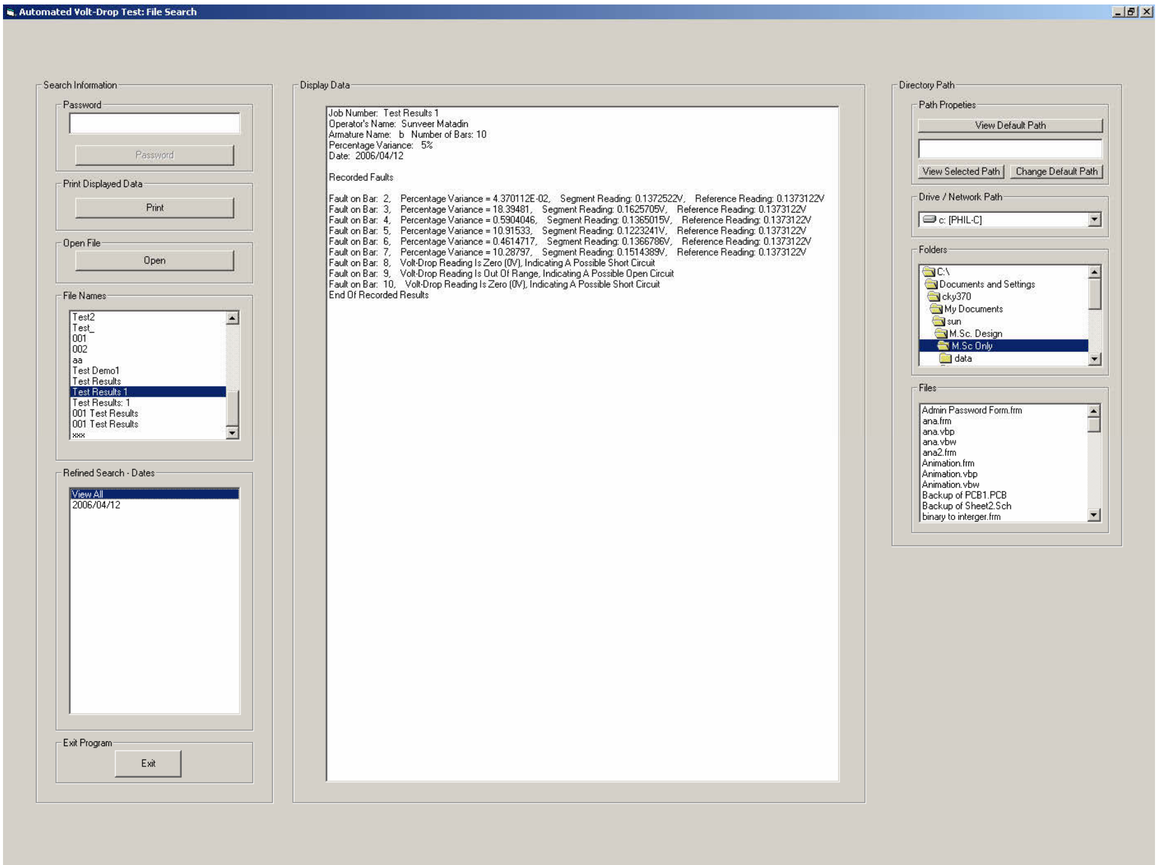
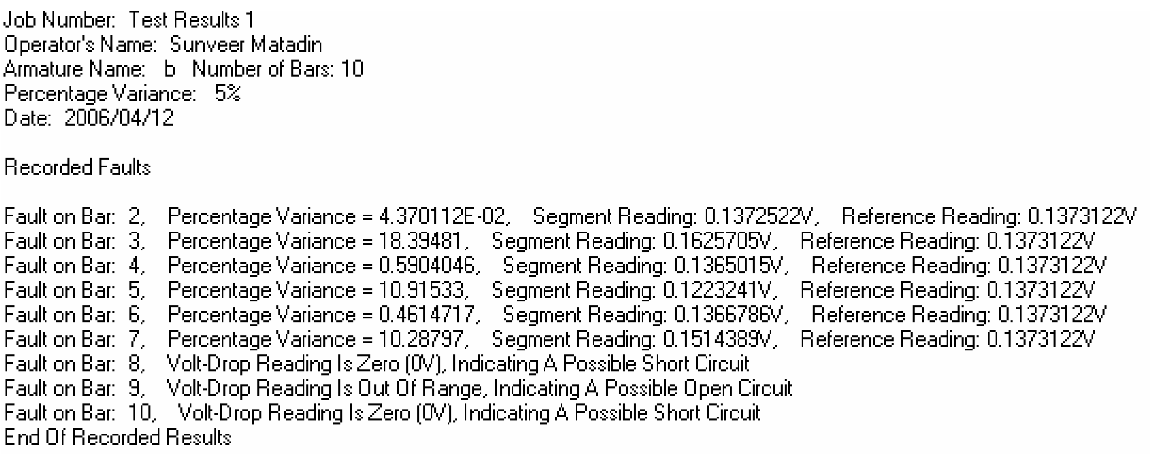


FIGURE 3-37A: REMOTE GRAPHIC USER INTERFACE (RGUI) DATA DISPLAY


Job Number: Test Results 1
Operator's Name: Sunveer Matadin
Armature Name: b Number of Bars: 10
Percentage Variance: 5%
Date: 2006/04/12

Recorded Faults

Fault on Bar: 2, Percentage Variance = 4.370112E-02, Segment Reading: 0.1372522V, Reference Reading: 0.1373122V
Fault on Bar: 3, Percentage Variance = 18.39481, Segment Reading: 0.1625705V, Reference Reading: 0.1373122V
Fault on Bar: 4, Percentage Variance = 0.5904046, Segment Reading: 0.1365015V, Reference Reading: 0.1373122V
Fault on Bar: 5, Percentage Variance = 10.91533, Segment Reading: 0.1223241V, Reference Reading: 0.1373122V
Fault on Bar: 6, Percentage Variance = 0.4614717, Segment Reading: 0.1366786V, Reference Reading: 0.1373122V
Fault on Bar: 7, Percentage Variance = 10.28797, Segment Reading: 0.1514389V, Reference Reading: 0.1373122V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Fault on Bar: 10, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
End Of Recorded Results

FIGURE 3-37B: REMOTE GRAPHIC USER INTERFACE (RGUI) DISPLAY FORMAT

Chapter 4

Microcontrollers and Embedded Programming

In this chapter the core of the controller will be discussed. This core comprises a pair of microcontrollers that communicate with each other via their port pins in order to perform the appropriate physical tasks, at the precise time, based on information received from the GUI and transducers on the automated machine i.e. the Physical Test Station. Both are AT89S51 microcontrollers and are enhanced derivatives of the 8051 [9] family. These microcontrollers were chosen on the basis of them having the following essential features: four eight pin input/output ports, 4K bytes of Flash memory, two external interrupts, two sixteen bit timers and a full duplex UART serial channel. For further information on this microcontroller, see Appendix H for a comprehensive datasheet.

A microcontroller is the bridge between software instructions (commands) and electrical hardware. Programs written in C, Assembly [9] or any other compiler compatible language are compiled and assembled, and stored in the microcontroller memory which is most likely to be EEPROM technology. The speed at which these programs are stepped through (or executed) is dependent on the length of time that one machine cycle takes to execute and the number of machine cycles that are required for each instruction to execute. Depending on the instruction, data is either processed or input and output ports are addressed to either read signals or produce signals to or from interfacing electrical hardware.

The length of time that one machine cycle takes to execute depends on the frequency of the oscillator that provides the clocking source for the microcontroller. This design is not time critical which means that commands based on processed information did not have to execute at a very rapid rate. It is for this reason that a 12MHz quartz crystal was chosen to drive the on-chip oscillator resulting in a machine cycle of one microsecond (1µs) duration. The tasks performed by these microcontrollers do not involve complex mathematical calculations or algorithms. It is for this reason that code was written in assembly language as opposed to a higher level programming language. The advantages that assembly language has over higher level languages for these types of applications (bit manipulation, logic operations and input/output port interaction) are execution speed and the efficient use of program memory space. The Acebus development environment was used to develop and simulate the code for both microcontrollers. This tool allows the developer to write, assemble, simulate and debug code written in assembly language. In the simulation environment, code can be stepped through line-by-line and the changes in the respective registers, special function registers, input/output ports etc. are reflected accordingly. See Figure 4-1A and Figure 4-1bB for screen captures of the Acebus development environment and Appendix I for a labeled representation of the development environment.

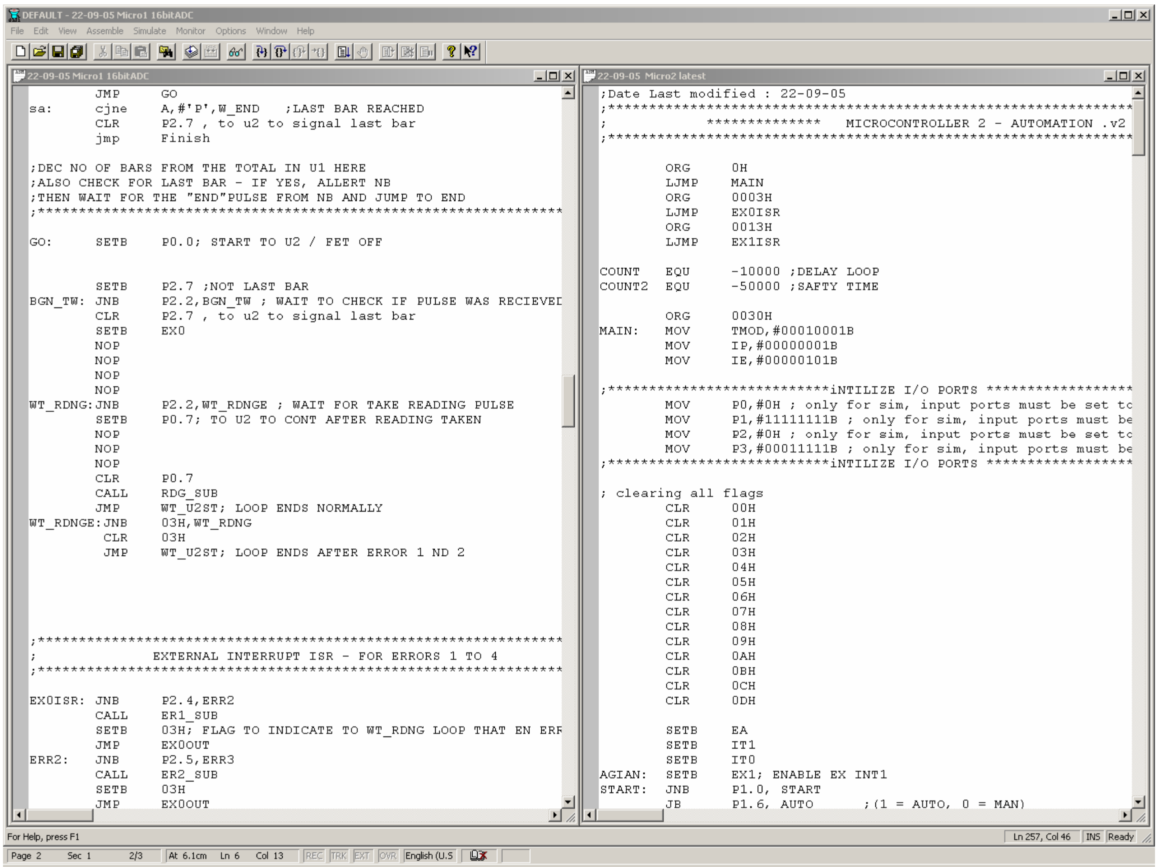


FIGURE 4-1A: SCREEN CAPTURE OF THE ACEBUS DEVELOPMENT ENVIRONMENT

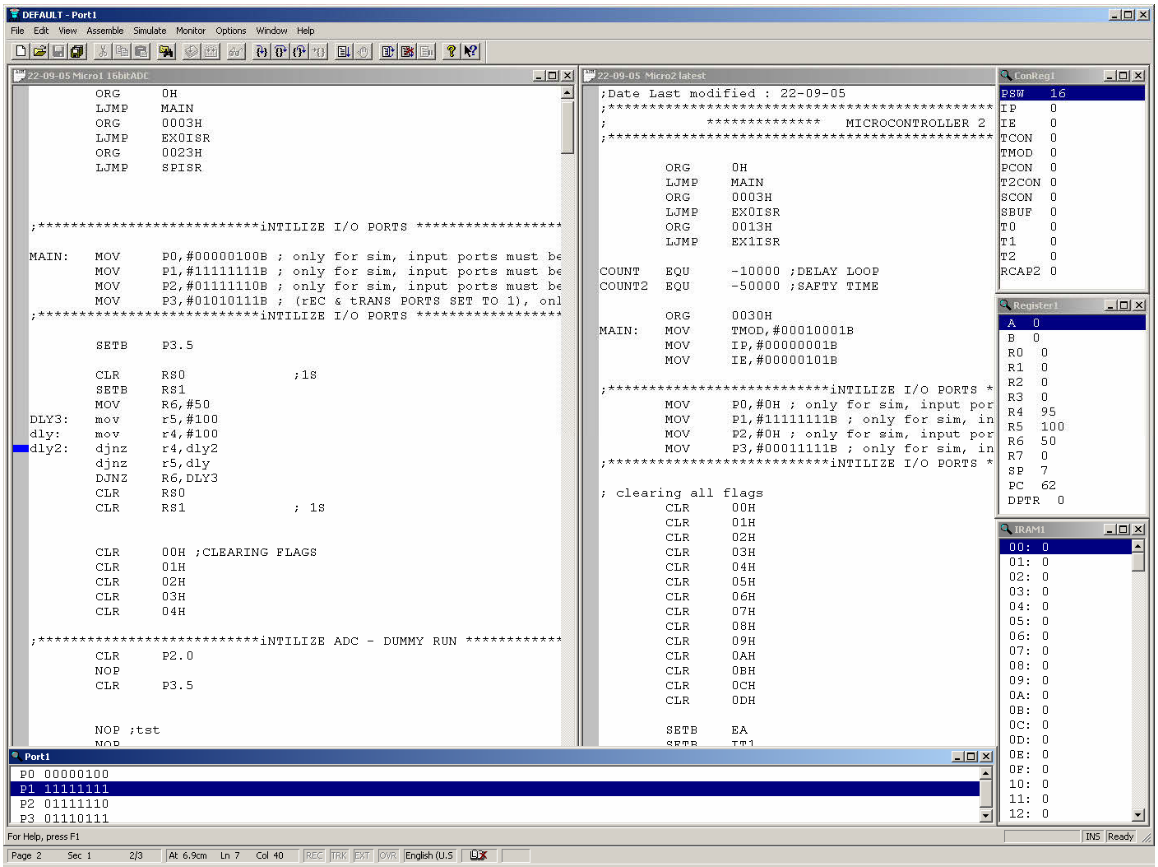


FIGURE 4-1B: SCREEN CAPTURE OF THE ACEBUS DEVELOPMENT ENVIRONMENT IN SIMULATION MODE

Each microcontroller has a specific function, one being communication and acquisition of data as performed by the Communication Microcontroller (CM) and the other being the control of the automation tasks as performed by the Automation Microcontroller (AM).

4.1 The Communication Microcontroller

The Communication Microcontroller communicates with the GUI via its onboard serial port and with the Automation Microcontroller and the Analogue-to-Digital Converter (ADC) via its input/output pins (I/O pins). See Appendix Q for a detailed discussion including flow diagrams and code extracts.

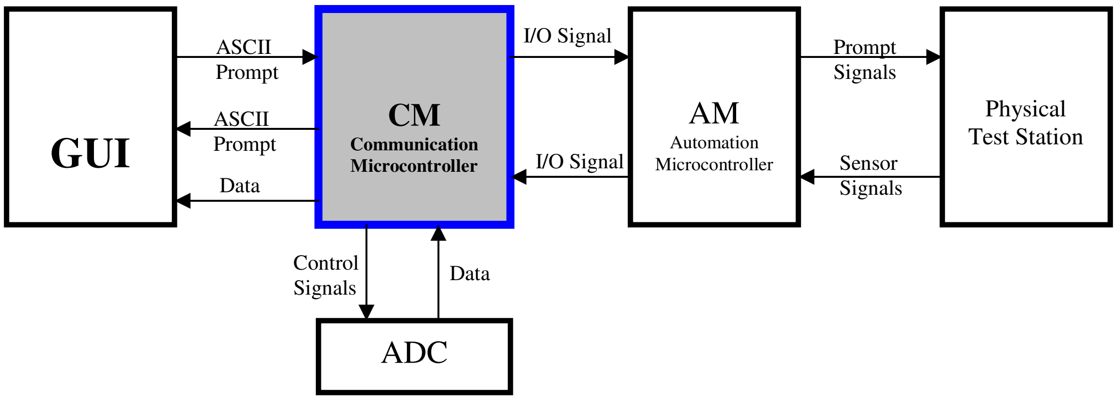
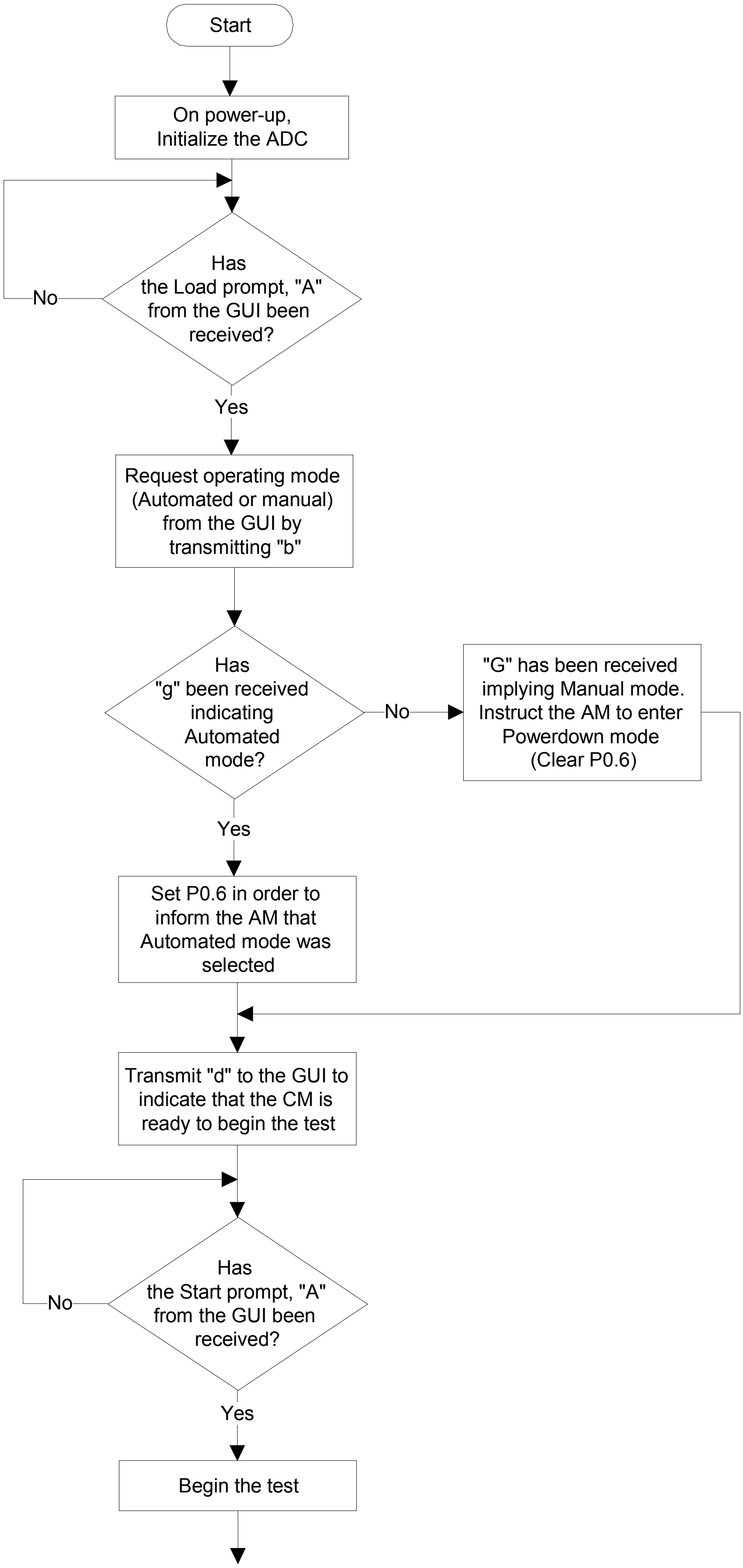


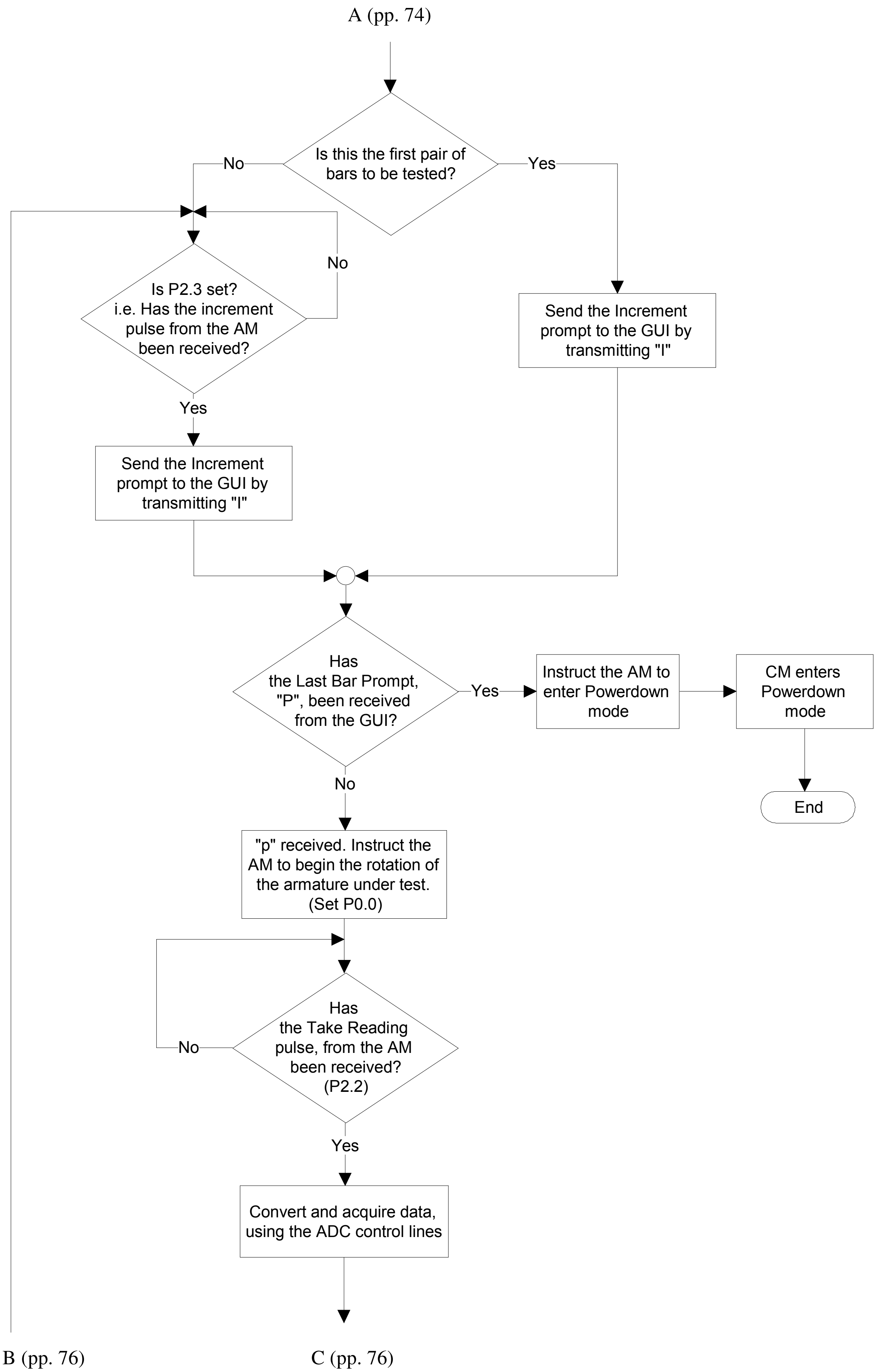
FIGURE 4-2: SYSTEM BLOCK DIAGRAM

The function of the CM includes the transmission and reception of prompts to and from the GUI, the control of the ADC, the capture of data (high and low bytes) and storage thereof in two registers in its memory and the transmission of this data to the GUI for analysis. When the analysis is complete the GUI prompts the CM which in turn signals the AM to continue with the test.

While the AM is in control it communicates with the CM in the event of any system errors. If no errors occur, the AM will hand over control to the CM in order for the CM to take the volt-drop readings after the test current has been switched on and the test probes have been lowered onto the bars of the commutator. These readings are then transmitted to the GUI and so the process continues until the last pair of bars has been tested. See Figure 4-3 for the flow diagram of the CM. A discussion follows thereafter.


Start
On power-up, Initialize the ADC
Has the Load prompt, "A" from the GUI been received?
No
Yes
Request operating mode (Automated or manual) from the GUI by transmitting "b"
Has "g" been received indicating Automated mode?
No
"G" has been received implying Manual mode. Instruct the AM to enter Powerdown mode (Clear P0.6)
Yes
Set P0.6 in order to inform the AM that Automated mode was selected
Transmit "d" to the GUI to indicate that the CM is ready to begin the test
Has the Start prompt, "A" from the GUI been received?
No
Yes
Begin the test

A (pp. 75)


A (pp. 74)
Is this the first pair of bars to be tested?
No
Yes
No
Is P2.3 set? i.e. Has the increment pulse from the AM been received?
Send the Increment prompt to the GUI by transmitting "I"
Yes
Send the Increment prompt to the GUI by transmitting "I"
Has the Last Bar Prompt, "P", been received from the GUI?
Yes
Instruct the AM to enter Powerdown mode
CM enters Powerdown mode
End
No
"p" received. Instruct the AM to begin the rotation of the armature under test. (Set P0.0)
No
Has the Take Reading pulse, from the AM been received? (P2.2)
Yes
Convert and acquire data, using the ADC control lines
B (pp. 76)
C (pp. 76)

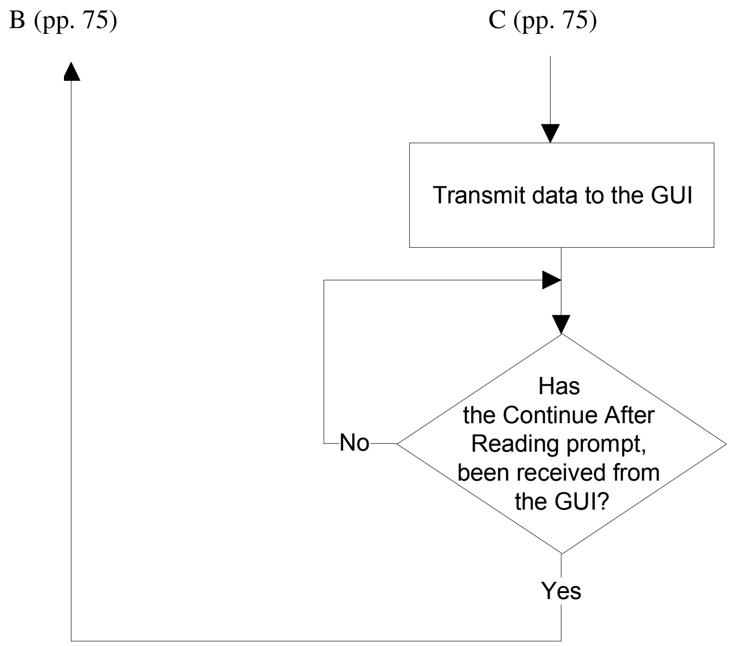


FIGURE 4-3: FLOW DIAGRAM FOR THE COMMUNICATIONS MICROCONTROLLER

On power up the CM initialises the ADC (i.e. the MAX 1166). With reference to the MAX 1166 datasheet, included as Appendix J, the ADC manufacturer's application information found on page 9 suggests that a 'dummy' conversion should be run in order to put the ADC in a known state after powering up from shut down. The CM then waits for the GUI to transmit a "Status: Ready" prompt, i.e. the ASCII code for the letter 'A'. When this has been received the CM transmits 'b' to the GUI to request the mode of operation in which the test is to be run. If a 'G' is received then the test is to be run in manual mode, the CM then informs the AM of this by Clearing (0) the CM P0.6 so that the AM can enter Powerdown mode.

The CM notes that the test is being run in manual mode by setting flag 04H in the bit addressable ram. This flag is tested in the CM Reading Subroutine in order to establish whether communication with the AM should be attempted. Recalling that AM is in Powerdown mode during a manual test any attempt by the CM to communicate with the AM will be futile and will ultimately leave the CM in a continuous wait loop as it will be waiting for communication signals from the AM that will never arrive. When flag 04H is tested in the Reading Subroutine and is found to be Set (1), the CM will not attempt to communicate with the AM as the test is being run in manual mode. However, if this flag is tested and is found to be Low (0) the CM will establish communication with the AM as the test will be running in automated mode. If a ‘g’ is received, the test will be run in the automated mode. The AM will be informed of this by Setting (1) the CM P0.6. Once the CM captures the mode of operation it transmits a ‘d’ to the GUI to indicate that it is ready to begin the test. As mentioned previously in the discussion relating to the GUI Start control, it is once the ‘d’ is received that the Start Button is enabled. On clicking the Start button an ‘A’ is transmitted by the GUI. On receipt of this prompt (‘A’) the controller begins the test.

For the first pair of bars to be tested the CM transmits an increment prompt to the GUI, which is the ASCII code for the letter ‘I’, without waiting for an increment signal from the AM. However, after the first pair of bars has been tested, the CM will wait for the increment signal from the AM before transmitting the ‘I’ prompt to the GUI. The increment signal from the AM is signaled by setting its output P0.0, High (logic level 1). See Appendix K for a complete list of Input/Output port utilisations for both microcontrollers.

The input P2.3 of the CM which is directly connected to P0.0 of the AM is then also read as a High. This High state on the CM input pin is recognised as an increment signal from the AM. This signal from the AM serves to inform the GUI, via the CM, that the system is ready to test the next pair of bars. When the increment prompt is transmitted to the GUI, the Bar_count subroutine is called in order to ascertain whether the last pair of bars has been tested. If it has been tested, the GUI transmits a ‘P’ to the CM to acknowledge that the test has been completed. On receiving this prompt the CM in turn informs the AM that the test is over and that Powerdown mode should be entered into. After verifying that the AM has received the command to enter Powerdown the CM itself enters Powerdown.

Note that in manual mode, the CM does not read an increment pulse from the AM as the AM is in Powerdown mode. An increment signal is generated by the user pressing on a switch that is connected to P3.6 which sends the increment prompt to the GUI.

The end of a test is signaled by the receipt of a ‘B’ prompt from the GUI. This prompt is transmitted when the END control button is clicked on the GUI. The prompt ‘B’ is transmitted regardless of the mode in which the test has been run. However in the automated mode the CM does not wait for the receipt of this prompt to enter Powerdown as it is already aware of the end of the test due to the AM increment signal and the GUI Bar_count subroutine.

If the last pair of bars has not yet been tested, the GUI transmits ‘p’. When the CM receives this signal it instructs the AM to begin the rotation of the armature under test by setting P0.0 High. The CM waits for the AM to detect the next pair of bars, stop the armature rotation, switch on the test current and lower the test probes onto the detected bars. Once the AM receives a signal from the detection unit, indicating that the test probes are on the commutator, it signals the CM to take a reading. When the CM reads P2.2 as a High it calls the subroutine that captures the volt-drop reading for the pair of bars under test. This subroutine will be discussed in detail later in this chapter. The captured data is stored as a High Byte and Low Byte in two registers in the CM memory (RAM). The CM then transmits each byte to the GUI where it is analysed. Upon completion of the calculation and the analysis process by the GUI, the GUI transmits an ASCII ‘E’ to the CM. This prompt serves to inform the CM that the data has been analysed and that the GUI is ready to proceed to the next pair of bars.

It should be noted that as an additional feature, one hundred consecutive readings are captured at 1000μs intervals and averaged for each pair of bars. The CM and GUI Reading Subroutines were therefore modified to enable this functionality. The details and discussion offered in this chapter are aimed at providing an understanding of the basic features and concepts before the more complex additional features are discussed in Chapter 6.

On receipt of this prompt, the CM informs the AM that it too is ready to proceed to the next pair of bars by setting its P0.7 High (1). On receiving a High on P1.7, the AM confirms that it is ready to proceed to the next pair of bars by setting its P0.1 High (1) which is the increment signal that the CM reads on its P2.3. When P2.3 is read as a High (1) the CM transmits the increment prompt (‘I’) to the GUI.

The CM follows this process until the last pair of bars has been tested or until any one of the four possible system errors interrupts the process flow. When such an interrupt is encountered there is a branch from the main program flow to an interrupt handling procedure (an ISR) that caters specifically for the encountered error. Once the error has been 'handled' control is handed back to the main program. These Interrupts, their associated Interrupt Service Routines (ISRs) and critical subroutines will be discussed in the sections that follow. See Appendix L for the source code for both the Communication and Automation microcontrollers.

4.1.1.1 External Interrupts

The CM makes use of External Interrupt 0 by enabling and disabling it on demand and initialising it with a low-level interrupt priority and negative-edge activation. The function of this interrupt is to indicate and service system errors if or when they occur and to inform the GUI (by transmitting a 'O') when a manual Emergency Stop has been initiated by pressing on the Emergency Stop switch (on P3.2) on the Test Station or by the activation of a safety interlock. Once the GUI has been informed of an Emergency Stop, the CM enters Powerdown mode.

Error1 occurs when a pair of bars is not detected within a specified time, Error2 occurs when the test probes are not present on the surface of the commutator within a pre-selected default time, Error3 occurs when the test current is not switched off after a pre-selected default time and Error4 occurs when the test probes are not raised to their original position within a specified time. The AM is the first to recognise any errors should they occur as system monitoring signals produced by proximity switches and other transducers are input to the AM via the interfacing digital system. The AM then sets High (1) output pins that correspond to the error that has occurred. See Appendix K and Table 4-5.

Automation Microcontroller (AM) – Automation Control		
P2.6	(27)	**O** – Error 4 – Test Probes Not Raised.
P3.5	(15)	**O** – Error 1 – Pair Not Detected.
P3.6	(16)	**O** – Error 2 – Test Probes Not Lowered.
P3.7	(17)	**O** – Error 3 – Current On-Time Exceeded.

TABLE 4-1: TABLE OF THE AM ERROR OUTPUT INDICATION PINS

These output pins are connected to individual input pins on the CM as well as the External 0 interrupt as depicted in Appendix K and Table 4-6.

Communications Microcontroller (CM) – Communication & Signalling		
P2.4	(25)	**I** – Error 1 – Pair Not Detected.
P2.5	(26)	**I** – Error 2 – Test Probes Not Lowered.
P2.6	(27)	**I** – Error 3 – Current On-Time Exceeded.
P3.2	(12)	**I** – **External Interrupt 0** – All Error Inputs Connected here as well.
P3.4	(14)	**I** – Error 4 – Test Probes Not Raised.

TABLE 4-2: TABLE OF THE CM ERROR INPUT INDICATION PINS

When a system error occurs, the AM signals the CM by setting the associated pin High (1). When any one of the error lines go High (1) the interfacing digital system also triggers External Interrupt 0.

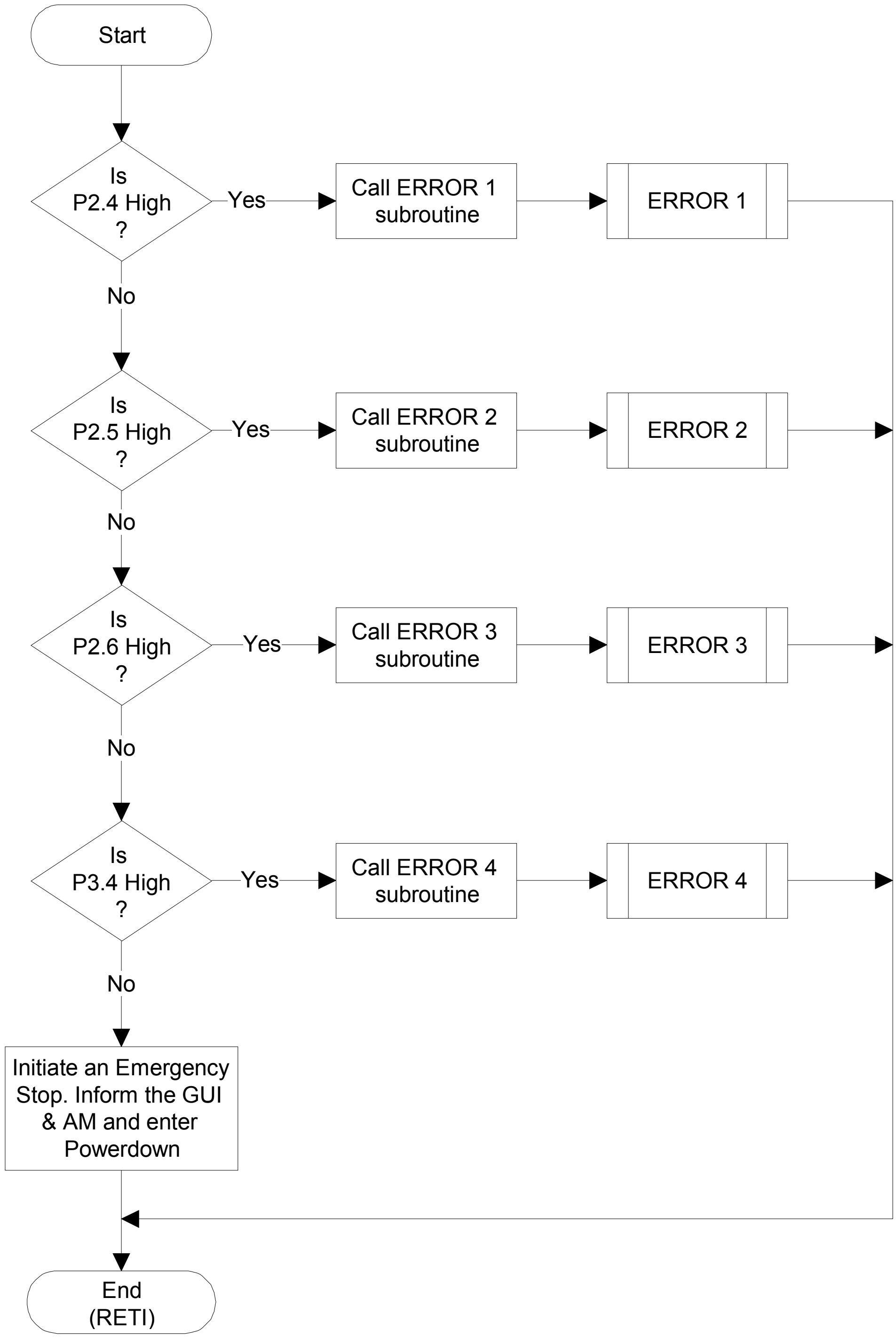


FIGURE 4-4: FLOW DIAGRAM FOR EXTERNAL INTERRUPT 0 – CM

When the interrupt is triggered the External Interrupt 0 ISR is initiated. Once in the ISR, each input error pin is tested for a High (1) status and when an error pin is identified the associated subroutine is called to handle it.

4.1.1.2 The Reading Subroutine

The Reading Subroutine is responsible for communication with the Reading subroutine in the AM, controlling the ADC via the ADC control lines, capturing the recorded data from the ADC and transmitting this data to the GUI.

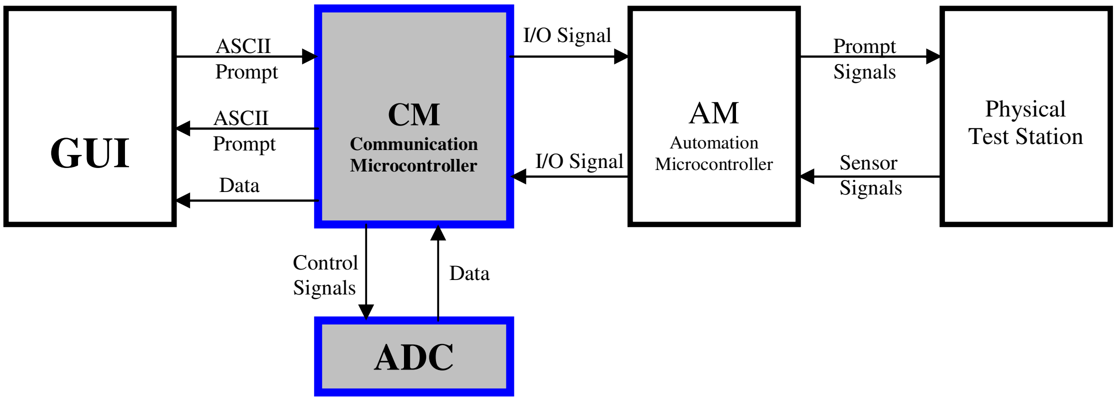
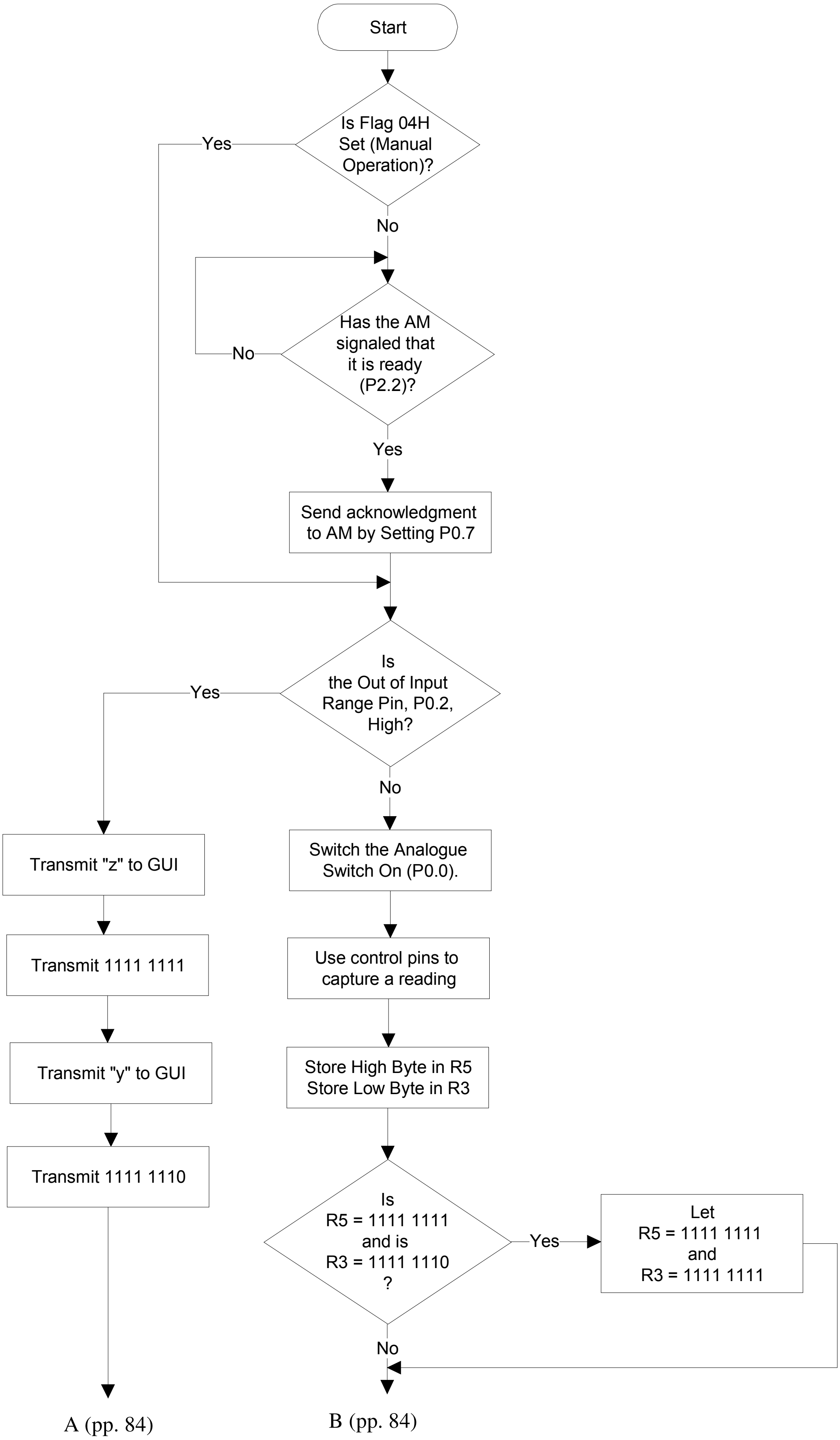


FIGURE 4-5: SYSTEM BLOCK DIAGRAM


Start
Is Flag 04H Set (Manual Operation)?
Yes
No
Has the AM signaled that it is ready (P2.2)?
No
Yes
Send acknowledgment to AM by Setting P0.7
Is the Out of Input Range Pin, P0.2, High?
Yes
No
Transmit "z" to GUI
Transmit 1111 1111
Transmit "y" to GUI
Transmit 1111 1110
Switch the Analogue Switch On (P0.0).
Use control pins to capture a reading
Store High Byte in R5
Store Low Byte in R3
Is R5 = 1111 1111 and is R3 = 1111 1110 ?
Yes
Let R5 = 1111 1111 and R3 = 1111 1111
No
A (pp. 84)
B (pp. 84)

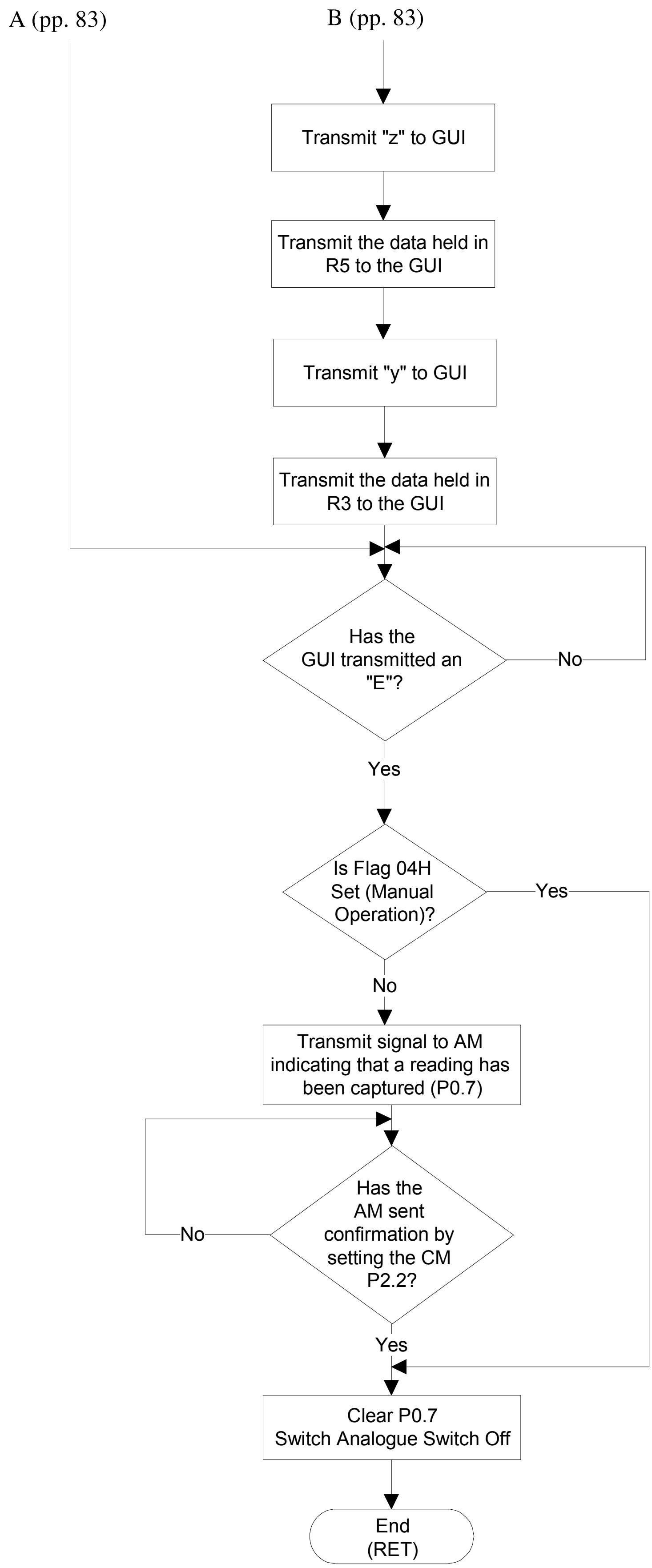


FIGURE 4-6: READING SUBROUTINE FLOW DIAGRAM

Once called the first operation undertaken by this subroutine is to verify whether flag 04H has been set. Flag 04H is set when the system is to be operated in Manual mode. When running in Manual mode the AM is in Powerdown and will therefore not respond to any communication signals from the CM. When operating in the Automated mode there is constant communication between the AM and the CM in order to maintain synchronisation.

Whilst operating in Manual mode this communication is fruitless as the CM will be waiting for signals from the AM which will never be transmitted. The CM will therefore be caught in an endless waiting loop. The reason for the testing of the 04H flag is to ensure that the CM knows if it should communicate with the AM (whilst in Automated mode) or if all its communication instructions should be skipped, whilst in Manual mode as discussed earlier in this chapter. Flag 05H is used to indicate that 100 successive readings are to be taken. This is an additional feature and will be discussed in Chapter 6.

If the system is in Automated mode, P2.2 is tested in order to verify that the AM has called and is presently executing its Reading subroutine and to ensure that it is ready to take a reading. The CM then confirms having received this signal by setting its P0.7 pin. As mentioned above, these steps are skipped when in Manual mode. Next, P0.2 is tested in order to verify that the reading about to be taken is within the maximum input range of the ADC and other interfacing circuitry. The exact mechanics behind this process will be discussed in detail in Chapter 5. However in order to facilitate a better understanding, the author will briefly discuss the principle and concept used.

Although the test is setup by the technician to record values within a particular range, 200mV to 350mV, the possibility exists that a volt-drop equal to the potential of the Test Supply can be recorded across a pair of bars. This will occur when the pair of bars being tested is connected to an open circuited winding. According to tests carried out by the author, the typical Test Supply potential when setting the aforementioned range is between ten and fifteen volts (10V to 15V) depending on the type and rating of the armature under test. As will be explained in chapter five the first stage in the input circuitry is more than capable of handling these values as well as negative input potentials, as in the case when the polarity of the Test Supply Current or the orientation of the input test probes is reversed. The ADC input stage cannot handle such potentials. The ADC absolute maximum rating for the input pin is positive 6 volts to negative 0.3V (+6V to -0.3V). It is for this reason that an Analogue Switch (MAX 4622) is placed on the ADC input line. This switch is only switched on by the CM when the interfacing analogue circuitry confirms that the potential on the ADC input line is safely within its operating range. This circuitry is explained in Chapter 5, Section 5.3.

If the CM P0.2 is High (1), the Analogue Switch is off due to the input value being out-of-range. In this case 1111 1111 (binary code) is transmitted as the High Byte and 1111 1110 (binary code) is transmitted as the Low Byte to the GUI as the reading for the pair presently under test. Upon receiving this value the GUI immediately recognises the out-of-range reading and displays a possible open circuit on this pair of bars. After this transmission the CM sits in a wait loop, waiting for the GUI to transmit the Continue Test prompt, i.e. 'E'. Note that in order to facilitate the 100 reading additional feature, a second prompt is used to verify that all 100 readings have been captured. This prompt is the ASCII code for the character 'S'. Further details on this additional feature will be provided in Chapter 6.

If P0.2 is low, the Analogue Switch is and the ADC can read the input potential. The ADC control pins are then prompted and read by the CM in order to capture a reading. The High Byte is stored in the CM register 5, R5 and the Low Byte is stored in the CM register 3, R3. See Appendix K for a list of the registers used for both the AM and CM.

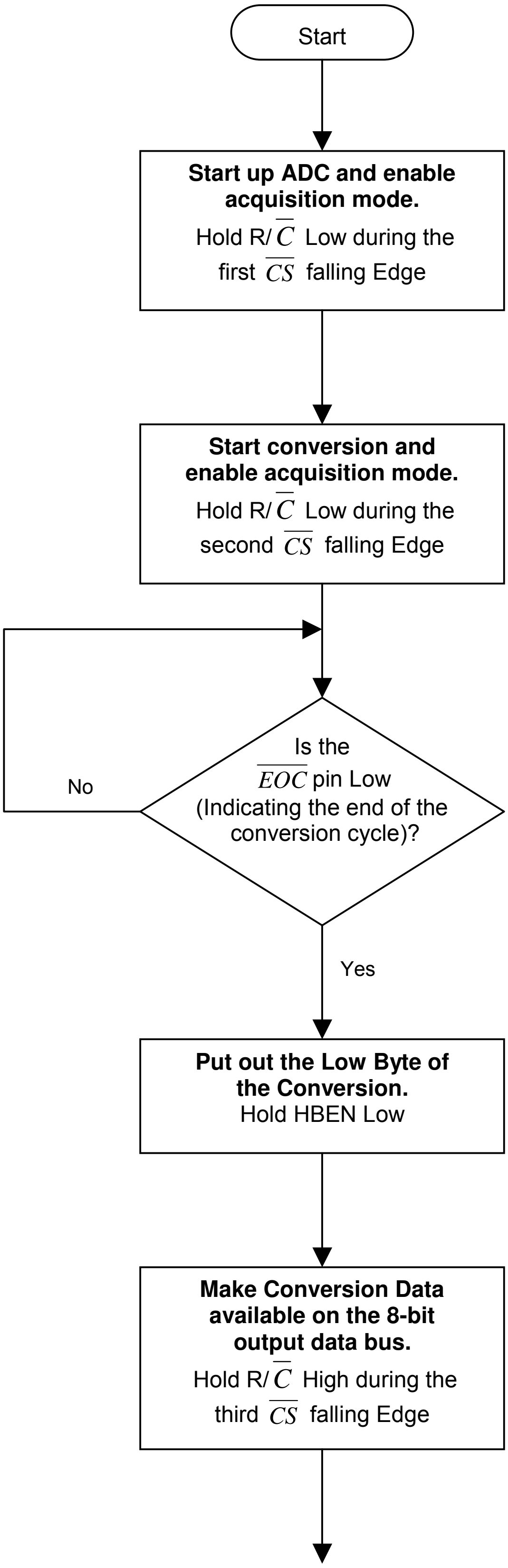
The next step is to check if R5 holds 1111 1111 and R3 holds 1111 1110. This is the previously mentioned out-of-range default value. If the default value has been recorded, the value held in R3 is changed to 1111 1111. This new value and the out-of-range default value should normally not be recorded on a non-fault bar. As discussed in Chapter 3, the ASCII code for the letter 'z' is transmitted to the GUI before the High Byte (the value held in R5) of the captured reading is transmitted to the GUI. The ASCII code for the letter 'y' is transmitted to the GUI before the Low Byte (the value held in R3) of the captured reading is transmitted to the GUI. The CM then waits for the GUI to process the transmitted data and informs the CM that it is ready to continue by transmitting an ‘E’ (the Continue Test prompt).

On receiving this prompt the CM again tests if flag 04H is set High (1). If it is not set High, then using P0.7 and P2.2 as described above, the CM communicates with the AM to inform it that the reading has been successfully captured, transmitted and analysed and that it should ready itself to proceed with the next task in the process. If the flag 04H is set, then this communication process is skipped as mentioned earlier. The CM then switches off the analogue switch on the ADC input line in order to protect the ADC in the event of an out-of-range input value on the next pair of bars. The subroutine is then exited and control is returned to the calling program at the statement immediately following the CALL instruction.

4.1.2 ADC Control

The ADC control pins and the associated connection pins on the CM are listed below. The $\overline{CS}$, Convert Start ADC input pin, is connected to the CM P3.5 pin which is configured as an output pin. The R/$\overline{C}$, Read/$\overline{Convert}$ ADC input pin is connected to the CM P2.0 pin which is configured as an output pin. The $\overline{EOC}$, End Of Conversion ADC output pin, is connected to the CM P2.1 pin which is configured as an input pin.

And finally, the HBEN, High-Byte Enable ADC input pin is connected to the CM P3.3 pin which is configured as an output pin. Figure 4-7 depicts the flow diagram that describes the process that is followed when the ADC captures a reading. Figure 4-8 depicts the flow diagram that shows the steps taken by the CM to implement the process followed in Figure 4-7. Figure 4-9 depicts the timing diagram for the ADC control process. See Appendix J to view the ADC (MAX 1166) datasheet.


Start
Start up ADC and enable acquisition mode.
Hold R/$\overline{C}$ Low during the first $\overline{CS}$ falling Edge
Start conversion and enable acquisition mode.
Hold R/$\overline{C}$ Low during the second $\overline{CS}$ falling Edge
Is the $\overline{EOC}$ pin Low (Indicating the end of the conversion cycle)?
No
Yes
Put out the Low Byte of the Conversion.
Hold HBEN Low
Make Conversion Data available on the 8-bit output data bus.
Hold R/$\overline{C}$ High during the third $\overline{CS}$ falling Edge

A (pp. 89)

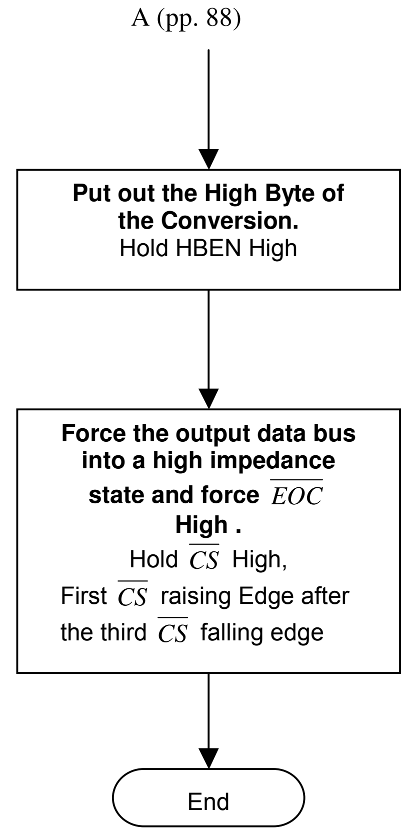
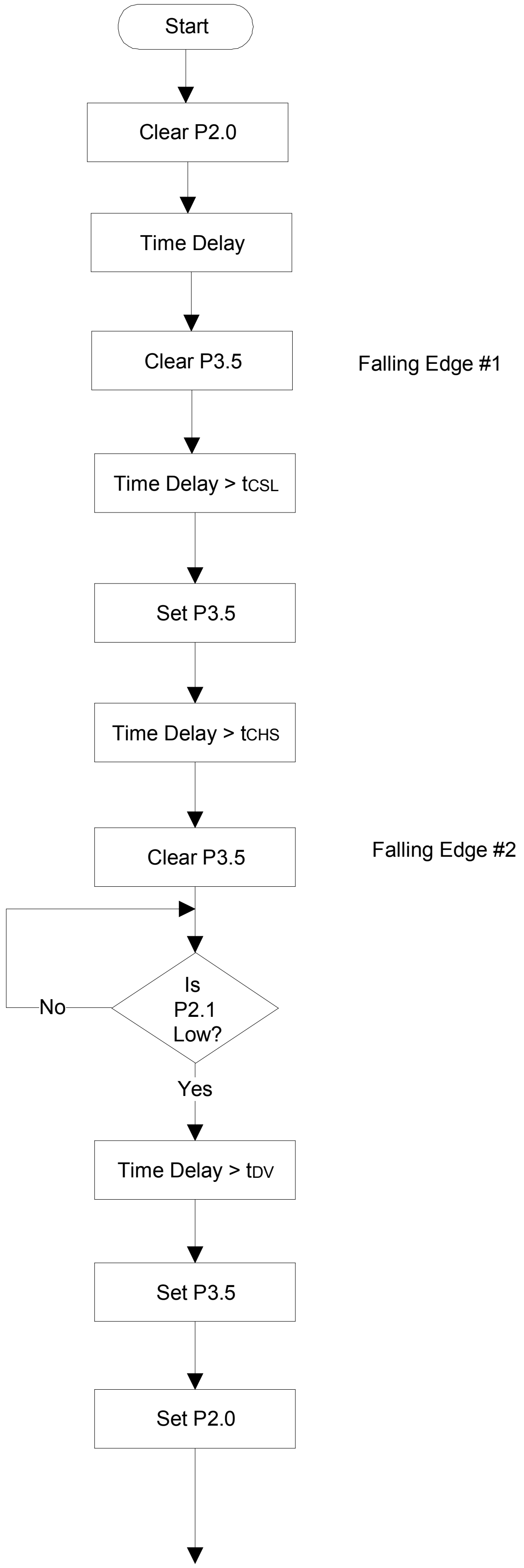


FIGURE 4-7: FLOW DIAGRAM FOR THE ADC CONTROL PROCESS


Start
Clear P2.0
Time Delay
Clear P3.5
Falling Edge #1
Time Delay > tCSL
Set P3.5
Time Delay > tCHS
Clear P3.5
Falling Edge #2
Is P2.1 Low?
No
Yes
Time Delay > tDV
Set P3.5
Set P2.0

A (pp. 91)

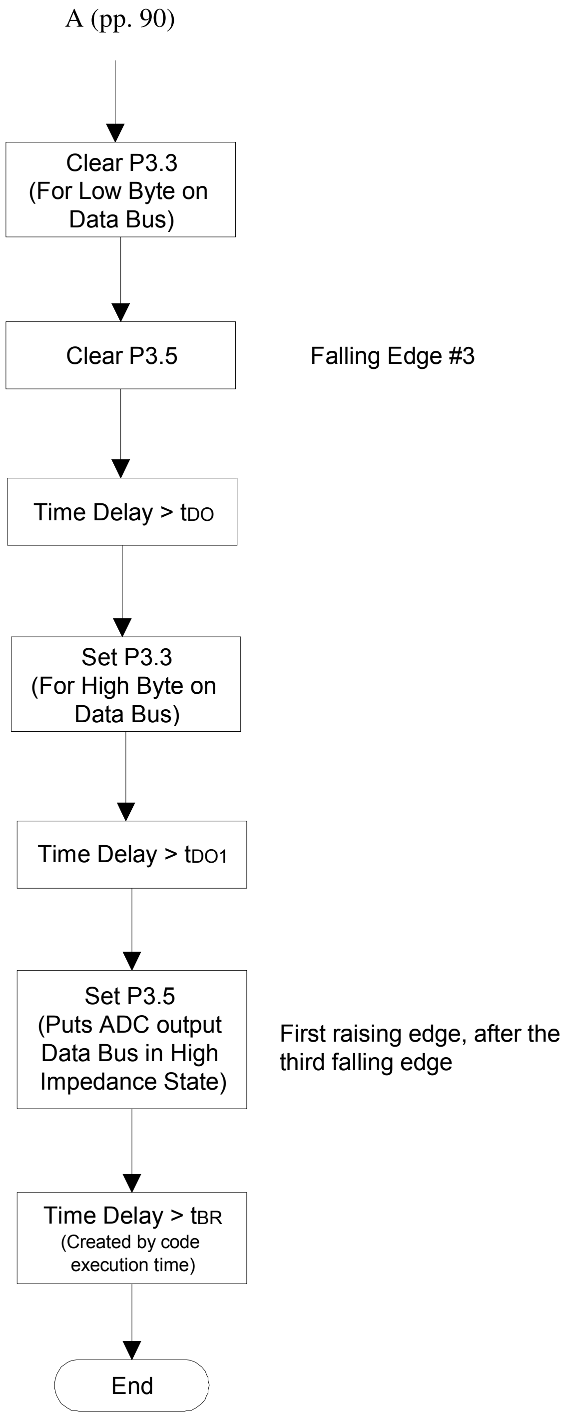
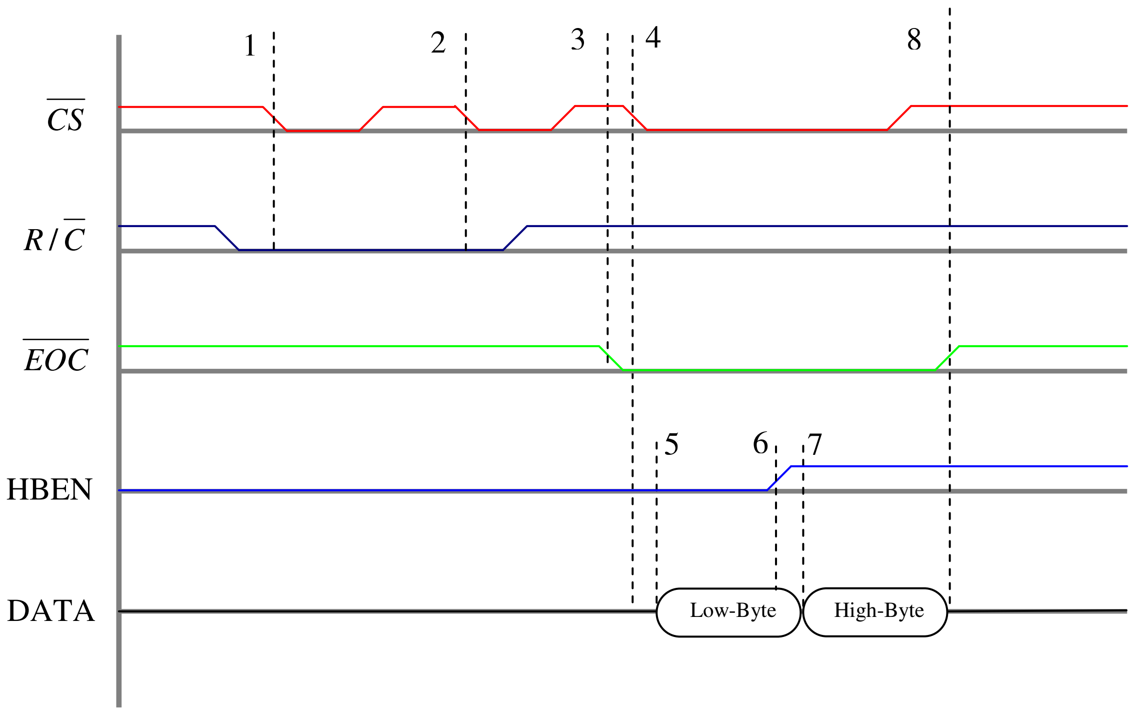


FIGURE 4-8: FLOW DIAGRAM OF STEPS TAKEN BY THE CM TO IMPLEMENT THE ADC CONTROL PROCESS



1. $\overline{CS}$ Falling Edge 1
2. $\overline{CS}$ Falling Edge 2
3. $\overline{EOC}$ Drives Low To Signal The End Of Conversion
4. $\overline{CS}$ Falling Edge 3
5. Valid Data Low-Byte Placed On The 8-Bit Output Bus
6. HBEN Toggled From Low To High
7. Valid Data High-Byte Placed On The 8-Bit Output Bus
8. Data Bus Forced to High Impedance State and $\overline{EOC}$ Is Forced High, After the First Rising Edge of $\overline{CS}$ Following the Third Falling Edge

FIGURE 4-9: TIMING DIAGRAM FOR ADC CONTROL PROCESS

4.2 Automation Microcontroller

The Automation Microcontroller (AM) controls the Physical Test Station based on input signals received from the Physical Test Station itself, as well as commands and prompts received from the CM and the GUI via the CM.

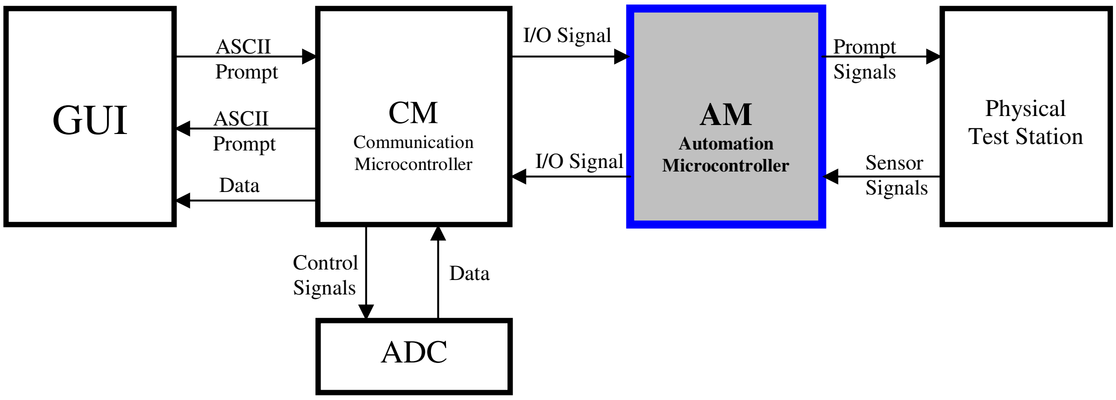


FIGURE 4-10: SYSTEM BLOCK DIAGRAM

This section will describe the tasks undertaken by the AM and the manner in which these tasks are executed. See Appendix Q for a detailed discussion including flow diagrams and code extracts. The previous section provided detailed explanations on all the relevant microcontroller functionalities, such as Timers, Interrupts, Subroutines etc. This section will concentrate solely on discussing the AM's use of these functionalities to efficiently complete specific tasks. In order to provide an overview of the AM's process flow a diagrammatic depiction is presented in the form of a flow diagram in Figure 4-12.

4.2.1 Explanation of functions, tasks and flow process

The program for the AM was developed using three control levels based on interrupts and interrupt priorities. The first level is the base level where the Main program has control. Here the required initialisations are carried out as well as the control and timing of the Armature Drive Motor and the calling of Error 1 subroutine, should Error 1 occur. When a pair of bars is detected, External Interrupt 1 is triggered and the External Interrupt 1 Interrupt service routine assumes control thereby entering the second control level. The EX1 ISR is responsible for stopping the Armature Drive Motor, the lowering and raising of the Detection Unit, switching of the Test Current, communication with the CM in order to capture the volt-drop readings and calling of error subroutines should the associated errors occur. The third level is the domain of the External Interrupt 0 (EX0) ISR. EX0 is assigned a higher priority than EX1 and can therefore interrupt the EX1 ISR as in the case when the test probes have reached the surface of the detected bars. In fact this is the function of EX0, i.e. to ascertain the status of the Detection Unit. When the test probes reach the surface of the bars EX0 is triggered, the Detection Unit Drive Motor is stopped and the time taken for the probes to be lowered to the surface of the bars is recorded in the EX0 ISR. EX0 is also triggered when the test probes have been raised to their initial position.

In summary, the base level allows for initialisations and also prompts the Armature Drive Motor to begin the rotation of the armature under test. When a pair of bars is detected EX1 is triggered and EX1s ISR is initiated as the second control level and assumes control from the base level. In the EX1 ISR, the Armature Drive Motor is stopped, the Detection Unit Drive Motor is prompted to lower the Detection Unit and the Test Current is switched on. The time taken for the test probes to reach the bars allows the test current to settle. Once the test probes on the Detection Unit reach the surface of the bars EX0 is triggered, the EX1 ISR is interrupted and the EX0 ISR executes initiating control level three and assuming control from the EX1 ISR. When the EX0 ISR has stopped the Detection Unit Drive Motor and has completed recording the relevant times, the ISR is exited and control is handed back to the EX1 ISR hence control level two.

The EX1 ISR then proceeds to communicate with the CM and a volt-drop reading is taken after which the Detection Unit Drive Motor is prompted to raise the Detection Unit. When the Detection Unit Drive Motor reaches its initial position EX0 is again triggered thereby initiating control level three and assuming control from the EX1 ISR and control level two. The EX0 ISR stops the Detection Unit Drive Motor and exits handing control back to EX1 ISR and control level two. EX1 ISR is then also exited and control is handed to the base control level and the Main program. Based on the commands from the GUI via the CM, the cycle is repeated until the last bar is tested. See Figure 4-11 for a diagrammatic representation of the above discussion. A more detailed explanation of the Automation Microcontrollers process flow follows after Figure 4-12.

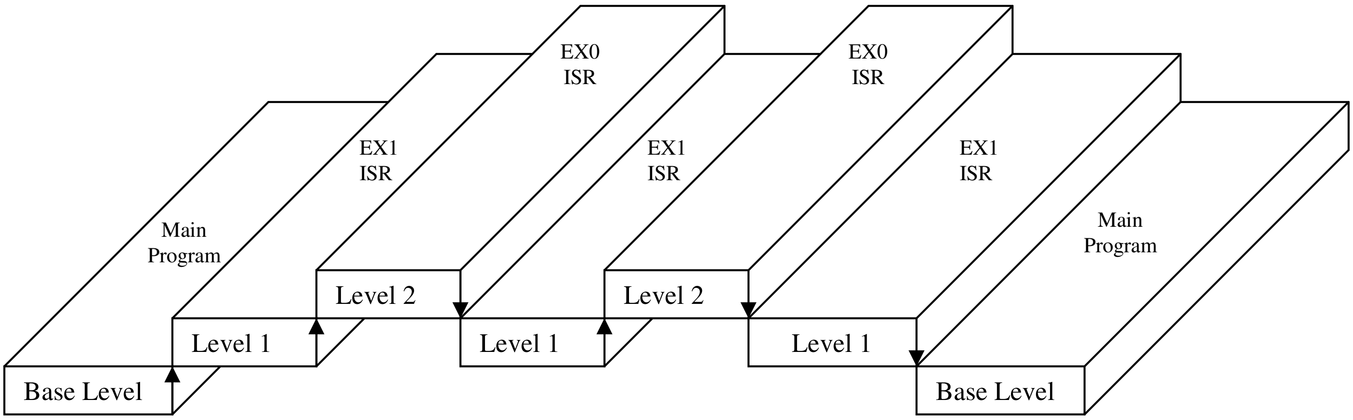
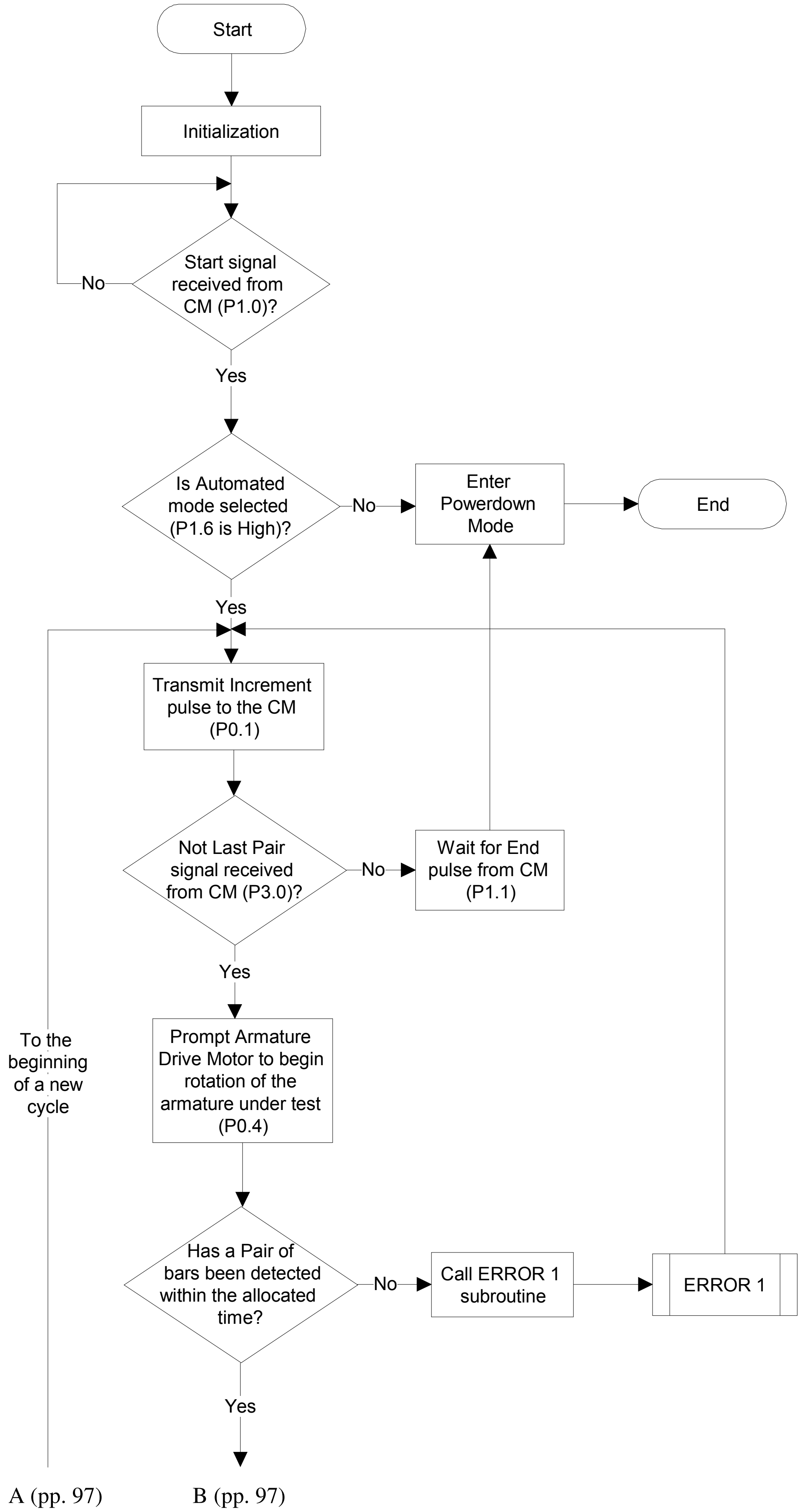
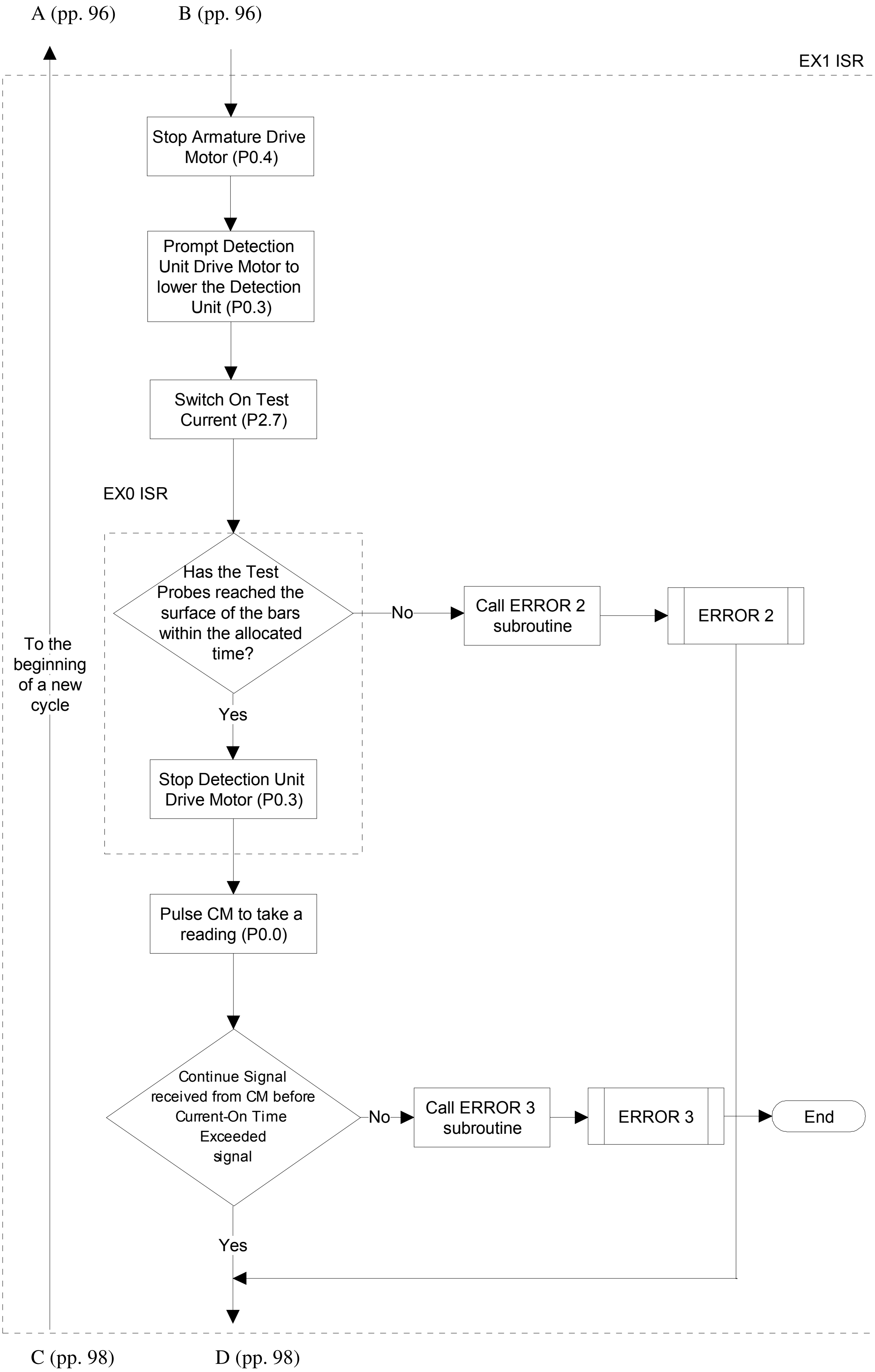


FIGURE 4-11: DIAGRAMMATIC REPRESENTATION OF THE THREE LEVEL CONTROL SYSTEM


Start
Initialization
Start signal received from CM (P1.0)?
No
Yes
Is Automated mode selected (P1.6 is High)?
No
Enter Powerdown Mode
End
Yes
Transmit Increment pulse to the CM (P0.1)
Not Last Pair signal received from CM (P3.0)?
No
Wait for End pulse from CM (P1.1)
Yes
Prompt Armature Drive Motor to begin rotation of the armature under test (P0.4)
To the beginning of a new cycle
Has a Pair of bars been detected within the allocated time?
No
Call ERROR 1 subroutine
ERROR 1
Yes
A (pp. 97)
B (pp. 97)


A (pp. 96)
B (pp. 96)
EX1 ISR
Stop Armature Drive Motor (P0.4)
Prompt Detection Unit Drive Motor to lower the Detection Unit (P0.3)
Switch On Test Current (P2.7)
EX0 ISR
Has the Test Probes reached the surface of the bars within the allocated time?
No
Call ERROR 2 subroutine
ERROR 2
Yes
Stop Detection Unit Drive Motor (P0.3)
To the beginning of a new cycle
Pulse CM to take a reading (P0.0)
Continue Signal received from CM before Current-On Time Exceeded signal
No
Call ERROR 3 subroutine
ERROR 3
End
Yes
C (pp. 98)
D (pp. 98)

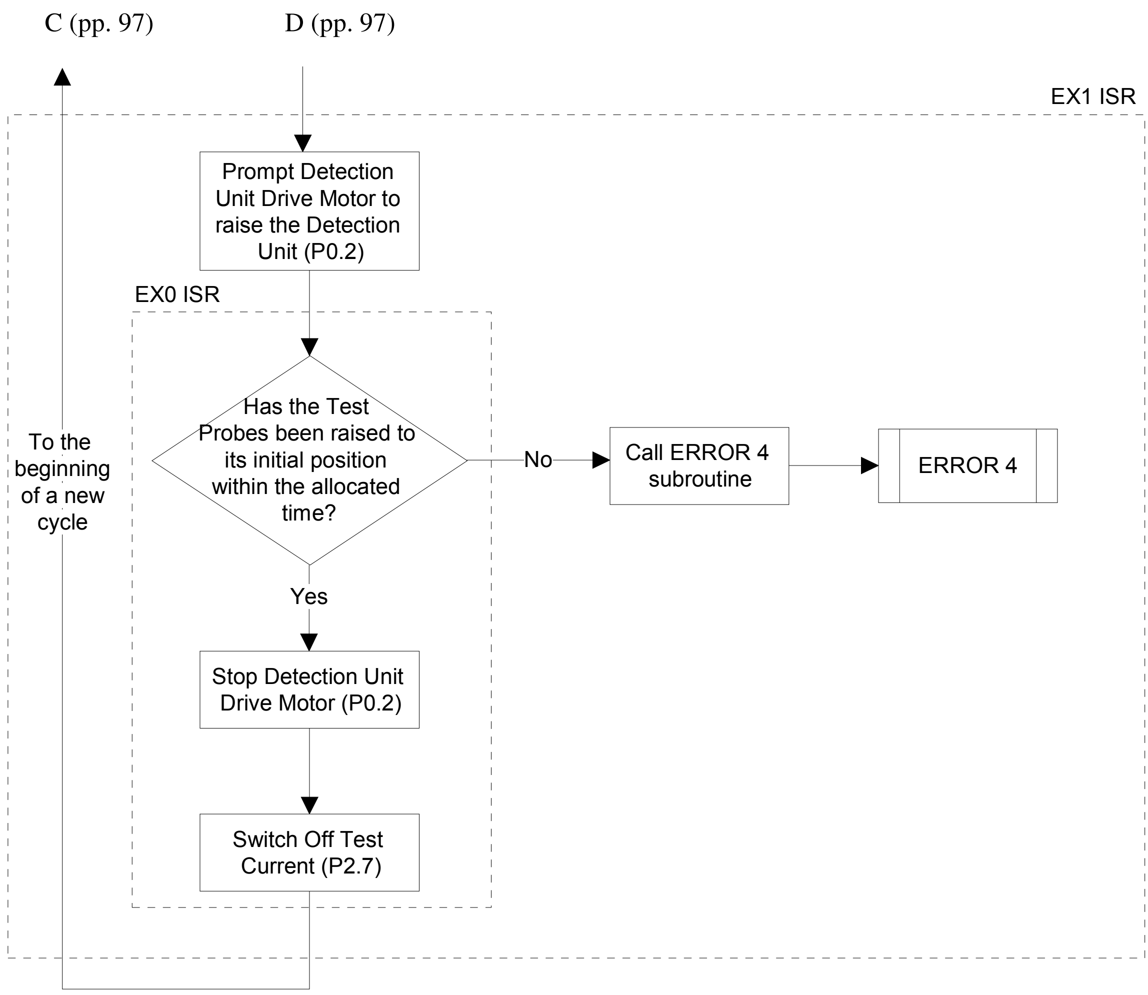


FIGURE 4-12: FLOW DIAGRAM FOR THE AUTOMATION MICROCONTROLLER

The AM first executes an initialisation process in which all the timers, interrupts and input/output ports that will be utilised for the duration of a test are initialised. Thereafter the AM waits for the start pulse from the CM on P1.0. Upon receiving this pulse, the AM tests P1.6 to ascertain whether the test will be run in the Automated or Manual mode. If P1.6 is High (1) then the Manual mode has been selected and the AM initiates Powerdown mode. If P1.6 is Low (0) then the Automated mode has been selected and the AM Sets (1) and Clears (0) P0.1, which is responsible for signaling 'Increment The Number Of Bars'.

The AM then waits for the GUI to inform it, via the CM, whether or not the last pair of bars has been tested. If P3.0 is Low (0), then the last pair of bars has been tested and the AM waits for the End command from the GUI via the CM. Once this is received, the AM enters Powerdown mode. If P3.0 is High (1), then the last pair has not been tested and the command is given to the Armature Drive Motor to initiate the rotation of the armature under test by setting P0.4 High (1). The AM then waits for the next pair of bars to be detected while timing the period between the initiation command and moment when the pair of bars has been detected. Detection of a pair of bars triggers External Interrupt 1 (EX1). If EX1 is not triggered before the maximum allowable time for detection is exceeded, Error 1 has occurred and the associated subroutine is called. Recall that Error 1 occurs when a pair of bars has not been detected within the maximum allowable time. The maximum allowable time for detection for each of the first three pairs is a preset value of 10 seconds.

The time duration recorded on the third pair of bars is stored to be used to calculate a tolerance or the maximum allowable time for the detection of a pair of bars after initiating the rotation of the armature under test. This new maximum allowable time will be the Detection Reference Time for the duration of the test. The time recorded on the third pair plus twenty percent is used as the reference value, i.e.

$$\text{Detection Reference Time} = \text{Third Pair Time Recording} \times 1.2$$

From the fourth pair of bars onwards, if EX1 is not triggered before the Detection Reference Time has expired, Error 1 subroutine is called. The use of the Detection Reference Time allows for greater control of the system as the unique reference value that is used for the duration of the test is based on the bar widths and spaces between the bars of the particular armature under test. In this way an error is detected sooner than if a preset value that catered for all armatures was used, hence the possibility of excessive damage to the system and the armature under test due to a system error is reduced. The reason that the Detection Reference Time is calculated based on the time recorded for the third pair of bars is simply because the system is given time to settle during the first and second cycles.

The question that now arises is what happens if a detection error occurs on the third pair of bars, i.e. when the time is being recorded to calculate the Detection Reference Time? The answer is that if Error 1 was called before External Interrupt 1 was triggered, then a time period will not be recoded as all time recordings is done by the

External Interrupt 1 interrupt service routine (ISR). The Error 1 subroutine does not have the capability to perform any time interval recording. Hence the value that will be used to calculate the Detection Reference Time will now be recorded on the next detection cycle, i.e. on the fourth pair of bars. However, to introduce redundancy, the Error 1 subroutine also takes appropriate measures when this event occurs. Note that the use of timers to record time, set preset intervals and introduce delays is discussed in Section 4.1.4.

When a pair of bars has been detected before the Detection Reference Time has exceeded, hence triggering EX1, the rotation of the armature under test is immediately stopped by Clearing (0) P0.4. The rest of the process from this point forward is executed in the External Interrupt 1 ISR. From this ISR, the signal to the Detection Unit Drive Motor to begin lowering the Detection Unit is given. The Test Current is also switched on by Setting (1) P2.7. The Test Current is switched on before the Test Probes on the Detection Unit reach the bars as opposed to when they are already on the bars. This is done to prevent large voltage spikes due to the switching of the large test current to the inductive load (i.e. the inductance (L) of the armature under test), from damaging the input circuitry.

The Test Probes must not be confused with the Test Current Probes. The Test Current Probes are the probes from which the Test Current is injected though the armature under test via an IGBT. The Test Current Probes are lowered onto the commutator and are fixed into place at the start of the test and are in no way attached to the Detection Unit. These probes are not raised off or lowered onto the commutator as in the case of the Test Probes on the Detection unit. The Test Current is switched on when a reading is to be taken and is switched off when a reading is complete and the Test Probes have been raised off the surface of the commutator.

The Test Current probes are never raised off the surface of the commutator at any time during the test. When the IGBT is switched off, the collapsing magnetic energy that is stored in the armature is dissipated via an onboard fly-back diode. Fly-back diodes are a standard feature on most modern IGBT units and are built into the semiconductor structure of the IGBT to provide onboard protection in a single unit. The Test Current is switched on between 2 and 4 seconds after it was last switched off depending on the speed of rotation and the spacing of the commutator bars. The low switching frequency allows for sufficient time for the stored magnetic energy to be dissipated via the onboard fly-back diode hence there is no arcing.

The spring mounted Test Probes are fixed onto the Detection Unit. These probes are lowered and raised when a reading is to be taken. A minute current flows through these test probes due to the extremely high input impedance of the Data Acquisition Module, more specifically the input impedance of the precision Instrumentation Amplifier, the INA 118, as discussed in Section 5.3. It is due to this high input impedance and the low Test Supply Voltage of typically +15VDC maximum that arcing does not occur when the test probes are raised off and lowered onto the commutator when the Test Current is flowing through the armature. Tests on the Data Acquisition Module proved that no arcing takes place when the test probes are raised off and lowered onto the commutator while a Test Current was allowed to flow through the armature.

The only undesirable electrical effect that would have to be catered for is the bouncing of the input signal due to the mechanical bounce created when spring loaded test probes make contact with the surface of the bars. This bounce will create oscillations in the input signal however, the amplitude of these oscillations should not exceed the amplitude of the input signal when it has settled. This means that although there will be oscillations due to the bounce, there will be no voltage spikes as created when switching the Inductive load. In order to cater for the above-mentioned oscillations, the ADC is instructed to perform acquisition and conversion only after a delay period has been enforced.

If the test probes on the detection unit do not reach the surface of the bars within a preset time then Error 2 occurs and the associated subroutine is called. When the test probes reach the surface of the bars within the allocated time, the Detection Unit outputs a signal which triggers External Interrupt 0 (EX0). As mentioned previously, EX0 is assigned a higher priority than EX1. Error 2 will be initiated when the preset allowable time of ten seconds, for reaching the surface of the bars, expires before EX0 is triggered. If EX0 is triggered before the aforementioned time expires, the EX0 ISR is initiated. The EX0 ISR stops the Detection Unit Drive Motor and stores the time that was taken for the test probes to reach the surface of the bars by copying the values held in the timer registers. Once on the surface of the bars, the AM signals the CM that a volt-drop reading can now be taken be Setting (1), P0.0. The AM then waits for one of two signals from the CM. The first is the signal received on P1.7, which informs the AM that the reading has been successfully taken by the CM, transmitted to the GUI, analysed and stored. Now both the GUI and the CM are ready to proceed.

The second signal is received on P3.1 which informs the AM that the maximum allowable time that the Test Current can be switched on for an individual volt-drop reading has been exceeded. The timing of the Test Current on-time is carried out by external interfacing circuitry and is discussed in Section 5.1.6. If P3.1 is Set (1) before P1.7, Error 3 has occurred. The Error 3 subroutine is then called and due to the severity of the effects of such high currents being applied to the armature under test for a prolonged period of time, an Emergency Stop is automatically initiated and the AM immediately halts the task that was being carried out, switches off the Test Current by Clearing (0) P2.7 and safely shuts the system down before entering Powerdown mode. If however, P1.7 is Set (1) before P3.1 then the volt-drop reading will be captured with no system irregularities and the process flow continues as normal.

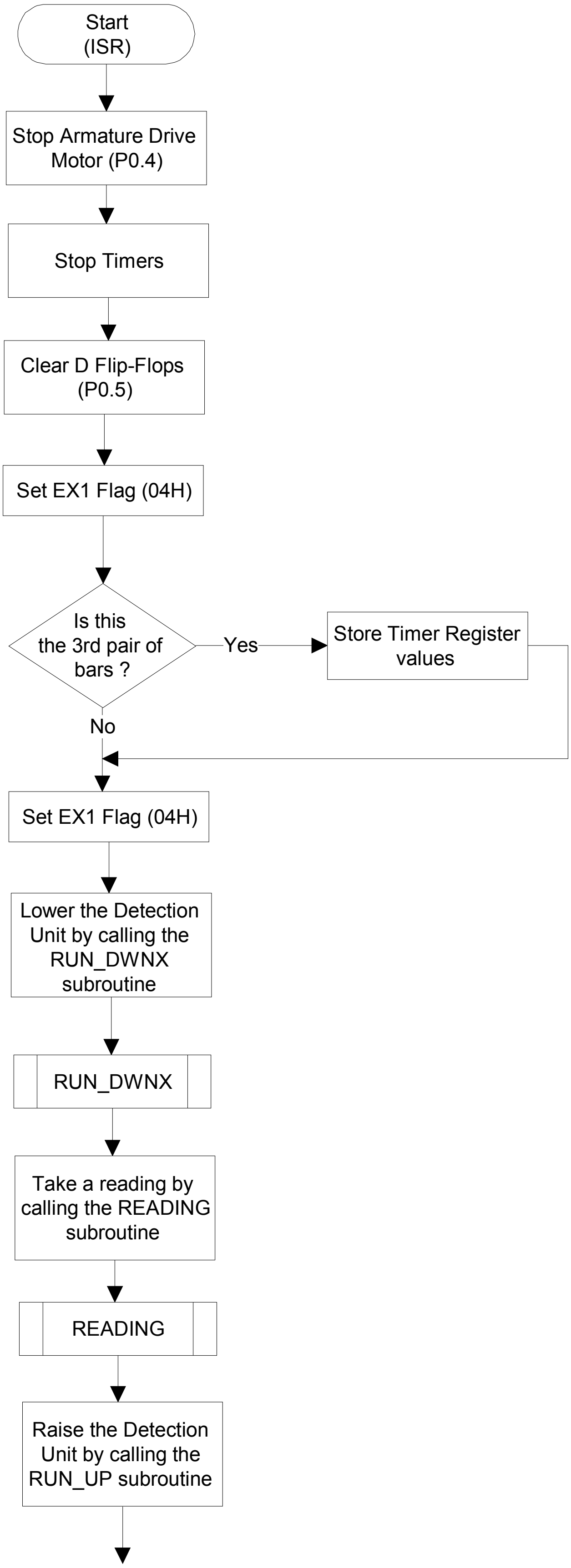
The next step is to prompt the Detection Unit Drive Motor to begin raising the test probes off the surface of the bars. Here again EX0 is triggered when the Detection Unit reaches its initial position. If, however, EX0 is not triggered before the maximum allowable time has elapsed Error 4 occurs and the associated subroutine is called. This maximum allowable predetermined time for this process is called the Unit Raising Reference Time. This period is derived by adding twenty percent of the time taken for test probes to reach the surface of the bars (during lowering) to the recorded time itself, i.e.

Unit Raising Reference Time = Recorded Test Probe Lowering Time x 1.2

When EX0 is triggered before the Unit Raising Reference Time expires, the Detection Unit Drive Motor is stopped and control is returned to the EX1 ISR, which in turn returns control to the Main program. The Main program then transmits an Increment signal to the GUI via the CM and waits for the response. This cycle continues until each pair of bars on the commutator of the armature under test has been tested.

4.2.1.1 External Interrupt 1 and External Interrupt 1 ISR

External Interrupt 1 is triggered when the optical sensors on the detection unit detects a pair of bars and signals this event via a D flip-flop and an interfacing digital network. On triggering this interrupt, the program is immediately paused and the program vectors off to the location in memory that is allocated to the EX1 ISR (0013H). Due to its size, eight bytes is too little space to hold the entire ISR. The ISR has to therefore be located elsewhere in memory and identified by a label. Once at the vectored address, i.e. 0013H, a long jump is initiated to the ISR using the label EX1ISR to identify the ISR's location in memory. The label is the starting point of the ISR and once identified, the ISR executes and returns control to the interrupted program i.e. the Main program in this case using the Return Form Interrupt (RETI) statement. Figure 4-13 depicts the flow diagram for the EX1 ISR.


Start
(ISR)
Stop Armature Drive Motor (P0.4)
Stop Timers
Clear D Flip-Flops (P0.5)
Set EX1 Flag (04H)
Is this the 3rd pair of bars ?
Yes
Store Timer Register values
No
Set EX1 Flag (04H)
Lower the Detection Unit by calling the RUN_DWNX subroutine
RUN_DWNX
Take a reading by calling the READING subroutine
READING
Raise the Detection Unit by calling the RUN_UP subroutine

A (pp. 105)

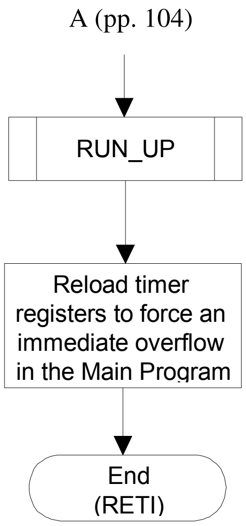


FIGURE 4-13: EXTERNAL INTERRUPT 1 ISR FLOW DIAGRAM

On entering the ISR, the first task carried out is to stop the rotation of the Armature Drive Motor by Clearing (0) P0.4 and also stopping the Timers by Clearing (0) TR1 and TR0. The next task is to Clear (0) the D flip-flops that produce the triggering pulse. This is accomplished by setting port pin P0.5 High (1) for a short period before clearing it again. This is done to ensure that the D flip-flops are in a known state for the next detection cycle. The operation of the input detection circuitry will be discussed in Chapter 5. Next, the EX1 flag, 04H, is set. This indicates to the Main program that External Interrupt 1 was triggered and that EX1 ISR did execute.

Following this, the ISR checks whether the pair of bars that were detected are the third pair. If it is the third pair, then the values that are stored in the timer registers are copied into registers R4 (high byte) and R5 (low byte). Further, the value stored in register R3 (Timer 1 overflow count) is copied into register R6 in Register Bank 0, see Appendix K. These values are used in the calculation of the Detection Reference Time.

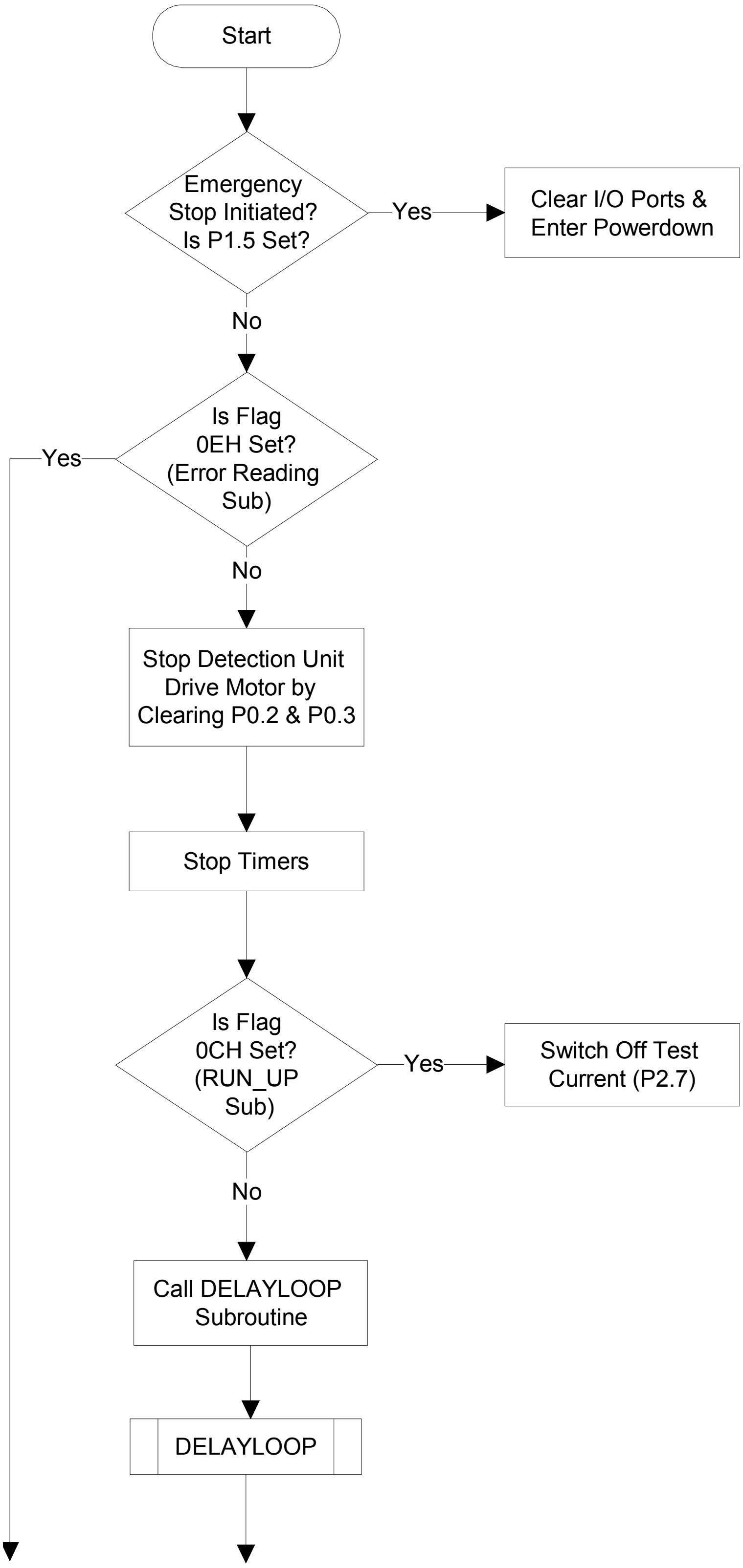
The Detection Unit Drive Motor is prompted to begin lowering the unit and the test probes onto the surface of the commutator by calling the RUN_DWNX subroutine. Once the test probes are on the surface of the bars the READING subroutine is called. This subroutine communicates with the CM READING subroutine in order to capture a volt-drop reading for that pair of bars. When the process reading is complete the

RUN_UP subroutine is called to raise the bars to its initial position. Note that all subroutines will be discussed in the section entitled Subroutines.

Finally, prior to exiting the ISR and returning control to the Main program, the timer registers and the Timer 1 overflow count register, R3, is reloaded with values that will force an almost immediate timer overflow thereby forcing the maximum allowable time to be exceeded, as discussed earlier. Control is then returned to the Main program.

4.2.1.2 External Interrupt 0 and External Interrupt 0 ISR

External Interrupt 0 is triggered when the test probes on the Detection Unit has reached the bars under test (when the unit is being lowered), the test probes have been raised to their initial position (when the unit is being raised), when an Emergency stop has been initiated (by pressing the Emergency Stop switch on the Test Station) or if one of the systems Safety Interlocks are triggered. When triggered the program vectors off to 0003H where it is redirected using a jump statement to the location in memory where the label EX0ISR resides. The location of this label is the beginning point of the EX0 ISR code.



A (pp. 108)   B (pp. 108)

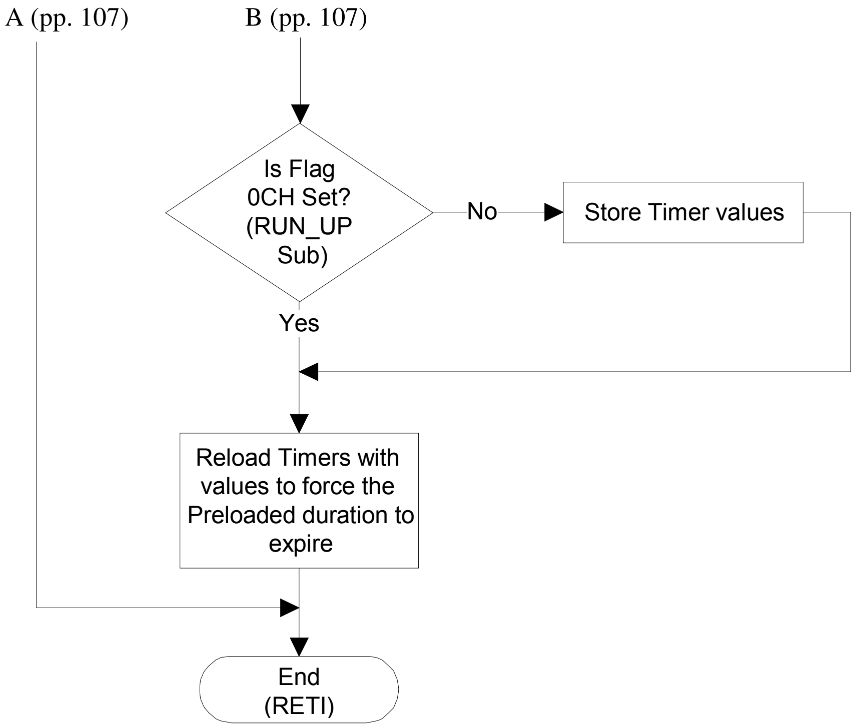


FIGURE 4-14: EX0 ISR FLOW DIAGRAM

The first task undertaken by the interrupt service routine is to test port pin P1.5. If this pin is High (1) then EX0 was triggered by the initiation of an emergency stop or one of the systems Safety Interlocks was triggered. The ISR then jumps to the End label where the input/output ports are cleared and Powerdown mode is entered into. If P1.5 was Low (1) then the interrupt was triggered by the test probes reaching the surface of bars when being lowered or its initial position when being raised.

However, the ISR has to further ascertain if the interrupt was triggered while the ERROR READING PROCEDURE Subroutine was being executed by testing flag 0EH. This flag is Set (1) by the ERROR READING PROCEDURE Subroutine when a manual reading has to be taken due to an error and when it is Set (1), the EX0 ISR is to ignore the interrupt and exit the ISR. The ERROR READING PROCEDURE Subroutine will be further discussed later in this chapter. When flag 0EH is tested and found to be Low (0), the interrupt was not triggered during the execution of the ERROR READING PROCEDURE Subroutine. Both the raising and lowering motion is then stopped by Clearing (0) the port pins responsible for prompting the action, i.e. P0.2 and P0.3 respectively. Thereafter, the Timers are stopped by Clearing (0) TR1 and TR0. Following this, flag 0CH is tested. This flag is set by the RUN_UP subroutine to indicate that the Detection Unit was in the process of being raised at the moment of the interrupt.

If 0CH is set, i.e. High (1), the Detection Unit was being raised before the ISR, which means that a reading was already completed and the test probes are off the surface of the bars and at its initial position when this interrupt was triggered. It is then required that the Test Current is switched off and this is accomplished by Clearing P2.7. If flag 0CH was not set, i.e. Low (0), then the interrupt was triggered when the test probes reached the surface of the bars in order to take a volt-drop reading. The Test Current is therefore left on. After this process a delay is enforced by calling the DELAYLOOP subroutine.

The EX0 flag, 08H, is then set to indicate that this interrupt has been triggered and that the associated ISR has executed. Next, flag 0CH is retested. In this case if the flag is not set (which implies that the interrupt was triggered when the Detection Unit was being lowered) the values in the timer registers are stored in Register Bank 1, register R1 (high byte) and R2 (low byte).

The Timer 1 overflow value that is stored in register R3 is copied into register R7 in Register Bank 0, see Appendix K. These values are recalled and used to calculate the Unit Raising Reference Time.

Prior to exiting and returning control to EX1 ISR the timer registers and the Timer 1 overflow count register, R3, are reloaded to force an almost immediate timer overflow hence forcing the maximum allowable time to be exceeded, as discussed earlier. Control is then handed back to the EX1 ISR by executing the RETI statement.

Chapter 5

Hardware Design

This chapter discusses the hardware design that enables the software that is executing within the embedded mirocontrollers and the GUI to be transformed into physical pulses and signals that control actuators that initiate the motion of objects in the physical world. Hardware also converts, conditions and monitors signals that are produced by transducers, which monitor the external environment, into signals and pulses that are decipherable and understood by the embedded microcontrollers.

This enables the system to respond to various inputs by executing the appropriate blocks of code in response to specific events. The author used the Protel Design Environment to draw schematics and develop the layout and routing of the PCB (Printed Circuit Board). The controller circuit was drawn in modules that link to each other using Netlables (this is a functionality that is available in the Protel Development Environment). The "Bottom-Up" design approach was used to develop this schematic. This approach involves drawing modules on independent sheets and using a Master Sheet (Entitled "Master" in this design) to facilitate linking between all schematic sheets using the above-mentioned Netlables.

Drawing schematics in modules that link to each other makes the circuit easy to understand and modify if need be, as it is uncluttered and easy to isolate a problem area. Each module will be discussed independently however; the reader will be informed as to how the module being discussed is connected to interfacing modules. The complete circuit schematic which includes all the modules discussed can be found in Appendix M, all datasheets can be found in Appendix J, and all test results are presented in Chapter 7. Also see Appendix R for a more detailed discussion covering all hardware modules.

5.1 Digital System Design

The digital system includes all digital circuitry, from the embedded controllers to the logic gates and drivers that are used in signal conditioning and level shifting respectively. The first modules to be discussed will be the Automation Microcontroller module and the Communication Microcontroller module. In both cases the 40 pin AT89S51 microcontroller was used.

5.1.1 The Communication Microcontroller Module

The Communication Micrcontroller module interfaces and communicates with the ADC by pulsing and reading the ADC control pins, HBEN, $\overline{CS}$, $\overline{EOC}$ and R/$\overline{C}$ as well as receiving the 8 bit output from the ADC parallel output bus. This module also communicates with the Automation Microcontroller, reads the status on the Manual Reading switch and reacts to a forced emergency stop whether it was initiated by pressing the Emergency Stop switch or by the activation of any one of the four safety interlocks. See Figure 5-1 for a representation of the Communication Microcontroller Module and Appendix M for the complete circuit schematic.

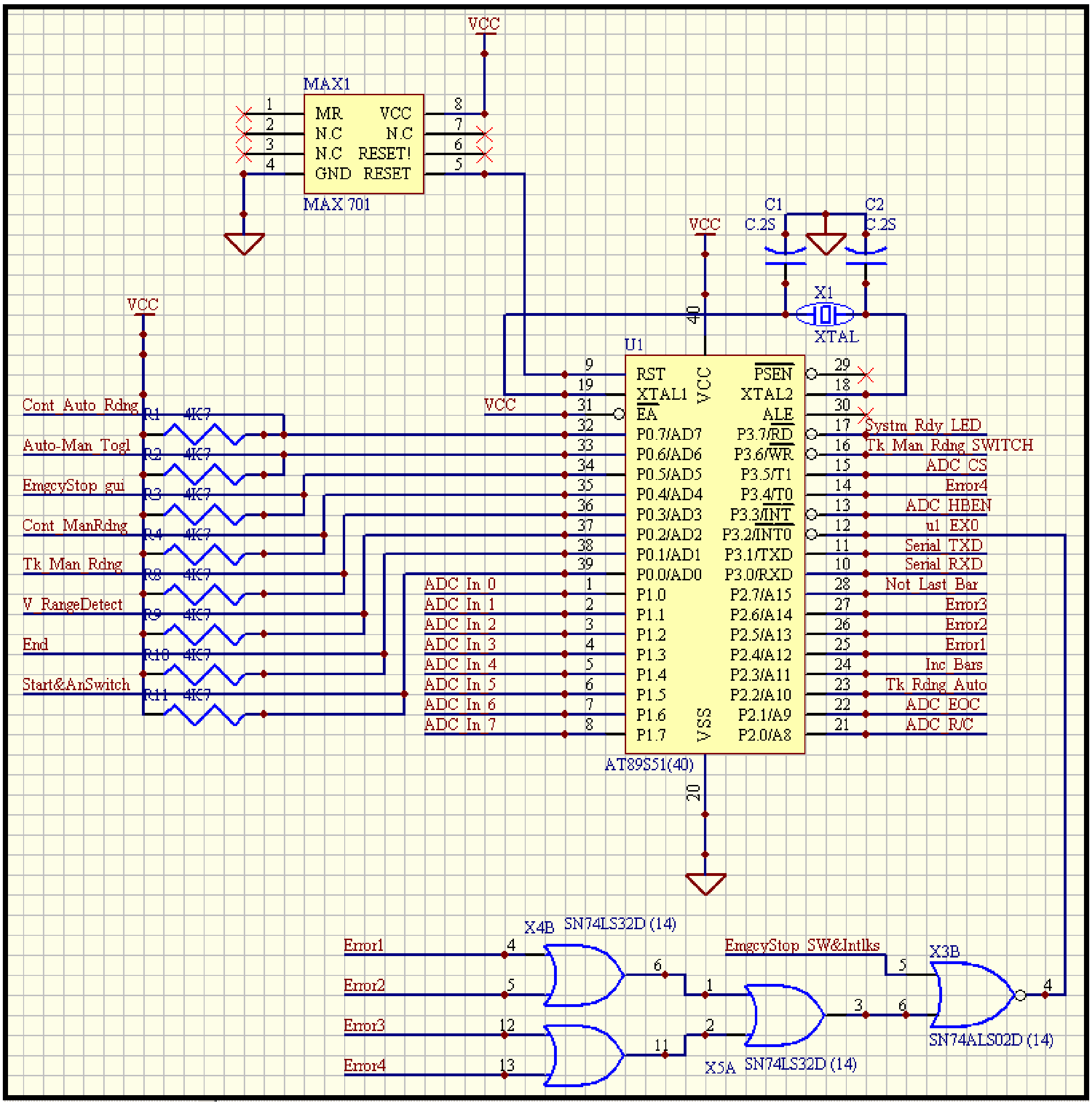


FIGURE 5-1: THE COMMUNICATION MICROCONTROLLER MODULE.

The on-chip oscillator is driven by a quartz crystal X1 with the aid of two stabilising capacitors (C1 and C2). Using a 12MHz crystal and noting that each machine cycle is 12 oscillator periods, each machine cycle is calculated to be 1µs in duration, as shown below.

$$T = \frac{1}{12MHz} = 83.33333 \text{ x}10^{-9}$$

$$T_{\text{Machine Cycle}} = 83.33333 \text{ x}10^{-9} \text{ x } 12 \text{ periods} = 1\mu s$$

The reset pin (9) of the microcontroller is connected to the Reset pin of MAX 701 (see Appendix J for a complete datasheet for the MAX 701). The MAX 701 is a supervisory circuit that monitors the supply to the microcontroller in order to detect Brown-out conditions. A Brown-out[5] occurs when the supply falls to a level that is appreciably lower than the normal supply level for a prolonged amount of time. This will cause components that are powered by this supply to behave erratically and unpredictably. In the event of a Brown-out, which in the case of the MAX 701 is anything equal to or less than 4.65V, the Reset pin of the MAX 701 goes High (4.65V or the present available positive logic High voltage) and is held at this level until the supply returns to its normal rating.

This procedure effectively holds the microcontroller in a Reset state until the supply is within its normal operating range. Note that holding the Reset pin (9) of the AT89S51 high (1) for at least two machine cycles effectively resets the microcontroller. The MAX 701 also provides a Reset-On-Power-up pulse to the microcontroller. This ensures that the microcontroller is in a known state on power-up i.e. all its input/output ports, internal registers, special function registers, program counter etc. are loaded with the default reset values reflected on Page 6 of the AT89S51 datasheet found in Appendix J.

The author originally used the RC network to provide the reset pulse on power-up but the author's experience has shown that this network behaves erratically and is therefore unreliable in environments where EMI (Electromagnetic Interference) is a factor.

The MAX 701 solved the EMI related problems, specifically relating to Reset-On-Power-up. There were various other methods adopted to negate the effects of EMI on the circuit as a whole. Some of these include, but are not limited to, proper PCB layout and design, which involved, amongst other things, placing the microcontrollers in the center of the board and the quartz crystals as close to the microcontroller oscillator pins (XTAL1 and XTAL2) as possible.

[5] Brown-out refers to the condition where the rms supply voltage falls to a value that is appreciably lower than the normal value but not zero. In the case of a Black-out, the supply falls to zero, i.e. there is a complete loss of the supply.

Reduced track lengths, avoiding 90° bends in tracks, routing power and signal tracks away from each other, designing multilayer PCBs with paired power and ground planes, placing 0.1µF capacitors across all ICs with the addition of a 4.7µF capacitor directly across the microcontrollers. Along with these, the circuit was kept compact and a common grounded guard ring was routed around the edge of the PCB.

The first line of defense against EMI is the metal enclosure in which the circuit is housed. Keeping the size of the holes on the enclosure as small as possible and ensuring that the lid makes proper electrical contact with the rest of the enclosure, results in the metal enclosure forming a Faraday Cage around the circuit. To further reduce the impact of EMI via conductors from the external environment, shielded cables were used.

The interconnections between the Automation and Communications microcontrollers are summarised in the respective Microcontroller Port Utilisation tables found in Appendix K. The connections from the Communications Microcontroller to other devices are also summarised in the Communications Microcontroller Port Utilisation table found in Appendix K. Note that the $\overline{EA}$ (External Access) pin is connected to VCC. When the $\overline{EA}$ pin is held low (0) the microcontroller executes programs from external ROM. Holding the pin high (1) forces the microcontroller to execute programs from internal ROM.

The input to External Interrupt 0, P3.2, is an OR and NOR gate network which allows any of the system errors (Error 1, 2, 3 or 4) or an Emergency Stop, labeled "*EmgcyStop_SW&Intlks*", (initiated by pressing the Emergency Stop switch or triggering a Safety Interlock) to trigger the interrupt. The Emergency Stop signal is an input to both microcontrollers that enforces a complete system stop by interrupting both microcontrollers and forcing them to enter a safe shutdown procedure before entering power-down themselves. This Emergency Stop is initiated by the triggering of switches (push-button and interlock) on the physical system and should not be confused with the Emergency Stop that is initiated by clicking on the Emergency Stop button on the GUI, although both events yield the same end result. Including

Emergency Stop triggers from various sources makes the entire system safer in the occurrence of an undesirable or dangerous event. The Emergency Stop is generated by an independent network which will be discussed later in this chapter.

5.1.2 The Automation Microcontroller Module

The Automation Microcontroller module is responsible for the control of the system's actuators which include the Armature Drive Motor and the Detection Unit Drive Motor as well as the switching of the Test Current Supply via an IGBT. It also receives input signals from the physical system to indicate the system status and the occurrence of events whether desirable or undesirable.

These input signals include the signal indicating the detection of a pair of bars, labeled "*u2_EX1_Bar_Dect*", the signal that indicates that the Detection Unit has reached its initial position, labeled "*Detect_Unit_Switches*", as well as Emergency Stop signals, labeled "*EmgcyStop_gui*" and "*EmgcyStop_SW&Intlks*". All of the above mention signals, except "*EmgcyStop_gui*", are generated by independent networks which will be discussed later in this chapter. The "*EmgcyStop_gui*" signal is generated by the Communication Microcontroller to inform the Automation Microcontroller that an Emergency Stop has been initiated via the GUI. See Figure 5-2 for a representation of the Automation Microcontroller Module and Appendix M for the complete circuit schematic.

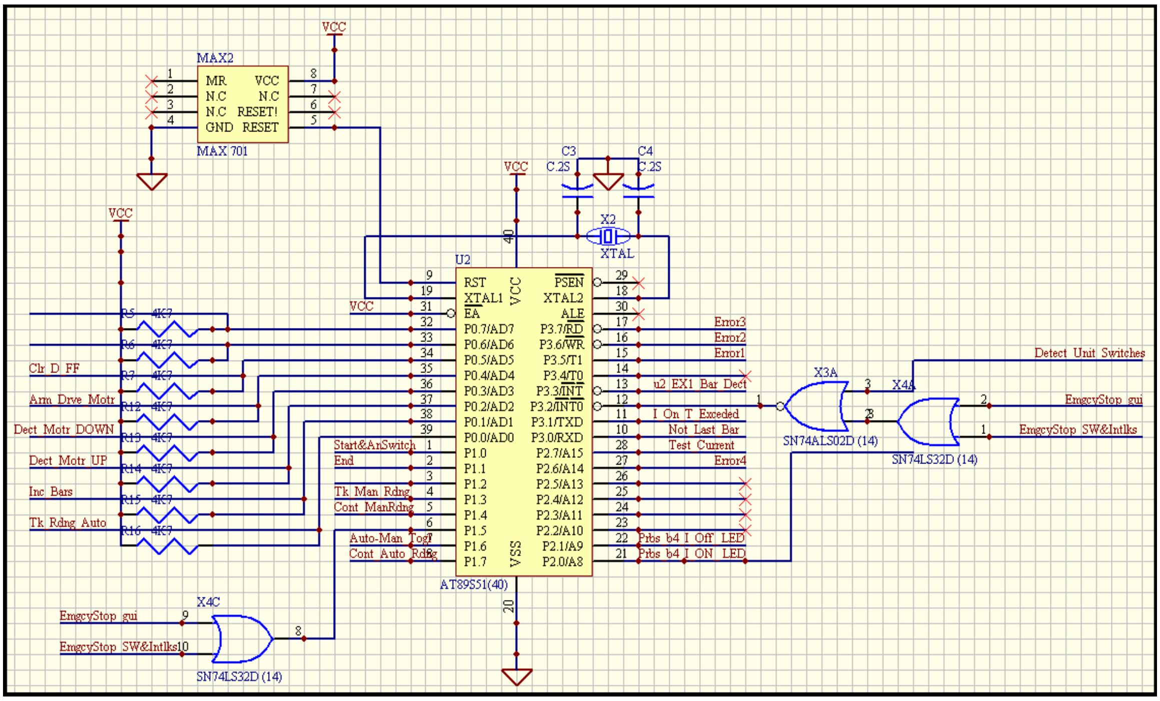


FIGURE 5-2: THE AUTOMATION MICROCONTROLLER MODULE

The Automation Microcontroller is set up in exactly the same way as the Communications Microcontroller. The interconnections between the Automation and Communications microcontrollers are summarised in the respective Microcontroller Port Utilisation tables in Appendix K. The connections from the Automation Microcontroller to other devices are also summarised in the Automation Microcontroller Port Utilisation table in Appendix K.

The input to External Interrupt 0, P3.2, is an OR and NOR gate network which triggers the interrupt in the occurrence of any of the two Emergency Stop events ("*EmgcyStop_gui*" and "*EmgcyStop_SW&Intlks*") or the occurrence of the bar detection event ("*Detect_Unit_Switches*"). The input to port pin P1.5 is also an OR gate with "*EmgcyStop_gui*" and "*EmgcyStop_SW&Intlks*" as input signals. The reason for this becomes apparent when the reader recalls the discussion in Chapter 4 concerning the External Interrupt 0 ISR for the Automation Microcontroller.

The first task undertaken by the interrupt service routine is to test port pin P1.5. If this pin is High (1) then EX0 was triggered by the initiation of an emergency stop".

As soon as External Interrupt 0 (EX0) is triggered, the associated ISR first checks if P1.5 is High (1), indicating that any one of the Emergency Stop sources had been triggered. If this is the case, the system shut down and controller power-down procedures are entered into. If this not the case and P1.5 is Low (0) then the interrupt was triggered due to the detection of a pair of bars, i.e. the"*Detect_Unit_Switches*" signal. Hence this port pin is only used to decipher whether an interrupt was initiated due to an emergency stop or the detection of a pair of bars.

5.1.3 The Bar Detection Module

The Bar Detection module is responsible for alerting the Automation Microcontroller when a pair of bars has been detected. The actual detection of each copper bar on the commutator of the armature under test is undertaken using optical sensors that detect the reflection of an emitted laser beam. The Omron E3X-NA11 amplification unit together with the Omron E32-DC200 fiber optic unit (with reflective sensors) was used to carry out this task. See Appendix J for complete datasheets. The combination of these two units allow for the accurate detection of a copper bar from a distance of between 50mm and 70mm above the surface of the commutator. See Figure 5-3 and Figure 5-6 for images of the commutator and the copper bars that are to be detected.

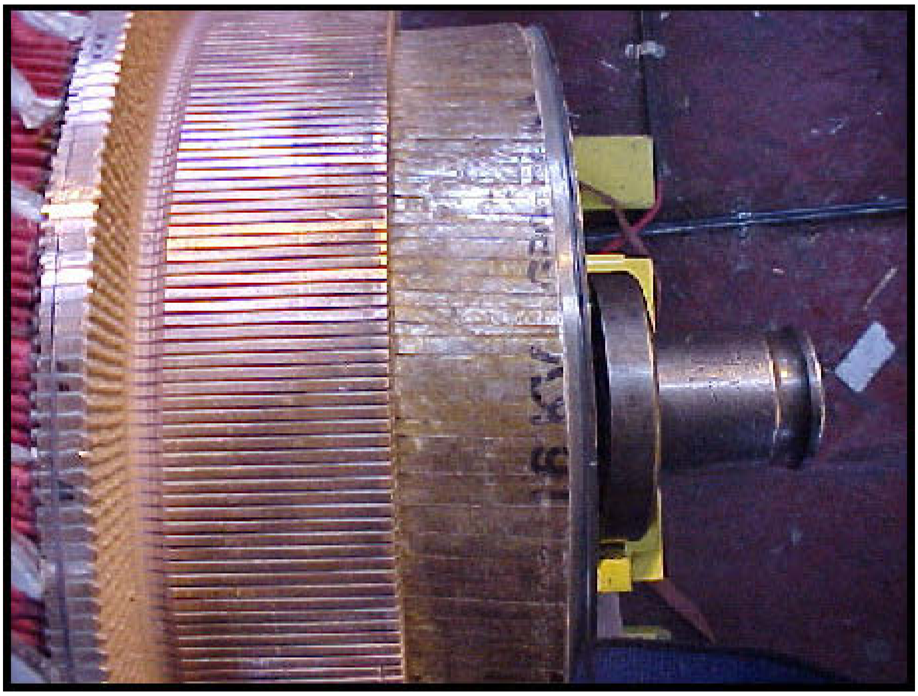


FIGURE 5-3: TYPICAL COMMUTATOR OF AN ARMATURE UNDER TEST

FIGURE 5-4: COPPER BARS ON A COMMUTATOR

The above images depict a typical commutator, however in this case, the reader will notice that there are grooves present between each copper bar. Grooves are created by a process called Undercutting which entails the use of a motorised, revolving, circular saw blade typically 20mm in diameter. These grooves are not present in all commutators that are to be tested. In some instances the armature that is to be tested still has an epoxy resin (from the VIP stage of the armature refurbishing process) between the bars. Due to the Turning stage (using a lathe) in the armature refurbishing process the surface of the commutator is smooth, with the copper bars and the epoxy resin being exactly the same level. It is for this reason that a high accuracy proximity sensor was abandoned. After testing various sensors, the optical sensor produced the best results and proved to be the most reliable means of detecting the copper bars.

The sensor is set on Light On mode. In this mode, an open collector NPN transistor, which is the output of the Omron E3X-NA11, is switched on when a reflected beam is detected by the reflective sensor.

The optical sensors are supplied with +15V and the outputs from these sensors provide a clock pulse to respective positive-edge-triggered D flip-flops. The output of the D flip-flops provide the two inputs to the NAND gate which in-turn triggers the External Interrupt 1 pin on the Automation Microcontroller when driven low (0). This signal, "*u2_EX1_Bar_Dect*", must go low (0) only when a pair of bars has been detected. It must return to high (1) when the D flip-flops are cleared by the Automation Microcontroller and go low (0) again when the next pair or bars are detected. The network shown in Figure 5-5 fulfils the above triggering requirements. See Figure 5-7 for a timing diagram for the bar detection network.

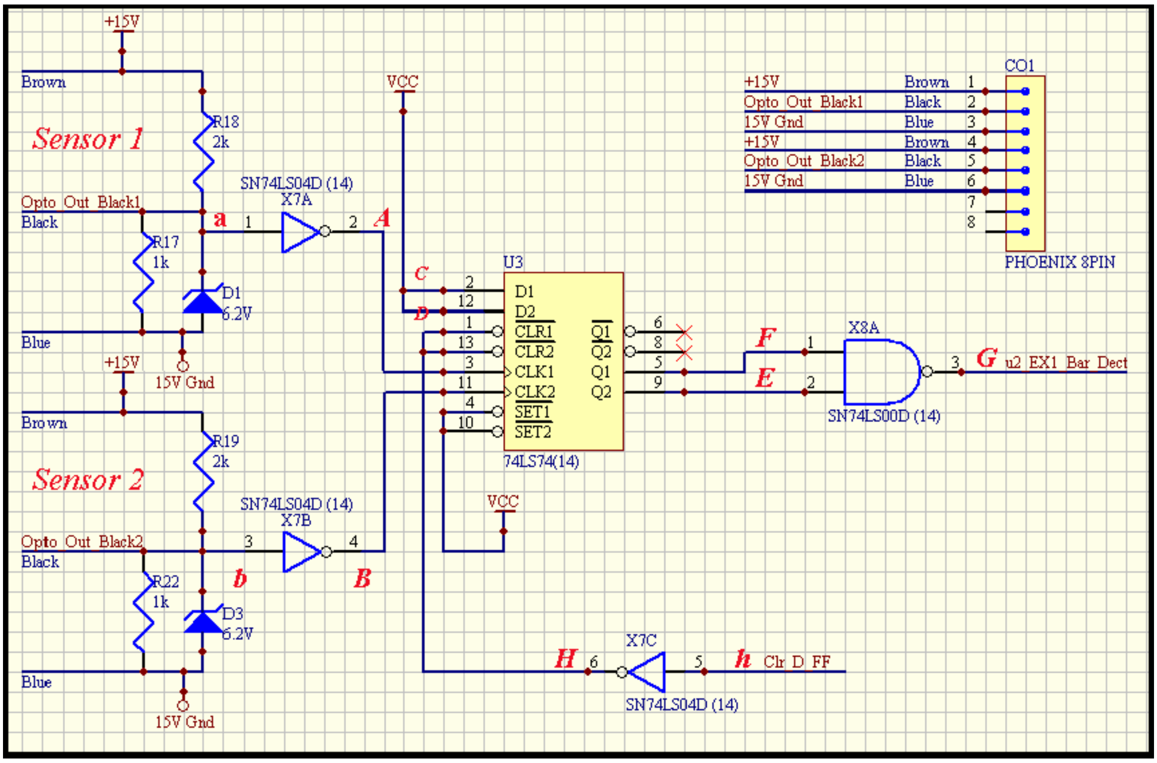


FIGURE 5-5: BAR DETECTION NETWORK

The voltage divider resistor-network ensures that 5V is present at the output when the transistor is off (implying that no bars have been detected) and 0V (V_{CE} to be exact) is present at the output when the transistor is on (implying that a bar has been detected). A 6.2V zener diode, with a very low response time, or a Tranzorb, depending on the operating environment, is placed in parallel with the output resistor for protection purposes to ensure that the output of the voltage divider resistor-network will not exceed 6.2V.

Initially, the network that was used as a level shifter to provide a TTL level input to the digital interface from the optical sensor output of 0V to 15V was a simple series resistor and zener diode network as depicted in the figure below.

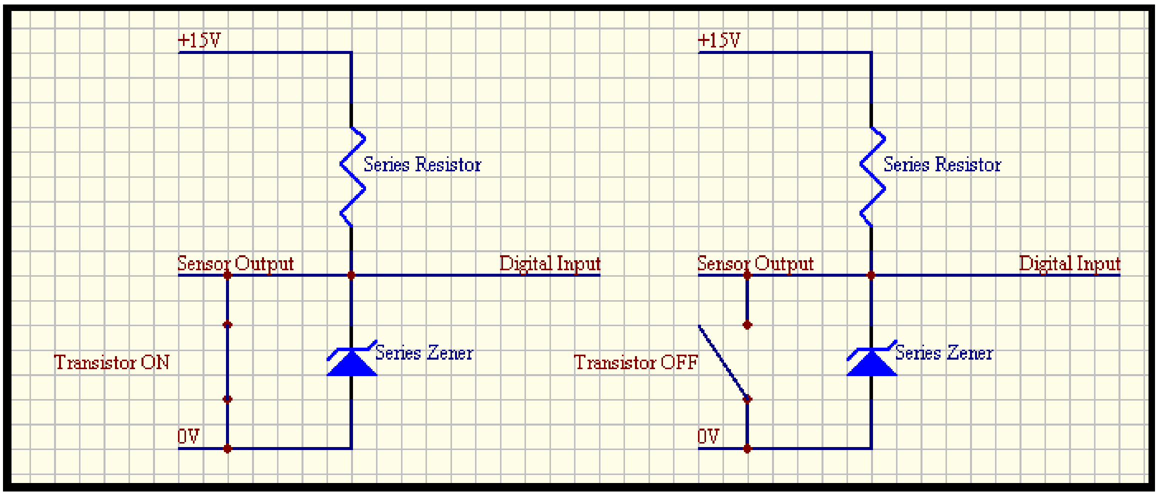


FIGURE 5-6: INITIAL LEVEL SHIFTER NETWORK

It may seem like an adequate solution, however, when one considerers the fact that the zener diode has response time, although very small, one will become aware of a potential problem that may arise when using this series network. The instant that the NPN transistor in the output circuit of the optical sensor is switched off, the zener diode is still essentially “off” as it does not respond instantaneously to the applied source. Ideally, the zener diode will be seen as an open circuit to the rest of the network for this period of time.

This being the case, the output of this series network, which is the input to the NOT gate, will for all intents and purposes, be pulled up to +15V by the series resistor which acts as a pull-up resistor for the period before the zener diode responds or “switches on”. This +15V input is well above the absolute maximum rating for the IC and will ultimately damage it. The author used the word ultimately because, due to the very small response time of the zener diode, the IC will only be exposed to +15V for a very short period. The IC may therefore not be damaged instantly however, repeated exposure to such high input potentials will damage the IC over time.

It is for the above reason that the voltage divider comprising of a 1kΩ and 2kΩ with adequate protection was used. This network produces a 5V drop across the 1KΩ resistor when a +15V source is applied.

$$V_{R1K} = \frac{1K}{1K + 2K} \text{ x } 15V = 5V$$

This network ensures that the input to the NOT gate is exposed to a maximum of 6.2V which is within recommended operating range for the IC.

The output of the resistor-zener network enters a NOT gate which inverts the signal producing an output high (1) when a bar has been detected and a low (0) when no bars have been detected. The output of this NOT gate clocks a positive-edge-triggered D flip-flop whenever a bar has been detected. Because the D input of the flip-flop is tied high (Vcc) when clocked, the output of the flip-flop, Q, goes high. The output of the D flip-flop provides the input to the NAND gate which triggers the external interrupt pin on the Automation Microcontroller. The microcontroller clears both D flip-flops in order to put them in a known state, as soon as it enters the Interrupt Service Routine (ISR) that it vectored to when a pair of bars have been detected.

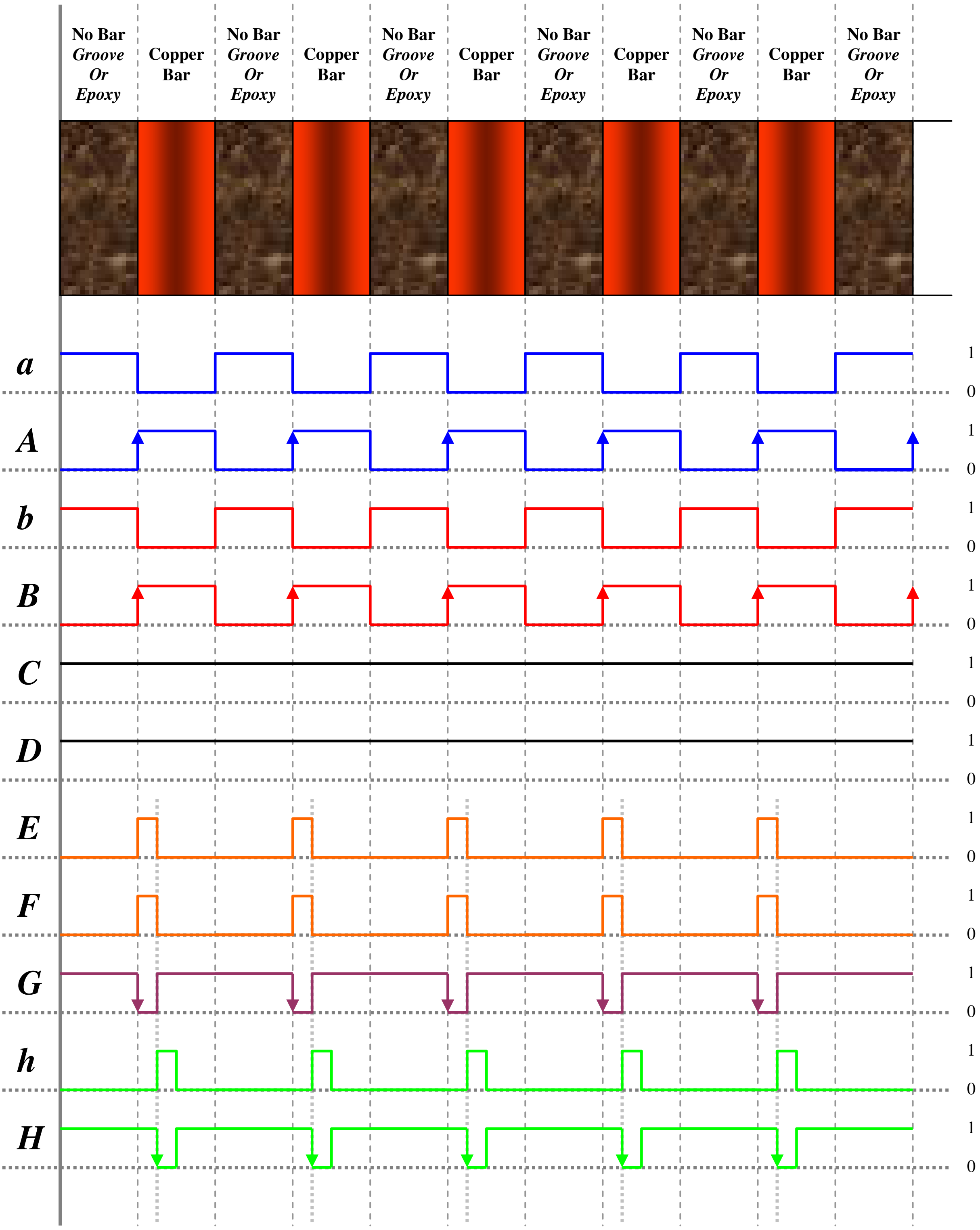


FIGURE 5-7: TIMING DIAGRAM FOR THE DETECTION NETWORK

The discussion that follows is with reference to Figure 5-7 and Figure 5-5 and describes the operation of the Bar Detection module. Assume that the commutator is rotating slowly and Sensor 1 detects a bar, the output of the NOT gate [point A] is high (1). The low-to-high transition (positive edge) clocks the D flip-flop producing an output [at point F] that is also high (1). If, at this point, Sensor 2 has not yet detected a bar the output of the NAND gate remains high (1). The commutator will continue slowly rotating with Sensor 1 directly over it's bar until Sensor 2 detects a bar. For the purposes of this explanation, assume that Sensor 2 has also detected a bar at the same time that Sensor 1 has detected a bar (Ideal situation with an ideal commutator) the output of the NOT gate [point B], is high (1). The low-to-high transition (positive edge) clocks the D flip-flop producing an output [at point E] that is high (1). With both the inputs to the NAND gate being high (1), the output [at point G] goes low (0).

This high-to-low transition (negative edge) triggers External Interrupt 1 of the Automation Microcontroller. The microcontroller clears both flip-flops in the associated ISR. When rotation resumes, control is handed back to the Bar Detection module. At this point both sensors indicate that they detect a bar. This is because the Armature Rotation Drive Motor was stopped as soon as both bars were detected. The outputs of the NOT gates at both point A and point B are now high (1). These high outputs however, do not clock the D flip-flops as they are positive edge triggered. Since the clock did not go low (0) before going high (1), the outputs of the flip-flops remain cleared (0) implying that the output of the NAND gate remains high (1). As the commutator rotates the sensors will pass over the groove (or epoxy resin gap) between a pair of consecutive bars.

This causes the output of the sensors to produce a low (0), via the NOT gates. On the detection of the next bar, a low-to-high transition will be created and this positive edge will again trigger the D flip-flops. It is thus clear that the Bar Detection module only detects the NEXT pair of bars to be tested by using positive edge triggered flip-flops to reject the high (1) signal from the sensors when they are still over the pair of bars that were previously detected. Note that although theoretically both bars should be detected at the exact same time by their respective optical sensors, this is not the case practically. There are two reasons for this, one being that when the commutator is undercut, some of the copper is also cut into producing bars and gaps of varying widths. The other reason is dirt, spots or marks on a bar that do not allow for the reflection of the laser. If the bars and the gaps between bars were the exact same width throughout the circumference of the commutator and the commutator was clean, as in the case of a new commutator, both bars will be detected at the exact same time.

5.2 The Data Acquisition Module

The Data Acquisition module is responsible for measuring the difference in potential between two successive bars, signal conditioning to reject any inputs outside the expected input range and converting the input analogue signal to a sixteen-bit word that is to be transmitted to the Graphic User Interface (GUI) via the Communications Microcontroller. See Figure 5-8 and Figure 5-9 for the block diagram describing this module.

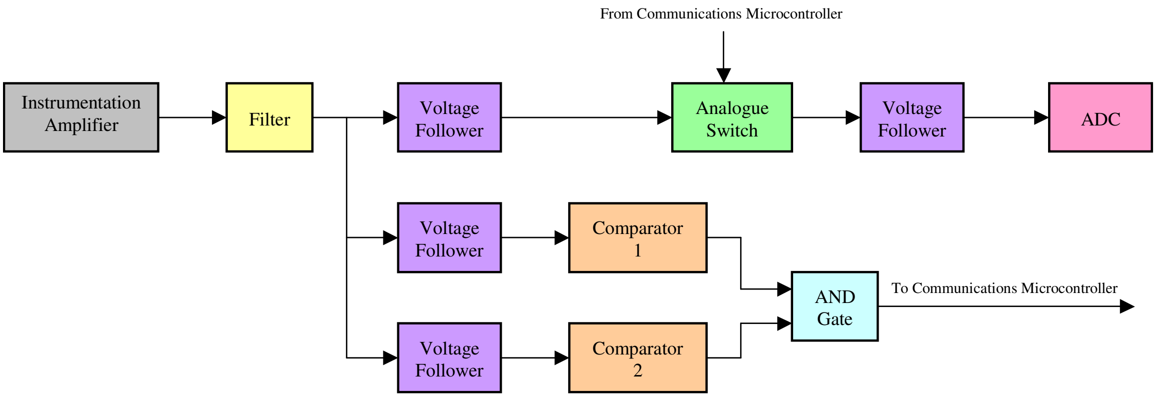


FIGURE 5-8: BLOCK DIAGRAM FOR THE DATA ACQUISITION MODULE

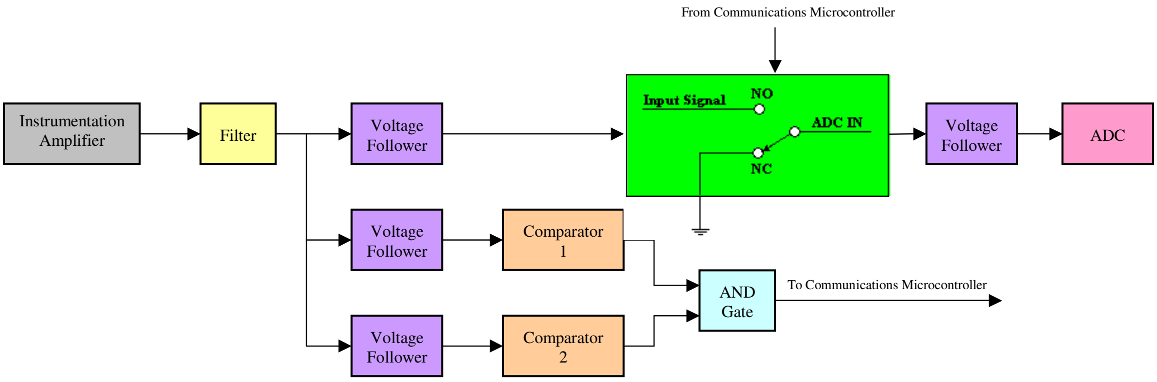


FIGURE 5-9: DETAILED BLOCK DIAGRAM FOR THE DATA ACQUISITION MODULE

Before discussing this module any further it is important for the reader to know the type and magnitude of the input signal that is to be measured. The test supply is a maximum of +15V / 400A. The typical potential difference (or volt drop) expected to be measured between a pair of successive bars, on any armature that is to be tested, is in the range of between 100mV and 350mV for a healthy winding. Before the test begins the test technician will verify that readings within this range are produced by measuring the volt drop across the first pair of bars and, if need be, varying the magnitude of the test supply or varying the arc length of the test supply probes or both to ensure that the reading produced is within the stipulated range.

The technician will thereafter measure the volt drop across at least five other successive pairs of bars that lie within the arc length of the test supply probes in order to verify the range. If the readings on these bars fall outside the range that was set on the first pair of bars the implication is that the windings of first pair of bars are unhealthy or damaged. In this case the input range must be set and verified on one of the other five measured pairs of bars.

The expected input range discussed above only applies to healthy windings, i.e. windings that are not open circuited, shot circuited or damaged. If a winding is open circuited the volt drop across the connected pair of bars will be equal to the supply potential. If a winding is short circuited the volt drop across the pair of connected bars will be zero volts. If a winding is damaged the volt-drop across the connected pair of bars will fall outside the preset variance (or tolerance) from the reference reading specified at the beginning of the test. The input signals are DC with no expected AC components. Any AC components encountered are regarded as noise and will be rejected and/or filtered.

A precision Instrumentation Amplifier, the INA 118 is used to acquire the potential difference (or volt drop) between two successive bars. See Appendix J for the complete datasheet for the INA 118. This amplifier features amongst other things, a high Common Mode Rejection (CMR) of 110dB (at a gain of 10) and input protection of up to $\pm$ 40V. It also offers a non-linearity of typically $\pm$ 0.0005% of the full-scale range (at a gain of 10). Some of the specifications mentioned above are stipulated at a gain of 10. This is because a gain of 10 is set (using the external resistor, R_G – see datasheet) to amplify the input signal from the hundreds of millivolts to the volt range. Hence, an input of 350mV will be amplified to 3.5V. This is done in order to utilise the full input range of the sixteen-bit Analogue-to-Digital Converter hence maximising the 16-bit resolution and reducing the effects of any conversion errors should they occur.

A sixteen-bit, successive approximation, Analogue-to-Digital Converter, the MAX 1166, with an input range of between –0.3V and V_{Ref} (4.096V) is used to convert the input signal to a sixteen-bit word (2 eight-bit wide, parallel output words). See Appendix J for the complete datasheet for the MAX 1166. The operation of the ADC was discussed in detail in Chapter 4, under the section entitled ADC Control. The ADC was set-up to make use of the internal reference voltage as prescribed in the datasheet and shown in Figure 5-10.

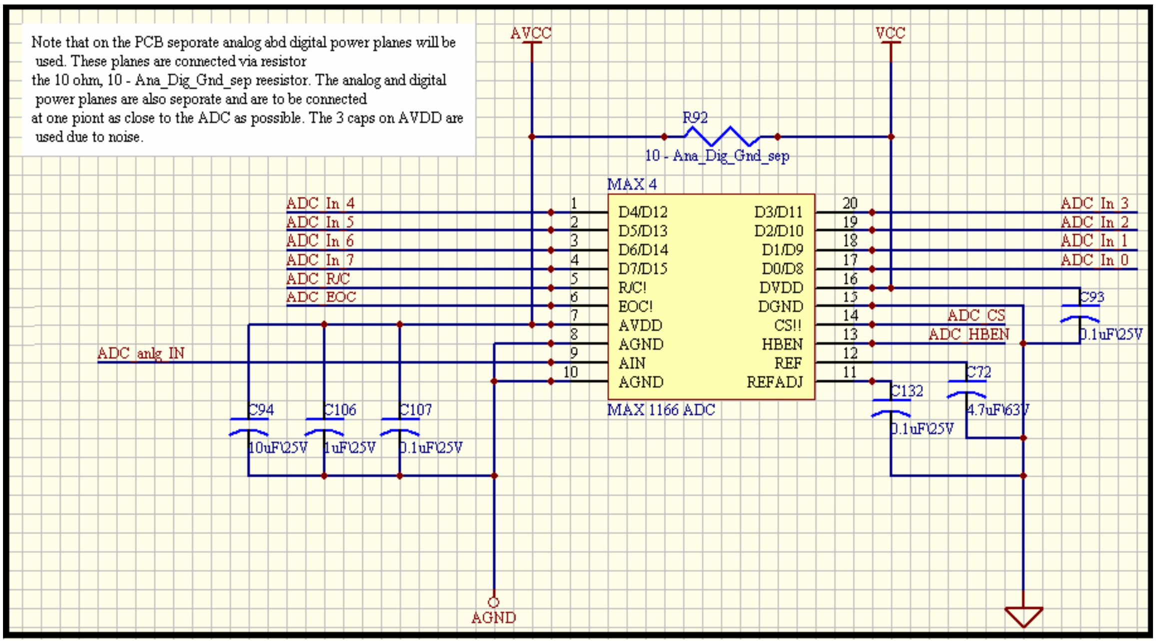


FIGURE 5-10: ANALOGUE-TO-DIGITAL CONVERTER NETWORK

The ADC features, amongst other things, sixteen-bit resolution, a high speed sampling rate, an eight-bit wide parallel output and an accuracy of $\pm$ 2 LSB (Least Significant Bit). With an internal V_{Ref} of 4.096V and sixteen bit resolution, the smallest voltage increment that the input signal can broken down into is:

$$\text{Resolution in Volts} = 4.096 / 65536 = 62.5\mu V$$

i.e. each digital bit is equal to an analogue step of 62.5µV.

As mentioned earlier, the input signal is amplified by a factor of 10, the true analogue step size (after being scaled down in software) is 6.25μV. Similarly, the true input voltage range after being scaled down by software will be 0 to 350mV.
This implies that a variance of

$$\text{Variance (\%)} = \frac{6.25\ \mu\text{V}}{350\text{mV}} \text{ x } 100 = 1.786 \text{ x } 10^{-3}\%$$

can theoretically/ideally be detected by the system. This value has two important connotations, the first being the fact that the smallest input change that can be detected is well below 1%, hence the percentage variance from the reference reading can be calculated with a great degree of accuracy. The second connotation is that the ADC error of $\pm$ 2 LSB will be almost negligible when considering the percentage variance from the reference value.

Recalling that the input range for the ADC is between –0.3V and V_{Ref} (4.096V), the ADC has to be protected from any inputs outside this range as they will potentially damage the ADC. Out of range input signals can be produced in two ways, the first being due to an open circuit. In this case, the potential difference across the pair of bars that are connected to an open circuited winding will equal to the potential of the test supply current (which may be as high as 15V). The second way an out of range reading can be produced is by the reversal of the orientation of the test probes with respect to the test supply probes.

This means that when the test current positive probe is to the right of the negative probe and the positive test probe is to the left of the negative test probe (or versa-visa) a negative reading of equal magnitude to the positive reading will be produced. This situation can arise when the test technician setting up the test reverses the polarity of the test supply or when the test technician is taking a manual reading and uses an independent (unauthorised) set of test probes to take a manual reading and unknowingly reverses the orientation of the polarity of the inputs with respect to the potential of the test supply probes. Although this situation should not occur, protection has to be designed into the system to prevent any hardware damage should this situation somehow occur. The reader may ask why an ADC with an equal positive and negative input range (e.g. $\pm$ 5V) is not used.

The answer to this is – the expected input range is between 0 and 3.5V (after amplification). And with a sixteen-bit ADC that has a positive input range (eg. +5V), all sixteen bits are dedicated to conversions within this positive range. If a sixteen-bit ADC with an equal positive and negative range was to be used, eight bits will be dedicated to the positive range, 0 to +5V, and the other eight bits will be dedicated to the negative range, 0 to –5V. Hence only an eight bit resolution can be expected for the readings of importance i.e. those within the 0 to 5V range. The eight bits dedicated to the conversion of negative values will only be used in events of unwanted or undesirable readings that are produced by an incorrect system set up or use. In the author's opinion, the eight bit resolution used for the negative range of inputs is wasted. The author has hence elected to use a sixteen-bit ADC with only a positive input range and has devised a method of rejecting all unwanted and potentially damaging input signals. This method will be discussed in the paragraphs that follow.

With reference to Sheet 4 of the circuit schematic found in Appendix M, the first stage of the data acquisition module is the INA 118 instrumentation amplifier. This stage is followed by a filtering stage that comprises capacitors of various values which facilitates more efficient filtering over a range of frequencies. Seeing as the output of the instrumentation amplifier is expected (and required) to be purely DC in nature, any AC components found on this signal must be filtered before the signal progresses to the next phase of the system. It is for this reason that capacitors were used as low-pass filters instead of low-pass high order passive or active filters with cut-off frequencies set very low (almost zero Hertz, in this case).

In the phase that follows, three Voltage Followers (or Buffers) makes three identical copies of the original signal. A Voltage Follower is simply an Op-Amp (LM 741 in this case) with its output fed directly into its inverting input. The non-inverting input is the input pin for the signal. This network produces an output with zero gain, i.e. an output that is equal to the input. A fourth Voltage Follower is placed at the input to the ADC.

Note that all the Op-Amp and Comparator ICs that are used make provision for a potentiometer that is used to nullify the output offset voltage. These potentiometers are also used for "tuning" purposes to ensure that the signal which is the input to the ADC is equal to the signal at the input end of the data acquisition module provided that the magnitude of the signal is within the allowable ADC input range.

Three identical copies of the input signal are made purely to maintain the integrity of the input signal to the ADC. Two comparator stages are required to determine whether the input signal is outside the ADC input range. These two stages are in parallel implying that they each require a perfect copy of the original input signal. The third copy of the input signal flows directly to the ADC input via an analogue switch. If only one signal was used in each of the comparison stages before being input to the ADC, the integrity of that one signal would be compromised, i.e. the ADC input signal will vary from the original input signal to the data acquisition module.

Recalling that the input of the ADC must be within the –0.3V to 4.096V range, a comparison must be done in order to reject all inputs outside this range. This comparison is done in two parallel stages. The first stage determines if the input signal is less than the ADC reference voltage, V_{Ref}, which is equal to 4.096V. In order to do this a comparator (the LM 311) is used with the input signal connected to the comparator's inverting input and a reference voltage connected to the non-inverting input pin. The reference voltage is set up using a voltage divider network that comprises a 2kΩ and a 9kΩ resistor both with a 1% tolerance. With these values the expected reference at zero percent variance is:

$$V_{Ref} = \frac{9k\Omega}{9k\Omega + 2k\Omega} \text{ x } 5\text{V} = 4.091\text{V}$$

with a $\pm$ 1% V_{Ref} variance of the range between 4.076V and 4.105V.

The output of LM 311 is open-collector, with pin 7 being the collector end and pin 1 being the emitter end of the output transistor. Connecting the collector (pin 7) via a pull-up resistor to the +5V supply and connecting the emitter (pin 1) to ground, the comparator outputs a High (1), i.e. +5V, when the non-inverting input is greater than the inverting input and a Low (0), 0V (or V_{ce}) when the inverting input is greater than the non-inverting input. The output of this comparison stage is connected to the first of two inputs of an AND gate.

The second comparison stage is tasked to ensure that all negative input signals are rejected. Here the input signal is connected to the non-inverting input pin of the comparator (LM 311) and the reference is connected to the inverting input. The reverence voltage, $V_{Ref,}$ is set to 0V by connecting the inverting input directly to ground. However, the reader should note that a voltage divider network which is set up between –15V and ground (Gnd) is provided in the event that a slightly negative reference is required due to the operating environment. To set a 0V reference using this network the resistor to ground is replaced with a physical jumper and the resistor to the negative supply is not inserted. The output of this comparison stage is connected to the second of the two inputs to the AND gate.

When the input signal is within range the first comparator stage will produce a High input signal to the AND gate because the potential at the inverting pin will be greater than that at the non-inverting pin. The second comparator stage will also produce a High input signal to the AND gate for the same reason. The output of the AND gate is hence High. The output of the AND gate ("*V_RangeDetect*") provides the input to the Communication Microcontroller's P0.2. Before a reading can be taken this input port (i.e. P0.2) is tested to verify if it is High (1).

If this is the case, the Analogue Switch (MAX 4622) is switched on by the Communication Microcontroller port pin P0.0, allowing the signal to pass through to the ADC input pin. See Appendix J for a complete datasheet for the MAX 4622. If this port pin is Low, the analogue switch is left off, connecting the ADC input pin to ground. The MAX 4622 analogue switch has a low on-resistance, with a normally open, normally closed and a common pin. It can be operated from a bipolar supply of $\pm$18V, although in this case the operating supply is $\pm$15V. This allows the analogue switch to control any input within this range without any damage which makes it perfect for this application. When the input pin of this device is low, as in the case where the input signal is found to be outside the allowable range, the common pin is "connected" to the normally closed pin which in this case is connected to ground. When the input pin of this device is High, as in the case where the input signal is found to be within the allowable range, the common pin is "connected" to the normally open pin which in this case is connected to output pin of the first voltage follower stage which represents the input signal to the data acquisition unit.

For completeness, if the input signal is higher than the preset reference, V_{Ref}, of the first comparison stage as in the case where an open circuit is detected on a winding connected to the pair of bars under test, the output of the comparison stage will be Low. This is because the inverting input will be at a higher potential than the non-inverting input. The output of the AND gate will therefore be Low hence ensuring that the Communication Microcontroller keeps the analogue switch off. This in turn ensures that the ADC input remains connected to ground, i.e. 0V, and not to the out-of-range input signal.

If the input signal is lower than the preset reference, 0V, of the second comparison stage, as in the case where the orientation of the test probes is reversed with respect to that of the Test Supply probes, the output of the comparison stage will be Low. This is because the inverting input will be at a higher potential than the non-inverting input. The output of the AND gate will be Low ensuring that the Communication Microcontroller keeps the analogue switch off. This in turn ensures that the ADC input remains connected to ground, i.e. 0V, and not to the out-of-range input signal. It is in this way that all out-of-range inputs are rejected by the data acquisition module.

This method was not the first approach that was tried. After much research and experimentation with adaptive (variable) gain Op-Amp networks, arithmetic using a number of Op-Amp stages, scaling and using various switching devices such as relays, BJTs and FETs, this approach was found to be the simplest, most effective and most accurate method of rejecting out-of-range input signals while still maintaining the integrity of the original input signal.

Chapter 6

Additional Features

In order to gain a greater level of accuracy and provide engineers and technicians with more valuable data, three additional features were added to the basic system. These include:

- The ability to automatically take repetitive readings on a single pair of bars
- Automatically record each reading and the average of all the readings for a pair of bars on an Excel Spreadsheet. Also automatically saving Excel Spreadsheets at the end of tests.
- Calibration of the system using the GUI Calibration Tool.

6.1 Automatic Repetitive Readings

The system has now been setup to take one hundred (100) consecutive readings in roughly 1000μs intervals. This implies that the duration for one complete, one hundred reading recordings is roughly 100ms. This is achieved by introducing a variable called "MultiReading" in the Calculation Subroutine of the GUI. This variable is loaded with a value of one hundred and decremented each time the Calculation Subroutine is called. As long as the value held in variable "MultiReading" is not equal to zero, the ASCII code for the character "E" is transmitted to the Communication Microcontroller. When "MultiReading" holds zero, the ASCII code for the character "S" is transmitted.

Additions for each reading, as well as the average of the 100 readings for each bar are to be recorded in an Excel Spreadsheet. This Spreadsheet is created as an object, when the Load button is.

The author has setup the Spreadsheet such that each row from column 1 to 100, holds "raw" readings as they are acquired. Column 102 of each row will contain the average for that row. Further, the reference reading raw data and the average calculated is represented in bold font.

After all 100 readings have been recorded the average is calculated using a For Loop to read the data from each column in the current row and adding it to the sum of the previous readings in that row. The sum of all 100 readings is recorded in variable SumBarReading which is divided by 100 to acquire the average. This average is stored in variable AvgBarReading and is recorded in column 102 in the current row.

The Excel Spreadsheet containing all the data recorded for a test is automatically saved in the same default location as the Test Fault Log files under the Name, Date and Time of the test when the Save or Print button is clicked.

Using these Spreadsheets data can be further analysed by makingthrough the use of graphs and other mathematical tools.

Also included as an additional feature is the systems ability to indicate a possible Open or Short Circuit. A Short circuit is identified when the system records a value of zero for more than 50 repetitive readings on the same pair of bars. This count takes place in variable "ZeroIn". It should be noted that the ADC represents zero volts by 0111 1000 0111 1000. The decimal representation of this code, broken into a High and Low byte is 120 120. This is exactly the condition that is tested in order to increment variable, "ZeroIn".

If ZeroIn is greater than 50, the Spreadsheet recordings for each cell of this 100 cycle reading will be changed to "Adjusted" and the average reading held in column 102 of that row will be changed to 0. The value held in variable "AvgBarReading" is also changed to 0.

In the case of an Open Circuit, the reader will recall that the Input Analogue Circuitry alerts the Communication Microcontroller when the reading is out of range. The Communication Microcontroller then transmits 1111 1111 1111 1110 to the GUI. Note that this is a unique code that is only transmitted on the occurrence of an out of range reading. Recall that if ever this code is encountered during a normal reading acquisition, the Communication Microcontroller converts the acquired code to 1111 1111 1111 1111 before transmitting it to the GUI. Also, note that the port pin on the Communication Microcontroller i.e. P0.2 is set high by the input analogue circuitry to indicate that the orientation of the system input test probed is revered with respect to the polarity of the Test Supply Current probes.

This condition will however never occur during the automated process provided that the test was set up correctly by the test technician. This implies that whenever 1111 1111 1111 1110 is encountered during a reading acquisition cycle, it can only indicate that an Open Circuit has been detected. When this value is encountered by the Calculation Subroutine as decimal 65534, variable/flag "StnBit_WDflg" is set to true.

6.2 The Calibration Tool

The ideology behind the GUI Calibration Tool is to facilitate calibration by the system administrator whenever necessary. This tool aids the calibration process which has to be carried out by specially trained personnel. Presently, the Calibration Tool is used to simply acquire and record the system readings for a respective known injected value. The author is experimenting with software calibration techniques and in the future will implement algorithms based on these techniques to enable software calibration of the system.

This will imply that the user can account for any offsets and variations that may occur over time in software as opposed to hardware tuning. To demonstrate the ability and possibilities of the Calibration Tool, the author has included an algorithm based on the nullification of errors using two linear Best-Fit curves. A true size representation of the calibration screen can be found in Appendix N and a screen capture of the calibration screen is shown in Figure 6-2.

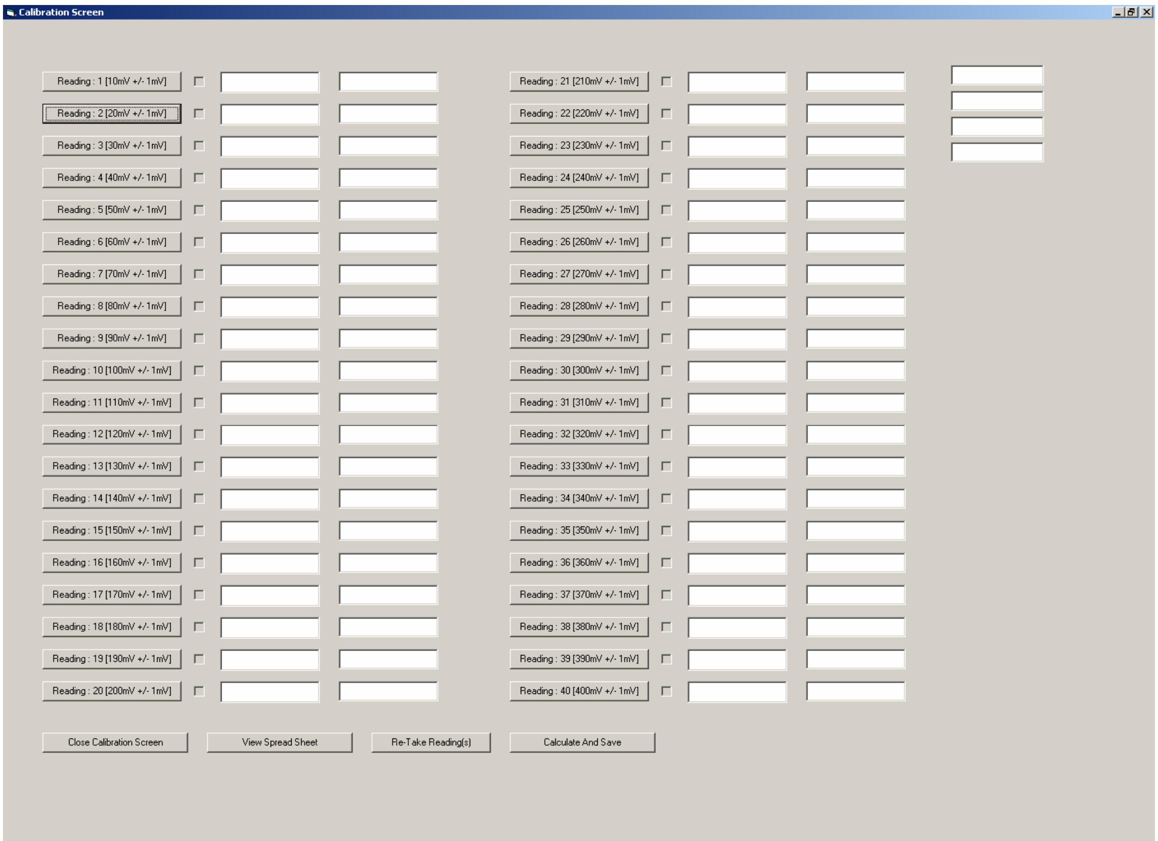


FIGURE 6-2: SCREEN CAPTURE OF THE CALIBRATION SCREEN

The Calibration Screen is a separate form that is called by clicking on the Calibration Setup button on the main GUI. The user is then prompted for the Administrator's Password. The Calibration Screen is only made visible if the correct password is entered.

As shown, there are two Text Boxes, one Check Box and one Button for each of the forty readings that are to be taken. An injection value is specified for each reading with an allowable variance of $\pm$ 1mV. The voltage value being injected into the controller's data acquisition module is to be entered into the first Text Box before the button is clicked.

When the button is clicked, the value that the data acquisition system acquires for the voltage that is being injected is recorded in an Excel Spreadsheet along with the injection value that was entered in the first Text Box. The acquired value is also displayed in the second Text Box for the present reading. Note that an average of 100 readings is also used here however, only the average is recorded in the Spreadsheet.
The CalibrationSub subroutine is responsible for this process. See Appendix C for the subroutine coding.

After a reading has been taken the button is disabled and the Check Box is checked to indicate completion. Readings can be retaken by the Re-Take Reading button. After all forty readings have been taken the Calculate And Save button is clicked to perform the relevant calculations and save the calibration factor in a specified file.

The calculation carried out here is completed in three phases. The first phase involves the calculation of the gradient and the Y-intercept of the best-fit linear plot for the injection values that were entered in the first Text Box. The second phase entails the calculation of the gradient and the Y-intercept of the best-fit linear plot for the values acquired by the data acquisition system which were displayed in the second Text Box. These plots are obtained by using the Least Squares Approximation technique. The following equations were used to calculate the gradient and the Y-intercept respectively, for each plot.

$$\text{Gradient} = \frac{\text{n} \times (\text{sum of } x_i \times y_i) - (\text{sum of } x_i) \times (\text{sum of } y_i)}{\text{n} \times (\text{sum of } x_i \times x_i) - (\text{sum of } x_i)^2} \qquad 6\text{-}1$$

$$\text{Y-intercept} = ((\text{sum of } y_i) - \text{Gradient} \times (\text{sum of } x_i)) \,/\, \text{n} \qquad 6\text{-}2$$

Where, n = total number of points or samples

i = point or sample index

x = x coordinate of a point or sample

y = y coordinate of a point or sample

Source: *Calculus and Analytic Geometry (9th Edition)* [17]

Once the gradient and Y-intercepts for each best-fit linear plot has been calculated, a straight line equation for each is derived with the value of y being the same for both and representing the point or reading number.

$$y_{Injection} = m_{Injection}x_{Injection} + c_{Injection} \qquad 6\text{-}3$$

$$y_{Acquired} = m_{Acquired}x_{Acquired} + c_{Acquired} \qquad 6\text{-}4$$

Now, $x_{Injection}$, represents a value on the best-fit linear plot for the injected voltage for a given reading, point or sample as represented by the y-coordinate $y_{Injection}$, for that point. For example, the coordinate for point (1, 0.25) means reading number 1, with a value of 0,25V as represented by ($y_{Injection}$, $x_{Injection}$). The same applies to the acquired readings and plots. See Figure 6-3 for a diagrammatic representation of the above paragraph.

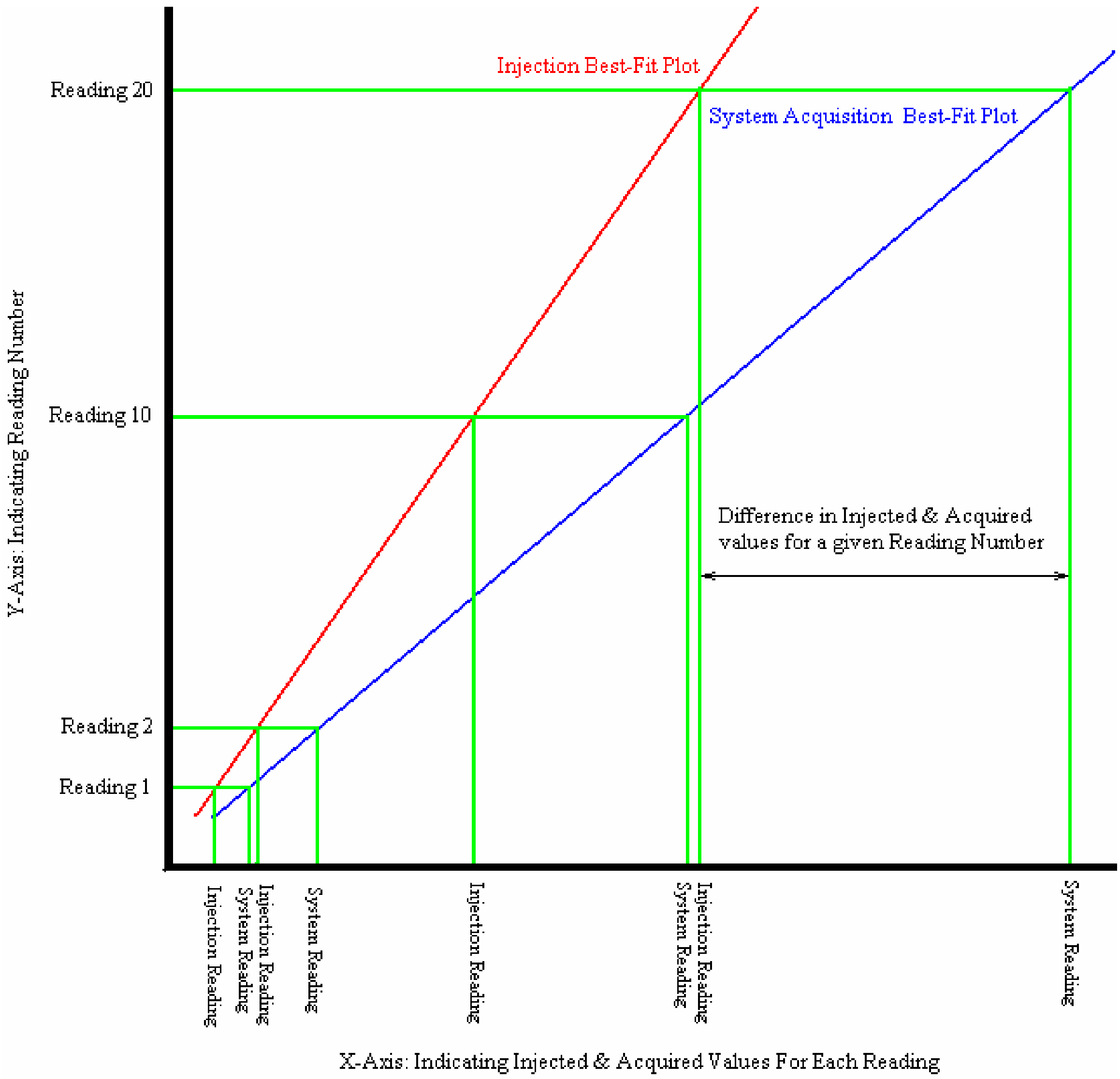


FIGURE 6-3: DIAGRAMMATIC REPRESENTATION OF THE LEAST SQUARED APPROXIMATION METHOD

Phase three of the calculation entailed equating both of the above equations ($y_{Injection}$ = $y_{Acquired}$ = point number) and calculating the calibration factor as follows:

$$m_{Injection}x_{Injection} + c_{Injection} = m_{Acquired}x_{Acquired} + c_{Acquired} \quad 6\text{-}5$$

$$m_{Injection}x_{Injection} = m_{Acquired}x_{Acquired} + c_{Acquired} - c_{Injection} \quad 6\text{-}6$$

$$x_{Injection} = (m_{Acquired}x_{Acquired} + c_{Acquired} - c_{Injection}) / m_{Injection} \quad 6\text{-}7$$

Rearranging,

$$x_{Injection} = x_{Acquired} \times (m_{Acquired} / m_{Injection}) + ((c_{Acquired} - c_{Injection}) / m_{Injection}) \quad 6\text{-}8$$

The calibration factor therefore aims to get the best-fit Injection plot as close to the best-fit acquisition plot as possible for the entire range of input values. This is accomplished by manipulating the acquired value, $x_{Acquired}$, such that it is equal to the injected value $x_{Injection}$, for that specific reading number. This manipulation is carried out in the Calculation Subroutine by implementing Equation 6-8 as follows:

$$x_{Calibrated} = x_{Acquired} \times (m_{Acquired} / m_{Injection}) + ((c_{Acquired} - c_{Injection}) / m_{Injection}) \qquad 6\text{-}9$$

Where,

$x_{Calibrated}$ is the true value calculated from the system acquired value, $x_{Acquired}$.

This calibration factor is then saved along with the date of the calibration procedure in a file entitled Calibration1 which is located in a specially created folder named Calibration[6] in the Program files folder on the C drive. Each time the Load button on the GUI is clicked this file is opened and the calibration factor is loaded into variables "gradient" and "intercept" which are used in the Calculation subroutine. If on first use the system has not been calibrated or the calibration file has been erased, a default value of 1 is loaded into "gradient" and 0 into "intercept". The user is also made aware that the system needs to be calibrated by means of a message box.

Each time the system is calibrated, the previous calibration factor and date are replaced by the new ones. In order to facilitate this calibration functionality, the Communication Microcontroller has to be made aware that it should only take a reading when it is prompted and not communicate with the Automation Microcontroller or any of the sensor or transducer modules. This is accomplished by transmitting the ASCII code for the letter "H" when any one of the forty calibration buttons on the calibration screen are clicked. Also, when one of these buttons are clicked the CalibFlagClear flag is set to "False". This is done so that when this flag is tested at the beginning of the Calculation subroutine and is found to be false the Calibration subroutine is called to handle the incoming data. When this flag is set to "True", indicating that a test is in progress the Calculation Subroutine handles all incoming data.

[6]When installing the GUI onto a Desktop Computer or Notebook, the installer must create a folder entitled Calibration in the Program files folder on the C drive.

6.3 Multiple User Names And Passwords

Access to this functionality is obtained through clicking on the View User Profile button on the GUI. The user will then be prompted to enter the Administrator's Password before proceeding. The Administrator can then allow a user to enter his name and personal unique password. Once all entries have been made, the Administrator clicks on the Enter New User button. This opens (or creates if not in existence) a file named "B_2_B_Pwd" in the Calibration folder which is found in the Program files folder on the C drive. The new user details are then added to this file.

Note that if the Password and Confirm Password entries do not match the user is asked to reenter a password. The Administrator also has the option of deleting a user's records from this file, thus effectively revoking his/her rights to access the system. When a user intends on using the system, he/she enters a password and clicks on the GUI Enter button. This action opens the password file "B_2_B_Pwd" and verifies if the password exists. If it does exist, the User Name associated with that password is automatically displayed in the Name Text Box on the GUI. See Figure 6-4 for a screen capture of this functionality.

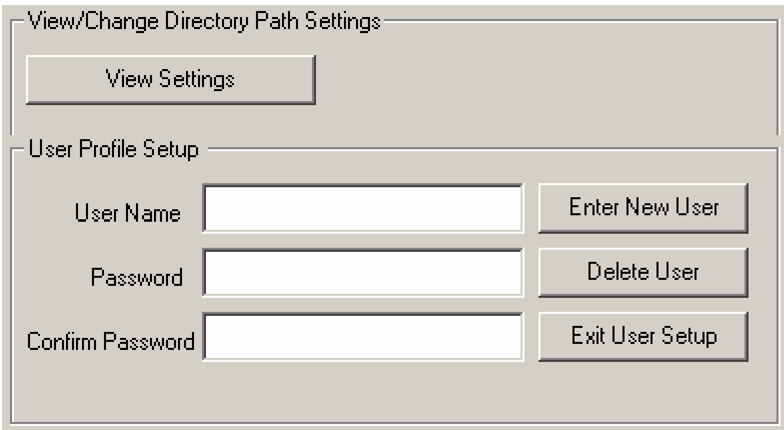


FIGURE 6-4: MULTIPLE USER NAMES AND PASSWORDS SETUP FRAME

6.4 GUI Special Function (Simulator) Controls

The GUI Special Function Controls have no bearing on the GUI functionality. These controls are made available to a SuperUser, in this case only the author, who has a unique user name and password. The Special Function Controls allows the SuperUser to simulate inputs from the Controller. It is thus in essence a Graphic User Interface Simulator. As the GUI and the controller were developed in parallel there was no means of assessing the GUI when it became necessary to test it in terms of its responses to input prompts and data, as well as the outputs it generated based on its calculations.

A simulator had to therefore be developed to mimic the controller and the data that it transmitted. The simulator functionality is useful in the event of a system failure or malfunction where the author can determine if the GUI or the controller or both is at fault by testing them independently. These controls are also useful for de-bugging purposes in the event of future modifications and additional functionalities. In order to display the simulator screen (or frame) the Super User first clicks on the View Controls button that is found in the GUI Special Function Controls frame depicted in the Figure 6-5.

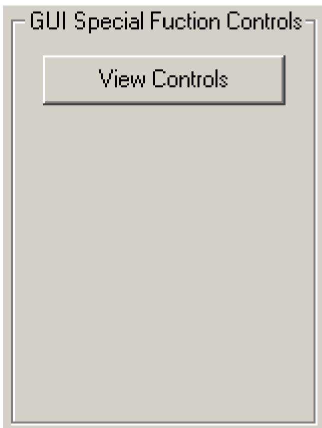


FIGURE 6-5: GUI SPECIAL FUNCTION CONTROLS FRAME

Upon clicking this button an identification frame appears prompting the Super User for a username and password, as shown in Figure 6-6.

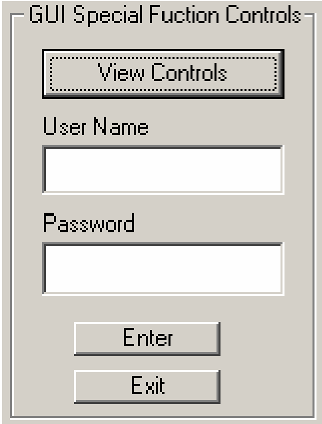


FIGURE 6-6: SUPERUSER IDENTIFICATION FRAME

When the correct user username and password is entered, the Simulator is made available to the SuperUser as shown in the figure below. The Super User simply clicks on the Exit button to exit from this frame and returns to the default frame that is depicted in Figure 6-5.

FIGURE 6-7: GUI SIMULATOR THAT SIMULATES CONTROLLER TRANSMISSION

Recall that the OnComm procedure is developed such that it is initiated when received data is present in the serial port buffer. This data is then copied from the buffer into the variable, **SerIn**,

Let SerIn = MSComm1.Input

before the Select Case routine is invoked.

In order to mimic the controller, the data must be received in much the same way as when data is being received from the controller. The problem however arises when one considers that there will be no data present in the serial port buffer. This means that the OnComm procedure will never be initiated. The simulator has to therefore input data (mimicked received data) to the very first storage facility after the serial port buffer. This facility is the variable, **SerIn**.

The simulator therefore writes all data that was entered into the "Mscom In Sim" input box to this variable and since the Select Case routine is not initiated automatically as in the case of the OnComm procedure it has to be manually initiated using the Case Select button. The GUI transmitted output may also be read in the "Out" text box provided that the code simulated writes to the original serial port as well as the Out text box. Code Extract 6-5 shows the source code for the Case Select button.

Note that the code is exactly the same as that of the OnComm procedure except for the fact that the mimicked data is being read from Text Box 17 and is copied directly into **SerIn**.

Chapter 7

Test Results

Various tests were conducted with results recorded to measure the system's performance and verify the system process flow and event sequencing. Tests were carried out in two phases. The first phase was aimed at quantifying the Data Acquisition accuracy, repeatability and all round performance. The second phase was aimed at verifying the automated flow process and to ensure that the correct sequence of events was followed as programmed.

For the first phase of tests, forty voltage values were injected at intervals of 10mV $\pm$ 1mV and the GUI Calibration Tool was used to acquire and record the forty respective system readings. The readings are taken in exactly the same manner as it would be in a normal test, i.e. 100 successive readings which will be averaged to produce the final value for the respective injected voltage value.

The first test carried out in this phase was aimed at determining the repeatability of the system, i.e. to quantify the variation between the maximum and minimum readings acquired by the system for the same injected voltage value. Note that the results of this test are influenced by the Test Supply which was measured to have a worst case ripple of $\pm$ 1mV.

The complete results of this test, comprising 100 readings for each acquisition cycle, can be found on the disc included as Appendix O. The spreadsheet entitled "Repeatability Test As Recorded" is an unedited spreadsheet that depicts the manner in which readings are recorded by the system. The spreadsheet entitled "Repeatability Test with Highlights" has been edited by the author to present the recorded data to the reader in a manner that is easier to analyse. With reference to Column CX the maximum average acquired was 0.187902V and the minimum average acquired was 0.187048V producing a variance range of 0.000854V.

The second test in this phase was aimed at quantifying the variances of the acquired values from the true, injected values, determining the output linearity of the system and ascertaining the relationship between the input injected values and the system output recorded values. The complete results of this test, comprising 100 readings for each acquisition cycle, can be found on the disc included as Appendix O.

The Spreadsheet entitled "System Evaluation" shows the data that was acquired and recorded during this test. Columns A to CX are the original data columns and depict the data that was recorded during each reading cycle. Column CY represents the voltage that was injected into the system in order to produce the respective system reading and recording. Column CZ shows the absolute value of the difference between the injected and recorded values, i.e. the system error, and Column DA represents the reading number. It should be noted here again that the results of this test depends on the ripple of the Test Supply.

The author noted that the system's acquired values vary more from the true injected values for the lower range of injected values, i.e. for injected values less than 0.08V. As the input voltage (injected voltage) increases the variation from the true value reduces. Recalling that the expected input range for any test that is to be carried out by this system is within the range of 100mV to 350mV, these variances for the lower input values are tolerable, as it will have little bearing on actual test results due to the decreasing error as the input voltage increases to within the typical 100mV to 350mV input range. If need be, more time and resources can be spent on reducing this variation when the system is installed. For the expected input range of 100mV to 350mV, the maximum error that was measured during this test was 0.00112V which when calculated as a percentage of the injected voltage (i.e. 0.15V) for that measurement is:

$$\text{Maximum Percentage Error} = \frac{0.00112\text{V}}{0.15\text{V}} \text{ x } 100 \qquad \ldots\ldots\ldots \quad 7\text{-}1$$

$$= 0.75\ \%$$

The graphs shown in Figures 7-1 to 7-6 summarises the results of this test. The input (injected value) curves and best-fit input linear curves are plotted and compared with the output (acquired values) curves and best-fit output linear curves. This is done in order to compare the variation of the output from the input injection values throughout the range of the Data Aquisation System. As can be seen from these graphs and the best fit linear graph equations, the variation between the injected values and the system acquired values is minimal therefore implying an almost straight line, $y = x$ relationship between the system input and recorded output values, as depicted in Figure 7-6.

When plotting the Output Vs Input curve and deriving the associated straight-line equation, i.e. $y = 1.004x - 0.0012$, it is clear the deviation from the ideal, $y = x$, curve is minimal. In simple terms this means that whatever potential is present at the system input is acquired and recorded by the system with very little deviation from the original input value.

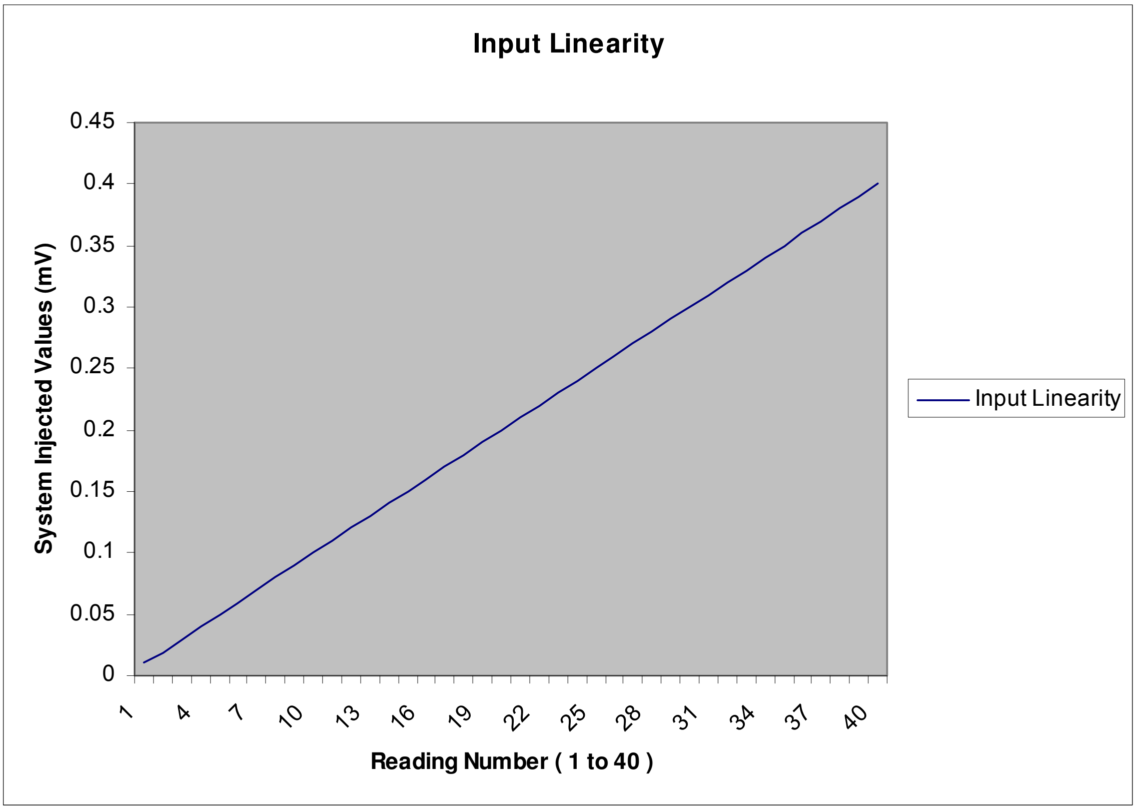


FIGURE 7-1: INPUT LINEARITY CURVE

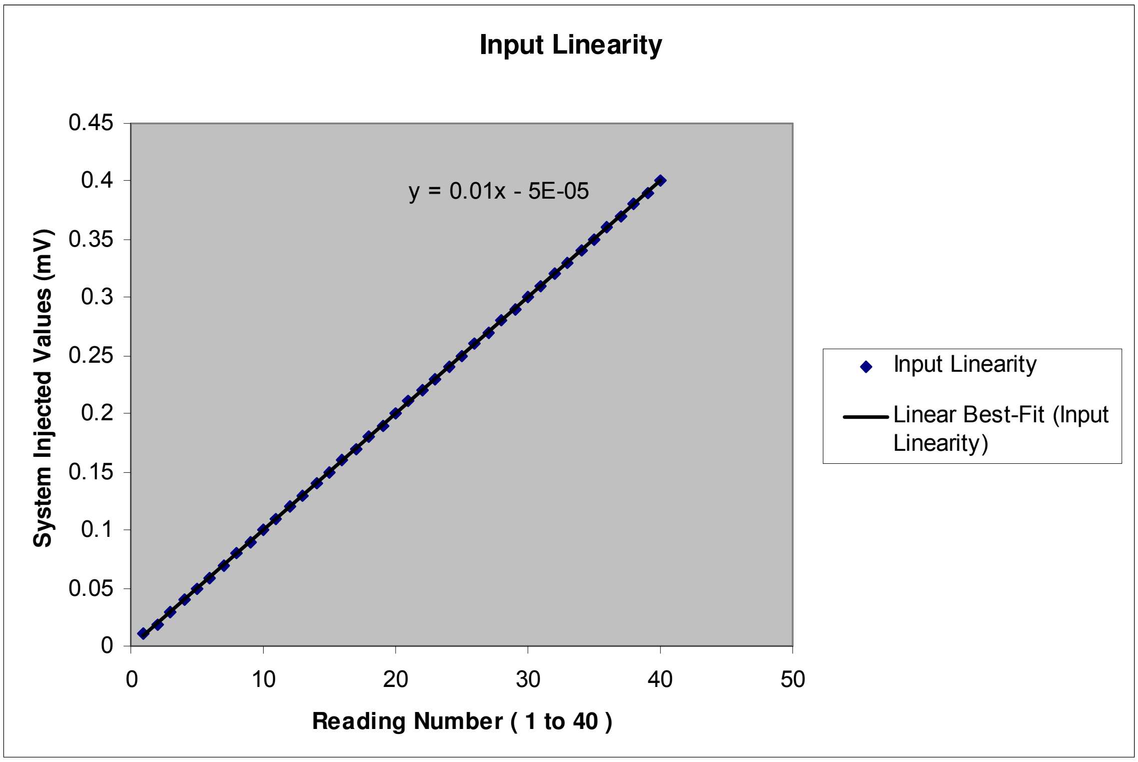


FIGURE 7-2: LINEAR BEST-FIT INPUT LINEARITY CURVE

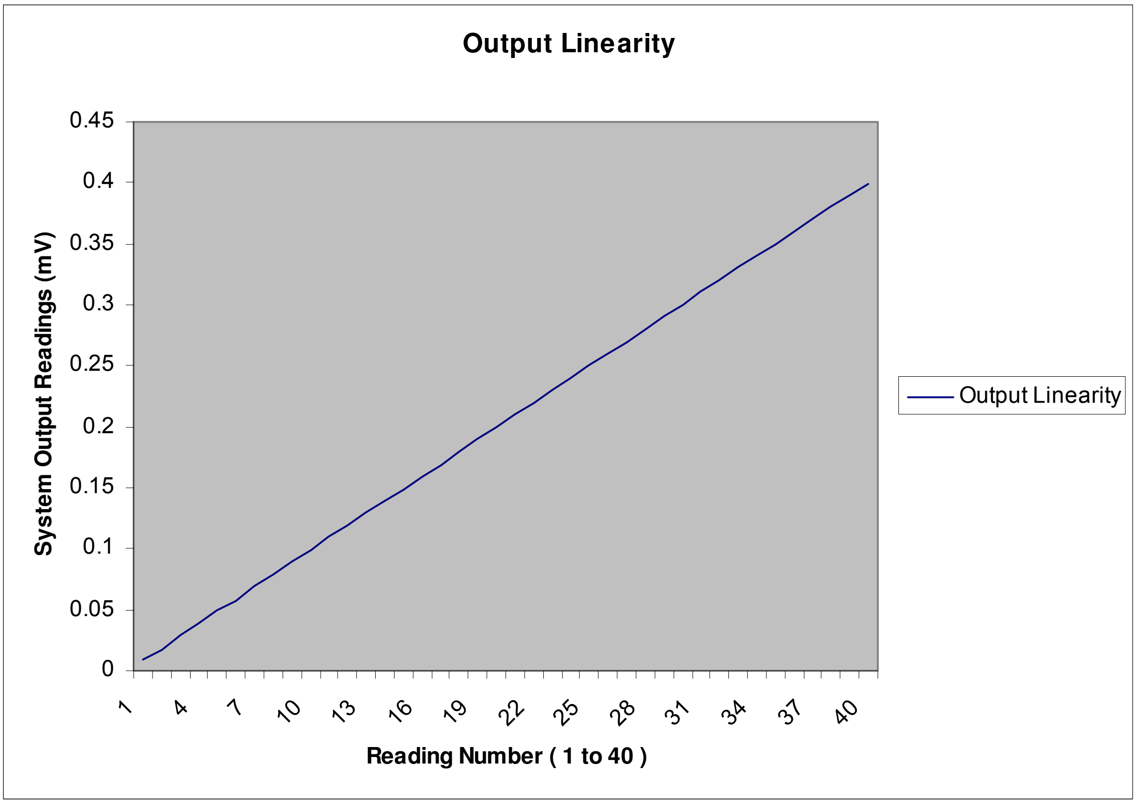


FIGURE 7-3: OUTPUT LINEARITY CURVE

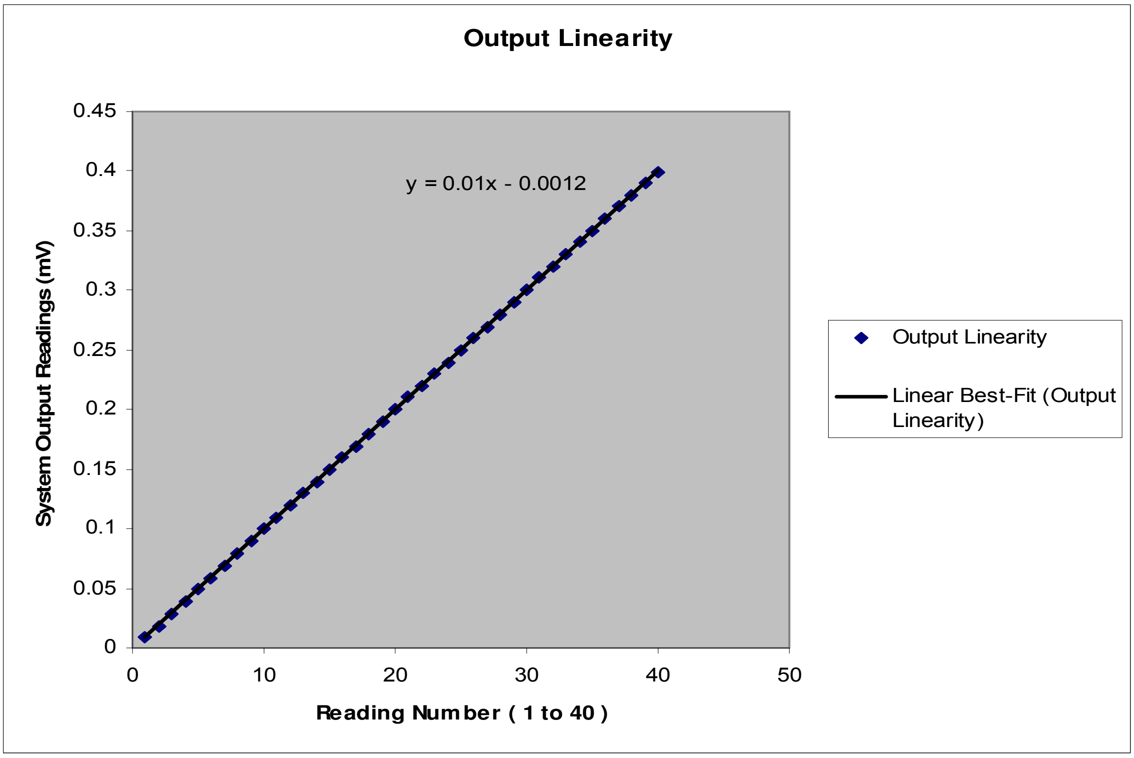


FIGURE 7-4: LINEAR BEST-FIT OUTPUT LINEARITY CURVE

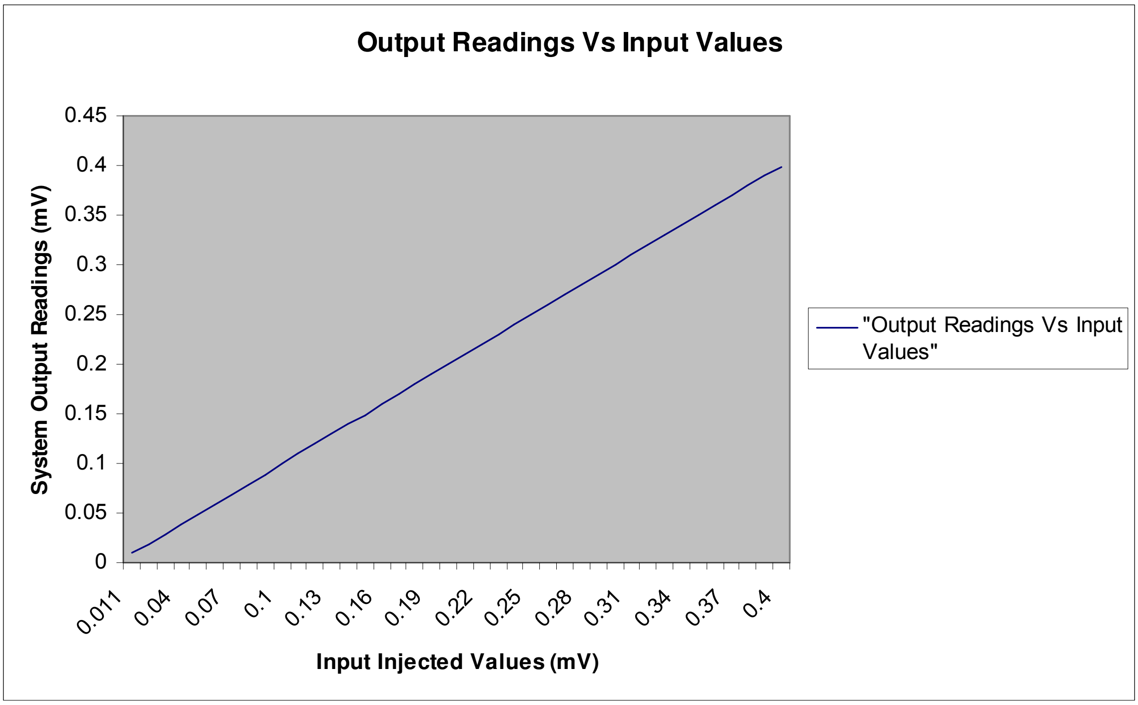


FIGURE 7-5: PLOT OF OUTPUT (ACQUIRED) READINGS VS INPUT (INJECTED) VALUES

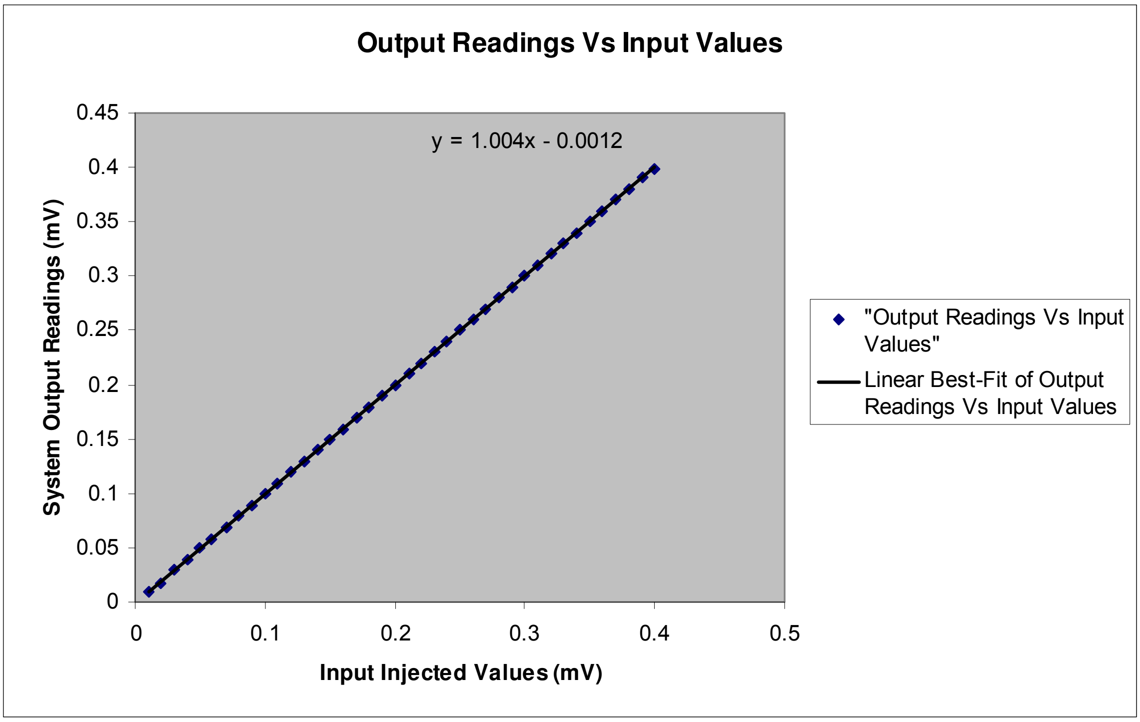


FIGURE 7-6: LINEAR BEST-FIT PLOT OF OUTPUT (ACQUIRED) READINGS VS INPUT (INJECTED) VALUES

Test three in this phase concentrated on the analysis of the data. As mentioned previously, if the potential difference across a pair of bars varies from the reference reading by a percentage that is larger than the percentage variance selected by the technician at the beginning of the test, a fault containing all the necessary details must be logged. At the end of the test, a test report containing all the faults as well as the test details and selected parameters must be printed. This information is also saved as a soft copy, as an update to the file that is associated with the armature under test by the component's serial number.

For this test, a simple series resistor and potentiometer network was set up on a test bench. All the resistor values were identical, 10kΩ, and were to represent/simulate bars that were healthy, i.e. bearing no faults. The resistor represented/simulated bars 1, 2, 4 and 6. Bars 3, 5 and 7 were represented/simulated by potentiometers that were set such that the potential difference across them varied from the reference value (0.13594V) by a percentage that was greater the pre-selected 5% variance. The test report for this test can be found in Appendix E and the data recorded during this test can found on the disc provided as Appendix O under the file named “001 Test Results 2006-4-12 14H16M31”. Note that the name of the file represents the serial number that was entered, i.e. 001 Test Results, and the date and time of the test.

With reference to Appendix E and O the reader will note all the recorded faults. The simulated short circuit fault that was logged on Bar 8 was created by simply shorting the system’s input probes. As discussed in the previous chapter and with reference to Appendix O, each cell in this row holds “Adjusted” except for column 102 of this row which holds 0. In the case of an Open Circuit, the binary word (1111 1111 1111 1110) that was transmitted by the Communication Microcontroller upon encountering this condition alerts the Calculation Subprogram that an Open Circuit has been detected. The value here is not important, all that matters is that a fault was logged on this bar indicating an Open Circuit. However, for completeness the value of 0.411646 is calculated using an algorithm in the Calculation subroutine in the GUI. Note that this algorithm contains the variable “Gain” which the reader will recall was set to 9.95, the outcome when 1111 1111 1111 1110 is received by the GUI is:

```
Let ActVolReadRes = (4.096 / 65536)
Let ActVolRead = (StnBit_WD * ActVolReadRes)
Let mVActVolRead = ActVolRead / Gain
```

i.e.

```
Let ActVolReadRes = 4.096 / 65536 = 0.0000625
Let ActVolRead  = 65534 x 0.0000625 = 4.095875
Let mVActVolRead = 4.095875 / 9.95 = 0.411646
```

And finally, on the tenth pair of bars, an Emergency Stop was initiated.

The second phase of tests involved the testing of the automation processes. For these tests a digital oscilloscope that is capable of handling sixteen digital inputs was used to record the sequence of events as a test was carried out. The first test that was carried out was aimed at confirming the timing and the process flow of the system. See Figure 7-7 for the results from this test.

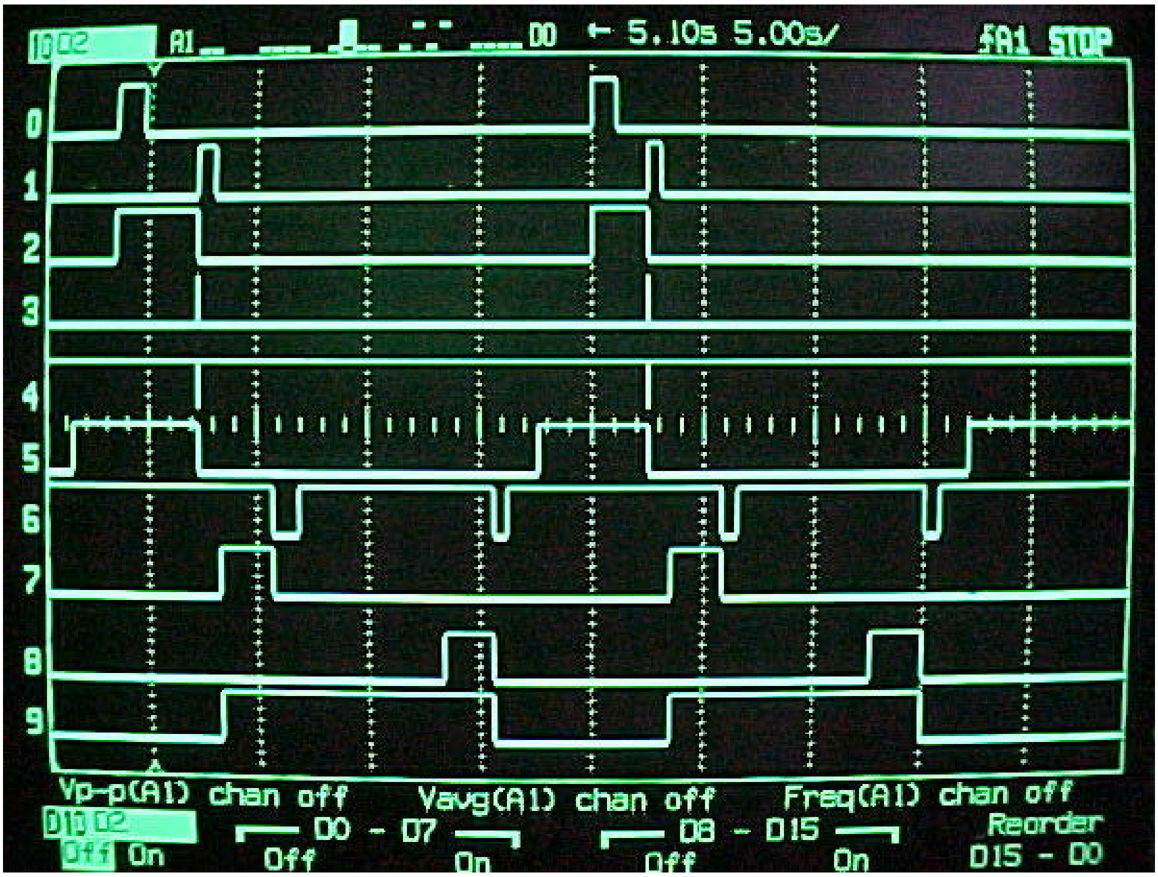


FIGURE 7-7: SYSTEM TIMING DIAGRAM

Where,

Signal 0	Represents the output of the first optical sensor
Signal 1	Represents the output of the second optical sensor
Signal 2	Represents the output of the D flip-flop to which the first optical sensor is connected
Signal 3	Represents the output of the D flip-flop to which the Second optical sensor is connected
Signal 4	Represents the input to the External Interrupt 1 pin of the Automation Microcontroller
Signal 5	Represents the output signal that controls the Armature Drive Motor
Signal 6	Represents input to the External Interrupt 0 pin of the Automation Microcontroller
Signal 7	Represents the output signal that controls the Detection Unit Drive Motor for the lowering motion
Signal 8	Represents the output signal that controls the Detection Unit Drive Motor for the raising motion
Signal 9	Represents the output signal that controls the Test Supply Current

Every test cycle begins by pulsing the Armature Drive Motor to begin rotating the armature under test, as signal 5 depicts. While rotating the armature optical sensors 1 and 2 detect the copper bars on the commutator. Upon detecting a bar, the respective optical sensor output goes high, clocking the gate of the D flip-flop that it is connected to causing its output to also go high. This is depicted by signals 0 and 2, and signals 1 and 3. As soon as both D flip-flop outputs are high, External Interrupt 1 is triggered via a NAND Gate as depicted by signal 4. The External Interrupt 1 ISR is then initiated. The Armature Drive Motor is stopped immediately, (Signal 5). Following this, the D flip-flops are "Cleared" (output = 0). This is evident when one looks at the point when External Interrupt 1 is triggered. After a few microseconds, the Armature Drive Motor signal goes Low followed by the outputs of the D flip-flops (Signals 1 and 3) both going low.

Note that for this test the optical sensors were manually triggered, hence the output returns low after the triggering source is removed. Ordinarily, the outputs of the optical sensors will only return low when the gap between the bars have been detected. Signals 0 and 1 going High indicates that a copper bar has been detected, and returning to Low indicated that the gap between the bars have been detected. This is shown in the figure below.

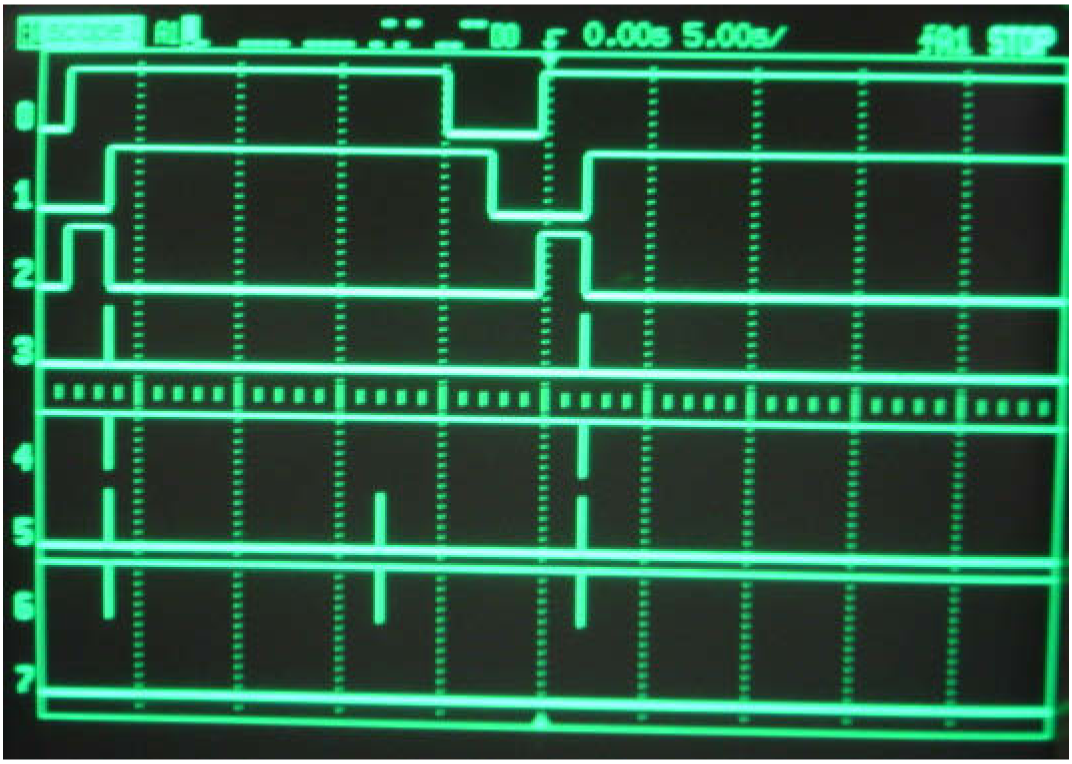


FIGURE 7-8: TIMING DIAGRAM FOR A TYPICAL BAR DETECTION CYCLE

Where,

Signal 0	Represents the output of the first optical sensor
Signal 1	Represents the output of the second optical sensor
Signal 2	Represents the output of the D flip-flop to which the First optical sensor is connected
Signal 3	Represents the output of the D flip-flop to which the Second optical sensor is connected
Signal 4	Represents the input to the External Interrupt 1 pin of the Automation Microcontroller
Signal 5	Represents the P0.5 on the Automation Microcontroller which provided the input signal to a Nand gate in order to clear the D flip-flops
Signal 6	Represents the output of the above-mentioned Nand Gate, which triggers External Interrupt 1.

Continuing with reference to Figure 7-7, shortly after the Armature Drive Motor has been stopped and the flip-flops cleared, the Detection Unit is lowered by pulsing the Detection Unit Drive Motor (Signal 7). At this point the Test Current is also switched on (Signal 9) for the reasons discussed in Chapter 4. When the test probes have reached the surface of the commutator as signaled by the inductive proximity switch on the Detection Unit, External Interrupt 0 is triggered as depicted by Signal 6. The External Interrupt 0 ISR immediately stops the lowering process.

The 100 cycle successive reading process then begins. Once this process is completed the Detection Unit is raised by pulsing the Detection Unit Drive Motor (Signal 8). Once raised to its initial position, as signaled by the inductive proximity switch on the physical test unit frame, External Interrupt 0 is again triggered. This time the ISR ends the raising process. The Test Supply Current is also switched off at this point. This is one complete automation cycle. The very same process is carried out for the next pair of bars. The control of the system's main components such as the Armature Drive Motor, Detection Unit Drive Motor and the IGBT, via their respective electronic drives and drivers is depicted in Figure 7-9.

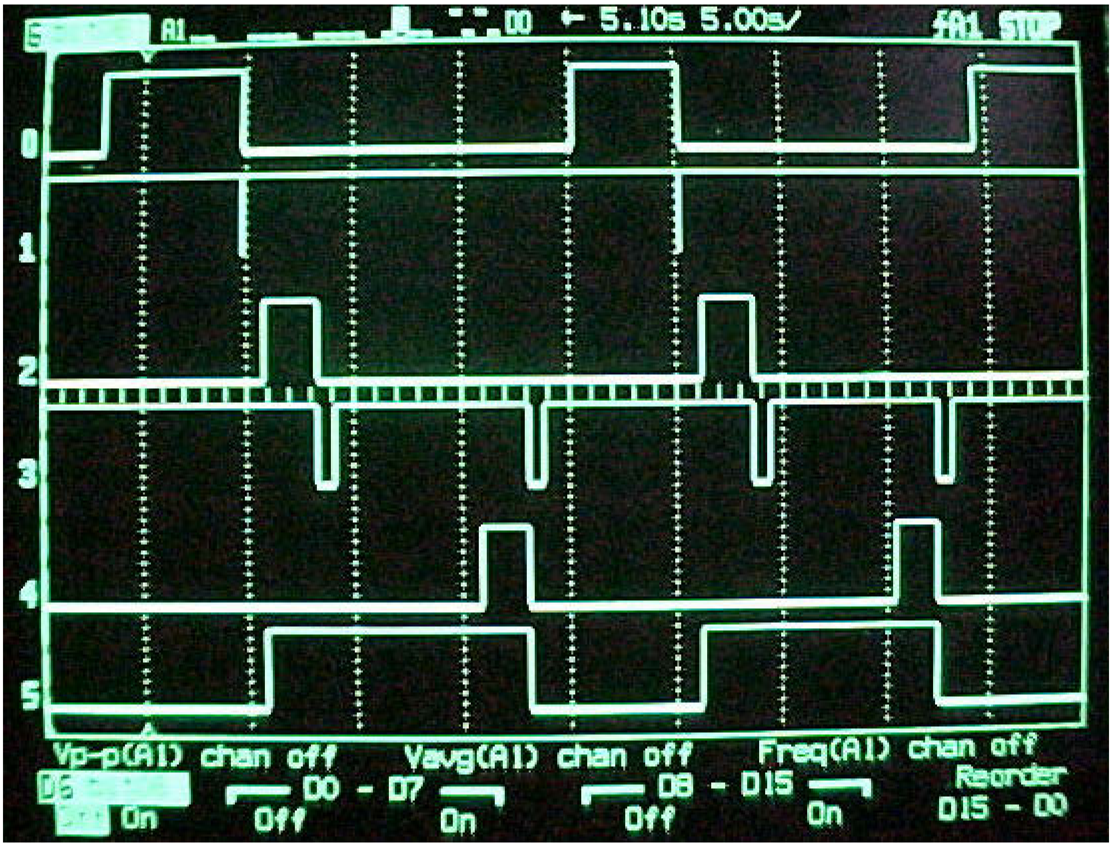


FIGURE 7-9: TIMING DIAGRAM FOR MAIN COMPONENT SWITCHING

Where,

Signal 0	Represents the output signal that controls the Armature Drive Motor
Signal 1	Represents the input to the External Interrupt 1 pin of the Automation Microcontroller
Signal 2	Represents the output signal that controls the Detection Unit Drive Motor for the lowering motion
Signal 3	Represents input to the External Interrupt 0 pin of the Automation Microcontroller
Signal 4	Represents the output signal that controls the Detection Unit Drive Motor for the raising motion
Signal 5	Represents the output signal that controls the Test Supply Current

The next two tests were concerned with the verification of the accuracy of the maximum allowable time that is reloaded into the timer registers for the detection process i.e. Detection Reference Time and for the raising of the detection unit, i.e. Unit Raising Reference Time. As discussed in Chapter 4 under the heading Automation Microcontroller, the same subroutine is used by both procedures therefore, if the calculation and reloading algorithm is correct for one, it will also hold true for the other.

With this in mind, the author chose to verify the Detection Reference Time. Note that unlike the Unit Raising Reference Time, the Detection Reference Time for the first three bars is a preset 10s. This is because the recorded time from which the Detection Reference Time is calculated is only taken on the third pair of bars for the reason discussed in Chapter 4. Recall from Chapter 4, "*The reason that the Detection Reference Time is calculated based on the time recorded for the third pair of bars is simply because the system is given time to settle during the first and second cycles.*" This means that Error 1 should occur if a pair of bars is not detected within 10s of the Armature Drive Motor being started, for the first three pairs of bars.

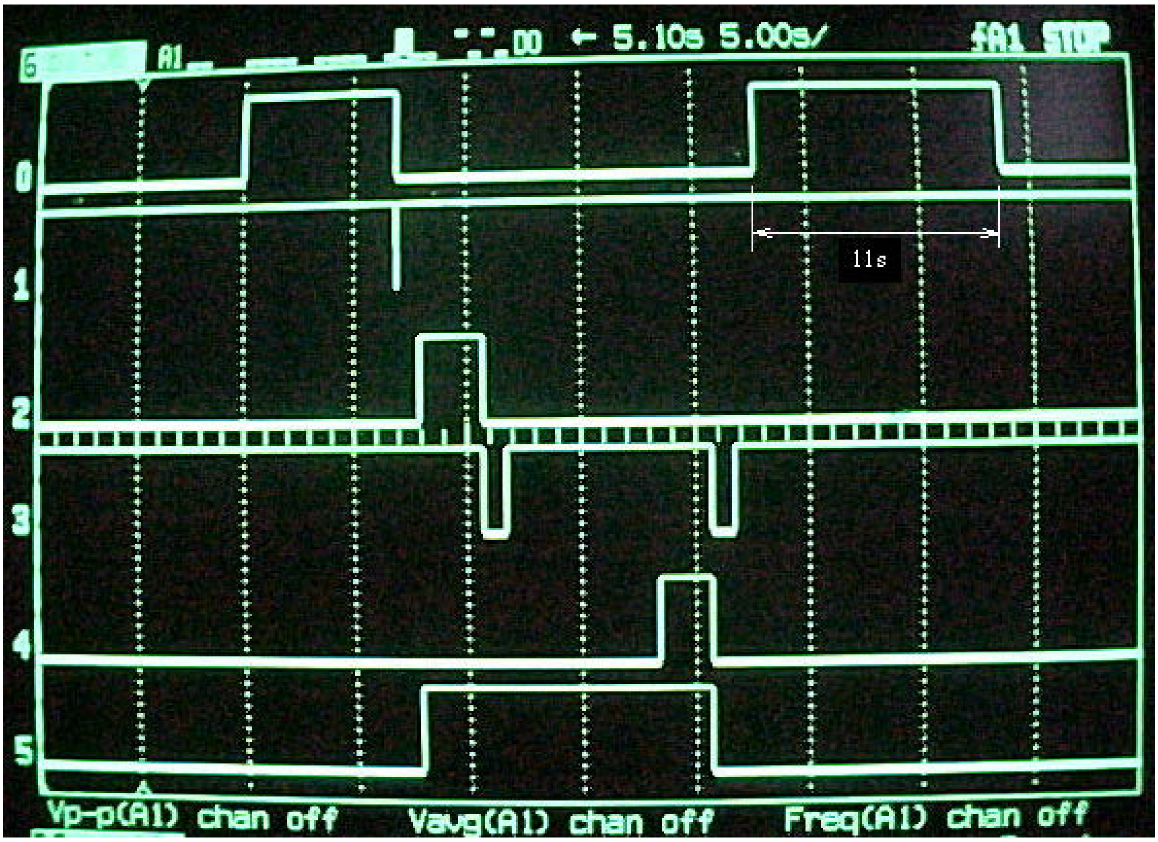


FIGURE 7-10: ERROR 1 INITIATION AFTER A 10S+1S, PREDEFINED, ALLOWABLE PERIOD HAS LAPSED

Where,

Signal 0	Represents the output signal that controls the Armature Drive Motor
Signal 1	Represents the input to the External Interrupt 1 pin of the Automation Microcontroller
Signal 2	Represents the output signal that controls the Detection Unit Drive Motor for the lowering motion

Signal 3	Represents input to the External Interrupt 0 pin of the Automation Microcontroller
Signal 4	Represents the output signal that controls the Detection Unit Drive Motor for the raising motion
Signal 5	Represents the output signal that controls the Test Supply Current

Figure 7-10 shows the first complete automation cycle for the first pair of bars but for the second automation cycle a pair of bars has not been detected, as shown by the External Interrupt 1 (Signal1) not being initiated, hence allowing the Armature Drive Motor to continue running until the 10s preset time has elapsed. This initiates the Error1 subroutine. The reader will notice that the Armature Drive Motor, Signal 0, was left to run for 11s. This is because of the 1s delay loop that was called immediately after initiating the Armature Drive Motor P0.4 to cater for real time switching delays.

```
SETB    P0.4
CALL    DELAYLOOP
```

The effect of this is that 11s will elapse due to the 10s predetermined allowable time only being counted after the 1s delay loop.

As shown in the next test's results, see Figure 7-11, the 1s delay loop has no effect on the calculated Detection Reference Time. This reference time is equal to the time recorded for the detection process on the third pair of bars plus an additional 20% of this recorded time.

Detection Reference Time = Third Pair Time Recording x 1.2

The reason that the 1s delay loop does not have any effect on this calculation is because the recording of this time was stopped after a 1s delay loop which was called immediately after the Armature Drive Motor was stopped. In other words, the time recording process was started 1s after the Armature Drive Motor was started and stopped 1s after the Armature Drive Motor was stopped, the net result being that the precise duration for which the Armature Drive Motor ran, was recorded. The exact same procedure was followed in recording the Test Probe Lowering Time which is used to calculate the Unit Raising Reference Time.

Unit Raising Reference Time = Recorded Test Probe Lowering Time x 1.2

The reference time recorded on the third pair of bars was 6 seconds and as can be seen in the figure below the maximum allowable time for a pair of bars to be detected, i.e. Detection Reference Time, is 7.2 seconds.

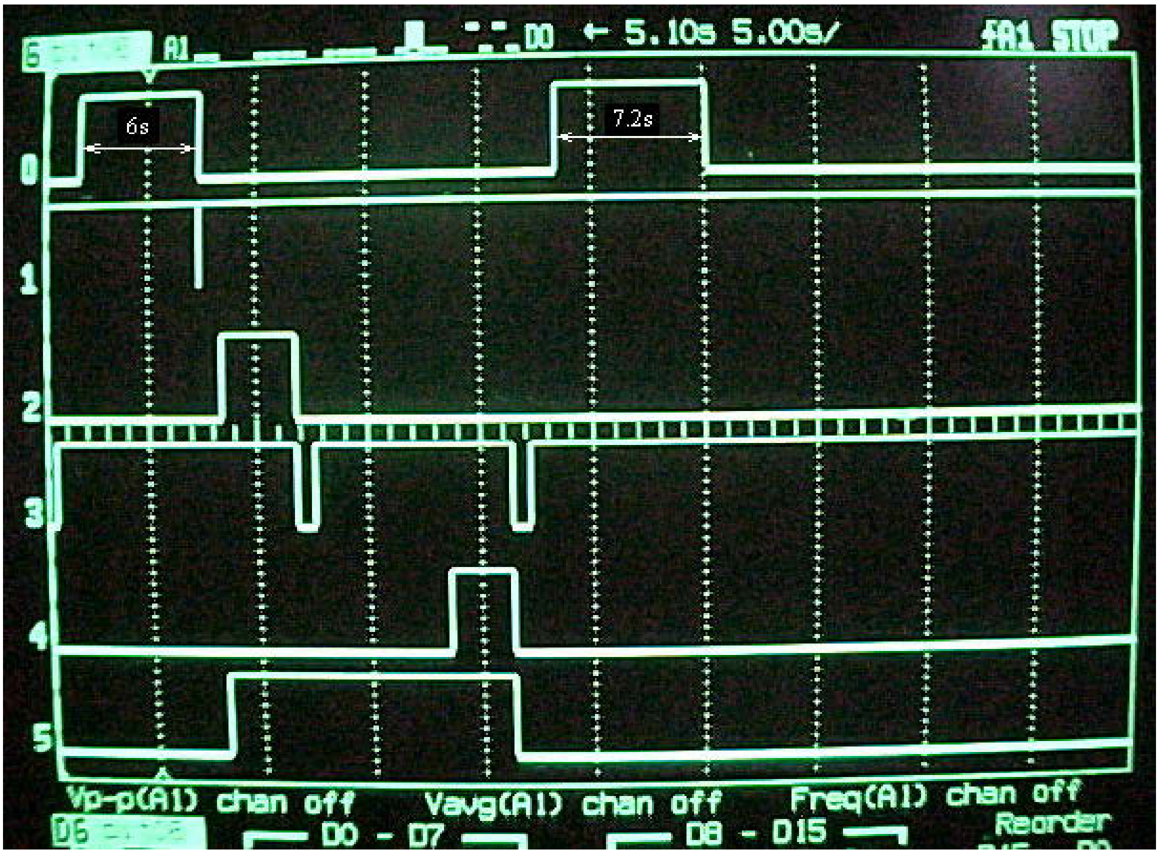


FIGURE 7-11: ERROR 1 INITIATED AFTER THE PRE-CALCULATED TIME OF 6S X 1.2 = 7.2S HAS LAPSED

Where,

Signal 0	Represents the output signal that controls the Armature Drive Motor
Signal 1	Represents the input to the External Interrupt 1 pin of the Automation Microcontroller
Signal 2	Represents the output signal that controls the Detection Unit Drive Motor for the lowering motion
Signal 3	Represents input to the External Interrupt 0 pin of the Automation Microcontroller
Signal 4	Represents the output signal that controls the Detection Unit Drive Motor for the raising motion
Signal 5	Represents the output signal that controls the Test Supply Current

The last test in this phase focused on the ADC control inputs and outputs. Although the fact that 100 volt-drop readings are acquired for each reading cycle, see Appendix

O, is proof that the ADC is operating as it should, the author thought that the following results should be included for completeness.

Figure 7-12 and Figure 7-13 depict the transitions that each of the ADC control pins undergo for each of the 100 readings taken. The time scale on which these results were recorded was 50μs/division.

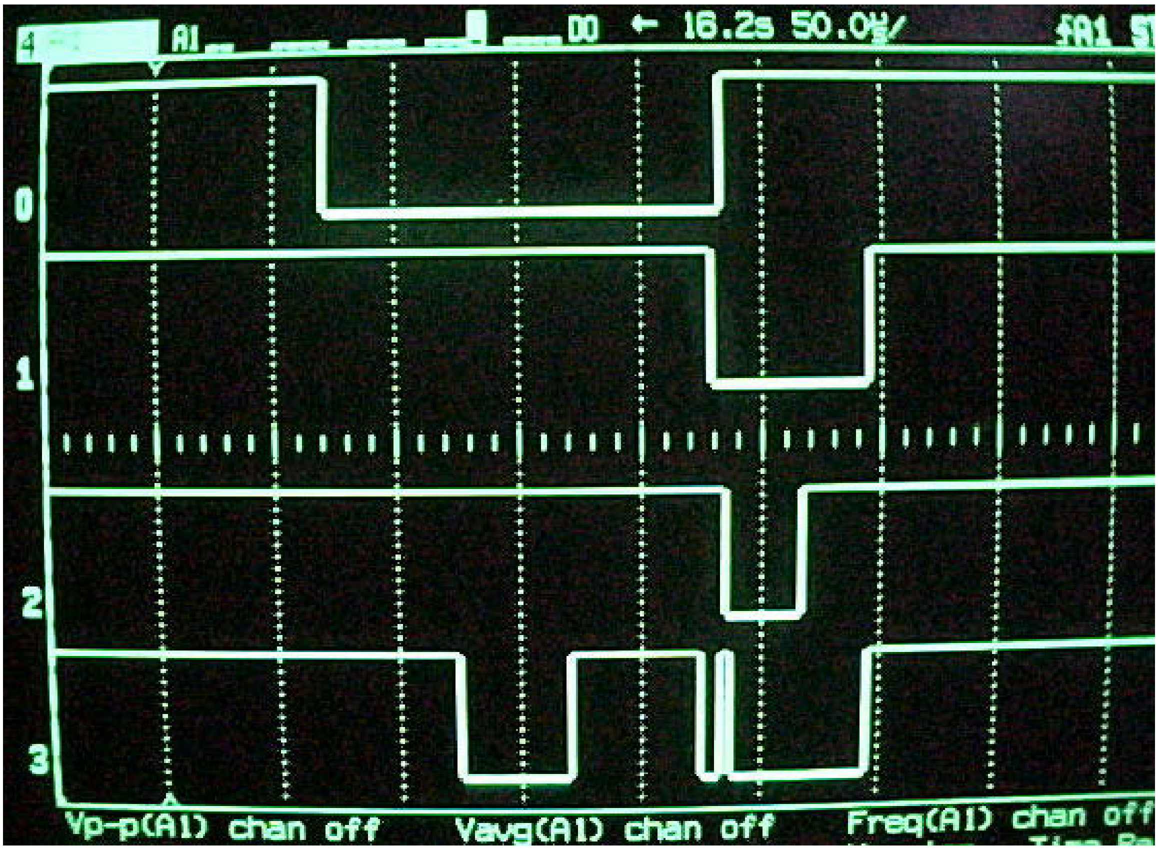


FIGURE 7-12: TIMING DIAGRAM FOR THE ADC INPUT AND OUTPUT CONTROL PINS

Where,

Signal 0	Represents the ADC input pin, $R/\overline{C}$
Signal 1	Represents the ADC output pin, $\overline{EOC}$
Signal 2	Represents the ADC input pin, HBEN
Signal 3	Represents the ADC input pin, $\overline{CS}$

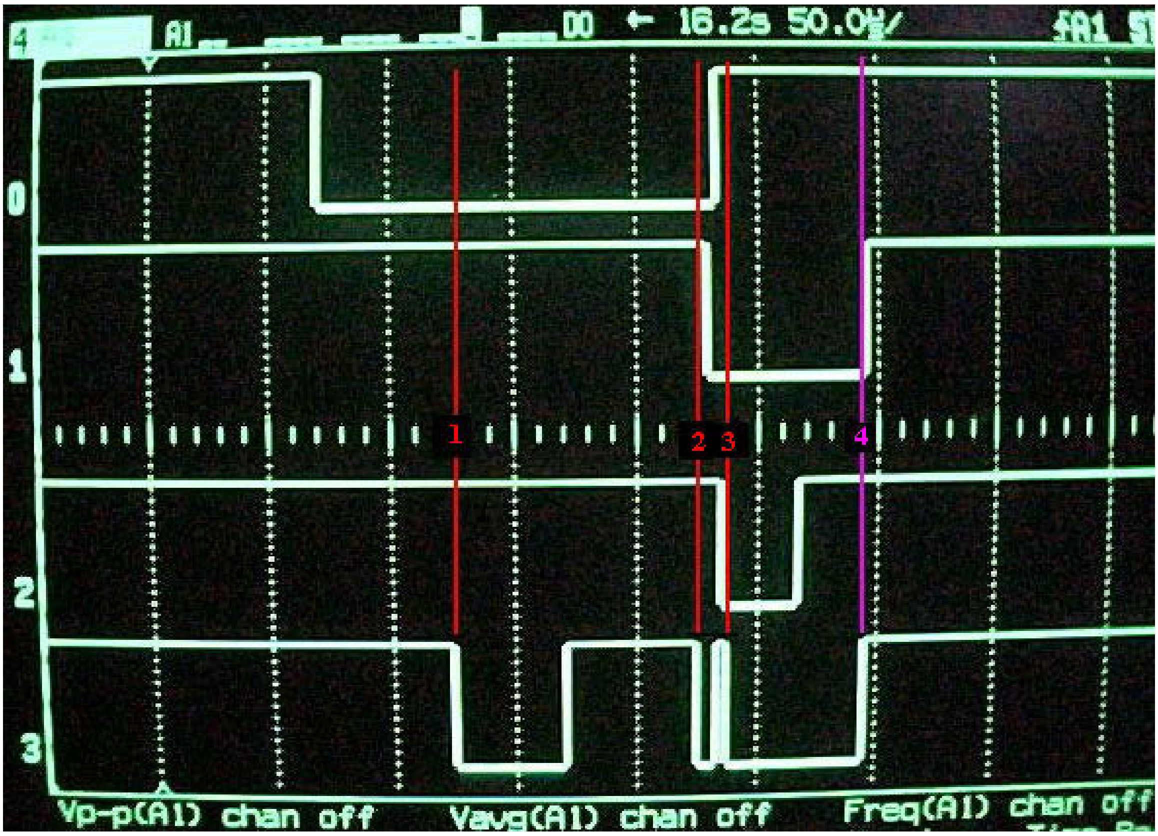


FIGURE 7-13: ANNOTATED TIMING DIAGRAM FOR THE ADC INPUT AND OUTPUT CONTROL PINS

Where,

Signal 0	Represents the ADC input pin, $R/\overline{C}$
Signal 1	Represents the ADC output pin, $\overline{EOC}$
Signal 2	Represents the ADC input pin, HBEN
Signal 3	Represents the ADC input pin, $\overline{CS}$

As presented in Chapter 4, the ADC control pins follow the same input and output sequence as specified in the datasheet. With reference to Figure 7-13, the reader will see that the first red marker, labelled 1, denotes the first $\overline{CS}$ falling edge. Holding $R/\overline{C}$ low during this transition puts the ADC into acquisition mode. The second red marker denotes the second $\overline{CS}$ falling edge. This initiates the start of a conversion. Holding $R/\overline{C}$ low during this transition puts the ADC into Standby Mode, i.e. the reference and buffer remain powered up after a conversion. Shortly after the second $\overline{CS}$ falling edge, the $\overline{EOC}$ line goes low signalling the end of a conversion to the Communications Microcontroller. Upon receiving this signal the Communications

Microcontroller sets the HBEN pin Low, in order to ensure that the low-byte (i.e. the least significant data byte) of the converted ADC data is available on the output data bus on the $\overline{CS}$ third falling edge. The $\overline{CS}$ third falling edge is then initiated, as denoted by red marker labelled 3. This action loads the ADC data onto the eight-bit output bus. The HBEN pin is then toggled so that the high-byte (i.e. the most significant data byte) of the ADC conversion is available on the output data bus. Following this, the first $\overline{CS}$ raising edge after the third falling edge, as denoted by the pink marker labelled 4, puts the ADC output bus back into a high impedance state, as well as forcing the $\overline{EOC}$ line High. The next $\overline{CS}$ falling edge will begin the next conversion cycle.

Conclusion

The research, design and development that was required for the controller used in the Automated Volt-Drop Test process was centred largely on the design of embedded systems for automation applications. Microcontroller based embedded systems offers the designer the flexibility to design any controller or system based on specific application requirements.

However with flexibility comes the requirement for a deeper level of design detail in which case the designer has to cater for every task, function and outcome using software, firmware and hardware. From the provision of responses to inputs from the external environment to achieving communication between the modules that make up the controller or system and the building of a product that can operate optimally in the environment that it is designed to, the designer has to conceptualise, design, build and test each module. The same applies to the development of a GUI. With design of a controller, one can tailor a GUI that suits the application using existing programming packages with very little cost. However this entails a deeper level of programming to achieve the required outcomes.

The designed controller, GUI and RGUI fulfil the requirements of the set-out objective, i.e. the design of an embedded controller and GUI for the automation of the armature Volt-Drop Test. This was confirmed by the automation phase test results and the data acquisition and computation test results which revealed a maximum percentage error of 0.75%. When compared to the present test methods this controller and GUI will introduce a higher degree of accuracy in terms of the actual volt-drop readings and greater efficiency in terms of ensuring that every winding is tested and that skilled staff are not under utilised by performing these tests. Further, this new process ensures that test records are automatically saved on file to build a history of the armatures tested and to verify the competency of the test technician and armature repair staff.

Although embedded controller designs are recommended for specialised or smaller controllers, with regard to larger scale process automation, off the shelf controllers and GUI packages are recommended. From the authors experience, embedded controllers prove to be more cost effective and robust in on-board locomotive applications especially when considering the older locomotives where relays, resistors and heavy current contacts switches are used instead of microprocessor control and power electronic components such as IGBTs. Custom designed embedded controllers are recommended as the controllers that are installed in these locomotives as part of modifications have to withstand the unusually high electrical noise, EMI, vibration, dust and temperature environment along with very irregular and electrically noisy power supplies. Off the shelf controllers often fail in this environment, hence controllers have to be designed and built to operate optimally in this environment. For common industrial environments, off the shelf controllers are sufficiently rugged to cope with the operating environment.

Off the shelf controllers, which include PLCs, may offer less flexibility and may require the purchase of a controller that incorporates features, functionality, input and output ports etc. that may be considered over-kill for smaller controller applications, however, they do offer built-in features, functionality and plug-and-play options for the interconnection of additional modules and GUI packages that will require minimal programming and hardware design. Built-in software functions and hardware operation have been tested in industry and have a proven record by the specific manufacturer.

An off the shelf GUI environment, SCADA for example, which will be used with PLCs offer a large array of functionalities that can easily be used with minimum programming required as compared to a tailored GUI but has the associated downside of the cost.

In summary, the design of an embedded controller, GUI and RGUI for the automation of the Volt-Drop Test was a task that involved detail design and testing along each phase of the project. For future automation projects in Spoornet workshops and test centres, it is recommended that the use of a off the shelf controller be investigated along with the design of embedded controllers.

The trade off that has to be considered in terms of embedded controller design is the flexibility to design a controller that is perfectly suited to the application and environment vs. the time and cost required for design and testing. The trade off to be considered in using off the shelf controllers is the ease of use and reduced time of implementation due to proven product history vs. the cost of purchasing these products and the possibility of unreliable performance in the operational environment.

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Appendices

Appendix A

GUI Screen Captures

Appendix B

List of ASCII prompts

Appendix C

GUI Source Code

Appendix D

Printout From A Saved File

Appendix E

Test Report Printout

Appendix F

Remote GUI (RGUI) Screen Capture

Appendix G

Remote GUI (RGUI) Source Code

Appendix H

The AT89S51 Microcontroller Datasheet

Appendix I

Acebus Development Environment
For Microcontroller Embedded Programming

Appendix J

Component Datasheets

Appendix K

Automation Microcontroller Port Utilisations
Communications Microcontroller Port Utilisations
Automation Microcontroller Register Utilisations
Communications Microcontroller Register Utilisations
Automation Microcontroller Bit Addressable Ram Used For Flags
Communications Microcontroller Bit Addressable Ram Used For Flags

Appendix L

Automation Microcontroller Source Code
Communications Microcontroller Source Code

Appendix L

Communications Microcontroller Source Code

Appendix L

Automation Microcontroller Source Code

Appendix M

Controller Circuit Schematic

Appendix N

Screen Capture For The Calibration Screen

Appendix O

Disc Containing Recorded Test Results & A GUI PowerPoint Presentation

Appendix P

Detailed Discussion on Graphic User Interface (GUI) Development

(Includes Flow Diagrams and Code Extracts)

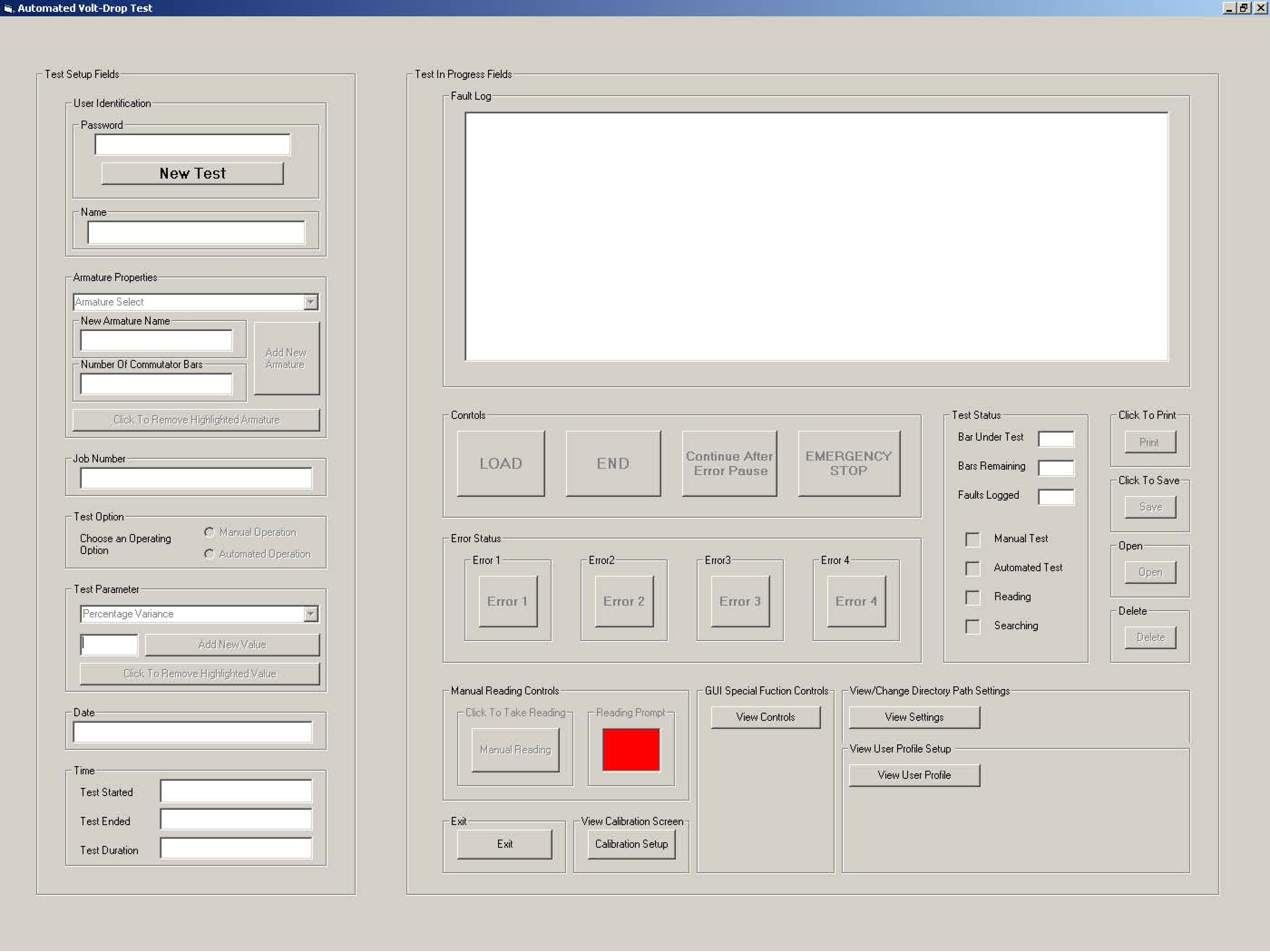
Appendix Q

Detailed Discussion on Microcontrollers and Embedded Programming

(Includes Flow Diagrams and Code Extracts)

Appendix R

Detailed Discussion on Hardware Design


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
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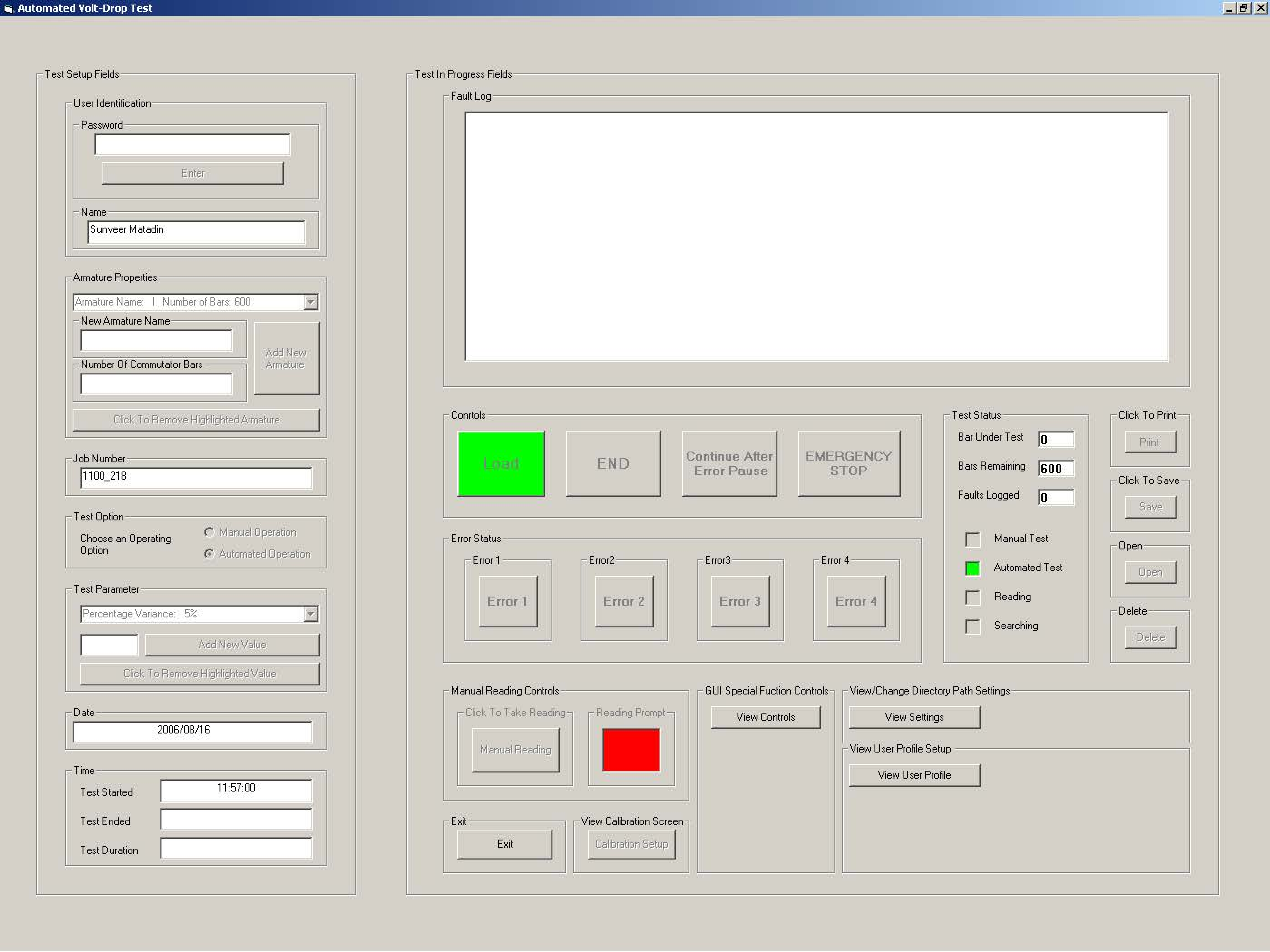
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I, Number of Bars: 600
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
11:57:00
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
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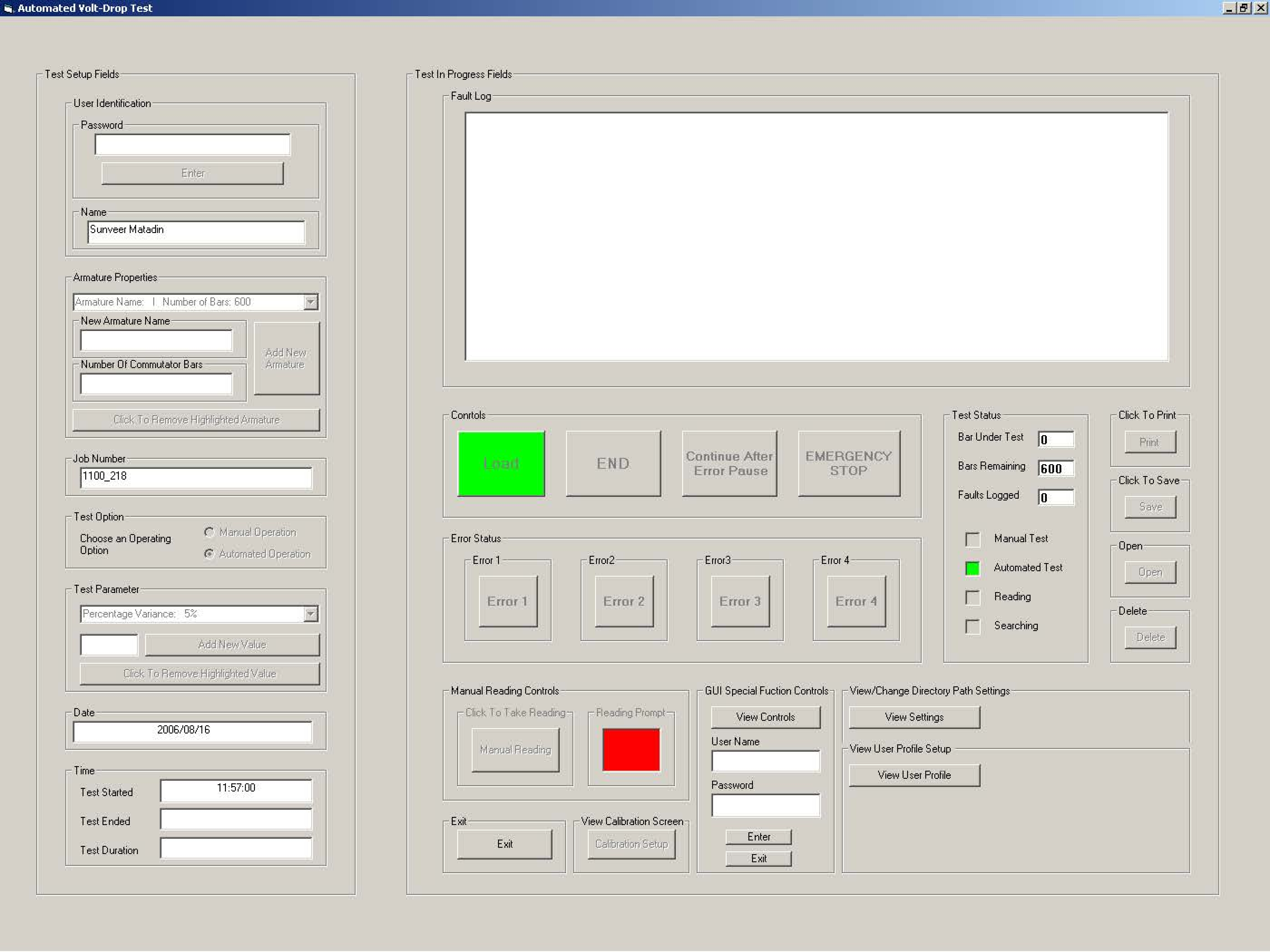
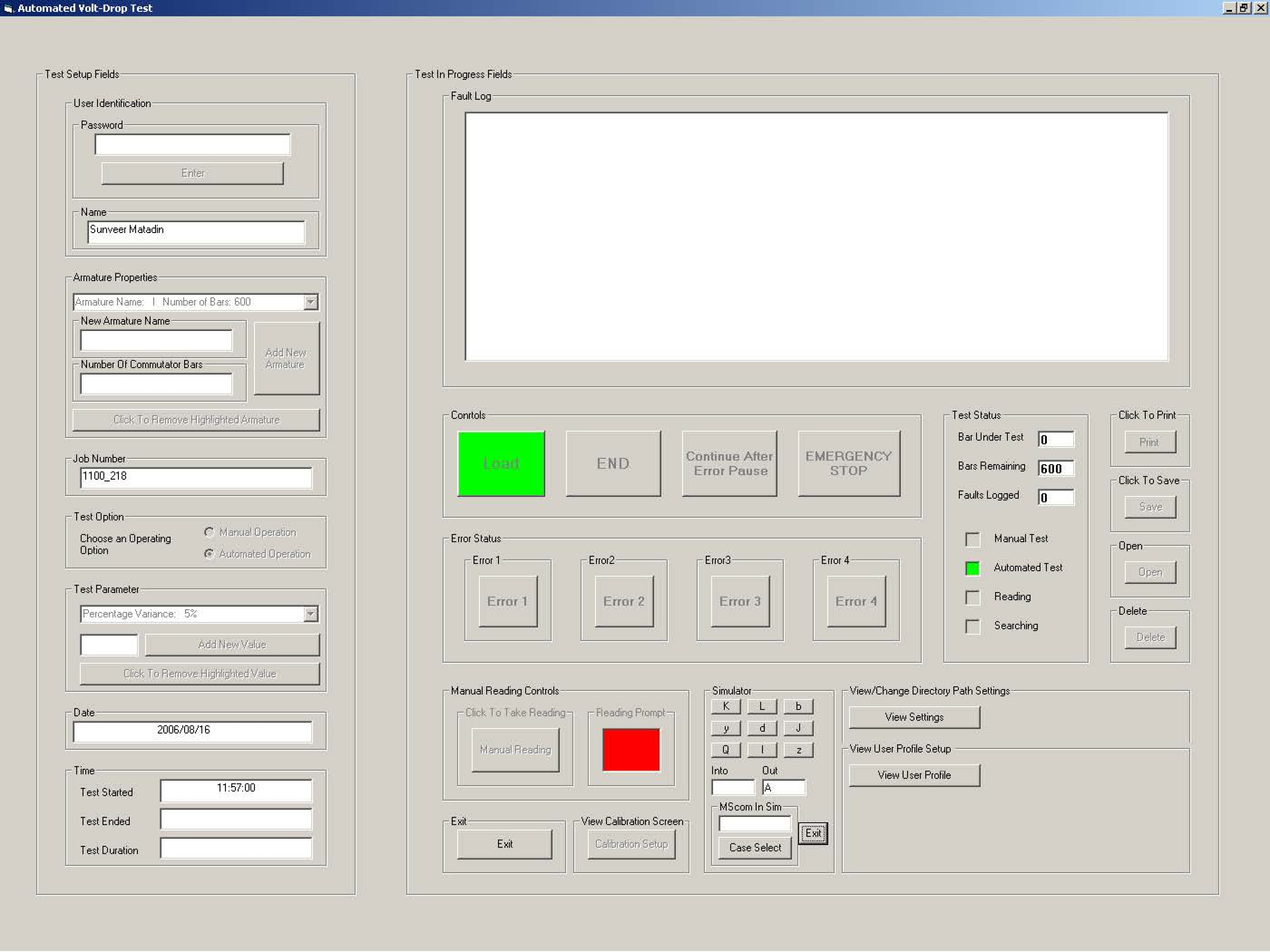
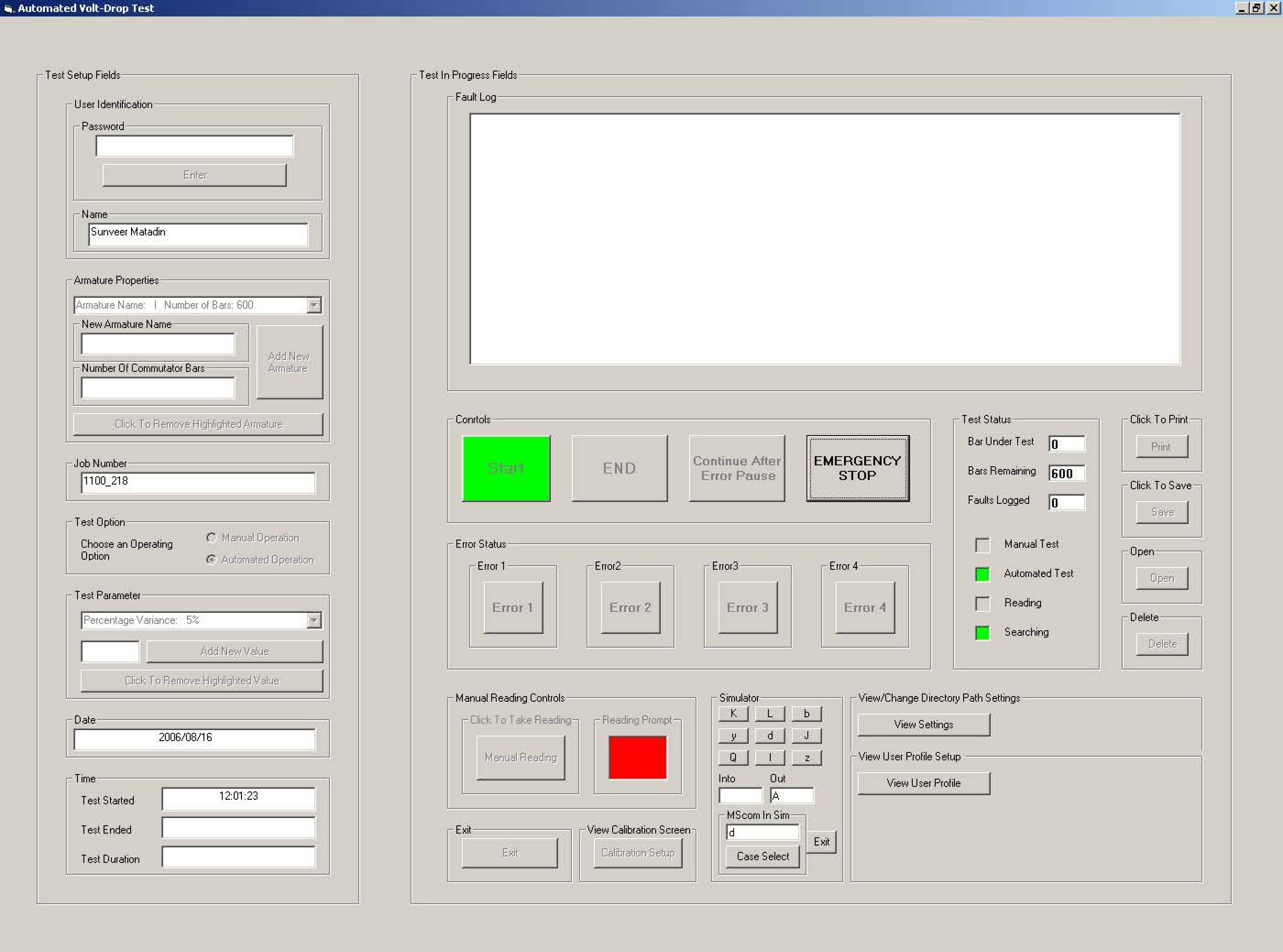
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I, Number of Bars: 600
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
11:57:00
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
User Name
Password
Enter
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I. Number of Bars: 600
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
11:57:00
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
A
MScom In Sim
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I, Number of Bars: 600
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
12:01:23
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Start
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
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b
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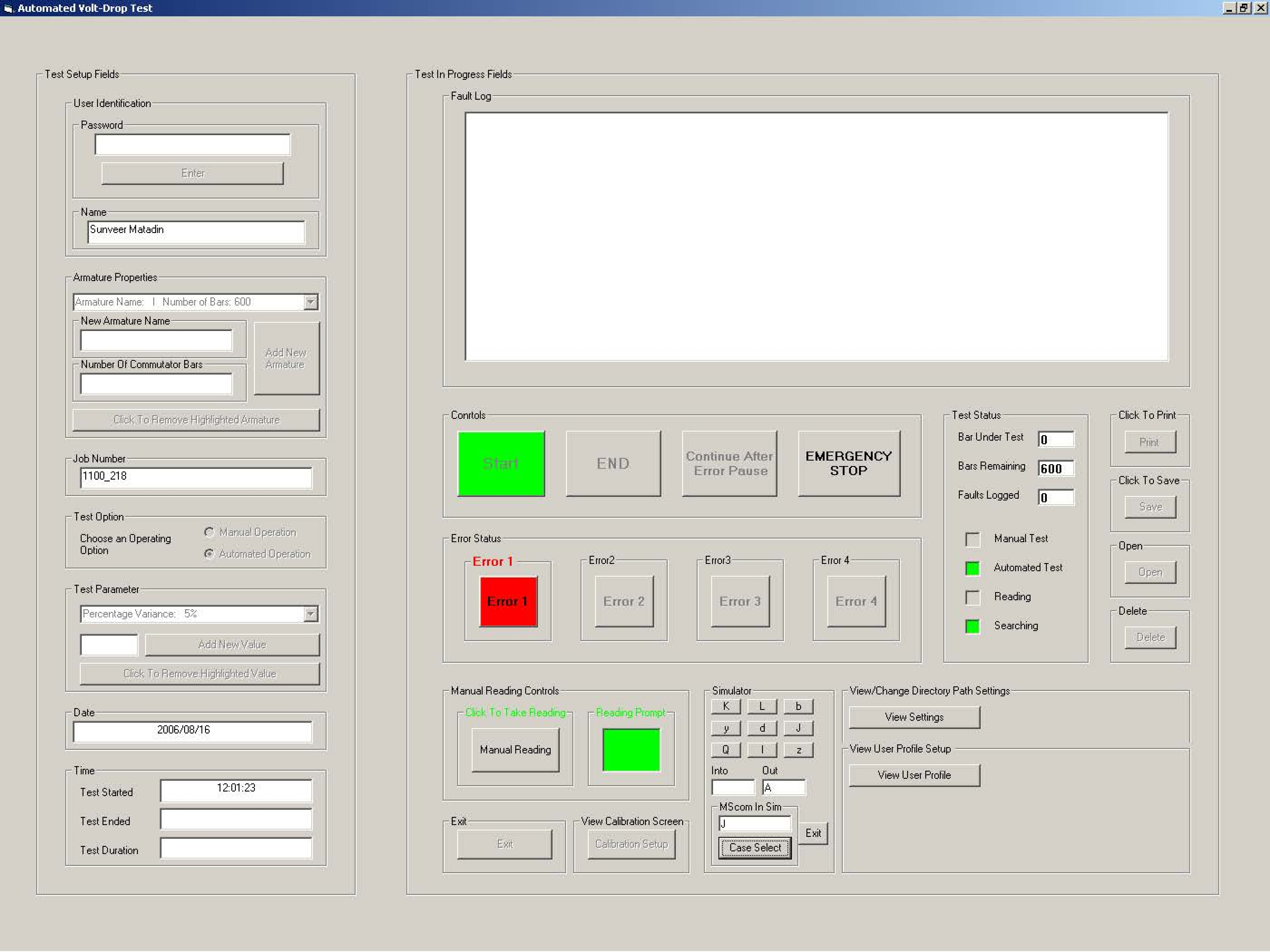
Q
I
z
Into
Out
A
MScom In Sim
d
Case Select
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I, Number of Bars: 600
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
12:01:23
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Start
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
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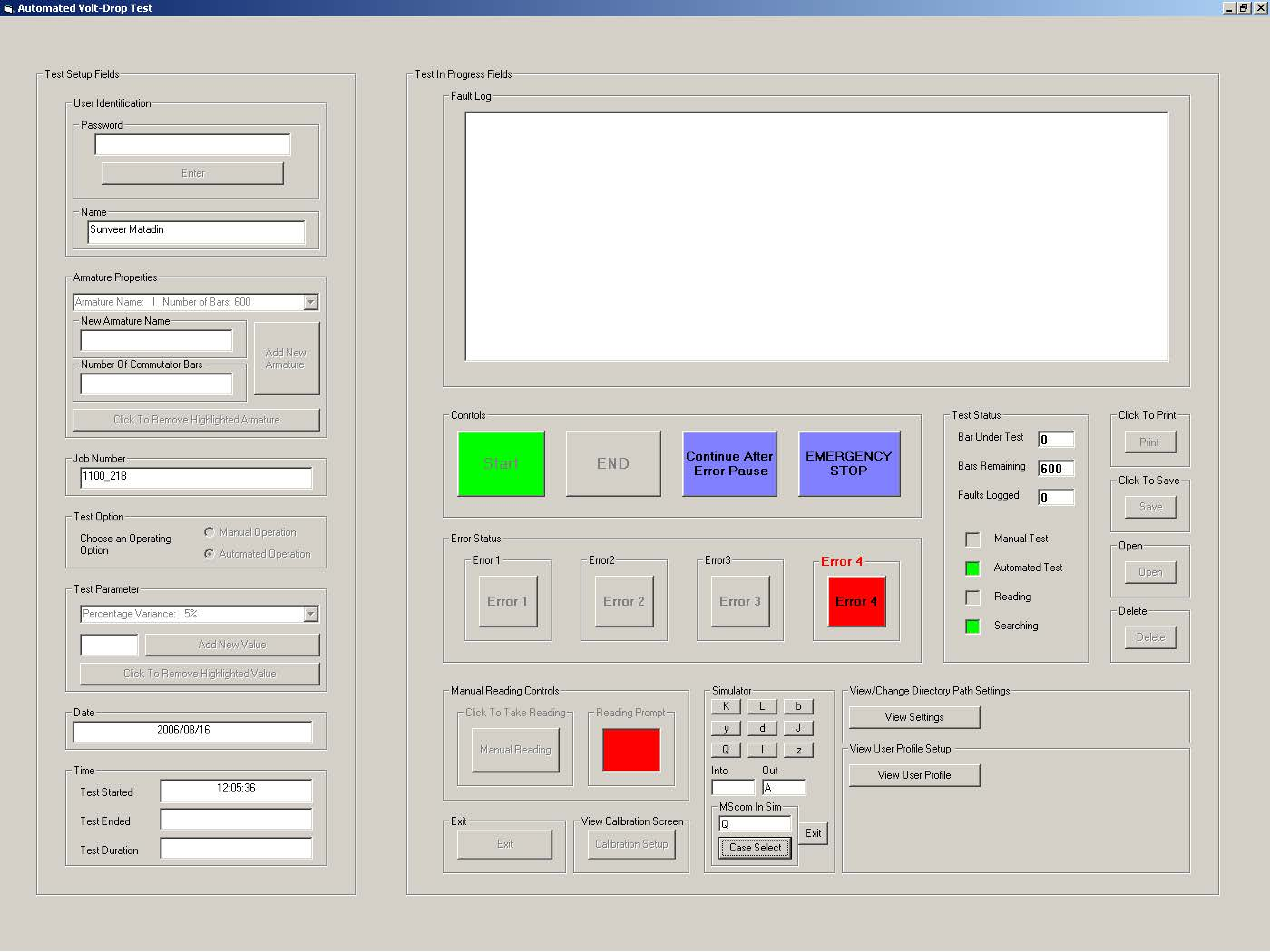
Case Select
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I, Number of Bars: 600
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
12:05:36
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Start
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
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Q
I
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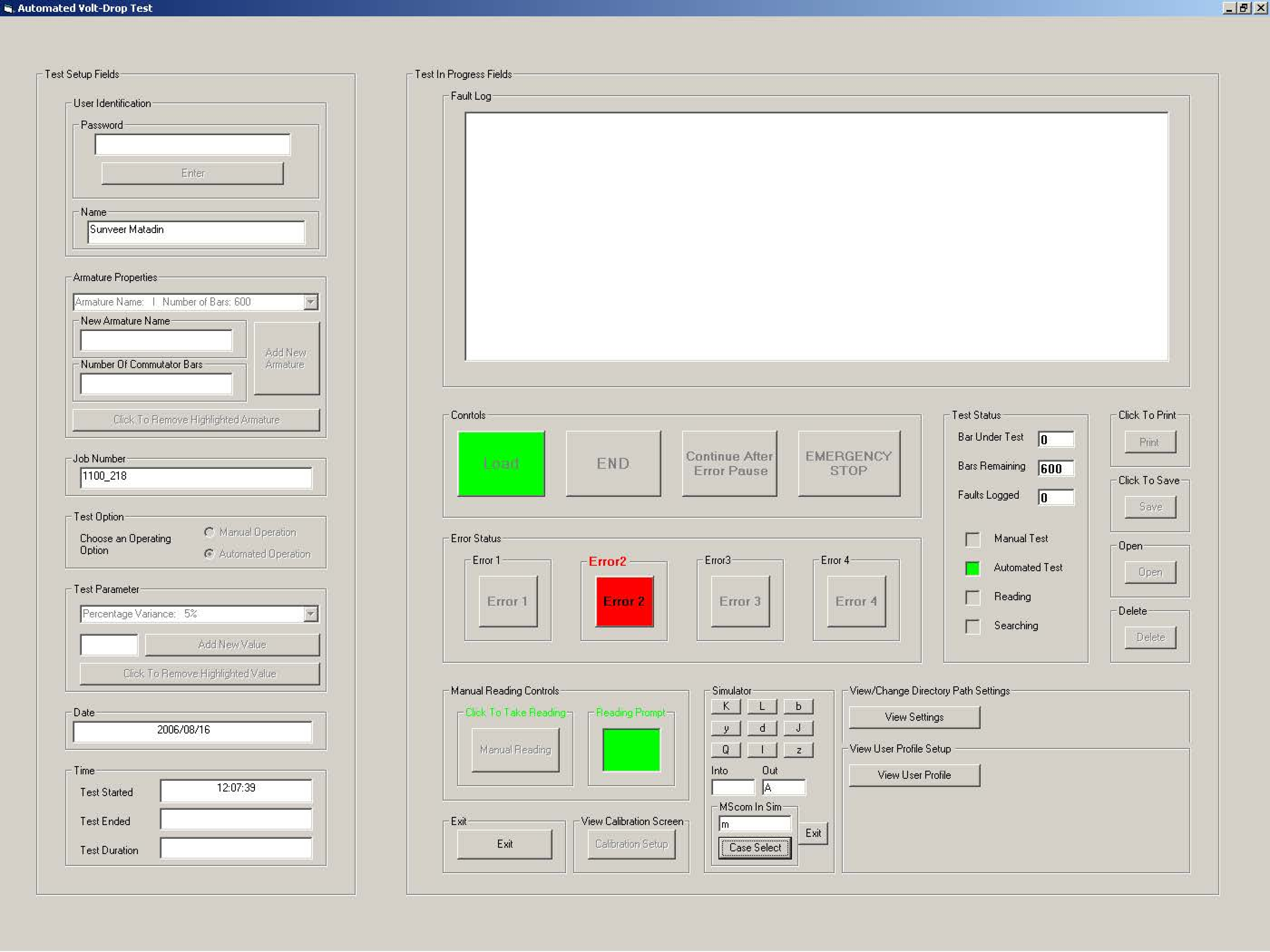
MScom In Sim
Q
Case Select
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup



Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I, Number of Bars: 600
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
12:07:39
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
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Case Select
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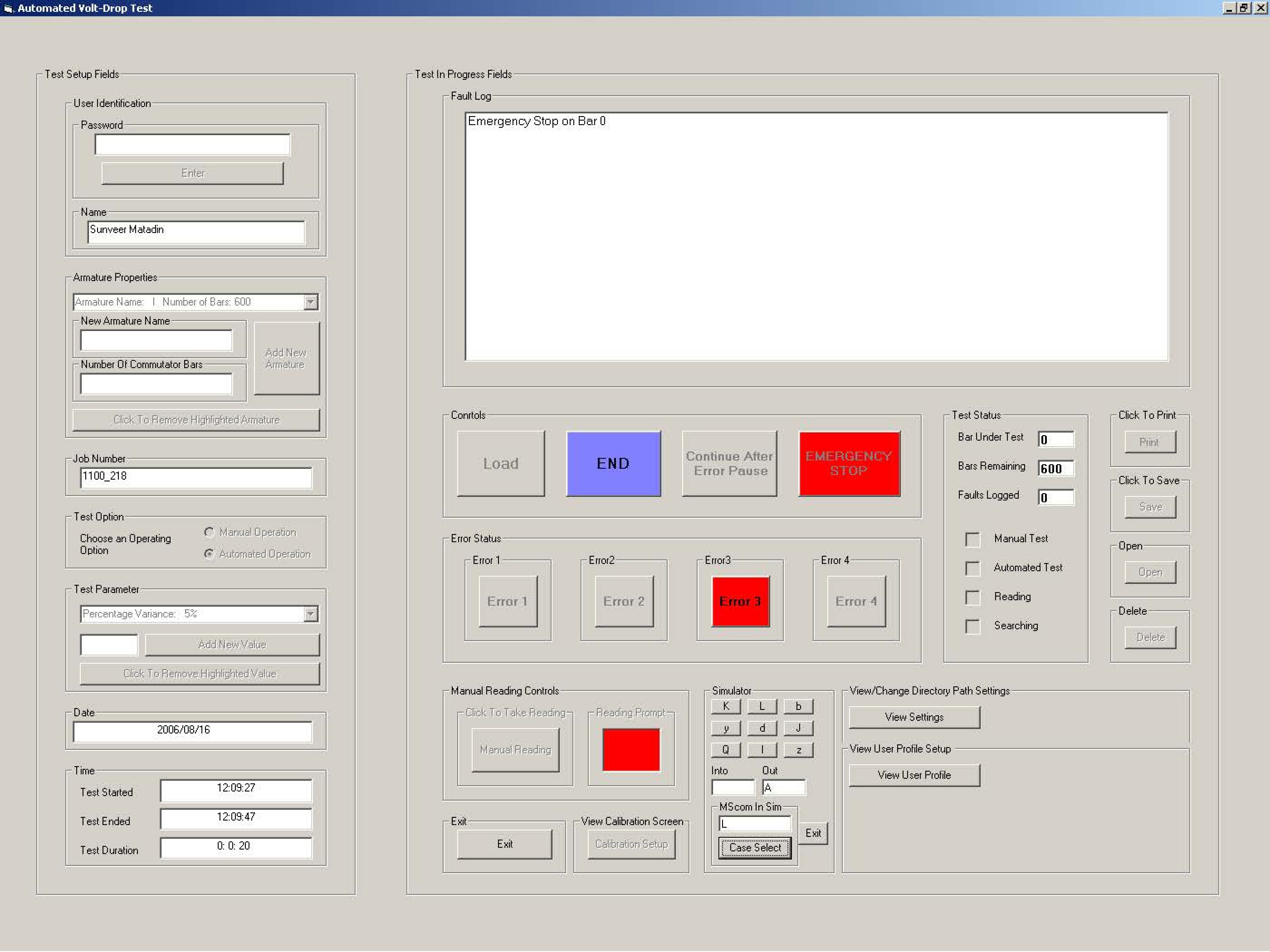
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: I. Number of Bars: 600
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
1100_218
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/08/16
Time
Test Started
12:09:27
Test Ended
12:09:47
Test Duration
0: 0: 20
Test In Progress Fields
Fault Log
Emergency Stop on Bar 0
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
600
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
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MScom In Sim
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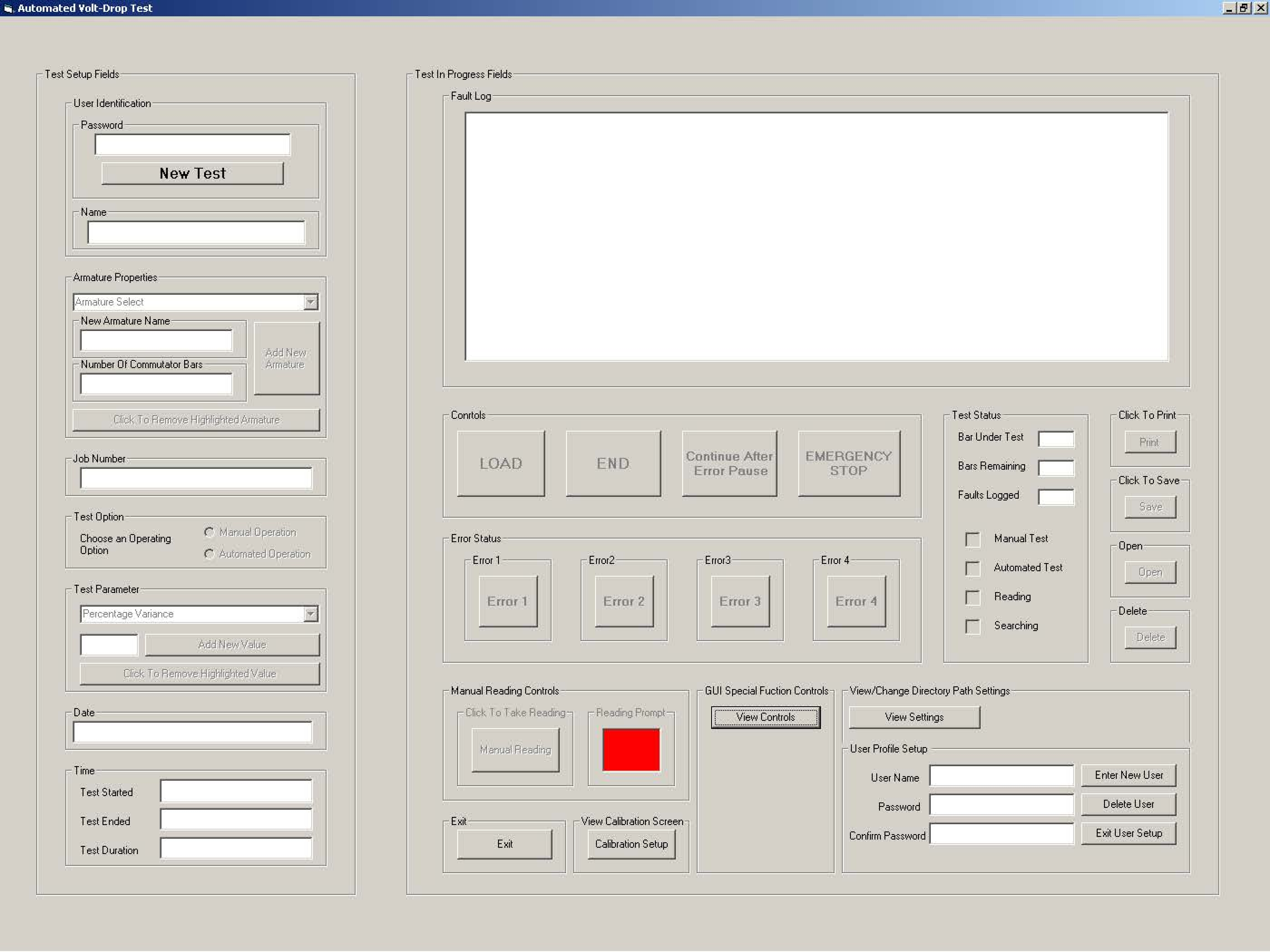
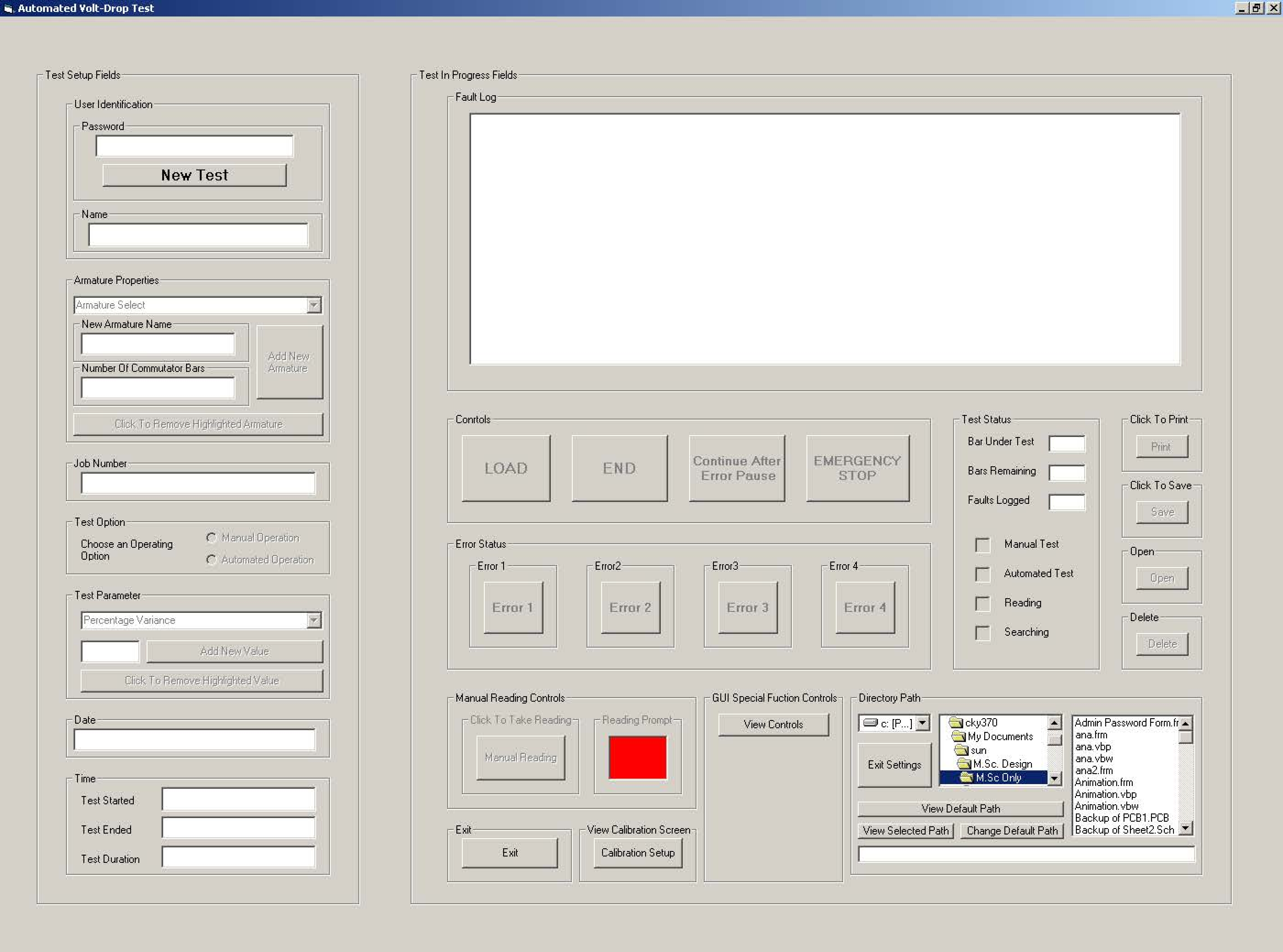
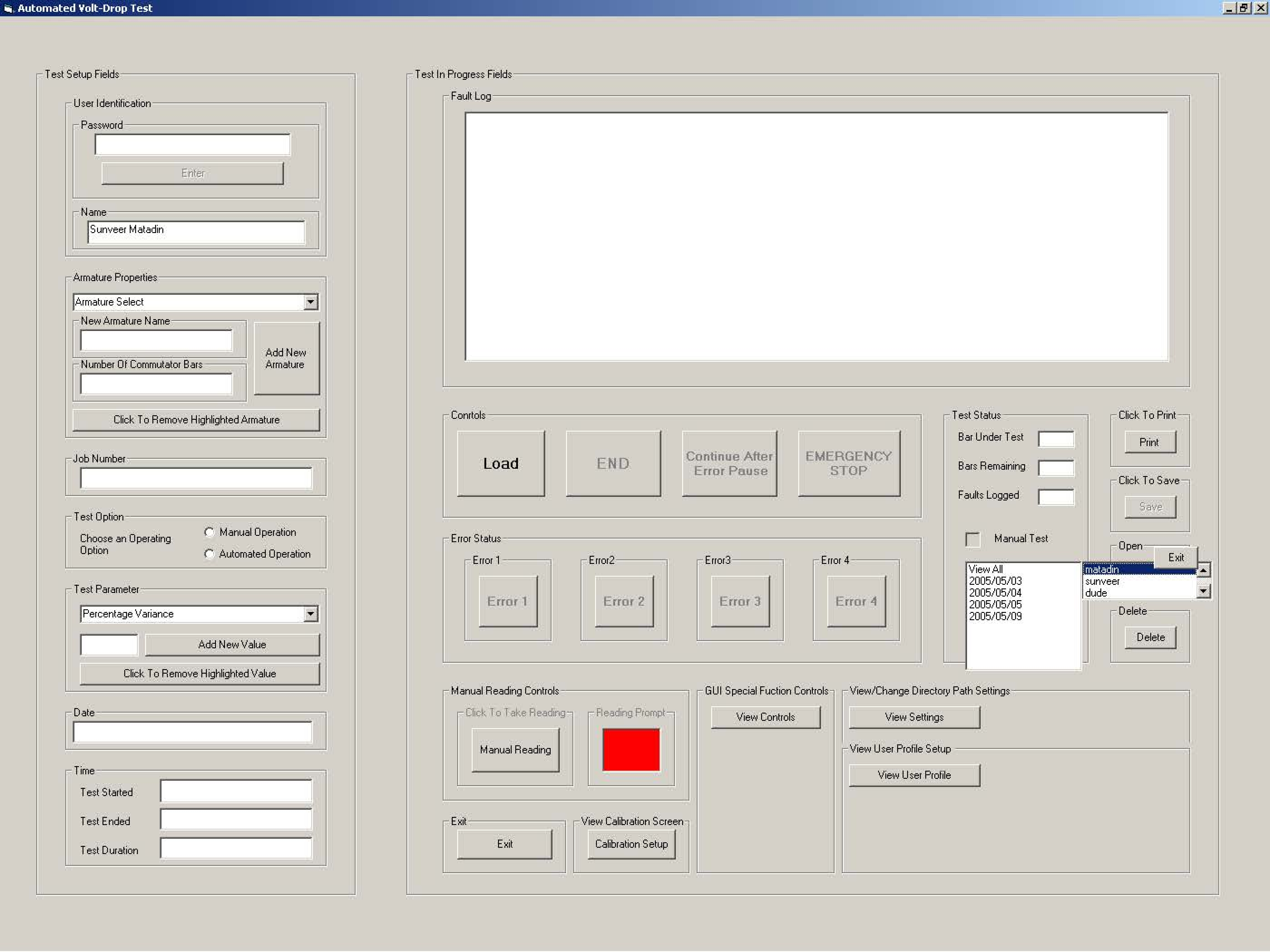
Case Select
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup



Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
User Profile Setup
User Name
Enter New User
Password
Delete User
Confirm Password
Exit User Setup
Exit
Exit
View Calibration Screen
Calibration Setup

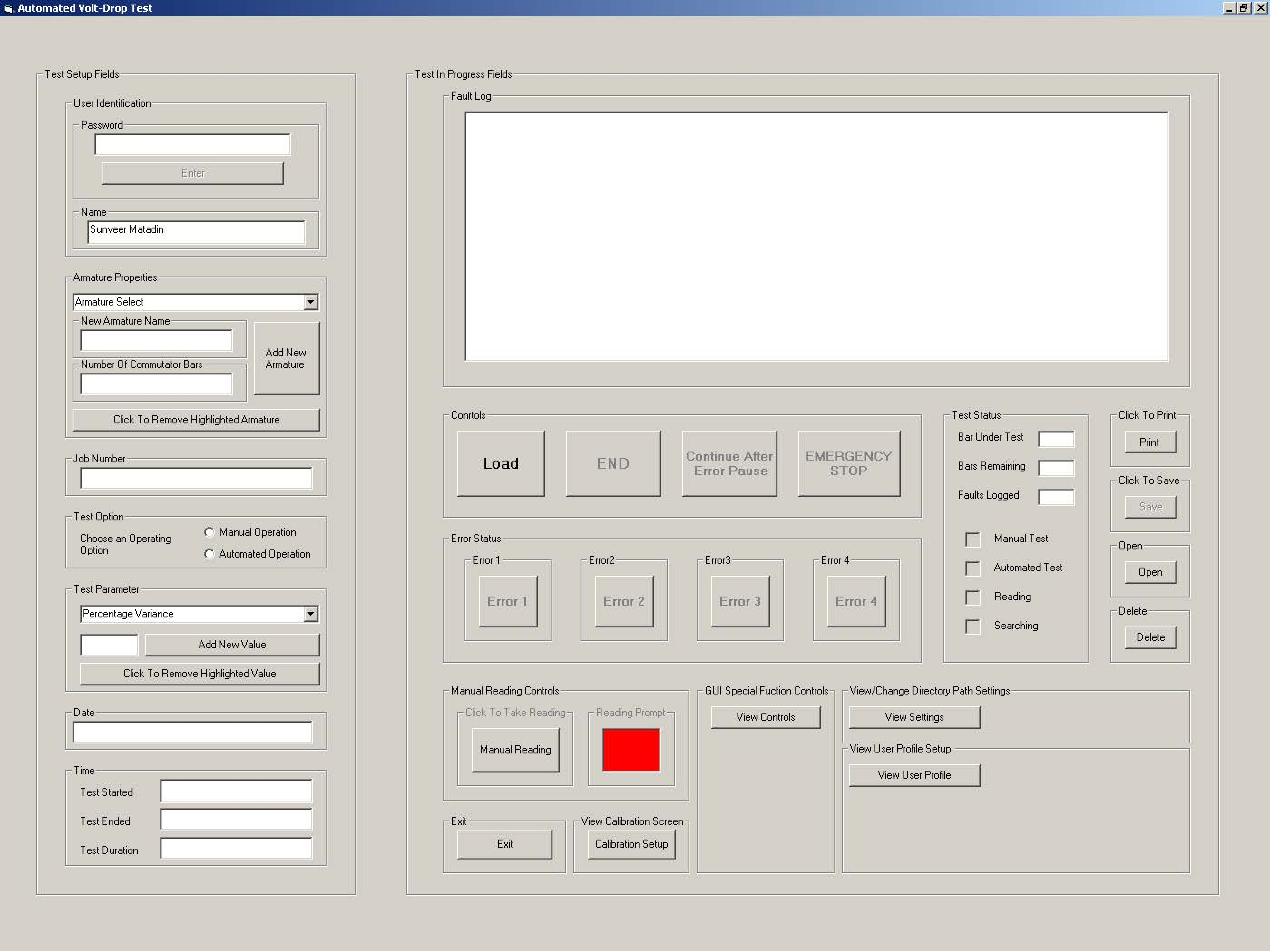

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
Directory Path
c: [P...]
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
Exit Settings
Admin Password Form.fr
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
View Default Path
View Selected Path
Change Default Path
Exit
Exit
View Calibration Screen
Calibration Setup

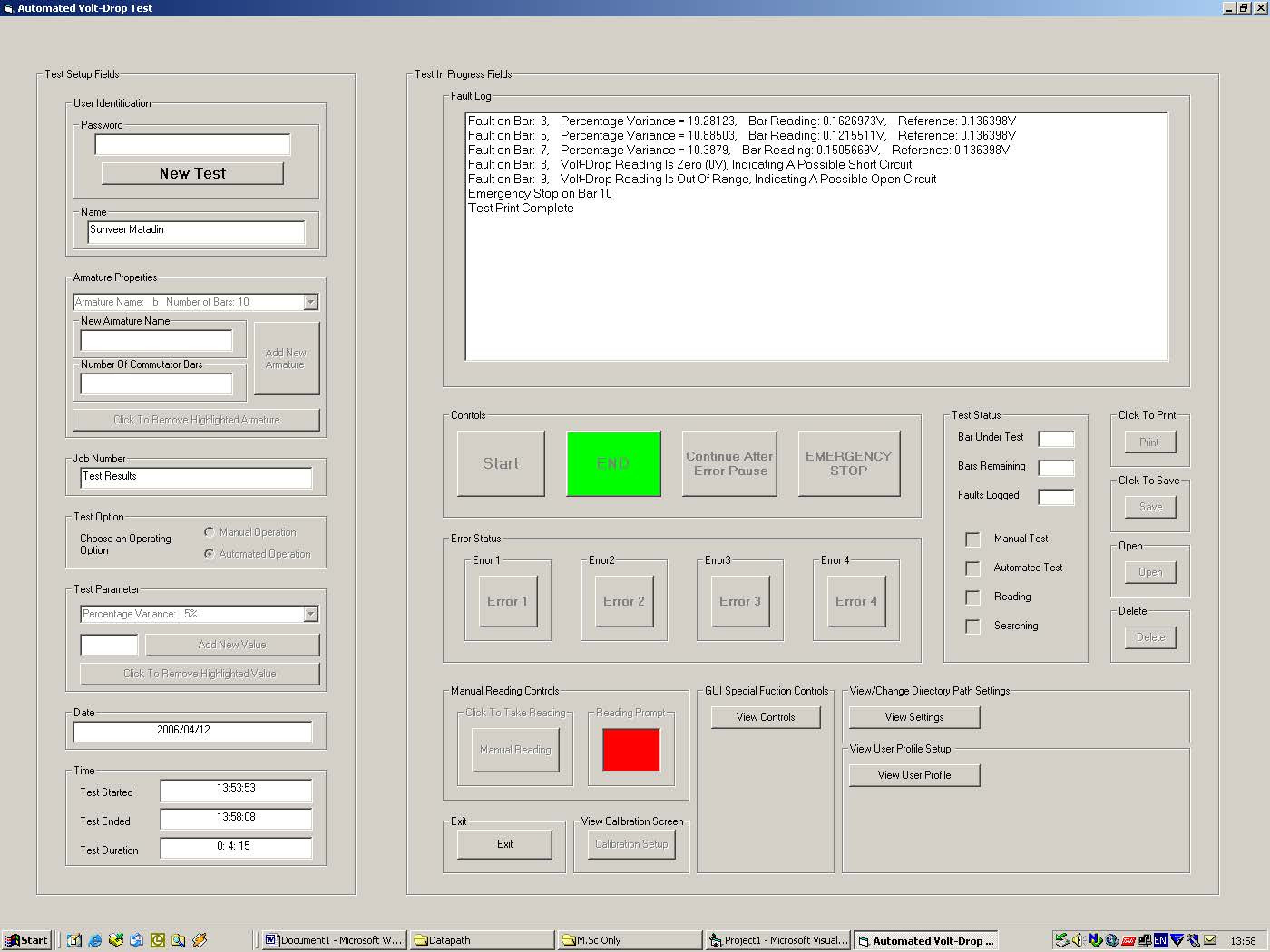

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
View All
2005/05/03
2005/05/04
2005/05/05
2005/05/09
Click To Print
Print
Click To Save
Save
Open
Exit
matadin
sunveer
dude
Delete
Delete
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

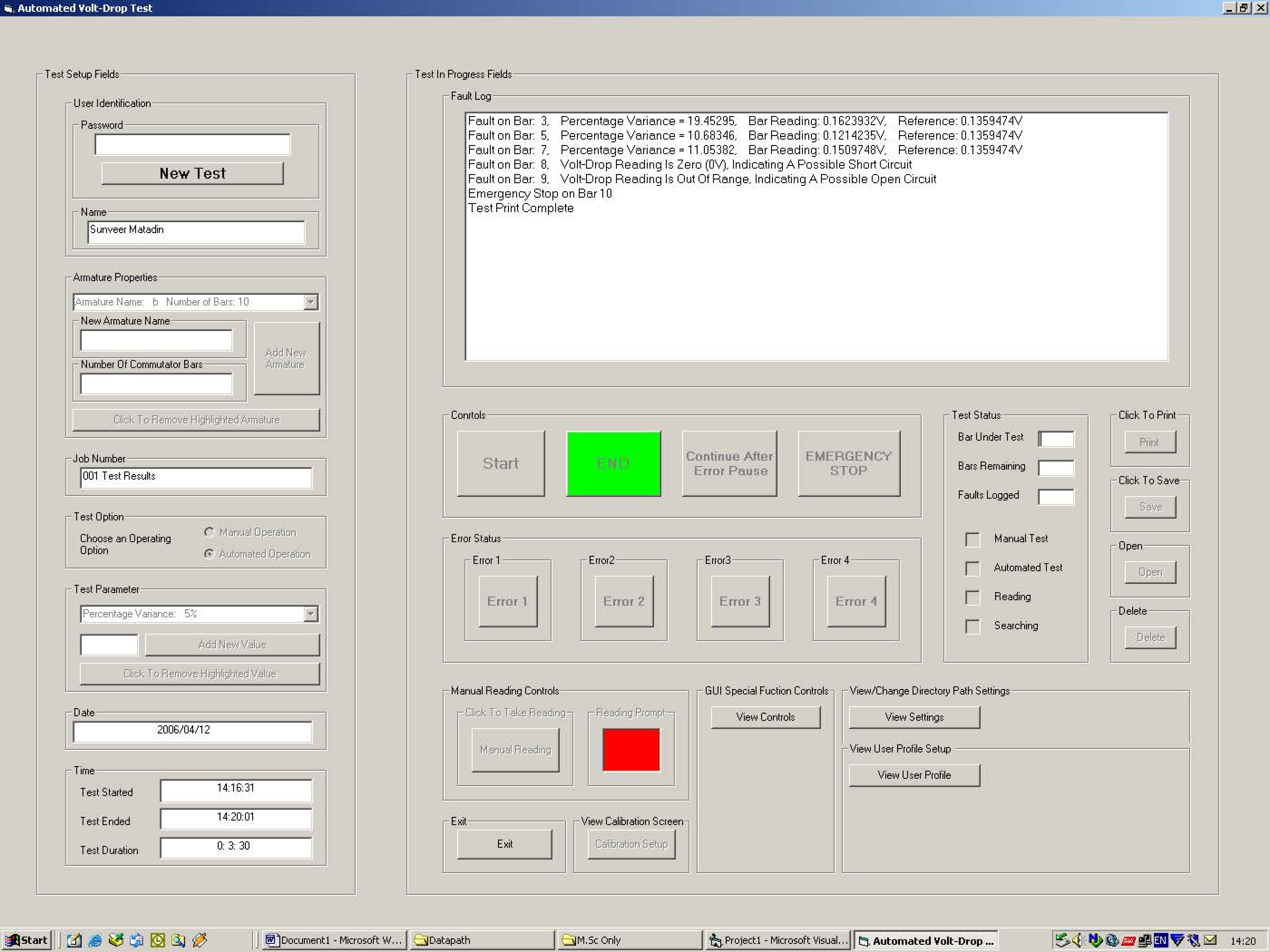
Automated Volt-Drop Test

Lock Out Password

LOCKED OUT


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Sunveer Matadin
Armature Properties
Armature Name: b Number of Bars: 10
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Results
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/04/12
Time
Test Started
13:53:53
Test Ended
13:58:08
Test Duration
0: 4: 15
Test In Progress Fields
Fault Log
Fault on Bar: 3, Percentage Variance = 19.28123, Bar Reading: 0.1626973V, Reference: 0.136398V
Fault on Bar: 5, Percentage Variance = 10.88503, Bar Reading: 0.1215511V, Reference: 0.136398V
Fault on Bar: 7, Percentage Variance = 10.3879, Bar Reading: 0.1505669V, Reference: 0.136398V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Emergency Stop on Bar 10
Test Print Complete
Controls
Start
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup
Start
Document1 - Microsoft W...
Datapath
M.Sc Only
Project1 - Microsoft Visual...
Automated Volt-Drop ...
EN
13:58


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Sunveer Matadin
Armature Properties
Armature Name: b Number of Bars: 10
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
001 Test Results
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/04/12
Time
Test Started
14:16:31
Test Ended
14:20:01
Test Duration
0: 3: 30
Test In Progress Fields
Fault Log
Fault on Bar: 3, Percentage Variance = 19.45295, Bar Reading: 0.1623932V, Reference: 0.1359474V
Fault on Bar: 5, Percentage Variance = 10.68346, Bar Reading: 0.1214235V, Reference: 0.1359474V
Fault on Bar: 7, Percentage Variance = 11.05382, Bar Reading: 0.1509748V, Reference: 0.1359474V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Emergency Stop on Bar 10
Test Print Complete
Controls
Start
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup
Start
Document1 - Microsoft W...
Datapath
M.Sc Only
Project1 - Microsoft Visual...
Automated Volt-Drop ...
EN
14:20

Communications Microcontroller ⇔ Notebook Protocols
Serial Communication

Variable	μ_1 (In)	μ_1 (Out)	NB (In)	NB (Out)	Protocol
Ask for Man/Auto		x	x		**b**
Volt Drop Reading		x	x		**Data**
Ready to begin test		x	x		**d**
Start (click)	x			x	**A**
End (click)	x			x	**B**
Continue After Error (click)	x			x	**C**
Take reading - Manual (signal)	x			x	**D**
Continue test (signal)	x			x	**E**
Emergency Stop (click)	x			x	**F**
Auto/Man Toggle (signal) Manual	x			x	**G**
Auto/Man Toggle (signal) Automatic	x			x	**g**
Manual Emergency Stop (Press -Switch on the frame)		**x**	**x**		**O**
Last Bar Reached (signal)	x			x	**P**
Last Bar Not Reached (signal)	x			x	**p**
Increment # of bars (signal)		x	x		**I**
Error 1 – Bars Not Detected (signal)		x	x		**J**
Error 2 – Probes not lowered (signal)		x	x		**m**
Error 3 – Current Time Exceeded (signal)		x	x		**L**
Error 4 – Probed not Raised (signal)		x	x		**Q**
Alert NB of incoming Test reading data (High Byte)		*x*	*x*		**z**
Alert NB of incoming Test Reading data (Low Byte)		*x*	*x*		**y**

End of 100 count reading continue signal	*x*			*x*	**S**
Perform Calibration Procedure	*x*			*x*	**H**

```
'******For arm sel File *******
'num -> no. of bars
'nam -> name of arm
'cnt -> record number
'****End For arm sel File *****

'************* save Directory path **************
Dim DefaultPath As String
'************* save Directory path **************

'*******Printing****************
Dim Print_flag  As Boolean ' for deleting file while print
'*******End Printing************
'*******Open & Del Files*********
'aa is the Job No field
'bb is the Operators Name field
'cc is the Armature Selection field
'dd is the Percentange Variance field
'ee is the Date field
'ff is the Recorded Faults field
Dim Save_Test As String ' file name of amature with specific job no
Dim Deletex As String
Dim Test_Date As String ' date of test for specific armature
'*****End Open & Del Files*******

'*********Calculation**********
Dim ActVolReadRes As Single ' holds resolution ie, ref voltage devided by 16 bit levels (4.096/
65535)
Dim ActVolRead As Single  ' holds actual voltage level of the current reading
Dim mVActVolRead As Single  'holds actual voltage level of the current reading in millivolts
Dim ActReference As Single  'holds actual reference level
Dim mVActReference As Single  'holds actual reference level in millivolts
Dim StnBit_WD As Long ' holds the 16 bit word
Dim StnBit_WDflg As Boolean
Dim Current_Variance As Single ' holds the variance of current reading fron ref
Dim Initial_Count As Integer ' counts the first 5 readings
Dim Initial_Error As Boolean ' flag to signal that the first (ref reading) was on an fault bar
Dim Reference As Long
Dim Bin2Dec As String
Dim AvgRefReading As Single ' average reference reading calculated after 100 cycles
'*********End Calculation*******
'********Serial In************
Dim SerIn As String
Dim High_Byte As String * 8
Dim Low_Byte As String * 8
Dim Incomming_HighB_Flag As Boolean
Dim Incomming_LowB_Flag As Boolean
'********End Serial In************
'*******Time calc********
Dim timef As Integer
Dim timed As Integer
Dim timee As Integer
Dim timea As Integer
Dim timeb As Integer
Dim timec As Integer
'*******End Time calc********

'*******100 READING COUNT*********************
Dim MultiReading As Integer
Dim RowCount As Integer

Dim ExcelSheet As Object
Dim Savetime As String
Dim SaveDate As String
'*******END 100 READING COUNT*****************

'*******************Reading Timer*********************
Dim TimerFlag As Boolean
'*******************Reading Timer*********************

'*****************specify hardware gain****************
Dim Gain As Single
'***************End specify hardware gain***************

'********************Calibration***********************
```

```
Dim CalibFlag As Boolean
Dim ReadingBoxIndex As Integer
Dim CalibRefIn As Single
Dim gradient As Single
Dim intercept As Single
'*****************End Calibration************************

'********************Admin Password Form*********************
Public AddNewArm As Boolean
Public RemoveArm As Boolean
Public AddNewVal As Boolean
Public RemoveVal As Boolean
Public CalPassW As Boolean
Public PathPassW As Boolean
Public DelFile As Boolean
Public UsrProf As Boolean
'********************Admin Password Form*********************

'*****************Lower range value adjust*******************
Dim ZeroIn As Integer
Dim HighBCount As Integer
Dim HighBCount1 As Integer
Dim HighBCount2 As Integer
Dim HighBCount3 As Integer
Dim HighBCount4 As Integer
Dim HighBCount5 As Integer
Dim SndEntry As Integer
'*****************Lower range value adjust*******************

Dim Auto_Man As String ' automatic / manual select
Dim No_of_Bars As Long  ' global variable for num of bars
Dim Percentage As Single ' global variable for & variance
Dim Pswd As String '  3 password tries
Dim PasswdFlag As Boolean ' flag to signal correct password
Dim Emergency As Boolean
Dim pa As Integer
Dim a As Integer

Private Sub Combo1_Click()
Dim dp As Integer
Let dp = Combo1.ListIndex
Let dp = dp + 1
Open DefaultPath & "Per.TXT" For Input As #3
    Do While Not EOF(3)
    Input #3, per, vlu
        If vlu = dp Then
        Let Percentage = Val(per)
        End If
    Loop
 Close #3
End Sub

Private Sub Combo2_Click()
Dim d As Integer
Let d = Combo2.ListIndex
Let d = d + 1
Open DefaultPath & "Arm.TXT" For Input As #1
    Do While Not EOF(1)
    Input #1, nam, num, cnt
        If cnt = d Then
        Let Text7.Text = num
        Let Text6.Text = 0
        Let Text8.Text = 0
        Let No_of_Bars = Val(num)
        End If
    Loop
 Close #1
End Sub

Private Sub Command1_Click()
Let AddNewArm = True
Form3.Visible = True
'Form3.Show 1
Form3.Text1.Text = ""
Form3.Text1.SetFocus
```

```
End Sub

Private Sub Command1_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
    If (Text3.Text <> "") Then
        Combo1.AddItem "Percentage Variance:    " & Text3.Text & "%"
        Let pa = Combo1.ListCount ' used as a record number, 1st item starts at 1
        Open DefaultPath & "Per.TXT" For Append As #3
        Write #3, Text3.Text, pa
        Let Text3.Text = ""
        Close #3
    Else
    MsgBox "Enter new Percentage Variance", vbOKOnly, "Enter Percentage Variance"
    End If
'Else
'MsgBox " You are Not Authorised to use this fuctionality"
End If
End Sub

Private Sub Command10_Click()
MsgBox " The next pair of bars has not been detected within the allowable period. A Manual Read
ing must now be taken", vbOKOnly, "Detection Error"
End Sub

Private Sub Command11_Click()
MsgBox " The Test Probes have not been lowered within the allowable period. A Manual Reading mu
st now be taken", vbOKOnly, "Detection Unit Lowering Error"
End Sub

Private Sub Command12_Click()
MsgBox " The Test Current has been Switched on for too long, and as a safety measure an Emergen
cy Stop has been invoked. Please Click End, check the device and Restart the Test", vbOKOnly, "
Test Current On-Time Exceeded"
End Sub

Private Sub Command13_Click()
MsgBox " The Test Probes have not been raised within the allowable time. Check the device and c
lick Continue After Error Pause OR Click Emerengcy Stop!", vbOKOnly, "Detection Unit Raising Er
ror"
End Sub

Private Sub Command14_Click()
Command15.Enabled = False
Command14.Enabled = False
If List1.List(0) <> "" Then
    If Left(List1.List(0), 11) = "Job Number:" Then
    Let Deletex = Fopen
    Printer.NewPage
    Let Print_Save_i = 0
        Do While Print_Save_i <= (List1.ListCount - 1)
        Printer.Print List1.List(Print_Save_i)
        Print_Save_i = Print_Save_i + 1
        Loop
    List1.AddItem "Test Print Complete"
    Printer.EndDoc

    '****************Print in Pic Box for Simulation ***************************
    'Timer1.Enabled = True
    '****************End Print in Pic Box for Simulation ***********************

    Else
    '****************Print in Pic Box for Simulation ***************************
    'Timer1.Enabled = True
    '****************End Print in Pic Box for Simulation ***********************

    Let Save_Test = Text9.Text
    Call FsaveSub
    Printer.NewPage
    Printer.FontBold = True
    Printer.FontSize = 9
    Printer.Print "________________________________________________________________________
_________________________________________________________"
```

```
    Printer.FontBold = False
    Printer.FontSize = 8
    Printer.Print ""
    Printer.Print Spc(49); "Automated Volt-Drop Test Report"
    Printer.FontBold = True
    Printer.FontSize = 9
    Printer.Print "__________________________________________________________________________________
_____________________________________________________________"
    Printer.Print ""
    Printer.Print Spc(5); "Job/Serial Number:  " & Text9.Text
    Printer.Print Spc(5); "Operator's Name:  " & Text2.Text
    Printer.Print Spc(5); Combo2.List(Combo2.ListIndex)
    Printer.Print Spc(5); Combo1.List(Combo1.ListIndex)
    Printer.Print Spc(5); "Date:  " & LTrim(Text11.Text)
    Printer.Print "__________________________________________________________________________________
_____________________________________________________________"
    Printer.Print ""
    Printer.FontSize = 12
    Printer.Print Spc(4); "Recorded Faults "
    Printer.FontBold = False
    Printer.FontSize = 8
    Printer.Print ""


    Let Print_current_i = 0
        Do While Print_current_i <= (List1.ListCount - 1)
        Printer.Print Spc(5); List1.List(Print_current_i)
        Print_current_i = Print_current_i + 1
        Loop

    Printer.FontBold = False
    Printer.Print ""
    Printer.FontSize = 9
    Printer.Print Spc(5); "I, " & Text2.Text & " acknowledge the above results and pledge to in
vestigate and/or remedy the"
    Printer.Print Spc(5); "above recorded faults (if any)."
    Printer.Print ""
    Printer.Print Spc(5); "Signature, " & Text2.Text & "    ________________________________________"
    Printer.Print ""
    Printer.Print ""
    List1.AddItem "Test Print Complete"
    Printer.FontBold = True
    Printer.Print "__________________________________________________________________________________
_____________________________________________________________"
    Printer.EndDoc
    End If
Else
MsgBox "No Data Available To Print", vbOKOnly, "Print Error"
Command14.Enabled = True
End If


End Sub

Private Sub Command15_Click()
Dim Add_Flag As Boolean
Command14.Enabled = False
Command15.Enabled = False
Let Add_Flag = False

Let Save_Test = Text9.Text

'*********************Save Excel Data************************
'objExcel.Application.Save "Sun"
'objExcel.Application.Quit

ExcelSheet.SaveAs DefaultPath & Text9.Text & Space(2) & SaveDate & Space(2) & Savetime
ExcelSheet.Application.Quit
Set ExcelSheet = Nothing
'*******************End Save Excel Data************************

If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
   Open DefaultPath & "Saved_List.TXT" For Input As #7 ' file for the list of all jobs saved

      Do While Not EOF(7)
```

```
        Input #7, Add_list
            If Add_list = Save_Test Then
                Let Add_Flag = True
            End If
        Loop
    Close #7
        If Add_Flag = False Then
            Let Add_Flag = False ' redundant
            Open DefaultPath & "Saved_List.TXT" For Append As #7
            Write #7, Save_Test
            Close #7
        End If
Else
    Open DefaultPath & "Saved_List.TXT" For Append As #7
    Write #7, Save_Test
    Close #7
End If

    Open DefaultPath & Save_Test For Append As #5
    Let i = 0
    Do While i <= (List1.ListCount - 1)
        Write #5, Text9.Text, Text2.Text, Combo2.List(Combo2.ListIndex), Combo1.List(Combo1.Lis
tIndex), LTrim(Text11.Text), List1.List(i)
        Let i = i + 1
    Loop
    Write #5, "End", "xxx", "xxx", "xxx", LTrim(Text11.Text), "End Of Recorded Results"
    Close #5

End Sub

Private Sub Command16_Click()
End
End Sub

Private Sub Command17_Click()
Frame37.Visible = True
Command46.Visible = True
Text20.Text = ""
Text21.Text = ""
Text22.Text = ""
Pswd = Pswd - 1
If Text1.Text <> "" Then
    If Dir("C:\Program Files\Calibration\" & "B_2_B_Pwd") <> "" Then
    Open "C:\Program Files\Calibration\" & "B_2_B_Pwd" For Input As #1
        Do While Not EOF(1)
        Input #1, UserName, UserPassword
            If UserPassword = Text1.Text Then
                'If Text1.Text = "AutoSun6" Then
                Let PasswdFlag = True
                Let Text2.Text = UserName
            End If
        Loop
        Close #1

    If PasswdFlag = True Then
                Text1.Text = ""
                Text1.Locked = True
                Let Emergency = False
                'Let Text2.Text = UserName
                Let Text2.Locked = True
                Let Text9.Locked = False
                'Let Text2.Text = ""
                Let Text9.Text = ""

                Combo2.Text = "Armature Select"
                Combo1.Text = "Percentage Variance"
                Option1 = False
                Option2 = False
                Let Command5.Caption = "Load"

                Let Command14.Enabled = False ' print
                Let Command15.Enabled = False ' save
                Let Command36.Enabled = True ' change default path

                        Let Text2.Locked = False
```

```
                    Let Text3.Locked = False
                    Let Text4.Locked = False
                    Let Text5.Locked = False
                    Let Text9.Locked = False

                    Let Command30.Enabled = True  'For delete and open
                    Let Command32.Enabled = True '
                    'Let Frame30.Enabled = True    '
                    'Let Frame31.Enabled = True     '
                    Command14.Enabled = True ' print

                Let Text3.Text = ""
                Let Text4.Text = ""
                Let Text5.Text = ""
                Let Command6.Enabled = False
                Let Command6.BackColor = &H8000000F
                Let Command1.Enabled = True
                Let Command2.Enabled = True
                Let Command3.Enabled = True
                Let Command4.Enabled = True
                Let Command5.Enabled = True ' enabled for LOAD, then disabled and then enabled
 for START after mscomm says micro is ready
                Let Command9.Enabled = True

                Let Combo1.Enabled = True
                Let Combo2.Enabled = True

                Let Option1.Enabled = True
                Let Option2.Enabled = True

                Let Command17.Enabled = False

                Let Command18.Enabled = False ' Lock out password
                Let Text10.Locked = True ' Lock out password

                'clearing flags and resetting variabled for calculation
                Let StnBit_WD = 0
                Let Current_Variance = 0
                Let Initial_Count = 0
                Let Initial_Error = False
                Let Reference = 0
                '*************************************************

                    '*******Initilize Serial Comm port 1*******
                    ' new code 20/11 to re-initilze  the sp and Clear the Out(transmit) buffer
                    'Rec data
                     MSComm1.PortOpen = False
                    MSComm1.RThreshold = 1
                    MSComm1.InputLen = 1
                    MSComm1.DTREnable = False

                    MSComm1.Settings = "2400,N,8,1"

                    MSComm1.CommPort = 1
                    MSComm1.PortOpen = True
                    'Trans data
                    MSComm1.OutBufferCount = 0
                    '**** End Initilize Serial Comm port 1*****

            Else
                If Pswd > 0 Then
                MsgBox "Incorrect Password, Tries left:  " & Pswd & "", vbOKOnly, "Incorrect Pa
ssword"
                Let Text1.Text = ""
                Text1.SetFocus
                Else
                MsgBox " You DO NOT have the authority to use this equipment. You have been LOC
KED OUT", vbOKOnly, "Lock Out"
                Let Text1.Text = ""
                Frame27.Visible = True
                Text10.Visible = True
                Command18.Visible = True
                End If
            End If
```

```
     Else
     MsgBox "A User Profile List Has Not Been Created", vbOKOnly, "User Profile Error"
     Text1.Text = ""
     End If
Else
MsgBox "Please Enter A Password In the Space Provided", vbOKOnly, "Enter Password"
Text1.SetFocus
End If
End Sub

Private Sub Command18_Click()

If Text10.Text = "AdminAutoSun6" Then
Frame27.Visible = False
Text10.Text = ""
Let Command18.Visible = False
Let Text10.Visible = False
Let Pswd = 3
End If
Text10.Text = ""
End Sub

Private Sub Command19_Click()
Command5.BackColor = &H8000000F 'simulator
Let Command5.Caption = "Start"
Command5.Enabled = True
Let Command8.Enabled = True
Screen.MousePointer = vbArrow
End Sub

Private Sub Command2_Click()
Let AddNewArm = True
Form3.Visible = True
'Form3.Show 1
Form3.Text1.Text = ""
Form3.Text1.SetFocus



End Sub

Private Sub Command2_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
    If MsgBox("Are You Sure That You Want to Delete The Selected Item?", vbYesNo, "Confirm Dele
te") = vbYes Then
        Dim pc As Integer

        Let pb = Combo1.ListIndex ' note: first item in box is at 0 therefore 1 must be added t
o = the listcount valne the record is saved under
        Combo1.Clear
        If Dir(DefaultPath & "Per.TXT") <> "" Then
            Open DefaultPath & "Per.TXT" For Input As #3
            Open "Del2" For Output As #4

                Do While Not EOF(3)
                Input #3, per, vlu ' vlu is the record num saved when adding and starts at 1
                    If vlu <> (pb + 1) Then   ' cos listindex begins at 0 and listcount starts a
t 1
                    Combo1.AddItem "Percentage Variance:    " & per & "%"
                    Let pc = Combo1.ListCount
                    Write #4, per, pc
                    End If
                Loop
            Close #3
            Close #4
            Kill DefaultPath & "Per.TXT"
            Name "Del2" As DefaultPath & "Per.TXT"
        Else: MsgBox "No Percentage Variance Values Found", vbOKOnly, "Percentage Variance Erro
r"
        End If
    End If
'Else
'MsgBox " You are Not Authorised to use this fuctionality"
End If
```

```
End Sub

Private Sub Command20_Click()
Command47.Visible = True
Text23.Visible = True
Text24.Visible = True
Command49.Visible = True
Label14.Visible = True
Label18.Visible = True
End Sub

Private Sub Command21_Click()
Text15.Text = Auto_Man
End Sub

Private Sub Command22_Click()
Call Bar_count
End Sub

Private Sub Command23_Click()
Let Command10.Enabled = True ' error1
        Command10.BackColor = QBColor(12)
        Frame14.ForeColor = QBColor(12)
        Frame14.FontSize = 10
        Frame14.FontBold = True
        Command9.Enabled = True
        Frame20.ForeColor = QBColor(10) ' enables man reading but and dsply
        Picture5.BackColor = QBColor(10) '
        Frame21.ForeColor = QBColor(10) '
        Command9.BackColor = QBColor(9)
End Sub

Private Sub Command24_Click()
Let Command11.Enabled = True ' error2
        Command11.BackColor = QBColor(12)
        Frame16.ForeColor = QBColor(12)
        Frame16.FontSize = 10
        Frame16.FontBold = True
        Frame20.ForeColor = QBColor(10) ' enables man reading but and dsply
        Picture5.BackColor = QBColor(10) '
        Frame21.ForeColor = QBColor(10) '
        Command9.BackColor = QBColor(9)
End Sub

Private Sub Command25_Click()
Let Command12.Enabled = True 'error3 is enabled and is disabled when Cont after pause or emgncy
 stop is clicked
        Command12.BackColor = QBColor(12)
        Frame17.ForeColor = QBColor(12)
        Frame17.FontSize = 10
        Frame17.FontBold = True
        Command7.Enabled = True
        Command7.BackColor = &HFF8080
        Command8.BackColor = &HFF8080
        Command8.Enabled = True
End Sub

Private Sub Command26_Click()
Let Command13.Enabled = True 'error4 is enabled and is disabled when Cont after pause or emgncy
 stop is clicked
        Command13.BackColor = QBColor(12)
        Frame15.ForeColor = QBColor(12)
        Frame15.FontSize = 10
        Frame15.FontBold = True
        Command7.Enabled = True
        Command7.BackColor = &HFF8080
        Command8.BackColor = &HFF8080
        Command8.Enabled = True
End Sub

Private Sub Command27_Click()
High_Byte = SerIn
End Sub

Private Sub Command28_Click()
```

```
Low_Byte = SerIn
Call Calculation
End Sub

Private Sub Command29_Click()
'************For simulation only**********************************
Let SerIn = Text17.Text

    If Incomming_LowB_Flag = True Then
    Low_Byte = SerIn
    Picture1.Print Low_Byte
    Let Incomming_LowB_Flag = False
    Let Incomming_HighB_Flag = False ' redundant
    Call Calculation
    ElseIf Incomming_HighB_Flag = True Then
    High_Byte = SerIn
    Picture1.Print High_Byte
    Let Incomming_HighB_Flag = False
    Else
    Select Case SerIn
    Case "a"
        Call Trans_Arm_Type
    Case "b"
        Text15.Text = Auto_Man
    Case "d"
        Command5.BackColor = &H8000000F
        Let Command5.Caption = "Start"
        Command5.Enabled = True
        Let Command8.Enabled = True
        Screen.MousePointer = vbArrow
    Case "O" 'Emergency Stop prompt when the Emergenct Stop switch on the test station is press
ed
        Command8.BackColor = QBColor(12)
        Command7.BackColor = &H8000000F
        Let Command6.Enabled = True
        Let Command6.BackColor = &HFF8080
        Let Picture6.BackColor = &H8000000F

        Call TestEnd_States
        Let Emergency = True
        Command8.Enabled = False
        List1.FontBold = True
        List1.AddItem "Emergency Stop on Bar " & Text6.Text
        List1.FontBold = False
    Case "I"
        Call Bar_count
    Case "J"
        Let Command10.Enabled = True ' error1
        Command10.BackColor = QBColor(12)
        Frame14.ForeColor = QBColor(12)
        Frame14.FontSize = 10
        Frame14.FontBold = True
        Command9.Enabled = True
        Frame20.ForeColor = QBColor(10) ' enables man reading but and dsply
        Picture5.BackColor = QBColor(10) '
        Frame21.ForeColor = QBColor(10) '
        Command9.BackColor = &HFF8080
    Case "m"
        Let Command11.Enabled = True ' error2
        Command11.BackColor = QBColor(12)
        Frame16.ForeColor = QBColor(12)
        Frame16.FontSize = 10
        Frame16.FontBold = True
        Frame20.ForeColor = QBColor(10) ' enables man reading but and dsply
        Picture5.BackColor = QBColor(10) '
        Frame21.ForeColor = QBColor(10) '
        Command9.BackColor = &HFF8080
    Case "L"
        Frame17.ForeColor = QBColor(12)
        Frame17.FontSize = 10
        Frame17.FontBold = True
        Command8.Enabled = True
        Command7.Enabled = True
        Command7.BackColor = &HFF8080
        Command8.BackColor = &HFF8080
```

```
        'Emergnct stop is automatically entered into hence the code below is a copy of the "Em
rgency Stop" button
        Command8.BackColor = QBColor(12)
        Command7.BackColor = &H8000000F
        Let Command6.Enabled = True
        Let Command6.BackColor = &HFF8080
        Let Picture6.BackColor = &H8000000F

        Call TestEnd_States
        Let Emergency = True
        Command8.Enabled = False
        List1.FontBold = True
        List1.AddItem "Emergency Stop on Bar " & Text6.Text
        List1.FontBold = False
        Let Command12.Enabled = True 'error3 is enabled and is disabled when Cont after pause c
r emgncy stop is clicked
        Command12.BackColor = QBColor(12)
    Case "Q"
        Let Command13.Enabled = True 'error4 is enabled and is disabled when Cont after pause c
r emgncy stop is clicked
        Command13.BackColor = QBColor(12)
        Frame15.ForeColor = QBColor(12)
        Frame15.FontSize = 10
        Frame15.FontBold = True
        Command8.Enabled = True
        Command7.Enabled = True
        Command7.BackColor = &HFF8080
        Command8.BackColor = &HFF8080
    Case "z"
        Let Incomming_HighB_Flag = True
        Picture8.BackColor = QBColor(4)
        Picture9.BackColor = &H8000000F
    Case "y"
        Let Incomming_LowB_Flag = True
    End Select
    End If

'*************End For simulation only**********************************
End Sub


Private Sub Command3_Click()
Let AddNewArm = True
Form3.Visible = True
'Form3.Show 1
Form3.Text1.Text = ""
Form3.Text1.SetFocus
End Sub

Private Sub Command3_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
    If (Text4.Text <> "") And (Text5.Text <> "") Then
        Combo2.AddItem "Armature Name:   " & Text4.Text & "    Number of Bars:   " & Text5.Text
        Let a = Combo2.ListCount ' used as a record number, 1st item starts at 1
        Open DefaultPath & "Arm.TXT" For Append As #1
        Write #1, Text4.Text, Val(Text5.Text), (a)
        Let Text4.Text = ""
        Let Text5.Text = ""
        Close #1
    Else
    MsgBox "Enter new Armature Name and Number of Bars", vbOKOnly, "Enter Data"
    End If
'Else
'MsgBox " You are Not Authorised to use this fuctionality"
End If
End Sub

Private Sub Command30_Click()
Dim X As String
Dim j As Boolean
Command14.Enabled = True
Save_Test = InputBox("Enter Job Number", "Enter The Job Number Of the Test You Wish To Open")
If Save_Test <> "" Then
```

```
    If Save_Test <> "Find" Then
        If Dir(DefaultPath & Save_Test) <> "" Then
         List1.Clear
         Open DefaultPath & Save_Test For Input As #5
                     Let j = False
                     Do While Not EOF(5)
                         Input #5, aa, bb, cc, dd, ee, ff
                             If j = False Then
                                 List1.AddItem "Job Number:  " & aa
                                 List1.AddItem "Operator's Name:  " & bb
                                 List1.AddItem cc
                                 List1.AddItem dd
                                 List1.AddItem "Date:  " & LTrim(ee)
                                 List1.AddItem ""
                                 List1.AddItem "Recorded Faults "
                                 List1.AddItem ""
                                 List1.AddItem ff
                                 Let j = True
                             Else
                                 List1.AddItem ff
                                     If aa = "End" Then
                                     Let j = False
                                     List1.AddItem ""
                                     List1.AddItem ""
                                     GoTo Next_Rec
                                     End If

                             End If
 Next_Rec:           Loop
                Close #5
        Else: MsgBox "The Requested Job Number Does Not Exist", vbOKOnly, "Request Error"
        End If

    Else
      If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
        Open DefaultPath & "Saved_List.TXT" For Input As #7
        List2.Clear
            Let Open_Hold = ""
                Do While Not EOF(7)
                Input #7, job
                    If Open_Hold <> job Then
                    List2.AddItem job
                    Let Open_Hold = job
                    End If
                Loop
                    If List2.ListCount <> 0 Then
                    List2.Visible = True
                    Command33.Visible = True
                    Else
                    MsgBox "There Are No Tests To View", vbOKOnly, "Data Error"
                    End If
             Close #7
       Else: MsgBox "There Are No Tests To View", vbOKOnly, "Data Error"
       End If
 End If
 Else: MsgBox "Job Number Was Not Entered", vbOKOnly, "Enter Data"
 End If

End Sub



Private Sub Command31_Click()
Let Text18.Text = ""
Text18.Text = Dir1.Path

If Right(Dir1.Path, 1) <> "\" Then
 Text18.Text = Text18.Text & "\"
End If
End Sub

Private Sub Command32_Click()
Let DelFile = True
'Form3.Visible = True
Form3.Show 1
```

```
Form3.Text1.Text = ""
'Form3.Text1.SetFocus
End Sub

Private Sub Command32_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
Save_Test = InputBox("Enter File Name", "Delete file")
    If Save_Test <> "" Then
        If Save_Test <> "Find" Then

            If Dir(DefaultPath & Save_Test) <> "" Then
                Open DefaultPath & Save_Test For Input As #5
                    If MsgBox("Are You Sure That You Want to Delete The Selected Item?", vbYesN
o, "Confirm Delete") = vbYes Then
                    Call Delete
                    End If
                Close #5

            Else: MsgBox " File Does Not Exist", vbOKOnly, "Data Error"
            End If
        Else
        If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
        Open DefaultPath & "Saved_List.TXT" For Input As #7
        List3.Clear
            Let Del_Hold = ""
                Do While Not EOF(7)
                Input #7, Delx
                    If Del_Hold <> Delx Then
                    List3.AddItem Delx
                    Let Del_Hold = Delx
                    End If
                Loop
                    If List3.ListCount <> 0 Then
                    List3.Visible = True
                    Command34.Visible = True
                    Else
                    MsgBox "There Are No Tests To View", vbOKOnly, "Data Error"
                    End If
            Close #7
        Else: MsgBox "There Are No Tests To View", vbOKOnly, "Data Error"
        End If

        End If
    Else: MsgBox "Job Number Not Entered", vbOKOnly, "Enter Data"
    End If
'Else
'MsgBox " You are Not Authorised to use this fuctionality"
End If
End Sub

Private Sub Command33_Click()
List2.Visible = False
Command33.Visible = False
List2.Clear
List4.Visible = False
List4.Clear
End Sub

Private Sub Command34_Click()
List3.Visible = False
Command34.Visible = False
List3.Clear
End Sub

Private Sub Command35_Click()
Frame37.Visible = True
Command46.Visible = True
Text20.Text = ""
Text21.Text = ""
Text22.Text = ""
Command35.Visible = False
Let Command36.Enabled = True
End Sub
```

```
Private Sub Command36_Click()
Let Text18.Text = ""
Text18.Text = Dir1.Path

If Right(Dir1.Path, 1) <> "\" Then
 Text18.Text = Text18.Text & "\"
End If

If Text18.Text <> "" Then

     Let AddNewArm = True
     Form3.Visible = True
     'Form3.Show 1
     Form3.Text1.Text = ""
     Form3.Text1.SetFocus

Else
MsgBox "No Path Specified", vbOKOnly, "Data Path Error"
End If
End Sub

Private Sub Command36_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
        If Dir("C:\Program Files\SavePath") <> "" Then
            Open "C:\Program Files\SavePath" For Input As #10 ' to save the default path
            Open "Temp" For Output As #11
            Write #11, Text18.Text
            Close #11
            Close #10
            Kill ("C:\Program Files\SavePath")
            Name "Temp" As "C:\Program Files\SavePath"
            Command17.Enabled = True
        Else
            Open "C:\Program Files\SavePath" For Output As #10
            Write #10, Text18.Text
            Close #10
            Command17.Enabled = True
        End If
    Let DefaultPath = Text18.Text
    'Else
'MsgBox " You are Not Authorised to use this fuctionality"
    End If
End Sub

Private Sub Command37_Click()
If Dir("C:\Program Files\SavePath") <> "" Then
    Open "C:\Program Files\SavePath" For Input As #10
    Input #10, DefaultPath ' holds the path to the saved files
    Let Text18.Text = DefaultPath
    Close #10
Else
    MsgBox "Default Path is Not Valid due to an Unauthorized change", vbOKOnly, "Data Path Erro
r"
End If
End Sub

Private Sub Command38_Click()
Picture2.Cls
Picture2.Visible = False
End Sub

Private Sub Command39_Click()
ExcelSheet.Application.Visible = True
End Sub

Private Sub Command4_Click()
Let AddNewArm = True
Form3.Visible = True
'Form3.Show 1
Form3.Text1.Text = ""
Form3.Text1.SetFocus

End Sub
```

```
Private Sub Command4_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
    ' When removing an item the listindex value is used to find the record using the
    ' record number it was stored under using the listcount prop. The problem is that the
    ' using listcount, the first item is at 1, and for the listindex prop, the 1st item in
    ' the combo box is at 0. Therefore 1 is added to listindex value in order to match the
    ' stored record value using listcount.
        If MsgBox("Are You Sure That You Want to Delete The Selected Item?", vbYesNo, "Confirm
Delete") = vbYes Then
        Dim c As Integer

            Let b = Combo2.ListIndex ' note: first item in box is at 0 therefore 1 must be adde
d to = the listcount valne the record is saved under
            Combo2.Clear
            If Dir(DefaultPath & "Arm.TXT") <> "" Then
                Open DefaultPath & "Arm.TXT" For Input As #1
                Open "Del" For Output As #2

                    Do While Not EOF(1)
                    Input #1, nam, num, cnt ' cnt is the record num saved when adding and start
s at 1
                        If cnt <> (b + 1) Then  ' cos listindex begins at 0 and listcount start
s at 1
                        Combo2.AddItem "Armature Name:    " & nam & "     Number of Bars:    " & n
um
                        Let c = Combo2.ListCount
                        Write #2, nam, num, c
                        End If
                    Loop
                Close #1
                Close #2
                Kill DefaultPath & "Arm.TXT"
                Name "Del" As DefaultPath & "Arm.TXT"
            Else: MsgBox "No Armature Properties Found", vbOKOnly, "Data Error"
            End If
        End If
 'Else
'MsgBox " You are Not Authorised to use this fuctionality"
 End If
End Sub

Private Sub Command40_Click()
Command41.Visible = True
Frame34.Visible = True
End Sub

Private Sub Command41_Click()
Command41.Visible = False
Frame34.Visible = False
End Sub

Private Sub Command42_Click()
Let CalPassW = True
Form3.Visible = True
'Form3.Show 1
Form3.Text1.Text = ""
Form3.Text1.SetFocus

End Sub



Private Sub Command43_Click()

If Text20.Text <> "" And Text21.Text <> "" And Text22.Text <> "" Then
    If Text21.Text = Text22.Text Then
        If Dir("C:\Program Files\Calibration\" & "B_2_B_Pwd") <> "" Then
        Open "C:\Program Files\Calibration\" & "B_2_B_Pwd" For Append As #1
        Write #1, Text20.Text, Text21.Text
        Close #1
        Else
        Open "C:\Program Files\Calibration\" & "B_2_B_Pwd" For Output As #1
        Write #1, Text20.Text, Text21.Text
        Close #1
```

```
        Text20.Text = ""
        Text21.Text = ""
        Text22.Text = ""
        End If
    Else
    MsgBox " The two Passwords that were entered Do Not match", vbOKOnly, "Password Error"
    Text21.Text = ""
    Text22.Text = ""
    End If
Else
MsgBox "Please Enter All The Requested Information Before Proceeding", vbOKOnly, "Input Data Er
ror"
End If

End Sub

Private Sub Command44_Click()
Frame37.Visible = True
Command46.Visible = True
Text20.Text = ""
Text21.Text = ""
Text22.Text = ""
End Sub

Private Sub Command42_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
Form2.Visible = True
Let CalibFlag = True
'***********multiple reading initialization************
Let MultiReading = 0
Let RowCount = 0

Set ExcelSheet = CreateObject("Excel.Sheet")

'*********End multiple reading initialization**********

'for test
If Dir("C:\Program Files\Calibration\" & "Calibration1.txt") <> "" Then
Open "C:\Program Files\Calibration\" & "Calibration1.txt" For Input As #1
Input #1, gradient, intercept, ddate
Close #1
Else
MsgBox "The system has not been Calibrated or the Calibtation Factor File does not exist. The T
est will, however, still continue", vbOKOnly, "No Calibration Warning"
Let gradient = 1
Let intercept = 0
End If
'for test


'******************specify hardware gain****************
Let Gain = 9.95
'***************End specify hardware gain***************
'Else
'MsgBox " You are Not Authorised to use this fuctionality"
End If
End Sub

Private Sub Command45_Click()
If Text20.Text <> "" Then
    If Dir("C:\Program Files\Calibration\" & "B_2_B_Pwd") <> "" Then
    Open "C:\Program Files\Calibration\" & "B_2_B_Pwd" For Input As #1
    Open "C:\Program Files\Calibration\" & "B_2_B_Pwd2" For Output As #2
        Do While Not EOF(1)
        Input #1, UserName, UserPassword
            If UserName <> Text20.Text Then
            Write #2, UserName, UserPassword
            End If
        Loop
    Close #1
    Close #2
    Kill "C:\Program Files\Calibration\" & "B_2_B_Pwd"
    Name "C:\Program Files\Calibration\" & "B_2_B_Pwd2" As "C:\Program Files\Calibration\" & "B
_2_B_Pwd"
```

```
    Text20.Text = ""
    Text21.Text = ""
    Text22.Text = ""
    Else
    MsgBox "A User Profile List Has Not Been Created", vbOKOnly, "Data Error"
    End If
Else
MsgBox "Please Enter User Name", vbOKOnly, "Enter Data"
End If
End Sub

Private Sub Command46_Click()
Let UsrProf = True
Form3.Visible = True
'Form3.Show 1
Form3.Text1.Text = ""
Form3.Text1.SetFocus


End Sub

Private Sub Command46_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
Frame37.Visible = False
Command46.Visible = False
End If
End Sub

Private Sub Command47_Click()
If Text23.Text = SuperUser & Text24.Text = SuperAutoSun6 Then
Frame38.Visible = False
Else
MsgBox " You are Not Authorised to use this fuctionality", vbOKOnly, "Unauthorized Action"
Command47.Visible = False
Text23.Visible = False
Text24.Visible = False
End If
End Sub

Private Sub Command48_Click()
Frame38.Visible = True
Command47.Visible = False
Text23.Text = ""
Text24.Text = ""
Text23.Visible = False
Text24.Visible = False
Label14.Visible = False
Label18.Visible = False
End Sub

Private Sub Command49_Click()
Command47.Visible = False
Text23.Visible = False
Text24.Visible = False
Command49.Visible = False
Label14.Visible = False
Label18.Visible = False
End Sub

Private Sub Command5_Click()
If Command5.Caption = "Start" Then
Picture9.BackColor = QBColor(10) 'search highlighted on first count
Set ExcelSheet = CreateObject("Excel.Sheet")
Command16.Enabled = False
End If

Command42.Enabled = False
'***********multiple reading initialization************
Let MultiReading = 0
Let RowCount = 0

'Set ExcelSheet = CreateObject("Excel.Sheet")

'*********End multiple reading initialization***********
```

```
'******************specify hardware gain****************
Let Gain = 9.95
'***************End specify hardware gain***************

'*************open Calibration factor file*******************
If Dir("C:\Program Files\Calibration\" & "Calibration1.txt") <> "" Then
Open "C:\Program Files\Calibration\" & "Calibration1.txt" For Input As #1
Input #1, gradient, intercept, ddate
Close #1
Else
MsgBox "The system has not been Calibrated or the Calibtation Factor File does not exist. The T
est will, however, still continue", vbOKOnly, "No Calibration Warning"
Let gradient = 1
Let intercept = 0
End If

'Let Text9.Text = gradient 'for test
'Let Text2.Text = intercept ' for test
'*************open Calibration factor file*******************
'Dim ADList As Integer
'Let Check = ""
'Let ADList = 0

'If Dir("DefaultPath & Save_Test") <> "" Then
'   Open "DefaultPath & Save_Test" For Input As #5
'   Do While (Not EOF(5))
 '  Input #5, aa, bb, cc, dd, ee, ff
'             If Check <> aa Then
'             Let ADList = ADList + 1
'             Let Check = aa
'             End If
'         Loop
'     Close #5
' End If


'If ADList <= 25 Then
    '**********log number of bars*************
    If Combo2.Text <> "" And Combo2.Text <> "Armature Select" Then
         '**********log % variance*************
        If Combo1.Text <> "" And Combo1.Text <> "Percentage Variance" Then

            If Option1 = True Or Option2 = True Then

                Do While Text2.Text = ""
                Text2.Text = InputBox("Enter User Name", "User Name Not Entered")
                Loop
                Do While Text9.Text = ""
                Text9.Text = InputBox("Enter Job Number", "Job Number Not Entered")
                Loop

                Screen.MousePointer = vbArrowHourglass ' change mouse icon when test is running
                '********** load begin time and date********
                Let Text11.Text = Space(30) & Date
                Let SaveDate = Year(Date) & "-" & Month(Date) & "-" & Day(Date)

                Let Text12.Text = Space(20) & Time
                timed = Second(Time)
                timee = Minute(Time)
                timef = Hour(Time)
                Let Savetime = Hour(Time) & "H" & Minute(Time) & "M" & Second(Time)

                '********Enable Control Buttons***********
                'Let Command6.Enabled = True ' only enabled after last bar is reached, or test
ended
                Let Command7.Enabled = False 'only enabled when error 3 or 4 occurs


                          '********End Enable Control Buttons***********

                '***************Disable fields when started**********
                Let Command30.Enabled = False   'For delete and open
                Let Command32.Enabled = False   '
                'Let Frame30.Enabled = False     '
```

```
                'Let Frame31.Enabled = False     '
                Let Fopen = ""                   '
                Let Deletex = ""                 '

                List1.Clear
                List2.Visible = False
                List2.Clear
                List3.Visible = False
                List3.Clear
                List4.Visible = False
                List4.Clear
                Command33.Visible = False
                Command34.Visible = False
                Let Print_flag = False  ' for deleting file while print

                Let Command1.Enabled = False
                Let Command2.Enabled = False
                Let Command3.Enabled = False
                Let Command4.Enabled = False
                Let Command5.Enabled = False
                Let Command9.Enabled = False
                Let Command14.Enabled = False 'print
                Let Command15.Enabled = False 'save
                Let Combo1.Enabled = False
                Let Combo2.Enabled = False
                Let Option1.Enabled = False
                Let Option2.Enabled = False
                Let Command17.Enabled = False
                Let Text1.Locked = True
                Let Text2.Locked = True
                Let Text3.Text = ""
                Let Text3.Locked = True
                Let Text4.Text = ""
                Let Text4.Locked = True
                Let Text5.Text = ""
                Let Text5.Locked = True
                Let Text9.Locked = True
                '********End Disable fields when started**********
                MSComm1.Output = "A"
                '************For simulation Only******************
                Text15.Text = "A"
                '**********End For simulation Only*****************

                Command5.BackColor = QBColor(10)
                Command5.Enabled = False

            Else
            MsgBox " Select Automated Or Manual Opperation", vbOKOnly, "Select Operation Mode"
            End If

        Else
        MsgBox "No Percentage Variance Value Selected", vbOKOnly, "Select Percentage Variance"
        End If
        '********End log % variance***********
    Else
    MsgBox "Armature Not Selected", vbOKOnly, "Select Armature"
    End If
        '********End log number of bars**********
'Else
   ' MsgBox "The File in which the Test Files are saved contains 50 Items and if Full, Delete I
tems before proceding."
   ' Command30.Enabled = False
    'Command32.Enabled = True

    'List1.Clear              'list boxes and commands for open and delete and list1
   ' List2.Visible = False
   ' List2.Clear
   ' List3.Visible = False
    'List2.Clear
    'Command33.Visible = False
    'Command34.Visible = False
'End If
End Sub

Private Sub Command6_Click()
```

```
MSComm1.Output = "B"
Command16.Enabled = True
'*************For simulation Only*******************
Text15.Text = "B"
'**********End For simulation Only******************
Command6.BackColor = QBColor(10)

Let Text6.Text = ""
Let Text7.Text = ""
Let Text8.Text = ""

Let Pswd = 3
Let PasswdFlag = False
Let Command18.Enabled = True ' Lock out password
Let Text1.Locked = False ' Lock out password
Let Command17.Enabled = True ' password

Let Command14.Enabled = True 'print
Let Command15.Enabled = True 'save

Let Text1.Locked = False ' Lock out password
Let Command17.Enabled = True ' password
Let Command8.Enabled = False
Command8.BackColor = &H8000000F
Call TestEnd_States
Command6.Enabled = False
Command35.Visible = True 'new test button


If Initial_Error = True Then ' if initial bar was a Fault bar
List1.FontBold = True
List1.AddItem "Note: Reference Value Error Occured, Bar 5 has be recorded as the Bar 1 ( First
Bar )"
List1.FontBold = False
MsgBox "Note: Reference Value Error Occured", vbOKOnly, "Reference Value Error"
End If

End Sub

Private Sub Command7_Click()
MSComm1.Output = "C"
'*************For simulation Only*******************
Text15.Text = "C"
'**********End For simulation Only******************
Command7.BackColor = &H8000000F
Command7.Enabled = False
Command8.BackColor = &H8000000F
Let Command12.Enabled = False 'error3
Command12.BackColor = &H8000000F
Frame17.ForeColor = &H80000012
Frame17.FontSize = 8
Frame17.FontBold = False

Let Command13.Enabled = False 'error4
Command13.BackColor = &H8000000F
Frame15.ForeColor = &H80000012
Frame15.FontSize = 8
Frame15.FontBold = False


End Sub

Private Sub Command8_Click()
MSComm1.Output = "F"
'*************For simulation Only*******************
Text15.Text = "F"
'**********End For simulation Only******************
Command8.BackColor = QBColor(12)
Command7.BackColor = &H8000000F
Let Command6.Enabled = True
Let Command6.BackColor = &HFF8080
Let Picture6.BackColor = &H8000000F

Call TestEnd_States
Let Emergency = True
```

```
Command8.Enabled = False
List1.FontBold = True
List1.AddItem "Emergency Stop on Bar " & Text6.Text
List1.FontBold = False
End Sub

Private Sub Command9_Click()
MSComm1.Output = "D" ' send signal to ready the switch to take man reading
'*************For simulation Only******************
Text15.Text = "D"
'**********End For simulation Only*****************
'Command9.BackColor = &H8000000F
'Command9.Enabled = False
Command9.Enabled = False 'disables man reading but and dsply
Frame20.ForeColor = &H8000000F '
Picture5.BackColor = QBColor(12) '
Frame21.ForeColor = &H8000000F

Let Command10.Enabled = False 'error4
Command10.BackColor = &H8000000F
Frame14.ForeColor = &H80000012
Frame14.FontSize = 8
Frame14.FontBold = False

Let Command11.Enabled = False 'error4
Command11.BackColor = &H8000000F
Frame16.ForeColor = &H80000012
Frame16.FontSize = 8
Frame16.FontBold = False

'Command8.Enabled = True


'***************************************************


'***below code is just to test & is not prog code****
'To delete a File
'Dim Arm As ArmData
'Close #1
'Kill DefaultPath & "Arm.TXT"


'Text1.Enabled = True
'Text1.Text = "Works"
'Text1.Enabled = False

''Picture10.FontSize = 13
''Picture10.Print "a"

'Command11.Enabled = True
'Command11.BackColor = QBColor(12)
'Frame14.ForeColor = QBColor(12)
'Frame14.FontSize = 10
'Frame14.FontBold = True


'Command12.Enabled = True
'Command12.BackColor = QBColor(12)
'Frame15.ForeColor = QBColor(12)
'Frame15.FontSize = 10
'Frame15.FontBold = True

'Command13.Enabled = True
'Command13.BackColor = QBColor(12)
'Frame16.ForeColor = QBColor(12)
'Frame16.FontSize = 10
'Frame16.FontBold = True

'Command10.Enabled = True
'Command10.BackColor = QBColor(12)
Frame17.ForeColor = QBColor(12)
Frame17.FontSize = 10
Frame17.FontBold = True
```

```
End Sub

Private Sub Dir1_Change()
Let File1.Path = Dir1.Path
End Sub

Private Sub Drive1_Change()
Let Dir1.Path = Drive1.Drive
End Sub

Private Sub Form_Load()


Let Pswd = 3
Let PasswdFlag = False
Let Emergency = False
Frame27.Visible = False
'****************Calibration***************
Let Form2.Visible = False
Let Form2.CalibFlagClear = True
Let CalibFlag = False

'*************End Calibration***************
List8.AddItem Form2.CalibFlagClear 'for test

'**************Load default path from c:program files****************
If Dir("C:\Program Files\SavePath") <> "" Then
    Open "C:\Program Files\SavePath" For Input As #10
    Input #10, DefaultPath ' holds the path to the saved files
    Close #10
Else
    MsgBox "Default Path is Not Valid due to an Unauthorized change", vbOKOnly, "Data Path Erro
r"
    'Let DefaultPath = "xxx"
    Command17.Enabled = False
End If
'************** End Load default path from c:program files**************

'******* Load Percentage Selection ****************************
'cnt is used as a record number and is the listcount value.
'cnt starts at 1 but when items are loaded into the combo box, the 1st item is at 0
If Dir(DefaultPath & "Per.TXT") <> "" Then
    Open DefaultPath & "Per.TXT" For Input As #3
        Do While (Not EOF(3))
        Input #3, per, vlu
        Combo1.AddItem "Percentage Variance:   " & per & "%"
        Loop
    Close #3
End If
'******* End Load Percentage Selection ************************


'******* Load Armature Selection *****************************
'cnt is used as a record number and is the listcount value.
'cnt starts at 1 but when items are loaded into the combo box, the 1st item is at 0
If Dir(DefaultPath & "Arm.TXT") <> "" Then
    Open DefaultPath & "Arm.TXT" For Input As #1
        Do While (Not EOF(1))
        Input #1, nam, num, cnt
        Combo2.AddItem "Armature Name:   " & nam & "   Number of Bars: " & num
        Loop
    Close #1
End If
'******* End Load Armature Selection ************************

'*******Initilize Serial Comm port 1*******
'Rec data
MSComm1.RThreshold = 1
MSComm1.InputLen = 1
MSComm1.DTREnable = False

MSComm1.Settings = "2400,N,8,1"

MSComm1.CommPort = 1
MSComm1.PortOpen = True
```

```
'Trans data
MSComm1.OutBufferCount = 0
'**** End Initilize Serial Comm port 1*****
'Text10.Locked = True

            Let Text2.Locked = True
            Let Text3.Locked = True
            Let Text4.Locked = True
            Let Text5.Locked = True
            Let Text9.Locked = True

End Sub

Private Sub List2_Click()
Let Save_Test = List2.Text
List1.Clear
Let Dspl_Date = ""
List4.Clear
List4.AddItem "View All"
Open DefaultPath & Save_Test For Input As #5
    Do While Not EOF(5)
    Input #5, aa, bb, cc, dd, ee, ff
        If (Dspl_Date <> ee) And (bb <> "xxx") Then
            List4.AddItem LTrim(ee)
            Let Dspl_Date = ee
        End If
    Loop

    If List4.ListCount = 1 Then
    MsgBox "There are no items to View", vbOKOnly, "Data Error"
    List4.Clear
    Else
    List4.Visible = True
    End If
Close #5

'Call FopenSub
'List2.Visible = False
'Command33.Visible = False
End Sub

Private Sub List3_Click()
Let Save_Test = List3.Text
    If MsgBox("Are You Sure That You Want to Delete The Selected Item?", vbYesNo, "Confirm Dele
te") = vbYes Then
    Call Delete
    End If
List3.Visible = False
Command34.Visible = False
End Sub

Private Sub List4_Click()
List1.Clear
Let Test_Date = List4.Text
Call FopenSub
List2.Visible = False
List4.Visible = False
Command33.Visible = False
End Sub

Private Sub MSComm1_OnComm()
If MSComm1.CommEvent = comEvReceive Then
Let SerIn = MSComm1.Input
' after emergency stop, the micro goes into powerdowm mode and "" is sent to the pc, this value
 crashes the program
' b4 power down P3 is loaded with 00000011B, keeping the serial pins 1, this should prevent a "
" value from being sent
' this code is kept here in the event an unexpected "" is sent, and thus prevent the program fr
om crashing
If SerIn = "" Then
Let SerIn = "x"
End If
Let Text19.Text = SerIn ' for tests only
List5.AddItem SerIn   ' for tests only
```

```
    If Incomming_LowB_Flag = True Then
    Low_Byte = Asc(SerIn)
    List6.AddItem Low_Byte
    ' for tests only
    Let Incomming_LowB_Flag = False
    Let Incomming_HighB_Flag = False ' redundant
    Call Calculation
    ElseIf Incomming_HighB_Flag = True Then
    High_Byte = Asc(SerIn)
    List7.AddItem High_Byte  ' for tests only
    Let Incomming_HighB_Flag = False
    Else
    Select Case SerIn
    'Case "a" ' bar count done in the nb therefore no need to transmit this data.
    '   Call Trans_Arm_Type
    Case "b"
        MSComm1.Output = Auto_Man
    Case "d"
        Command5.BackColor = &H8000000F
        Let Command5.Caption = "Start"
        Command5.Enabled = True
        Let Command8.Enabled = True
        Screen.MousePointer = vbArrow
    Case "O" 'Emergency Stop prompt when the Emergenct Stop switch on the test station is press
ed
        Command8.BackColor = QBColor(12)
        Command7.BackColor = &H8000000F
        Let Command6.Enabled = True
        Let Command6.BackColor = &HFF8080
        Let Picture6.BackColor = &H8000000F

        Call TestEnd_States
        Let Emergency = True
        Command8.Enabled = False
        List1.FontBold = True
        List1.AddItem "Emergency Stop on Bar " & Text6.Text
        List1.FontBold = False
    Case "I"
        Call Bar_count
    Case "J"
        Let Command10.Enabled = True ' error1
        Command10.BackColor = QBColor(12)
        Frame14.ForeColor = QBColor(12)
        Frame14.FontSize = 10
        Frame14.FontBold = True
        Command9.Enabled = True
        Frame20.ForeColor = QBColor(10) ' enables man reading but and dsply
        Picture5.BackColor = QBColor(10) '
        Frame21.ForeColor = QBColor(10) '
        Command9.BackColor = &HFF8080
    Case "m"
        Let Command11.Enabled = True ' error2
        Command11.BackColor = QBColor(12)
        Frame16.ForeColor = QBColor(12)
        Frame16.FontSize = 10
        Frame16.FontBold = True
        Command9.Enabled = True
        'Command8.Enabled = False
        Frame20.ForeColor = QBColor(10) ' enables man reading but and dsply
        Picture5.BackColor = QBColor(10) '
        Frame21.ForeColor = QBColor(10) '
        Command9.BackColor = &HFF8080
    Case "N"
        MsgBox "A Negative Potential has been detected. Correct the fault and Click Continue or
 Click Emenengcy Stop", vbOKOnly, "Error: Negative Input Value Detected"
    Case "L"
        Let Command12.Enabled = True 'error3 is enabled emgncy stop is automatic as the system
is already shut down on error3
        Command12.BackColor = QBColor(12)
        Frame17.ForeColor = QBColor(12)
        Frame17.FontSize = 10
        Frame17.FontBold = True
        Command8.Enabled = True
        Command7.Enabled = True
        Command7.BackColor = &HFF8080
```

```
        Command8.BackColor = &HFF8080

        'Emergnct stop is automatically entered into hence the code below is a copy of the "Eme
rgency Stop" button
        Command8.BackColor = QBColor(12)
        Command7.BackColor = &H8000000F
        Let Command6.Enabled = True
        Let Command6.BackColor = &HFF8080
        Let Picture6.BackColor = &H8000000F

        Call TestEnd_States
        Let Emergency = True
        Command8.Enabled = False
        List1.FontBold = True
        List1.AddItem "Emergency Stop on Bar " & Text6.Text
        List1.FontBold = False
        Let Command12.Enabled = True 'error3 is enabled emgncy stop is automatic as the system
is already shut down on error3
        Command12.BackColor = QBColor(12)
        '.........................................................................................
..................
    Case "Q"
        Let Command13.Enabled = True 'error4 is enabled and is disabled when Cont after pause o
r emgncy stop is clicked
        Command13.BackColor = QBColor(12)
        Frame15.ForeColor = QBColor(12)
        Frame15.FontSize = 10
        Frame15.FontBold = True
        Command8.Enabled = True
        Command7.Enabled = True
        Command7.BackColor = &HFF8080
        Command8.BackColor = &HFF8080
    Case "z"
        Let Incomming_HighB_Flag = True
        Picture8.BackColor = QBColor(4)
        Picture9.BackColor = &H8000000F
    Case "y"
        Let Incomming_LowB_Flag = True
    End Select
    End If
End If
End Sub

Private Sub Option1_Click()
Picture6.BackColor = QBColor(10)
Picture7.BackColor = &H8000000F
Let Auto_Man = "G"
End Sub

Private Sub Option2_Click()
Picture7.BackColor = QBColor(10)
Picture6.BackColor = &H8000000F
Let Auto_Man = "g"
End Sub

Private Sub Text15_Change()
xa: If Text15.Text = "E" Then
Call Calculation
GoTo xa
End If
End Sub

Private Sub Timer1_Timer()
'Let Form2.Text6 = "xxx"

'Timer1.Enabled = False
'For i = 1 To 102
'Let ExcelSheet.Application.Cells((RowCount + 1), i).Value = ""
'Let ExcelSheet.Application.Cells(RowCount, i).Value = ""
'Next i
'Let MultiReading = 0
'Let RowCount = RowCount - 1

'MSComm1.Output = "H"
'If Form2.CalibFlagClear = False Then
```

```
'Call CalibrationSub
'Else
'Call Calculation
'Let Form2.Text6 = "xxxyyy"
'End If


'Picture2.Cls
'****************Print in Pic Box for Simulation ****************************
'    Picture2.Visible = True
'    Picture2.Print "Job Number:  " & Text9.Text
'    Picture2.Print "Operator's Name:  " & Text2.Text
'    Picture2.Print Combo2.List(Combo2.ListIndex)
'    Picture2.Print Combo1.List(Combo1.ListIndex)
'    Picture2.Print "Date:  " & LTrim(Text11.Text)
'    Picture2.Print ""
'    Picture2.Print "Recorded Faults "
'    Picture2.Print ""
'****************End Print in Pic Box for Simulation ***********************
'****************Print in Pic Box for Simulation ****************************
'  Let Print_current_i = 0
'        Do While Print_current_i <= (List1.ListCount - 1)
'        Picture2.Print List1.List(Print_current_i)
'        Print_current_i = ((Print_current_i) + (1))
'        Loop

'****************End Print in Pic Box for Simulation ***********************

    '****************Print in Pic Box for Simulation ****************************
'    Picture2.Print ""
'    Picture2.Print "I, " & Text2.Text & " acknowledge the above results and pledge to investig
ate and/or remedy the"
'    Picture2.Print "above recorded faults (if any)."
'    Picture2.Print "Signature, " & Text2.Text & "    ___________________________________"
'    Picture2.Print ""
    '****************End Print in Pic Box for Simulation ***********************

End Sub

Public Sub TestEnd_States()
Let Command18.Enabled = True ' Lock out password


Let Picture6.BackColor = &H8000000F
Let Picture7.BackColor = &H8000000F
Let Picture8.BackColor = &H8000000F
Let Picture9.BackColor = &H8000000F

Let Text10.Locked = False ' password
Screen.MousePointer = vbArrow ' change mouse icon when test is NOT running
Command5.BackColor = &H8000000F
Command5.Enabled = False

Let Command7.Enabled = False
Command7.BackColor = &H8000000F
Let Command9.Enabled = False
Picture5.BackColor = QBColor(12)
Frame20.Enabled = False
Frame21.Enabled = False

Let Command10.Enabled = False ' error1
Command10.BackColor = &H8000000F
Frame14.ForeColor = &H80000012
Frame14.FontSize = 8
Frame14.FontBold = False

Let Command11.Enabled = False ' error2
Command11.BackColor = &H8000000F
Frame16.ForeColor = &H80000012
Frame16.FontSize = 8
Frame16.FontBold = False

Let Command12.Enabled = False 'error3
Command12.BackColor = &H8000000F
Frame17.ForeColor = &H80000012
```

```
Frame17.FontSize = 8
Frame17.FontBold = False

Let Command13.Enabled = False 'error4
Command13.BackColor = &H8000000F
Frame15.ForeColor = &H80000012
Frame15.FontSize = 8
Frame15.FontBold = False



'*************** Time&Date *************************
If Emergency = False Then

Let Text13.Text = Space(20) & Time
    timed = Second(Time) - timed
    If timed < 0 Then
    timed = 60 + timed
    timee = timee + 1
    End If

    timee = Minute(Time) - timee
    If timee < 0 Then
    timee = 60 + timee
    timef = timef + 1
    End If

    timef = Hour(Time) - timef
    If timef < 0 Then
    timed = 24 + timef
    End If
    Let Text14.Text = Space(20) & timef & ":" & Space(1) & timee & ":" & Space(1) & timed
End If
'*************** End Time&Date *************************


End Sub

Public Sub Trans_Arm_Type() ' might not be needed as the bar count is done in the nb.
Let HB_bars = No_of_Bars / 256
Let LB_bars = No_of_Bars Mod 256
MSComm1.Output = Chr(HB_bars) ' transmit High byte
MSComm1.Output = Chr(LB_bars) ' transmit Low byte

'*************For simulation Only*******************
Text15.Text = Chr(HB_bars) ' transmit High byte
Text18.Text = Chr(LB_bars) ' transmit Low byte
'**********End For simulation Only******************
End Sub

Public Sub Bar_count()
Let No_of_Bars = No_of_Bars - 1
If No_of_Bars < 0 Then ' <0 cos for the last bar this variable = 0
MSComm1.Output = "P"
Command6.BackColor = QBColor(9)
Command5.BackColor = &H8000000F
Command6.Enabled = True
'*************For simulation Only*******************
Text15.Text = "P"
'**********End For simulation Only******************
Else
MSComm1.Output = "p"
'*************For simulation Only*******************
Text15.Text = "p"
'**********End For simulation Only******************
Let Text7.Text = No_of_Bars
Let Text6.Text = Val(Text6.Text) + 1
End If
End Sub

Public Sub Calculation()
' List8.AddItem "enter" 'for test
'********************Calibration***********************
'If Form2.CalibFlagClear = True Then
'Let CalibFlag = False
```

```
'Else
'If Form2.CalibFlagClear = False Then
'Let CalibFlag = True
'End If

'List8.AddItem CalibFlag 'for test

'If CalibFlag = True Then
'Call CalibrationSub
'GoTo EndReading
'End If

'*****************End Calibration***********************
List8.AddItem "enter1" 'for test
Dim AvgBarReading As Single
Dim SumBarReading As Single

'**************for multiple readings*****************
If MultiReading = 0 Then
    Let MultiReading = 100
    'Let TimerFlag = True
    'Let Timer1.Enabled = True
End If

Let MultiReading = MultiReading - 1

If MultiReading = 99 Then
    Let RowCount = RowCount + 1
    Let ZeroIn = 0
    Let HighBCount = 0
    Let HighBCount1 = 0
    Let HighBCount2 = 0
    Let HighBCount3 = 0
    Let HighBCount4 = 0
    Let HighBCount5 = 0
    Let SndEntry = 0
    Let StnBit_WDflg = False
End If

Let ColumnCount = 100 - MultiReading
'************End for multiple readings***************
Picture8.BackColor = QBColor(4)
Picture9.BackColor = &H8000000F

' convert to 16 bit word
'Let Bin2Dec = High_Byte
'Call Binary2Decimal
'High_Byte = Bin2Dec
'*************For simulation Only******************
'Picture1.Print Bin2Dec
'**********End For simulation Only*****************
'Let Bin2Dec = Low_Byte
'Call Binary2Decimal
'Let Low_Byte = Bin2Dec
'*************For simulation Only******************
'Picture1.Print Bin2Dec
'**********End For simulation Only*****************
StnBit_WD = ((High_Byte * 256) + Low_Byte)
'*************For simulation Only******************
Picture1.Print StnBit_WD
'**********End For simulation Only*****************
'*************** Open Circuit Check****************
If StnBit_WD = 65534 Then
    Let StnBit_WDflg = True
End If
'*************** Open Circuit Check****************
'*************Lower Range Value Adjust*****************
If High_Byte And Low_Byte = 120 Then
    Let ZeroIn = ZeroIn + 1
End If

If High_Byte = 120 Then
    Let HighBCount = HighBCount + 1
End If
If High_Byte = 1 Then
```

```
    Let HighBCount1 = HighBCount1 + 1
End If
If High_Byte = 2 Then
    Let HighBCount2 = HighBCount2 + 1
End If
If High_Byte = 3 Then
    Let HighBCount3 = HighBCount3 + 1
End If
If High_Byte = 4 Then
    Let HighBCount4 = HighBCount4 + 1
End If
    If High_Byte = 5 Then
Let HighBCount5 = HighBCount5 + 1
End If
'*************Lower Range Value Adjust******************
'******************Actual Voltage Reading*****************

    Let ActVolReadRes = (4.096 / 65536)
    Let ActVolRead = (StnBit_WD * ActVolReadRes)
    Let mVActVolRead = ActVolRead / Gain
    'Let mVActVolRead = ((gradient * (ActVolRead / Gain)) + intercept) ' actual voltage with ca
libtation factor.
    'objExcel.Application.Cells(RowCount, ColumnCount) = mVActVolRead
    ExcelSheet.Application.Cells(RowCount, ColumnCount).Value = mVActVolRead
    If High_Byte <> 120 Then
        'ExcelSheet.Application.Cells((RowCount + 1), ColumnCount).Value = mVActVolRead
        Let SndEntry = SndEntry + 1
    End If

    'List1.AddItem mVActVolRead & "  ,  " & StnBit_WD & "  ,  " & Low_Byte & "  ,  " & High_Byt
e  ' f

    List8.AddItem RowCount 'for test
    List8.AddItem ColumnCount 'for test
    List8.AddItem mVActVolRead 'for test

If MultiReading > 0 Then
    MSComm1.Output = "E" ' to microcontroller ' 07-02-06
    '*************For simulation Only*******************
            Text15.Text = "E"
    '**********End For simulation Only******************
    GoTo EndReading
End If

If MultiReading = 0 Then
    Let SumBarReading = 0
        For col = 1 To 100
        Let SumBarReading = SumBarReading + ExcelSheet.Application.Cells(RowCount, col).Value
        Next col
    Let AvgBarReading = SumBarReading / 100 '100= no of readings
    'objExcel.Application.Cells(RowCount, 102) = AvgBarReading ' put the average of this row in
col 102
    ExcelSheet.Application.Cells(RowCount, 102).Value = AvgBarReading
End If
    '******************End Actual Voltage reagings*************

   '*************Lower Range Value Adjust******************
    If ZeroIn > 50 Then
            For adj = 1 To 100
            ExcelSheet.Application.Cells(RowCount, adj).Value = "Adjusted"
            Next adj
        ExcelSheet.Application.Cells(RowCount, 102).Value = "0"
        Let AvgBarReading = 0
    End If

    'List1.AddItem HighBCount & " ' " & HighBCount1 & " ' " & HighBCount2 & " ' " & HighBCount3
& " ' " & HighBCount4 & " ' " & HighBCount5

    'If (HighBCount1 > 10 Or HighBCount2 > 10 Or HighBCount3 > 10 Or HighBCount4 > 10 Or HighBC
ount5 > 10) Then
    '    For adj = 1 To 100
    '        If ExcelSheet.Application.Cells((RowCount + 1), adj).Value = "" Then
    '        Let ExcelSheet.Application.Cells((RowCount + 1), adj).Value = "0"
    '        End If
    '    Next adj
```

```
    '    Let SumBarReading = 0
    '    For col = 1 To 100
    '    Let SumBarReading = SumBarReading + ExcelSheet.Application.Cells(RowCount + 1, col).Va
lue
    '    Next col
    '    Let AvgBarReading = SumBarReading / SndEntry
    '    For adj = 1 To 100
    '    ExcelSheet.Application.Cells(RowCount, adj).Value = ExcelSheet.Application.Cells((RowC
ount + 1), adj).Value
    '    Let ExcelSheet.Application.Cells((RowCount + 1), adj).Value = ""
    '    Next adj
    '    ExcelSheet.Application.Cells(RowCount, 102).Value = AvgBarReading
    '    ExcelSheet.Application.Cells(RowCount, 102).Font.Bold = True

    'End If
       'For adj = 1 To 100
       'Let ExcelSheet.Application.Cells((RowCount + 1), adj).Value = ""
       'Next adj




    '**************set Reference value on first reading*************
        If Initial_Count = 0 Then
            'Let Reference = StnBit_WD
            'Let ActReference = (Reference * ActVolReadRes)
            'Let mVActReference = (ActReference / Gain)
            'objExcel.Application.Cells(RowCount, ColumnCount) = mVActReference
            For Acol = 1 To 100
            ExcelSheet.Application.Cells(RowCount, Acol).Font.Bold = True
            Next Acol
                 Let AvgRefReading = AvgBarReading
                 ExcelSheet.Application.Cells(RowCount, 102).Font.Bold = True
        End If

       Let Initial_Count = Initial_Count + 1
'***********End set Reference value on first reading***********


If AvgRefReading <> 0 Then ' checking if reference value = 0

' calc variance of current reading
    If Initial_Count > 0 Then
    'Current_Variance = (((Abs(StnBit_WD - Reference)) / Reference) * 100)'07-03-06
    Current_Variance = (((Abs(AvgBarReading - AvgRefReading)) / AvgRefReading) * 100)
    End If

'*******************Check For Open cct, Short cct And Comparisons With Refrence**************
*********************
    'If a value less than 20 is recorded, the CM is Indicating a possible SC and should be disp
layed as such.
'    If StnBit_WD > 20 Then ' the min value of 20 may be change depending on the typical Short
Circuit reading

       'If 65534 is recorded, the CM is Indicating an out of range reading. This should be dis
played as a possible OC.
       If StnBit_WDflg = True Then
       List1.AddItem "Fault on Bar:  " & Text6.Text & ",    Volt-Drop Reading Is Out Of Range,
 Indicating A Possible Open Circuit"
       Let Text8.Text = Val(Text8.Text) + 1
       ElseIf AvgBarReading = 0 Then
       List1.AddItem "Fault on Bar:  " & Text6.Text & ",    Volt-Drop Reading Is Zero (0V), In
dicating A Possible Short Circuit"
       Let Text8.Text = Val(Text8.Text) + 1
       Else
           ' compare to selected % variance and log if a fault
           If (Current_Variance > Percentage) Then
               List1.AddItem "Fault on Bar:  " & Text6.Text & ",    Percentage Variance = " &
Current_Variance & ",    Bar Reading: " & AvgBarReading & "V" & ",    Reference: " & AvgRefRead
ing & "V"
               Let Text8.Text = Val(Text8.Text) + 1
           End If
           'end current reading and comparison
       End If
       'end possible OC check
```

```
'     Else
'             List1.AddItem "Fault on Bar:  " & Text6.Text & ",    Volt-Drop Reading Is Almost
r Equal to Zero, Indicating A Possible Short Circuit"
'     End If
    'end possible SC check

'****************End: Check For Open cct, Short cct And Comparisons With Refrence*************
**********************

            Command9.Enabled = False 'disables man reading but and dsply
            Frame20.Enabled = False
            Picture5.BackColor = QBColor(12) '
            Frame21.Enabled = False

            Let Command10.Enabled = False ' error1
            Command10.BackColor = &H8000000F
            Frame14.ForeColor = &H80000012
            Frame14.FontSize = 8
            Frame14.FontBold = False

            Let Command11.Enabled = False ' error2
            Command11.BackColor = &H8000000F
            Frame16.ForeColor = &H80000012
            Frame16.FontSize = 8
            Frame16.FontBold = False



    ' checking the 1st 5 readings to see if the ref reading is from a fault bar.

    Let Initial_Count = Initial_Count + 1

        If (Initial_Count = 6) And (Val(Text8.Text) = 5) Then
        'Let Reference = StnBit_WD
        'Let ActReference = (Reference * ActVolReadRes)
        'Let mVActReference = (ActReference / 1000)

        Let AvgRefReading = AvgBarReading

        Let Text8.Text = ""
        Let No_of_Bars = ((Val(Text6.Text) + Val(Text7.Text)) - 1)
        Let Text7.Text = No_of_Bars
        Let Text6.Text = 1
        Let Initial_Error = True ' flag to indicate Ref value error.
        List1.FontBold = True
        List1.AddItem "Test Restarted, Bar 5 is reset as the Initial (First) Bar!"
        List1.FontBold = False
        End If

            MSComm1.Output = "S" ' to microcontroller ' 07-02-06

            Picture8.BackColor = &H8000000F
            Picture9.BackColor = QBColor(10)
            '*************For simulation Only*******************
            Text15.Text = "S"
            '**********End For simulation Only******************

Else
MsgBox " The Recorded reference value is 0 Volts & is therefore not Valid. Please Restart this
Test", vbOKOnly, "Invalid Reference Value"
        MSComm1.Output = "S" ' to microcontroller ' 07-02-06
        Picture8.BackColor = &H8000000F
        Picture9.BackColor = QBColor(10)
        '*************For simulation Only*******************
        Text15.Text = "S"
        '**********End For simulation Only******************
End If
EndReading:
End Sub

Public Sub Binary2Decimal()
Dim B2D_flag As Boolean
Dim B2D_a As String
Dim B2D_b As Integer
```

```
Dim B2D_d As Integer
Dim B2D_total As Integer

Let B2D_a = ""
Let B2D_a = Bin2Dec
Let B2D_l = 1
Let B2D_flag = False
Let B2D_b = Len(B2D_a)

Do While B2D_flag = False
Let B2D_c = InStr(B2D_l, B2D_a, "1", 0)
If B2D_c <> 0 Then
Let B2D_total = B2D_total + 2 ^ (B2D_b - B2D_c)
Let B2D_l = B2D_c + 1
Else
Let B2D_flag = True
End If
Loop
Let Bin2Dec = B2D_total
End Sub

Public Sub FopenSub()

    If Test_Date = "View All" Then
            Open DefaultPath & Save_Test For Input As #5
                Let j = False
                Do While Not EOF(5)
                    Input #5, aa, bb, cc, dd, ee, ff
                        If j = False Then
                            List1.AddItem "Job Number:  " & aa
                            List1.AddItem "Operator's Name:  " & bb
                            List1.AddItem cc
                            List1.AddItem dd
                            List1.AddItem "Date:  " & LTrim(ee)
                            List1.AddItem ""
                            List1.AddItem "Recorded Faults "
                            List1.AddItem ""
                            List1.AddItem ff

                            Let j = True
                        Else
                            List1.AddItem ff
                                If aa = "End" Then
                                Let j = False
                                List1.AddItem ""
                                List1.AddItem ""
                                End If
                        End If
                Loop
                Close #5
    Else
        Open DefaultPath & Save_Test For Input As #5
                Let j = False
                Do While Not EOF(5)
                    Input #5, aa, bb, cc, dd, ee, ff
                       If (Test_Date = LTrim(ee)) Then

                            If j = False Then
                                List1.AddItem "Job Number:  " & aa
                                List1.AddItem "Operator's Name:  " & bb
                                List1.AddItem cc
                                List1.AddItem dd
                                List1.AddItem "Date:  " & LTrim(ee)
                                List1.AddItem ""
                                List1.AddItem "Recorded Faults "
                                List1.AddItem ""
                                List1.AddItem ff
                                Let j = True
                            'End If
                            Else
                                List1.AddItem ff
                                    If aa = "End" Then 'xxx (or End) signals end of a test and
all the fields for the next test has to be printed
                                    Let j = False
                                    List1.AddItem ""
```

```
                                    List1.AddItem ""
                                    End If
                            End If
                        End If
                Loop
        Close #5
    End If
'**********************************************************************
'aa is the Job No field
'bb is the Operators Name field
'cc is the Armature Selection field
'dd is the Percentange Variance field
'ee is the Date field
'ff is the Recorded Faults field
'**********************************************************************
End Sub

Public Sub Delete()
If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
Open DefaultPath & "Saved_List.TXT" For Input As #7
    Open "Saved_List_Del" For Output As #8
        Do While Not EOF(7)
        Input #7, look
            If Save_Test <> look Then
                Write #8, look
            End If
        Loop
            Close #7
            Close #8
            Kill DefaultPath & "Saved_List.TXT"
            Name "Saved_List_Del" As DefaultPath & "Saved_List.TXT"
Else:  MsgBox "File Does Not Exist", vbOKOnly, "Data Error"
End If
'Close #5
If Dir(DefaultPath & Save_Test) <> "" Then
Kill (DefaultPath & Save_Test)
List1.Clear
End If
End Sub

Public Sub FsaveSub()

'*********************Save Excel Data************************
'objExcel.Application.Save (Text9.Text & Text11.Text)
'objExcel.Application.Quit

ExcelSheet.SaveAs DefaultPath & Text9.Text & Space(2) & SaveDate & Space(2) & Savetime
ExcelSheet.Application.Quit
Set ExcelSheet = Nothing

'*******************End Save Excel Data************************

Dim Add_Flagx As Boolean
Let Add_Flagx = False
Let Save_Test = Text9.Text ' redundant
If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
    Open DefaultPath & "Saved_List.TXT" For Input As #7 ' file for the list of all jobs saved

        Do While Not EOF(7)
         Input #7, Add_list
            If Add_list = Save_Test Then
                Let Add_Flagx = True
            End If
        Loop
    Close #7
        If Add_Flagx = False Then
            Let Add_Flagx = False ' redundant
            Open DefaultPath & "Saved_List.TXT" For Append As #7
            Write #7, Save_Test
            Close #7
        End If
Else
    Open DefaultPath & "Saved_List.TXT" For Append As #7
    Write #7, Save_Test
    Close #7
```

```
End If

        Open DefaultPath & Save_Test For Append As #5
        Let i = 0
        Do While i <= (List1.ListCount - 1)
        Write #5, Text9.Text, Text2.Text, Combo2.List(Combo2.ListIndex), Combo1.List(Combo1.Lis
tIndex), LTrim(Text11.Text), List1.List(i)
        Let i = i + 1
        Loop

        Write #5, "End", "xxx", "xxx", "xxx", LTrim(Text11.Text), "End Of Recorded Results"
        Close #5
End Sub

Public Sub CalibrationSub()
Let Form2.Text6 = "xxxyyysun"
Dim AvgBarReading As Single
Dim SumBarReading As Single

        '**************for multiple readings*****************
        If MultiReading = 0 Then
        Let MultiReading = 100
        Let TimerFlag = True
        Let Timer1.Enabled = True
        Let Form2.Text5.Text = Timer1.Interval
        End If

        Let MultiReading = MultiReading - 1

        If MultiReading = 99 Then
        Let RowCount = RowCount + 1
        Let ZeroIn = 0
        Let HighBCount = 0
        Let HighBCount1 = 0
        Let HighBCount2 = 0
        Let HighBCount3 = 0
        Let HighBCount4 = 0
        Let HighBCount5 = 0
        Let SndEntry = 0
        End If

        Let ColumnCount = 100 - MultiReading
        '************End for multiple readings***************



StnBit_WD = ((High_Byte * 256) + Low_Byte)
'*************For simulation Only******************
Picture1.Print StnBit_WD
'**********End For simulation Only*****************

'*************Lower Range Value Adjust*****************
If High_Byte And Low_Byte = 120 Then
Let ZeroIn = ZeroIn + 1
End If

If High_Byte = 120 Then
Let HighBCount = HighBCount + 1
End If
If High_Byte = 1 Then
Let HighBCount1 = HighBCount1 + 1
End If
If High_Byte = 2 Then
Let HighBCount2 = HighBCount2 + 1
End If
If High_Byte = 3 Then
Let HighBCount3 = HighBCount3 + 1
End If
If High_Byte = 4 Then
Let HighBCount4 = HighBCount4 + 1
End If
If High_Byte = 5 Then
Let HighBCount5 = HighBCount5 + 1
End If
'*************Lower Range Value Adjust*****************
```

```
'******************Actual Voltage Reading*****************

     Let ActVolReadRes = (4.096 / 65536)
     Let ActVolRead = (StnBit_WD * ActVolReadRes)
     Let mVActVolRead = ((ActVolRead) / Gain)   '[ removed for test ]

     ExcelSheet.Application.Cells(RowCount, ColumnCount).Value = mVActVolRead


     If High_Byte <> 120 Then
     ExcelSheet.Application.Cells((RowCount + 1), ColumnCount).Value = mVActVolRead
     Let SndEntry = SndEntry + 1
     End If

     Form2.List1.AddItem mVActVolRead & "   ,   " & StnBit_WD & "   ,   " & Low_Byte & "   ,   " & Hig
h_Byte  ' for test



If MultiReading > 0 Then
    MSComm1.Output = "E" ' to microcontroller ' 07-02-06
    GoTo EndReading2
End If

If MultiReading = 0 Then

'**************Reading Timer***************************
Let TimerFlag = False
Let Timer1.Enabled = False
'**************Reading Timer***************************
    Let SumBarReading = 0
    For col = 1 To 100
    Let SumBarReading = SumBarReading + ExcelSheet.Application.Cells(RowCount, col).Value
    Next col

    'For col = 1 To 100
    'Let ExcelSheet.Application.Cells(RowCount, col).Value = ""
    'Next col
    Let AvgBarReading = SumBarReading / 100 '100= no of readings
    'objExcel.Application.Cells(RowCount, 102) = AvgBarReading ' put the average of this row in
 col 102
    ExcelSheet.Application.Cells(RowCount, 102).Value = AvgBarReading
    ExcelSheet.Application.Cells(RowCount, 102).Font.Bold = True

    'For i = 0 To 39
    'If Form2.Command1(i).Value = True Then
    Let i = Form2.ReadingBoxIndex
    Let Text25.Text = i
    Let Form2.Text2(i).Text = AvgBarReading
    Let CalibRefIn = Val(Form2.Text1(i).Text)
    'ExcelSheet.Application.Cells(RowCount, 3).Value = CalibRefIn
    'ExcelSheet.Application.Cells(RowCount, 1).Value = RowCount
    'Let Form2.Command1(i).Enabled ExcelSheet.Application.Cells(RowCount, 2).Value = CalibRefIn
= False
    'End If
    'Next i
'************Lower Range Value Adjust*****************
    If ZeroIn > 50 Then
        For adj = 1 To 100
        ExcelSheet.Application.Cells(RowCount, adj).Value = "Adjusted"
        Next adj
        ExcelSheet.Application.Cells(RowCount, 102).Value = "0"
        Let Form2.Text2(i).Text = "0"
    End If

    Let Form2.Text6 = HighBCount & " ' " & HighBCount1 & " ' " & HighBCount2 & " ' " & HighBCou
nt3 & " ' " & HighBCount4 & " ' " & HighBCount5

    If (HighBCount1 > 10 Or HighBCount2 > 10 Or HighBCount3 > 10 Or HighBCount4 > 10 Or HighBCo
unt5 > 10) Then
        For adj = 1 To 100
            If ExcelSheet.Application.Cells((RowCount + 1), adj).Value = "" Then
            Let ExcelSheet.Application.Cells((RowCount + 1), adj).Value = "0"
```

```
                End If
            Next adj
            Let SumBarReading = 0
            For col = 1 To 100
            Let SumBarReading = SumBarReading + ExcelSheet.Application.Cells(RowCount + 1, col).Val
ue
            Next col
            Let AvgBarReading = SumBarReading / SndEntry
            For adj = 1 To 100
            ExcelSheet.Application.Cells(RowCount, adj).Value = ExcelSheet.Application.Cells((RowCo
unt + 1), adj).Value
            Let ExcelSheet.Application.Cells((RowCount + 1), adj).Value = ""
            Next adj
            ExcelSheet.Application.Cells(RowCount, 102).Value = AvgBarReading
            ExcelSheet.Application.Cells(RowCount, 102).Font.Bold = True
            Let i = Form2.ReadingBoxIndex
            Let Text25.Text = i
            Let Form2.Text2(i).Text = AvgBarReading
            Let CalibRefIn = Val(Form2.Text1(i).Text)
        End If


            'If HighBCount1 > 0 Then

            'ExcelSheet.Application.Cells(RowCount, adj).Value = "Adjusted"
            'Next adj
            'ExcelSheet.Application.Cells(RowCount, 102).Value = "0.0016"
            'Let Form2.Text2(i).Text = "0.0016"
            'End If
           '
            'If HighBCount2 > 0 Then
            'For adj = 1 To 100
            'ExcelSheet.Application.Cells(RowCount, adj).Value = "Adjusted"
            'Next adj
            'ExcelSheet.Application.Cells(RowCount, 102).Value = "0.0032"
            'Let Form2.Text2(i).Text = "0.0032"
            'End If

            'If HighBCount1 > 0 Then
            'For adj = 1 To 100
            'ExcelSheet.Application.Cells(RowCount, adj).Value = "Adjusted"
            'Next adj
            'ExcelSheet.Application.Cells(RowCount, 102).Value = "0.0048"
            'Let Form2.Text2(i).Text = "0.0048"
            'End If

            'If HighBCount1 > 0 Then
            'For adj = 1 To 100
            'ExcelSheet.Application.Cells(RowCount, adj).Value = "Adjusted"
            'Next adj
            'ExcelSheet.Application.Cells(RowCount, 102).Value = "0.0064"
            'Let Form2.Text2(i).Text = "0.0064"
            'End If

            'If HighBCount1 > 0 Then
            'For adj = 1 To 100
            'ExcelSheet.Application.Cells(RowCount, adj).Value = "Adjusted"
            'Next adj
            'ExcelSheet.Application.Cells(RowCount, 102).Value = "0.008"
            'Let Form2.Text2(i).Text = "0.008"
            'End If
          For adj = 1 To 100
          Let ExcelSheet.Application.Cells((RowCount + 1), adj).Value = ""
          Next adj
End If
'*************Lower Range Value Adjust*****************
'End If
    '*******************End Actual Voltage reagings************


               MSComm1.Output = "S" ' to microcontroller ' 07-02-06


               '*************For simulation Only*******************
               Text15.Text = "S"
```

```
            '**********End For simulation Only******************

'Else
'MsgBox " The Recorded reference value is 0 Volts & is therefore not Valid. Please Restart thi
 Test"
        'MSComm1.Output = "S" ' to microcontroller ' 07-02-06

        '*************For simulation Only*******************
        'Text15.Text = "S"
        '**********End For simulation Only******************
'End If
EndReading2:
End Sub
```

```
Dim cSum_Of_Prod_xy As Double
Dim cSum_x As Single
Dim cSum_y As Single
Dim cGrad As Single
Dim cIntcpt As Single
Dim cProd_x As Single
Dim cSum_Prod_x As Single

Dim aSum_Of_Prod_xy As Single
Dim aSum_x As Single
Dim aSum_y As Single
Dim aGrad As Single
Dim aIntcpt As Single
Dim aProd_x As Single
Dim aSum_Prod_x As Single

Dim Adj_m  As Single
Dim Adj_c  As Single

Public ReadingBoxIndex As Integer
Public CalibFlagClear As Boolean
Dim ExcelSheet As Object



Private Sub Command1_Click(Index As Integer)
Let CalibFlagClear = False
For i = 0 To 39
If Command1(i).Value = True Then
Let ReadingBoxIndex = i
Let Text3.Text = ReadingBoxIndex
Let Check1(i).Value = 1
Let Command1(i).Enabled = False
End If
Next i
Form1.MSComm1.Output = "H"
'*******for test******************
Let Text3.Text = ReadingBoxIndex
'If Form1.CalibFlag = True Then
Let Text4.Text = "True"
'Else
Let Text4.Text = "false"
'End If
'*******for test******************
End Sub

Private Sub Command2_Click()
Form2.Visible = False
Let CalibFlagClear = True
ExcelSheet.Application.Quit
Set ExcelSheet = Nothing
End Sub

Private Sub Command3_Click()
For i = 0 To 39
Let Command1(i).Enabled = True
Let Check1(i).Value = 0
Next i
End Sub

Private Sub Form2_Load()

End Sub

Private Sub Command4_Click()
ExcelSheet.Application.Visible = True
End Sub

Private Sub Command5_Click()
'Dim Incomp As Integer
'Let Incomp = 0
'For i = 0 To 39
'If Text1(i).Text = "" Or Text1(i).Text = "" Then
'Let Incomp = Incomp + 1
'End If
```

```
'Next i

'If Incomp = 0 Then

    Let cProd_xy = 0
    Let cSum_Of_Prod_xy = 0
    Let cSum_x = 0
    Let cSum_y = 0
    Let cGrad = 0
    Let cIntcpt = 0
    Let cProd_x = 0
    Let cSum_Prod_x = 0

    Let aProd_xy = 0
    Let aSum_Of_Prod_xy = 0
    Let aSum_x = 0
    Let aSum_y = 0
    Let aGrad = 0
    Let aIntcpt = 0
    Let aProd_x = 0
    Let aSum_Prod_x = 0

    For i = 0 To 39
    Let cProd_xy = (Val(Text1(i).Text) * (i + 1))
    Let cSum_Of_Prod_xy = cSum_Of_Prod_xy + cProd_xy
    Let cSum_x = cSum_x + Val(Text1(i).Text)
    Let cSum_y = cSum_y + (1 + i)
    Let cProd_x = ((Val(Text1(i).Text)) * Val((Text1(i).Text)))
    Let cSum_Prod_x = cSum_Prod_x + cProd_x

    Let aProd_xy = (Val(Text2(i).Text) * (i + 1))
    Let aSum_Of_Prod_xy = aSum_Of_Prod_xy + aProd_xy
    Let aSum_x = aSum_x + Val(Text2(i).Text)
    Let aSum_y = aSum_y + (1 + i)
    Let aProd_x = ((Val(Text2(i).Text)) * Val((Text2(i).Text)))
    Let aSum_Prod_x = aSum_Prod_x + aProd_x
    Next i

    Let cGrad = ((40 * cSum_Of_Prod_xy) - (cSum_x * cSum_y)) / ((40 * cSum_Prod_x) - ((cSum_x)
* (cSum_x)))
    Let cIntcpt = ((cSum_y) - (cGrad * cSum_x)) / 40

    Let aGrad = ((40 * aSum_Of_Prod_xy) - (aSum_x * aSum_y)) / ((40 * aSum_Prod_x) - ((aSum_x)
* (aSum_x)))
    Let aIntcpt = ((aSum_y) - (aGrad * aSum_x)) / 40

    '******************for test*******************
    Let Text3.Text = cGrad
    Let Text4.Text = cIntcpt
    Let Text5.Text = aGrad
    Let Text6.Text = aIntcpt
    '******************for test*******************

    'using y1 = m1x1 + c1 for the best fit calibrated injected linear plot
    'and
    'using y2 = m2x2 + c2 for the best fit actual system reading linear plot
    'we get
    'm1x1 + c1 = m2x2 + c2, (y1=y2)
    'therefore, x1 = x2 * [m2/m1] +[(c2-c1)/m1]
    ' x1 is the true, real or adjusted reading, given the untrue reading, x2.

    Let Adj_m = Text3.Text 'aGrad / cGrad
    Let Adj_c = Text4.Text '(aIntcpt - cIntcpt) / cGrad

    Let Adj_m = aGrad / cGrad
    Let Adj_c = (aIntcpt - cIntcpt) / cGrad


   Open "C:\Program Files\Calibration\" & "Calibration2" For Output As #2
   Write #2, Adj_m, Adj_c, Date
   Close #2
   If Dir("C:\Program Files\Calibration\" & "Calibration1.txt") <> "" Then
   Kill "C:\Program Files\Calibration\" & "Calibration1.txt"
   Else
   Open "C:\Program Files\Calibration\" & "Calibration1.txt" For Output As #1
```

```
    Close #1
    Kill "C:\Program Files\Calibration\" & "Calibration1.txt"
    End If
    Name "C:\Program Files\Calibration\" & "Calibration2" As "C:\Program Files\Calibration\" &
"Calibration1.txt"
' Else
' MsgBox "Input Fields Incomplete. Please Complete all Recordings before continuing"
' End If

End Sub

Private Sub Command6_Click()

End Sub

Private Sub Form_Load()
Set ExcelSheet = CreateObject("Excel.Sheet")
End Sub
```

```
Public AdminPasswordFlag As Boolean
Private Sub Command1_Click()
If Text1.Text = "AdminAutoSun6" Then
    Let AdminPasswordFlag = True

    If Form1.AddNewArm = True Then
    Form1.Command3.SetFocus
    End If
    If Form1.RemoveArm = True Then
    Form1.Command4.SetFocus
    End If
    If Form1.AddNewVal = True Then
    Form1.Command1.SetFocus
    End If
    If Form1.RemoveVal = True Then
    Form1.Command2.SetFocus
    End If
    If Form1.CalPassW = True Then
    'Form1.Command42.SetFocus
    End If
    If Form1.PathPassW = True Then
    Form1.Command36.SetFocus
    End If
    If Form1.DelFile = True Then
    Form1.Command32.SetFocus
    End If
    If Form1.UsrProf = True Then
    Form1.Command46.SetFocus
    End If
Else
MsgBox "You are NOT Authorized to perform this action"
End If

Form3.Visible = False
Let Form1.AddNewArm = False
Let Form1.AddNewVal = False
Let Form1.RemoveArm = False
Let Form1.RemoveVal = False
Let Form1.CalPassW = False
Let Form1.PathPassW = False
Let Form1.UsrProf = False
Let Form1.DelFile = False

End Sub

Private Sub Form_LostFocus()
Form3.Visible = False
End Sub
```

```
Public Type ArmData
name As String * 40
no As Integer
End Type
```

Date: 2005/05/05

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: ccccccc
Armature Name: h Number of Bars: 200
Percentage Variance: 15%
Date: 2005/05/05

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: zxzxzxzxzxzxzxz
Armature Name: e Number of Bars: 25
Percentage Variance: 25%
Date: 2005/05/05

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: vvvvvvvv
Armature Name: c Number of Bars: 15
Percentage Variance: 25%
Date: 2005/05/05

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: v1v1v1v1v1v1
Armature Name: c Number of Bars: 15
Percentage Variance: 5%
Date: 2005/05/05

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: matadin 05/05/05
Armature Name: d Number of Bars: 20
Percentage Variance: 20%
Date: 2005/05/05

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: matadin2 05/05/05
Armature Name: c Number of Bars: 15
Percentage Variance: 30%
Date: 2005/05/05

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: 09-05
Armature Name: e Number of Bars: 25
Percentage Variance: 15%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sun 09-05
Armature Name: d Number of Bars: 20
Percentage Variance: 25%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sun2 09-05
Armature Name: e Number of Bars: 25
Percentage Variance: 35%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sun3 09-05
Armature Name: d Number of Bars: 20
Percentage Variance: 15%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sun4 09-05
Armature Name: f Number of Bars: 50
Percentage Variance: 35%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sun5 09-05
Armature Name: e Number of Bars: 25
Percentage Variance: 20%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sunveer
Armature Name: d Number of Bars: 20
Percentage Variance: 20%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sunveer2
Armature Name: a Number of Bars: 5
Percentage Variance: 15%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: sunny 09- 05
Armature Name: f Number of Bars: 50
Percentage Variance: 40%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: matadin 09-05
Armature Name: c Number of Bars: 15
Percentage Variance: 25%
Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Job Number: matadin
Operator's Name: matadin 09-05
Armature Name: c Number of Bars: 15
Percentage Variance: 10%

Date: 2005/05/09

Recorded Faults

Emergency Stop on Bar 0
End Of Recorded Results

Automated Volt-Drop Test Report

Job/Serial Number: 001 Test Results
Operator's Name: Sunveer Matadin
Armature Name: b Number of Bars: 10
Percentage Variance: 5%
Date: 2006/04/12

Recorded Faults

Fault on Bar: 3, Percentage Variance = 19.45295, Bar Reading: 0.1623932V, Reference: 0.1359474V
Fault on Bar: 5, Percentage Variance = 10.68346, Bar Reading: 0.1214235V, Reference: 0.1359474V
Fault on Bar: 7, Percentage Variance = 11.05382, Bar Reading: 0.1509748V, Reference: 0.1359474V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Emergency Stop on Bar 10

I, Sunveer Matadin acknowledge the above results and pledge to investigate and/or remedy the above recorded faults (if any).

Signature, Sunveer Matadin ______________________________

Automated Volt-Drop Test Report

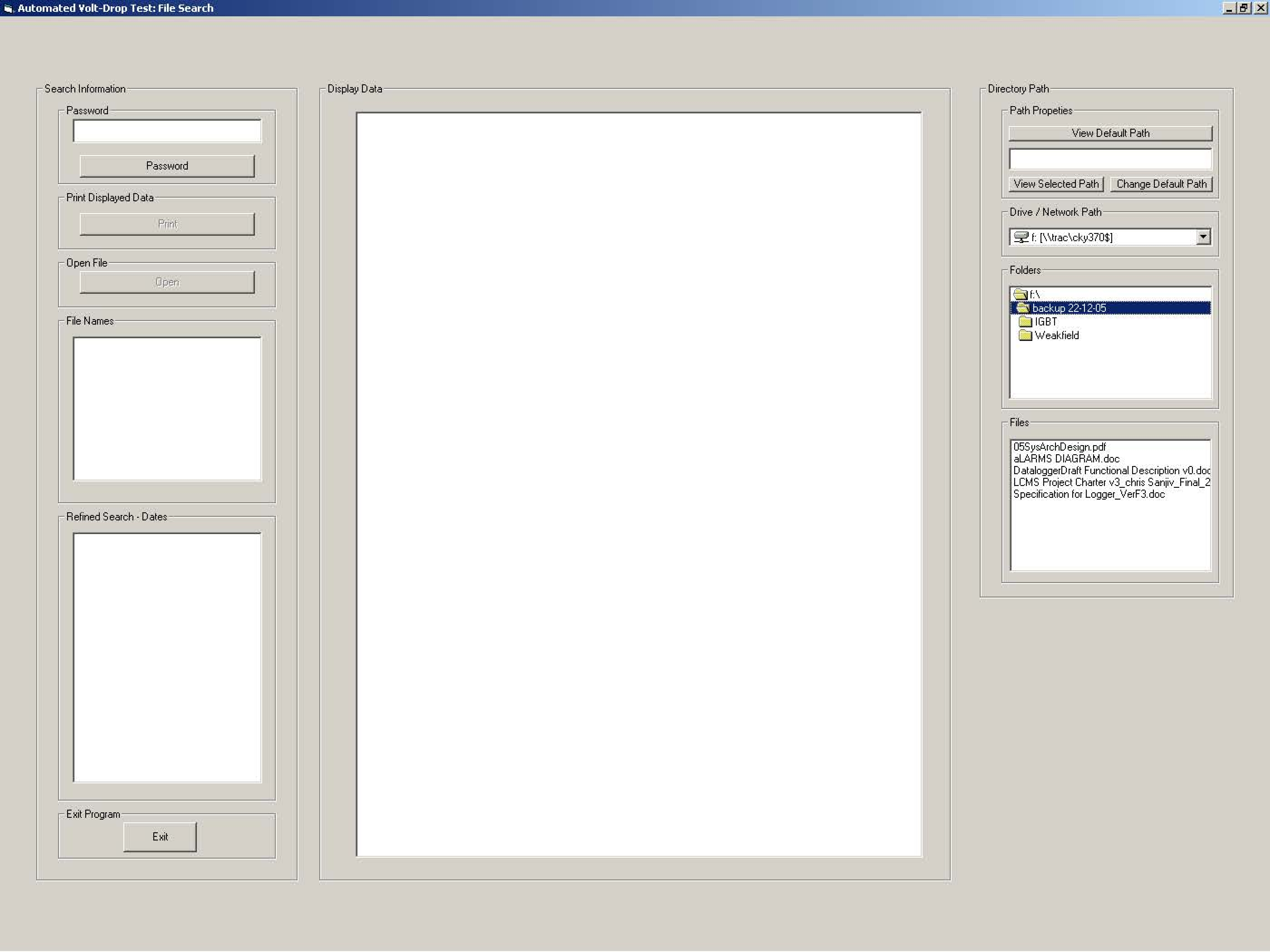
Job/Serial Number: Test Results
Operator's Name: Sunveer Matadin
Armature Name: b Number of Bars: 10
Percentage Variance: 5%
Date: 2006/04/12

Recorded Faults

Fault on Bar: 3, Percentage Variance = 19.28123, Bar Reading: 0.1626973V, Reference: 0.136398V
Fault on Bar: 5, Percentage Variance = 10.88503, Bar Reading: 0.1215511V, Reference: 0.136398V
Fault on Bar: 7, Percentage Variance = 10.3879, Bar Reading: 0.1505669V, Reference: 0.136398V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Emergency Stop on Bar 10

I, Sunveer Matadin acknowledge the above results and pledge to investigate and/or remedy the above recorded faults (if any).

Signature, Sunveer Matadin ______________________________


Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
Refined Search - Dates
Exit Program
Exit
Display Data
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
f: [\\trac\cky370$]
Folders
f:\
backup 22-12-05
IGBT
Weakfield
Files
05SysArchDesign.pdf
aLARMS DIAGRAM.doc
DataloggerDraft Functional Description v0.doc
LCMS Project Charter v3_chris Sanjiv_Final_2
Specification for Logger_VerF3.doc

```
Dim DefaultPath As String
Dim Pswd As Integer
Dim PasswdFlag As Boolean
Dim Test_Date As String
Dim Save_Test As String
'Dim Save_Test As String



Private Sub Command1_Click()
Dim X As String
Dim j As Boolean
 Save_Test = InputBox("Enter Job Number", "Enter The Job Number Of the Test You Wish To Open")
 If Save_Test <> "" Then
    If Save_Test <> "Find" Then
        If Dir(DefaultPath & Save_Test) <> "" Then
         List1.Clear
         Open DefaultPath & Save_Test For Input As #5
                    Let j = False
                    Do While Not EOF(5)
                        Input #5, aa, bb, cc, dd, ee, ff
                            If j = False Then
                                List1.AddItem "Job Number:  " & aa
                                List1.AddItem "Operator's Name:  " & bb
                                List1.AddItem cc
                                List1.AddItem dd
                                List1.AddItem "Date:  " & LTrim(ee)
                                List1.AddItem ""
                                List1.AddItem "Recorded Faults "
                                List1.AddItem ""
                                List1.AddItem ff
                                Let j = True
                            Else
                                List1.AddItem ff
                                    If aa = "End" Then
                                    Let j = False
                                    List1.AddItem ""
                                    List1.AddItem ""
                                    GoTo Next_Rec
                                    End If

                            End If
Next_Rec:               Loop
              Close #5
        Else: MsgBox "The Requested Job Number Does Not Exist"
        End If

   Else
     If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
       Open DefaultPath & "Saved_List.TXT" For Input As #7
       List2.Clear
           Let Open_Hold = ""
               Do While Not EOF(7)
               Input #7, job
                   If Open_Hold <> job Then
                   List2.AddItem job
                   Let Open_Hold = job
                   End If
               Loop
                   If List2.ListCount <> 0 Then
                   List2.Visible = True
                   'Command33.Visible = True
                   Else
                   MsgBox "There Are No Tests To View"
                   End If
           Close #7
     Else: MsgBox "There Are No Tests To View"
     End If
End If
Else: MsgBox "Job Number Was Not Entered"
End If
nd Sub

rivate Sub Command2_Click()
swd = Pswd - 1
```

```
If Text1.Text = "AutoSun6" Then
     Let PasswdFlag = True
     Text1.Text = ""
     Text1.Locked = True
     Command1.Enabled = True
     Command2.Enabled = False
     Command4.Enabled = True
Else
     If Pswd > 0 Then
     MsgBox " Incorrect Password, Tries left:  " & Pswd & ""
     Let Text1.Text = ""
     Else
     MsgBox " You DO NOT have the authority to use this equipment. You have been LOCKED OUT"
     Let Text1.Text = ""
     Frame1.Visible = True
     'Text10.Visible = True
'     Command18.Visible = True
     End If
End If
End Sub

Private Sub Command3_Click()
End
End Sub

Private Sub Command4_Click()
If List1.List(0) <> "" Then
     If Left(List1.List(0), 11) = "Job Number:" Then
     Let Deletex = Fopen
     Printer.NewPage
     Let Print_Save_i = 0
          Do While Print_Save_i <= (List1.ListCount - 1)
          Printer.Print List1.List(Print_Save_i)
          Picture1.Print List1.List(Print_Save_i)
          Print_Save_i = Print_Save_i + 1
          Loop
     List1.AddItem "Test Print Complete"
     Printer.EndDoc
     End If
Else
MsgBox "No Data Available To Print"
End If
End Sub

Private Sub Dir2_Change()

End Sub

Private Sub Command5_Click()
Let Text2.Text = ""
Text2.Text = Dir1.Path

If Right(Dir1.Path, 1) <> "\" Then
 Text2.Text = Text2.Text & "\"
End If

End Sub

Private Sub Command6_Click()
Let Text2.Text = ""
Text2.Text = Dir1.Path

If Right(Dir1.Path, 1) <> "\" Then
 Text2.Text = Text2.Text & "\"
End If

If Text2.Text <> "" Then
    If InputBox("Enter Password", "Enter Administrator's Password") = "AdminAutoSun6" Then
        If Dir("C:\Program Files\SavePath") <> "" Then
            Open "C:\Program Files\SavePath" For Input As #1 ' to save the default path
            Open "Temp" For Output As #2
            Write #2, Text2.Text
            Close #2
            Close #1
            Kill ("C:\Program Files\SavePath")
```

```
            Name "Temp" As "C:\Program Files\SavePath"
        Else
            Open "C:\Program Files\SavePath" For Output As #1
            Write #1, Text2.Text
            Close #1
            End If
    Let DefaultPath = Text2.Text
    Else
    MsgBox "You are NOT Authorised to perform this task"
    End If
Else
MsgBox "No Path Specified"
End If
End Sub

Private Sub Command7_Click()
If Dir("C:\Program Files\SavePath") <> "" Then
    Open "C:\Program Files\SavePath" For Input As #1
    Input #1, DefaultPath ' holds the path to the saved files
    Let Text2.Text = DefaultPath
    Close #1
Else
    MsgBox "Default Path is Not Valid, it has been changed"
End If
End Sub

Private Sub Dir1_Change()
Let File1.Path = Dir1.Path

End Sub

Private Sub Drive1_Change()
Let Dir1.Path = Drive1.Drive
End Sub

Private Sub Form_Load()
Let Pswd = 3
Let PasswdFlag = False
Let Command1.Enabled = False
Let Command4.Enabled = False
Frame1.Visible = False

If Dir("C:\Program Files\SavePath") <> "" Then
    Open "C:\Program Files\SavePath" For Input As #1
    Input #1, DefaultPath ' holds the path to the saved files
    Close #1
Else
    MsgBox "Default Path is Not Valid, it has been changed"
    'Let DefaultPath = "xxx"
End If
End Sub

Private Sub List2_Click()
Let Save_Test = List2.Text
List1.Clear
Let Dspl_Date = ""
List4.Clear
List4.AddItem "View All"
Open DefaultPath & Save_Test For Input As #5
    Do While Not EOF(5)
    Input #5, aa, bb, cc, dd, ee, ff
        If (Dspl_Date <> ee) And (bb <> "xxx") Then
            List4.AddItem LTrim(ee)
            Let Dspl_Date = ee
        End If
    Loop

    If List4.ListCount = 1 Then
    MsgBox "There are no items to View"
    List4.Clear
    Else
    List4.Visible = True
    End If
lose #5
nd Sub
```

```
Private Sub List4_Click()
List1.Clear
Let Test_Date = List4.Text
Call FopenSub
'List2.Visible = False
'List4.Visible = False
'Command33.Visible = False
End Sub

Public Sub FopenSub()
    If Test_Date = "View All" Then
            Open DefaultPath & Save_Test For Input As #5
                Let j = False
                Do While Not EOF(5)
                    Input #5, aa, bb, cc, dd, ee, ff
                        If j = False Then
                            List1.AddItem "Job Number:  " & aa
                            List1.AddItem "Operator's Name:  " & bb
                            List1.AddItem cc
                            List1.AddItem dd
                            List1.AddItem "Date:  " & LTrim(ee)
                            List1.AddItem ""
                            List1.AddItem "Recorded Faults "
                            List1.AddItem ""
                            List1.AddItem ff

                            Let j = True
                        Else
                            List1.AddItem ff
                                If aa = "End" Then
                                Let j = False
                                List1.AddItem ""
                                List1.AddItem ""
                                End If
                        End If
                Loop
                Close #5
    Else
        Open DefaultPath & Save_Test For Input As #5
                Let j = False
                Do While Not EOF(5)
                    Input #5, aa, bb, cc, dd, ee, ff
                       If (Test_Date = LTrim(ee)) Then

                            If j = False Then
                                List1.AddItem "Job Number:  " & aa
                                List1.AddItem "Operator's Name:  " & bb
                                List1.AddItem cc
                                List1.AddItem dd
                                List1.AddItem "Date:  " & LTrim(ee)
                                List1.AddItem ""
                                List1.AddItem "Recorded Faults "
                                List1.AddItem ""
                                List1.AddItem ff
                                Let j = True
                            'End If
                            Else
                                List1.AddItem ff
                                    If aa = "End" Then 'xxx (or End) signals end of a test and
all the fields for the next test has to be printed
                                    Let j = False
                                    List1.AddItem ""
                                    List1.AddItem ""
                                    End If
                            End If
                       End If
              Loop
       Close #5
   End If
'*********************************************************************
'aa is the Job No field
'bb is the Operators Name field
'cc is the Armature Selection field
'dd is the Percentange Variance field
```

```
'ee is the Date field
'ff is the Recorded Faults field
'***********************************************************************
End Sub
```

Features

- Compatible with MCS®-51 Products
- 4K Bytes of In-System Programmable (ISP) Flash Memory
  - Endurance: 1000 Write/Erase Cycles
- 4.0V to 5.5V Operating Range
- Fully Static Operation: 0 Hz to 33 MHz
- Three-level Program Memory Lock
- 128 x 8-bit Internal RAM
- 32 Programmable I/O Lines
- Two 16-bit Timer/Counters
- Six Interrupt Sources
- Full Duplex UART Serial Channel
- Low-power Idle and Power-down Modes
- Interrupt Recovery from Power-down Mode
- Watchdog Timer
- Dual Data Pointer
- Power-off Flag
- Fast Programming Time
- Flexible ISP Programming (Byte and Page Mode)

Description

The AT89S51 is a low-power, high-performance CMOS 8-bit microcontroller with 4K bytes of In-System Programmable Flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology and is compatible with the industry-standard 80C51 instruction set and pinout. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with In-System Programmable Flash on a monolithic chip, the Atmel AT89S51 is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications.

The AT89S51 provides the following standard features: 4K bytes of Flash, 128 bytes of RAM, 32 I/O lines, Watchdog timer, two data pointers, two 16-bit timer/counters, a five-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry. In addition, the AT89S51 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port, and interrupt system to continue functioning. The Power-down mode saves the RAM contents but freezes the oscillator, disabling all other chip functions until the next external interrupt or hardware reset.

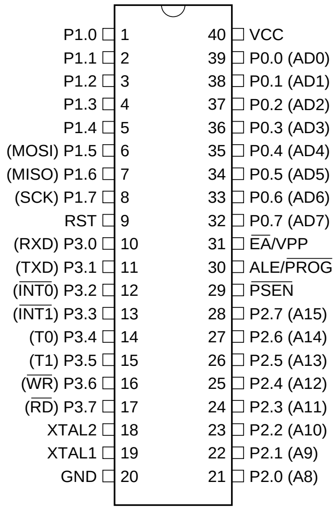
8-bit Microcontroller with 4K Bytes In-System Programmable Flash

AT89S51

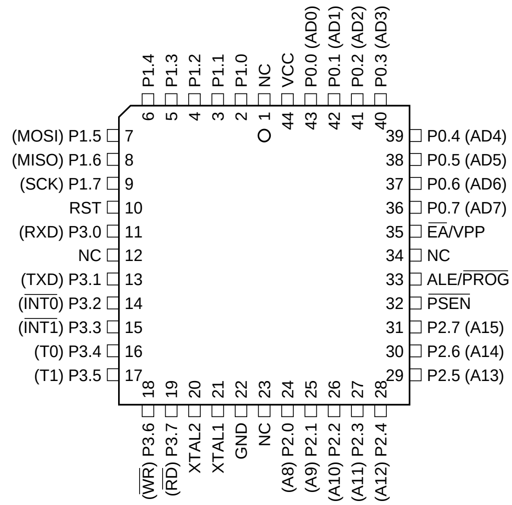
2487B–MICRO–12/03

Pin Configurations

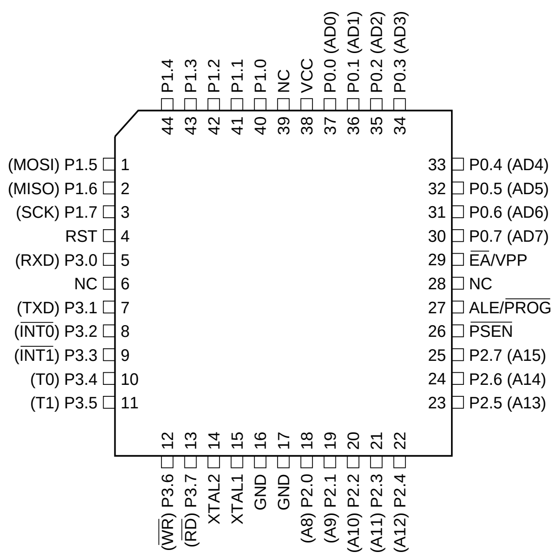
PDIP



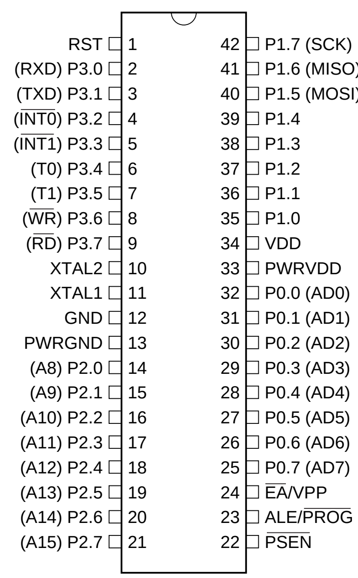
PLCC



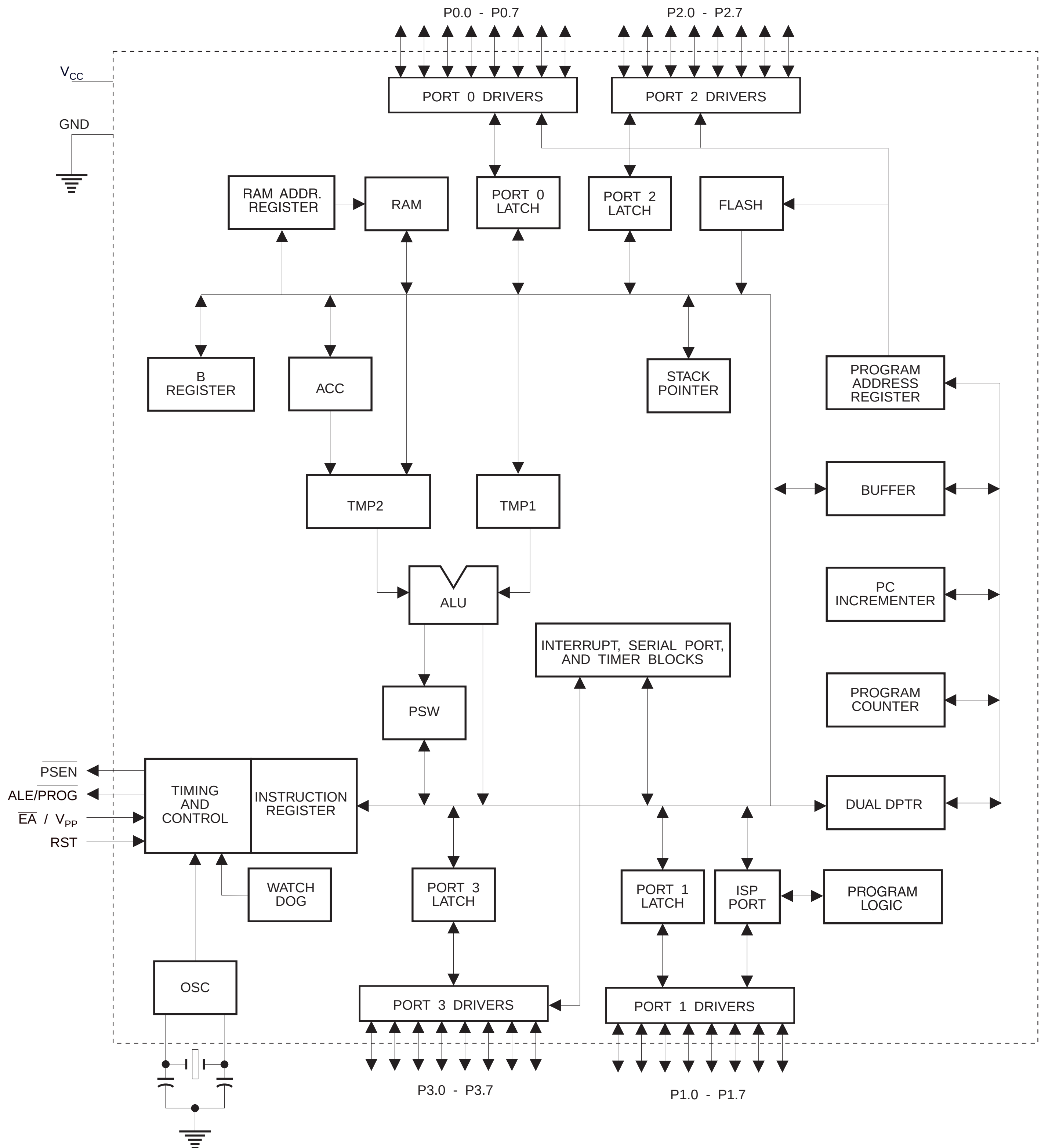
TQFP



PDIP



Block Diagram



Pin Description

VCC

Supply voltage (all packages except 42-PDIP).

GND

Ground (all packages except 42-PDIP; for 42-PDIP GND connects only the logic core and the embedded program memory).

VDD

Supply voltage for the 42-PDIP which connects only the logic core and the embedded program memory.

PWRVDD

Supply voltage for the 42-PDIP which connects only the I/O Pad Drivers. The application board **MUST** connect both VDD and PWRVDD to the board supply voltage.

PWRGND

Ground for the 42-PDIP which connects only the I/O Pad Drivers. PWRGND and GND are weakly connected through the common silicon substrate, but not through any metal link. The application board **MUST** connect both GND and PWRGND to the board ground.

Port 0

Port 0 is an 8-bit open drain bi-directional I/O port. As an output port, each pin can sink eight TTL inputs. When 1s are written to port 0 pins, the pins can be used as high-impedance inputs.

Port 0 can also be configured to be the multiplexed low-order address/data bus during accesses to external program and data memory. In this mode, P0 has internal pull-ups.

Port 0 also receives the code bytes during Flash programming and outputs the code bytes during program verification. **External pull-ups are required during program verification**.

Port 1

Port 1 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 1 output buffers can sink/source four TTL inputs. When 1s are written to Port 1 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 1 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

Port 1 also receives the low-order address bytes during Flash programming and verification.

Port Pin	Alternate Functions
P1.5	MOSI (used for In-System Programming)
P1.6	MISO (used for In-System Programming)
P1.7	SCK (used for In-System Programming)

Port 2

Port 2 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 2 output buffers can sink/source four TTL inputs. When 1s are written to Port 2 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 2 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

Port 2 emits the high-order address byte during fetches from external program memory and during accesses to external data memory that use 16-bit addresses (MOVX @ DPTR). In this application, Port 2 uses strong internal pull-ups when emitting 1s. During accesses to external data memory that use 8-bit addresses (MOVX @ RI), Port 2 emits the contents of the P2 Special Function Register.

Port 2 also receives the high-order address bits and some control signals during Flash programming and verification.

Port 3

Port 3 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 3 output buffers can sink/source four TTL inputs. When 1s are written to Port 3 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 3 pins that are externally being pulled low will source current (I_{IL}) because of the pull-ups.

Port 3 receives some control signals for Flash programming and verification.

Port 3 also serves the functions of various special features of the AT89S51, as shown in the following table.

Port Pin	Alternate Functions
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{\text{INT0}}$ (external interrupt 0)
P3.3	$\overline{\text{INT1}}$ (external interrupt 1)
P3.4	T0 (timer 0 external input)
P3.5	T1 (timer 1 external input)
P3.6	$\overline{\text{WR}}$ (external data memory write strobe)
P3.7	$\overline{\text{RD}}$ (external data memory read strobe)

RST

Reset input. A high on this pin for two machine cycles while the oscillator is running resets the device. This pin drives High for 98 oscillator periods after the Watchdog times out. The DISRTO bit in SFR AUXR (address 8EH) can be used to disable this feature. In the default state of bit DISRTO, the RESET HIGH out feature is enabled.

ALE/$\overline{\text{PROG}}$

Address Latch Enable (ALE) is an output pulse for latching the low byte of the address during accesses to external memory. This pin is also the program pulse input ($\overline{\text{PROG}}$) during Flash programming.

In normal operation, ALE is emitted at a constant rate of 1/6 the oscillator frequency and may be used for external timing or clocking purposes. Note, however, that one ALE pulse is skipped during each access to external data memory.

If desired, ALE operation can be disabled by setting bit 0 of SFR location 8EH. With the bit set, ALE is active only during a MOVX or MOVC instruction. Otherwise, the pin is weakly pulled high. Setting the ALE-disable bit has no effect if the microcontroller is in external execution mode.

$\overline{\text{PSEN}}$

Program Store Enable ($\overline{\text{PSEN}}$) is the read strobe to external program memory.

When the AT89S51 is executing code from external program memory, $\overline{\text{PSEN}}$ is activated twice each machine cycle, except that two $\overline{\text{PSEN}}$ activations are skipped during each access to external data memory.

$\overline{\text{EA}}$/VPP

External Access Enable. $\overline{\text{EA}}$ must be strapped to GND in order to enable the device to fetch code from external program memory locations starting at 0000H up to FFFFH. Note, however, that if lock bit 1 is programmed, $\overline{\text{EA}}$ will be internally latched on reset.

$\overline{\text{EA}}$ should be strapped to V_{CC} for internal program executions.

This pin also receives the 12-volt programming enable voltage (V_{PP}) during Flash programming.

XTAL1

Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the inverting oscillator amplifier

Special Function Registers

A map of the on-chip memory area called the Special Function Register (SFR) space is shown in Table 1.

Note that not all of the addresses are occupied, and unoccupied addresses may not be implemented on the chip. Read accesses to these addresses will in general return random data, and write accesses will have an indeterminate effect.

Table 1. AT89S51 SFR Map and Reset Values

0F8H									0FFH
0F0H	B 00000000								0F7H
0E8H									0EFH
0E0H	ACC 00000000								0E7H
0D8H									0DFH
0D0H	PSW 00000000								0D7H
0C8H									0CFH
0C0H									0C7H
0B8H	IP XX000000								0BFH
0B0H	P3 11111111								0B7H
0A8H	IE 0X000000								0AFH
0A0H	P2 11111111		AUXR1 XXXXXXX0				WDTRST XXXXXXXX		0A7H
98H	SCON 00000000	SBUF XXXXXXXX							9FH
90H	P1 11111111								97H
88H	TCON 00000000	TMOD 00000000	TL0 00000000	TL1 00000000	TH0 00000000	TH1 00000000	AUXR XXX00XX0		8FH
80H	P0 11111111	SP 00000111	DP0L 00000000	DP0H 00000000	DP1L 00000000	DP1H 00000000		PCON 0XXX0000	87H

User software should not write 1s to these unlisted locations, since they may be used in future products to invoke new features. In that case, the reset or inactive values of the new bits will always be 0.

Interrupt Registers: The individual interrupt enable bits are in the IE register. Two priorities can be set for each of the five interrupt sources in the IP register.

Table 2. AUXR: Auxiliary Register

AUXR Address = 8EH Reset Value = XXX00XX0B

Not Bit Addressable

	–	–	–	WDIDLE	DISRTO	–	–	DISALE
Bit	7	6	5	4	3	2	1	0

–	Reserved for future expansion
DISALE	Disable/Enable ALE
	DISALE Operating Mode
	0 ALE is emitted at a constant rate of 1/6 the oscillator frequency
	1 ALE is active only during a MOVX or MOVC instruction
DISRTO	Disable/Enable Reset-out
	DISRTO
	0 Reset pin is driven High after WDT times out
	1 Reset pin is input only
WDIDLE	Disable/Enable WDT in IDLE mode
WDIDLE	
0	WDT continues to count in IDLE mode
1	WDT halts counting in IDLE mode

Dual Data Pointer Registers: To facilitate accessing both internal and external data memory, two banks of 16-bit Data Pointer Registers are provided: DP0 at SFR address locations 82H-83H and DP1 at 84H-85H. Bit DPS = 0 in SFR AUXR1 selects DP0 and DPS = 1 selects DP1. The user should **ALWAYS** initialize the DPS bit to the appropriate value before accessing the respective Data Pointer Register.

Power Off Flag: The Power Off Flag (POF) is located at bit 4 (PCON.4) in the PCON SFR. POF is set to “1” during power up. It can be set and rest under software control and is not affected by reset.

Table 3. AUXR1: Auxiliary Register 1

AUXR1 Address = A2H Reset Value = XXXXXXX0B

Not Bit Addressable

	–	–	–	–	–	–	–	DPS
Bit	7	6	5	4	3	2	1	0

–	Reserved for future expansion
DPS	Data Pointer Register Select

DPS	
0	Selects DPTR Registers DP0L, DP0H
1	Selects DPTR Registers DP1L, DP1H

Memory Organization

MCS-51 devices have a separate address space for Program and Data Memory. Up to 64K bytes each of external Program and Data Memory can be addressed.

Program Memory

If the $\overline{EA}$ pin is connected to GND, all program fetches are directed to external memory.

On the AT89S51, if $\overline{EA}$ is connected to V_{CC}, program fetches to addresses 0000H through FFFH are directed to internal memory and fetches to addresses 1000H through FFFFH are directed to external memory.

Data Memory

The AT89S51 implements 128 bytes of on-chip RAM. The 128 bytes are accessible via direct and indirect addressing modes. Stack operations are examples of indirect addressing, so the 128 bytes of data RAM are available as stack space.

Watchdog Timer (One-time Enabled with Reset-out)

The WDT is intended as a recovery method in situations where the CPU may be subjected to software upsets. The WDT consists of a 14-bit counter and the Watchdog Timer Reset (WDTRST) SFR. The WDT is defaulted to disable from exiting reset. To enable the WDT, a user must write 01EH and 0E1H in sequence to the WDTRST register (SFR location 0A6H). When the WDT is enabled, it will increment every machine cycle while the oscillator is running. The WDT timeout period is dependent on the external clock frequency. There is no way to disable the WDT except through reset (either hardware reset or WDT overflow reset). When WDT overflows, it will drive an output RESET HIGH pulse at the RST pin.

Using the WDT

To enable the WDT, a user must write 01EH and 0E1H in sequence to the WDTRST register (SFR location 0A6H). When the WDT is enabled, the user needs to service it by writing 01EH and 0E1H to WDTRST to avoid a WDT overflow. The 14-bit counter overflows when it reaches 16383 (3FFFH), and this will reset the device. When the WDT is enabled, it will increment every machine cycle while the oscillator is running. This means the user must reset the WDT at least every 16383 machine cycles. To reset the WDT the user must write 01EH and 0E1H to WDTRST. WDTRST is a write-only register. The WDT counter cannot be read or written. When WDT overflows, it will generate an output RESET pulse at the RST pin. The RESET pulse duration is 98xTOSC, where TOSC = 1/FOSC. To make the best use of the WDT, it should be serviced in those sections of code that will periodically be executed within the time required to prevent a WDT reset.

WDT During Power-down and Idle

In Power-down mode the oscillator stops, which means the WDT also stops. While in Power-down mode, the user does not need to service the WDT. There are two methods of exiting Power-down mode: by a hardware reset or via a level-activated external interrupt, which is enabled prior to entering Power-down mode. When Power-down is exited with hardware reset, servicing the WDT should occur as it normally does whenever the AT89S51 is reset. Exiting Power-down with an interrupt is significantly different. The interrupt is held low long enough for the oscillator to stabilize. When the interrupt is brought high, the interrupt is serviced. To prevent the WDT from resetting the device while the interrupt pin is held low, the WDT is not started until the interrupt is pulled high. It is suggested that the WDT be reset during the interrupt service for the interrupt used to exit Power-down mode.

To ensure that the WDT does not overflow within a few states of exiting Power-down, it is best to reset the WDT just before entering Power-down mode.

Before going into the IDLE mode, the WDIDLE bit in SFR AUXR is used to determine whether the WDT continues to count if enabled. The WDT keeps counting during IDLE (WDIDLE bit = 0) as the default state. To prevent the WDT from resetting the AT89S51 while in IDLE mode, the user should always set up a timer that will periodically exit IDLE, service the WDT, and reenter IDLE mode.

With WDIDLE bit enabled, the WDT will stop to count in IDLE mode and resumes the count upon exit from IDLE.

UART

The UART in the AT89S51 operates the same way as the UART in the AT89C51. For further information on the UART operation, refer to the Atmel Web site (http://www.atmel.com). From the home page, select “Products”, then “Microcontrollers”, then “8051-Architecture”, then “Documentation”, and “Other Documents”. Open the Adobe® Acrobat® file “AT89 Series Hardware Description”.

Timer 0 and 1

Timer 0 and Timer 1 in the AT89S51 operate the same way as Timer 0 and Timer 1 in the AT89C51. For further information on the timers’ operation, refer to the Atmel Web site (http://www.atmel.com). From the home page, select “Products”, then “Microcontrollers”, then “8051-Architecture”, then “Documentation”, and “Other Documents”. Open the Adobe Acrobat file “AT89 Series Hardware Description”.

Interrupts

The AT89S51 has a total of five interrupt vectors: two external interrupts ($\overline{\text{INT0}}$ and $\overline{\text{INT1}}$), two timer interrupts (Timers 0 and 1), and the serial port interrupt. These interrupts are all shown in Figure 1.

Each of these interrupt sources can be individually enabled or disabled by setting or clearing a bit in Special Function Register IE. IE also contains a global disable bit, EA, which disables all interrupts at once.

Note that Table 4 shows that bit positions IE.6 and IE.5 are unimplemented. User software should not write 1s to these bit positions, since they may be used in future AT89 products.

The Timer 0 and Timer 1 flags, TF0 and TF1, are set at S5P2 of the cycle in which the timers overflow. The values are then polled by the circuitry in the next cycle.

Table 4. Interrupt Enable (IE) Register

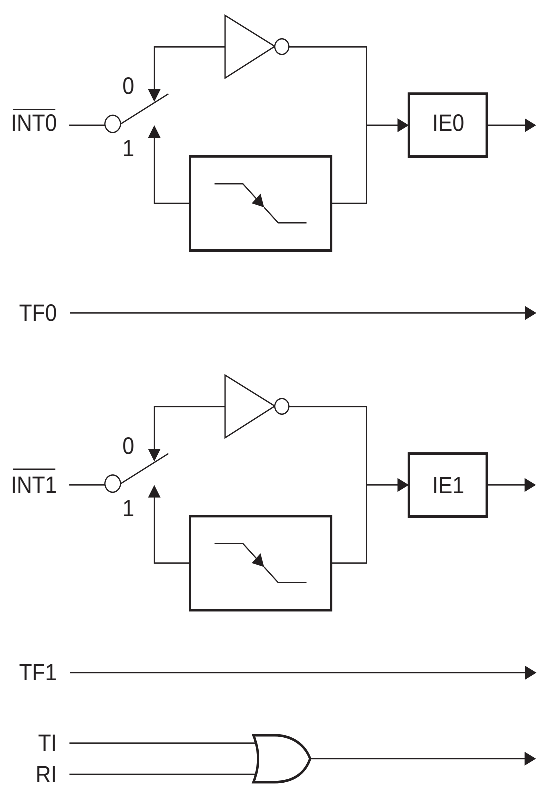
(MSB)							(LSB)
EA	–	–	ES	ET1	EX1	ET0	EX0

Enable Bit = 1 enables the interrupt.

Enable Bit = 0 disables the interrupt.

Symbol	Position	Function
EA	IE.7	Disables all interrupts. If EA = 0, no interrupt is acknowledged. If EA = 1, each interrupt source is individually enabled or disabled by setting or clearing its enable bit.
–	IE.6	Reserved
–	IE.5	Reserved
ES	IE.4	Serial Port interrupt enable bit
ET1	IE.3	Timer 1 interrupt enable bit
EX1	IE.2	External interrupt 1 enable bit
ET0	IE.1	Timer 0 interrupt enable bit
EX0	IE.0	External interrupt 0 enable bit
User software should never write 1s to reserved bits, because they may be used in future AT89 products.		

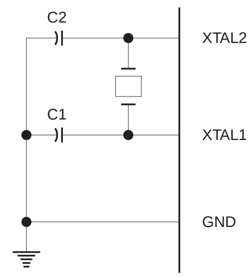
Figure 1. Interrupt Sources



Oscillator Characteristics

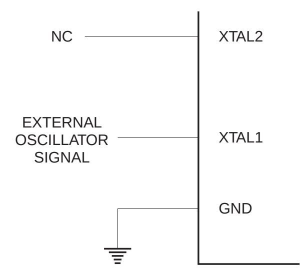
XTAL1 and XTAL2 are the input and output, respectively, of an inverting amplifier that can be configured for use as an on-chip oscillator, as shown in Figure 2. Either a quartz crystal or ceramic resonator may be used. To drive the device from an external clock source, XTAL2 should be left unconnected while XTAL1 is driven, as shown in Figure 3. There are no requirements on the duty cycle of the external clock signal, since the input to the internal clocking circuitry is through a divide-by-two flip-flop, but minimum and maximum voltage high and low time specifications must be observed.

Figure 2. Oscillator Connections



Note: C1, C2 = 30 pF $\pm$10 pF for Crystals
= 40 pF $\pm$10 pF for Ceramic Resonators

Figure 3. External Clock Drive Configuration



Idle Mode

In idle mode, the CPU puts itself to sleep while all the on-chip peripherals remain active. The mode is invoked by software. The content of the on-chip RAM and all the special function registers remain unchanged during this mode. The idle mode can be terminated by any enabled interrupt or by a hardware reset.

Note that when idle mode is terminated by a hardware reset, the device normally resumes program execution from where it left off, up to two machine cycles before the internal reset algorithm takes control. On-chip hardware inhibits access to internal RAM in this event, but access to the port pins is not inhibited. To eliminate the possibility of an unexpected write to a port pin when idle mode is terminated by a reset, the instruction following the one that invokes idle mode should not write to a port pin or to external memory.

Power-down Mode

In the Power-down mode, the oscillator is stopped, and the instruction that invokes Power-down is the last instruction executed. The on-chip RAM and Special Function Registers retain their values until the Power-down mode is terminated. Exit from Power-down mode can be initiated either by a hardware reset or by activation of an enabled external interrupt ($\overline{\text{INT0}}$ or $\overline{\text{INT1}}$). Reset redefines the SFRs but does not change the on-chip RAM. The reset should not be activated before V_{CC} is restored to its normal operating level and must be held active long enough to allow the oscillator to restart and stabilize.

Table 5. Status of External Pins During Idle and Power-down Modes

Mode	Program Memory	ALE	$\overline{PSEN}$	PORT0	PORT1	PORT2	PORT3
Idle	Internal	1	1	Data	Data	Data	Data
Idle	External	1	1	Float	Data	Address	Data
Power-down	Internal	0	0	Data	Data	Data	Data
Power-down	External	0	0	Float	Data	Data	Data

Program Memory Lock Bits

The AT89S51 has three lock bits that can be left unprogrammed (U) or can be programmed (P) to obtain the additional features listed in the following table.

Table 6. Lock Bit Protection Modes

Program Lock Bits				
	LB1	LB2	LB3	Protection Type
1	U	U	U	No program lock features
2	P	U	U	MOVC instructions executed from external program memory are disabled from fetching code bytes from internal memory, $\overline{EA}$ is sampled and latched on reset, and further programming of the Flash memory is disabled
3	P	P	U	Same as mode 2, but verify is also disabled
4	P	P	P	Same as mode 3, but external execution is also disabled

When lock bit 1 is programmed, the logic level at the $\overline{EA}$ pin is sampled and latched during reset. If the device is powered up without a reset, the latch initializes to a random value and holds that value until reset is activated. The latched value of $\overline{EA}$ must agree with the current logic level at that pin in order for the device to function properly.

Programming the Flash – Parallel Mode

The AT89S51 is shipped with the on-chip Flash memory array ready to be programmed. The programming interface needs a high-voltage (12-volt) program enable signal and is compatible with conventional third-party Flash or EPROM programmers.

The AT89S51 code memory array is programmed byte-by-byte.

Programming Algorithm: Before programming the AT89S51, the address, data, and control signals should be set up according to the Flash Programming Modes table (Table 7) and Figures 4 and 5. To program the AT89S51, take the following steps:

1. Input the desired memory location on the address lines.
2. Input the appropriate data byte on the data lines.
3. Activate the correct combination of control signals.
4. Raise $\overline{EA}/V_{PP}$ to 12V.
5. Pulse ALE/$\overline{PROG}$ once to program a byte in the Flash array or the lock bits. The byte-write cycle is self-timed and typically takes no more than 50 µs. Repeat steps 1 through 5, changing the address and data for the entire array or until the end of the object file is reached.

$\overline{\text{Data}}$ Polling: The AT89S51 features $\overline{\text{Data}}$ Polling to indicate the end of a byte write cycle. During a write cycle, an attempted read of the last byte written will result in the complement of the written data on P0.7. Once the write cycle has been completed, true data is valid on all outputs, and the next cycle may begin. $\overline{\text{Data}}$ Polling may begin any time after a write cycle has been initiated.

Ready/$\overline{\text{Busy}}$: The progress of byte programming can also be monitored by the RDY/$\overline{\text{BSY}}$ output signal. P3.0 is pulled low after ALE goes high during programming to indicate $\overline{\text{BUSY}}$. P3.0 is pulled high again when programming is done to indicate READY.

Program Verify: If lock bits LB1 and LB2 have not been programmed, the programmed code data can be read back via the address and data lines for verification. **The status of the individual lock bits can be verified directly by reading them back.**

Reading the Signature Bytes: The signature bytes are read by the same procedure as a normal verification of locations 000H, 100H, and 200H, except that P3.6 and P3.7 must be pulled to a logic low. The values returned are as follows.

(000H) = 1EH indicates manufactured by Atmel
(100H) = 51H indicates AT89S51
(200H) = 06H

Chip Erase: In the parallel programming mode, a chip erase operation is initiated by using the proper combination of control signals and by pulsing ALE/$\overline{\text{PROG}}$ low for a duration of 200 ns - 500 ns.

In the serial programming mode, a chip erase operation is initiated by issuing the Chip Erase instruction. In this mode, chip erase is self-timed and takes about 500 ms.

During chip erase, a serial read from any address location will return 00H at the data output.

Programming the Flash – Serial Mode

The Code memory array can be programmed using the serial ISP interface while RST is pulled to V_{CC}. The serial interface consists of pins SCK, MOSI (input) and MISO (output). After RST is set high, the Programming Enable instruction needs to be executed first before other operations can be executed. Before a reprogramming sequence can occur, a Chip Erase operation is required.

The Chip Erase operation turns the content of every memory location in the Code array into FFH.

Either an external system clock can be supplied at pin XTAL1 or a crystal needs to be connected across pins XTAL1 and XTAL2. The maximum serial clock (SCK) frequency should be less than 1/16 of the crystal frequency. With a 33 MHz oscillator clock, the maximum SCK frequency is 2 MHz.

Serial Programming Algorithm

To program and verify the AT89S51 in the serial programming mode, the following sequence is recommended:

1. Power-up sequence:

   Apply power between VCC and GND pins.

   Set RST pin to “H”.

   If a crystal is not connected across pins XTAL1 and XTAL2, apply a 3 MHz to 33 MHz clock to XTAL1 pin and wait for at least 10 milliseconds.
2. Enable serial programming by sending the Programming Enable serial instruction to pin MOSI/P1.5. The frequency of the shift clock supplied at pin SCK/P1.7 needs to be less than the CPU clock at XTAL1 divided by 16.
3. The Code array is programmed one byte at a time in either the Byte or Page mode. The write cycle is self-timed and typically takes less than 0.5 ms at 5V.
4. Any memory location can be verified by using the Read instruction that returns the content at the selected address at serial output MISO/P1.6.
5. At the end of a programming session, RST can be set low to commence normal device operation.

Power-off sequence (if needed):

Set XTAL1 to “L” (if a crystal is not used).

Set RST to “L”.

Turn V_{CC} power off.

$\overline{\text{Data}}$ Polling: The $\overline{\text{Data}}$ Polling feature is also available in the serial mode. In this mode, during a write cycle an attempted read of the last byte written will result in the complement of the MSB of the serial output byte on MISO.

Serial Programming Instruction Set

The Instruction Set for Serial Programming follows a 4-byte protocol and is shown in Table 8.

Programming Interface – Parallel Mode

Every code byte in the Flash array can be programmed by using the appropriate combination of control signals. The write operation cycle is self-timed and once initiated, will automatically time itself to completion.

Most major worldwide programming vendors offer worldwide support for the Atmel AT89 microcontroller series. Please contact your local programming vendor for the appropriate software revision.

Table 7. Flash Programming Modes

Mode	V_{CC}	RST	$\overline{\text{PSEN}}$	ALE/ $\overline{\text{PROG}}$	$\overline{\text{EA}}$/ V_{PP}	P2.6	P2.7	P3.3	P3.6	P3.7	P0.7-0 Data	P2.3-0 Address	P1.7-0 Address
Write Code Data	5V	H	L	(2)	12V	L	H	H	H	H	D_{IN}	A11-8	A7-0
Read Code Data	5V	H	L	H	H	L	L	L	H	H	D_{OUT}	A11-8	A7-0
Write Lock Bit 1	5V	H	L	(3)	12V	H	H	H	H	H	X	X	X
Write Lock Bit 2	5V	H	L	(3)	12V	H	H	H	L	L	X	X	X
Write Lock Bit 3	5V	H	L	(3)	12V	H	L	H	H	L	X	X	X
Read Lock Bits 1, 2, 3	5V	H	L	H	H	H	H	L	H	L	P0.2, P0.3, P0.4	X	X
Chip Erase	5V	H	L	(1)	12V	H	L	H	L	L	X	X	X
Read Atmel ID	5V	H	L	H	H	L	L	L	L	L	1EH	0000	00H
Read Device ID	5V	H	L	H	H	L	L	L	L	L	51H	0001	00H
Read Device ID	5V	H	L	H	H	L	L	L	L	L	06H	0010	00H

Notes: 1. Each $\overline{\text{PROG}}$ pulse is 200 ns - 500 ns for Chip Erase.
2. Each $\overline{\text{PROG}}$ pulse is 200 ns - 500 ns for Write Code Data.
3. Each $\overline{\text{PROG}}$ pulse is 200 ns - 500 ns for Write Lock Bits.
4. RDY/$\overline{\text{BSY}}$ signal is output on P3.0 during programming.
5. X = don’t care.

Figure 4. Programming the Flash Memory (Parallel Mode)

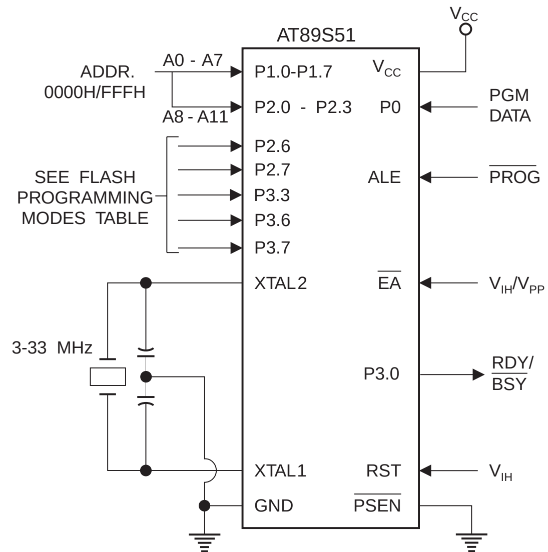
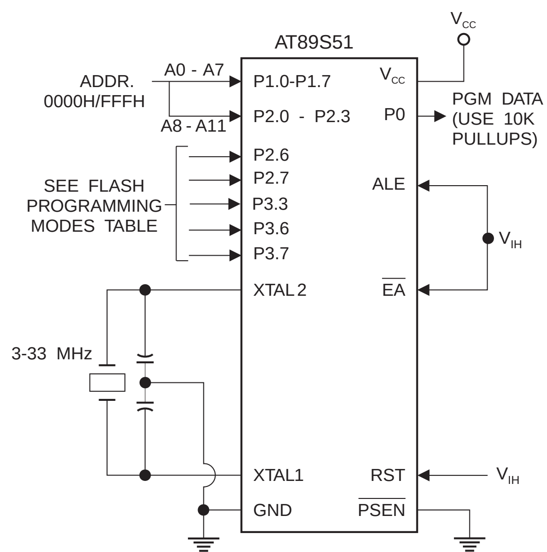


Figure 5. Verifying the Flash Memory (Parallel Mode)



Flash Programming and Verification Characteristics (Parallel Mode)

T_A = 20°C to 30°C, V_{CC} = 4.5 to 5.5V

Symbol	Parameter	Min	Max	Units
V_{PP}	Programming Supply Voltage	11.5	12.5	V
I_{PP}	Programming Supply Current		10	mA
I_{CC}	V_{CC} Supply Current		30	mA
$1/t_{CLCL}$	Oscillator Frequency	3	33	MHz
t_{AVGL}	Address Setup to $\overline{\text{PROG}}$ Low	$48t_{CLCL}$		
t_{GHAX}	Address Hold After $\overline{\text{PROG}}$	$48t_{CLCL}$		
t_{DVGL}	Data Setup to $\overline{\text{PROG}}$ Low	$48t_{CLCL}$		
t_{GHDX}	Data Hold After $\overline{\text{PROG}}$	$48t_{CLCL}$		
t_{EHSH}	P2.7 ($\overline{\text{ENABLE}}$) High to V_{PP}	$48t_{CLCL}$		
t_{SHGL}	V_{PP} Setup to $\overline{\text{PROG}}$ Low	10		µs
t_{GHSL}	V_{PP} Hold After $\overline{\text{PROG}}$	10		µs
t_{GLGH}	$\overline{\text{PROG}}$ Width	0.2	1	µs
t_{AVQV}	Address to Data Valid		$48t_{CLCL}$	
t_{ELQV}	$\overline{\text{ENABLE}}$ Low to Data Valid		$48t_{CLCL}$	
t_{EHQZ}	Data Float After $\overline{\text{ENABLE}}$	0	$48t_{CLCL}$	
t_{GHBL}	$\overline{\text{PROG}}$ High to $\overline{\text{BUSY}}$ Low		1.0	µs
t_{WC}	Byte Write Cycle Time		50	µs

Figure 6. Flash Programming and Verification Waveforms – Parallel Mode

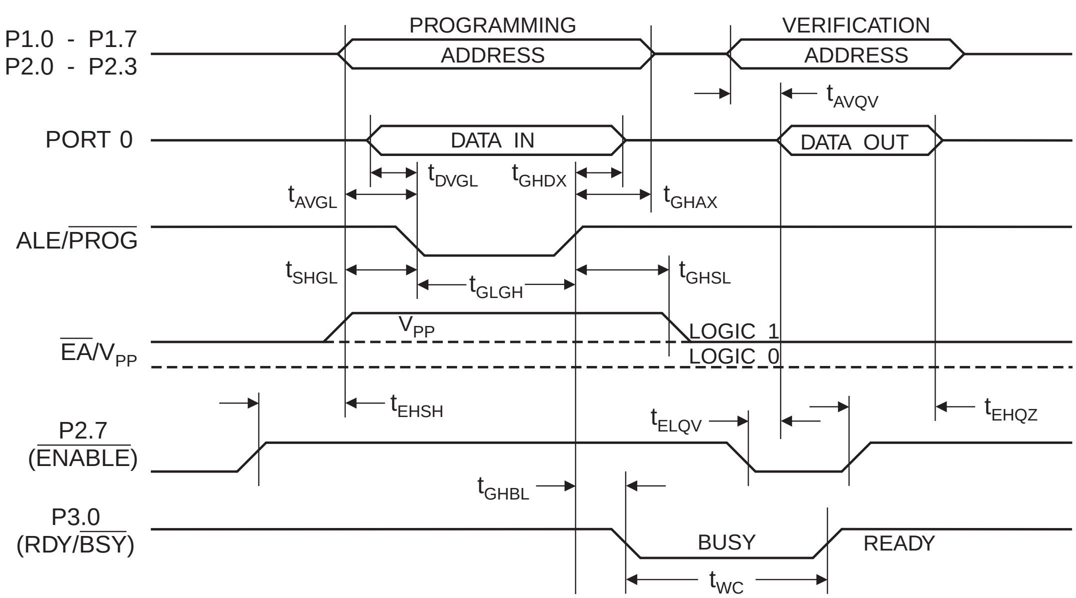
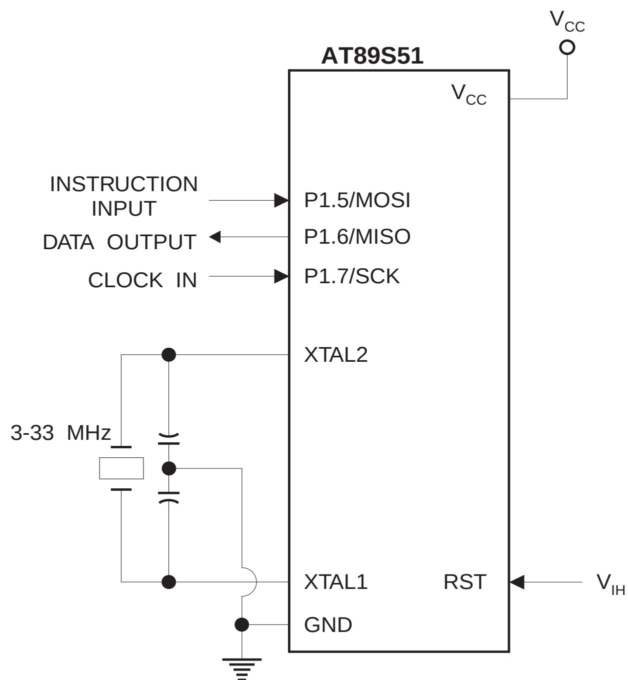


Figure 7. Flash Memory Serial Downloading



Flash Programming and Verification Waveforms – Serial Mode

Figure 8. Serial Programming Waveforms

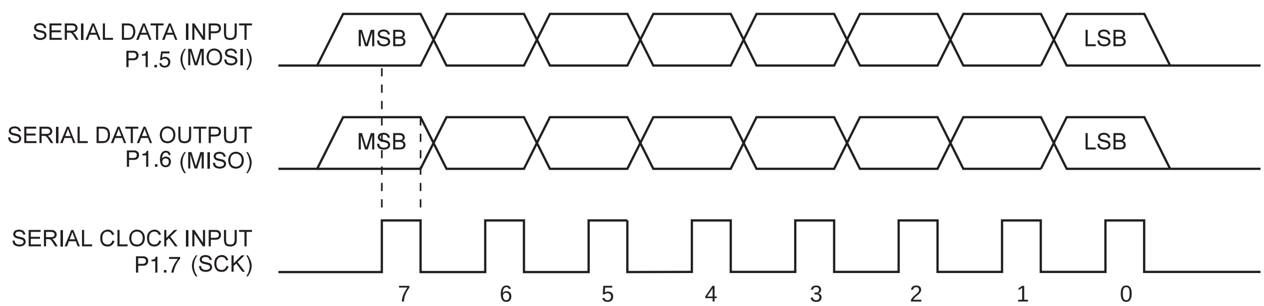


Table 8. Serial Programming Instruction Set

Instruction	Instruction Format Byte 1	Byte 2	Byte 3	Byte 4	Operation
Programming Enable	1010 1100	0101 0011	xxxx xxxx	xxxx xxxx 0110 1001 (Output on MISO)	Enable Serial Programming while RST is high
Chip Erase	1010 1100	100x xxxx	xxxx xxxx	xxxx xxxx	Chip Erase Flash memory array
Read Program Memory (Byte Mode)	0010 0000	xxxx A11 A10 A9 A8	A7 A6 A5 A4 A3 A2 A1 A0	D7 D6 D5 D4 D3 D2 D1 D0	Read data from Program memory in the byte mode
Write Program Memory (Byte Mode)	0100 0000	xxxx A11 A10 A9 A8	A7 A6 A5 A4 A3 A2 A1 A0	D7 D6 D5 D4 D3 D2 D1 D0	Write data to Program memory in the byte mode
Write Lock Bits[(1)]	1010 1100	1110 00 B1 B2	xxxx xxxx	xxxx xxxx	Write Lock bits. See Note (1).
Read Lock Bits	0010 0100	xxxx xxxx	xxxx xxxx	xxx LB3 LB2 LB1 xx	Read back current status of the lock bits (a programmed lock bit reads back as a "1")
Read Signature Bytes	0010 1000	xxxx A11 A10 A9 A8	A7 xxx xxx0	Signature Byte	Read Signature Byte
Read Program Memory (Page Mode)	0011 0000	xxxx A11 A10 A9 A8	Byte 0	Byte 1... Byte 255	Read data from Program memory in the Page Mode (256 bytes)
Write Program Memory (Page Mode)	0101 0000	xxxx A11 A10 A9 A8	Byte 0	Byte 1... Byte 255	Write data to Program memory in the Page Mode (256 bytes)

Note: 1. B1 = 0, B2 = 0 → Mode 1, no lock protection
B1 = 0, B2 = 1 → Mode 2, lock bit 1 activated
B1 = 1, B2 = 0 → Mode 3, lock bit 2 activated
B1 = 1, B2 = 1 → Mode 4, lock bit 3 activated

} Each of the lock bit modes need to be activated sequentially before Mode 4 can be executed.

After Reset signal is high, SCK should be low for at least 64 system clocks before it goes high to clock in the enable data bytes. No pulsing of Reset signal is necessary. SCK should be no faster than 1/16 of the system clock at XTAL1.

For Page Read/Write, the data always starts from byte 0 to 255. After the command byte and upper address byte are latched, each byte thereafter is treated as data until all 256 bytes are shifted in/out. Then the next instruction will be ready to be decoded.

Serial Programming Characteristics

Figure 9. Serial Programming Timing

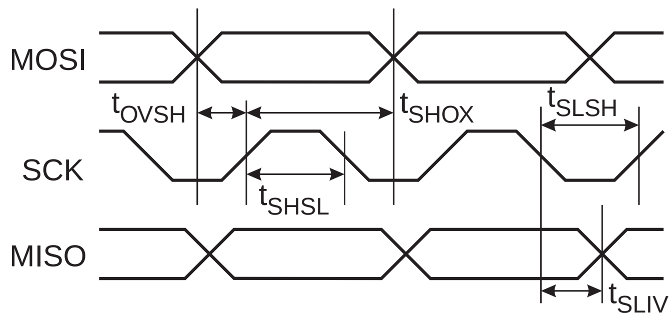


Table 9. Serial Programming Characteristics, T_A = -40° C to 85° C, V_{CC} = 4.0 - 5.5V (Unless Otherwise Noted)

Symbol	Parameter	Min	Typ	Max	Units
$1/t_{CLCL}$	Oscillator Frequency	3		33	MHz
t_{CLCL}	Oscillator Period	30			ns
t_{SHSL}	SCK Pulse Width High	$8\ t_{CLCL}$			ns
t_{SLSH}	SCK Pulse Width Low	$8\ t_{CLCL}$			ns
t_{OVSH}	MOSI Setup to SCK High	t_{CLCL}			ns
t_{SHOX}	MOSI Hold after SCK High	$2\ t_{CLCL}$			ns
t_{SLIV}	SCK Low to MISO Valid	10	16	32	ns
t_{ERASE}	Chip Erase Instruction Cycle Time			500	ms
t_{SWC}	Serial Byte Write Cycle Time			$64\ t_{CLCL} + 400$	μs

Absolute Maximum Ratings*

Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C
Voltage on Any Pin with Respect to Ground	-1.0V to +7.0V
Maximum Operating Voltage	6.6V
DC Output Current	15.0 mA

*NOTICE: Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC Characteristics

The values shown in this table are valid for T_A = -40°C to 85°C and V_{CC} = 4.0V to 5.5V, unless otherwise noted.

Symbol	Parameter	Condition	Min	Max	Units
V_{IL}	Input Low Voltage	(Except $\overline{EA}$)	-0.5	0.2 V_{CC}-0.1	V
V_{IL1}	Input Low Voltage ($\overline{EA}$)		-0.5	0.2 V_{CC}-0.3	V
V_{IH}	Input High Voltage	(Except XTAL1, RST)	0.2 V_{CC}+0.9	V_{CC}+0.5	V
V_{IH1}	Input High Voltage	(XTAL1, RST)	0.7 V_{CC}	V_{CC}+0.5	V
V_{OL}	Output Low Voltage(1) (Ports 1,2,3)	I_{OL} = 1.6 mA		0.45	V
V_{OL1}	Output Low Voltage(1) (Port 0, ALE, $\overline{PSEN}$)	I_{OL} = 3.2 mA		0.45	V
V_{OH}	Output High Voltage (Ports 1,2,3, ALE, $\overline{PSEN}$)	I_{OH} = -60 µA, V_{CC} = 5V ±10%	2.4		V
		I_{OH} = -25 µA	0.75 V_{CC}		V
		I_{OH} = -10 µA	0.9 V_{CC}		V
V_{OH1}	Output High Voltage (Port 0 in External Bus Mode)	I_{OH} = -800 µA, V_{CC} = 5V ±10%	2.4		V
		I_{OH} = -300 µA	0.75 V_{CC}		V
		I_{OH} = -80 µA	0.9 V_{CC}		V
I_{IL}	Logical 0 Input Current (Ports 1,2,3)	V_{IN} = 0.45V		-50	µA
I_{TL}	Logical 1 to 0 Transition Current (Ports 1,2,3)	V_{IN} = 2V, V_{CC} = 5V ±10%		-650	µA
I_{LI}	Input Leakage Current (Port 0, $\overline{EA}$)	0.45 < V_{IN} < V_{CC}		±10	µA
RRST	Reset Pulldown Resistor		50	300	KΩ
C_{IO}	Pin Capacitance	Test Freq. = 1 MHz, T_A = 25°C		10	pF
I_{CC}	Power Supply Current	Active Mode, 12 MHz		25	mA
		Idle Mode, 12 MHz		6.5	mA
	Power-down Mode(2)	V_{CC} = 5.5V		50	µA

Notes: 1. Under steady state (non-transient) conditions, I_{OL} must be externally limited as follows:
Maximum I_{OL} per port pin: 10 mA
Maximum I_{OL} per 8-bit port:
Port 0: 26 mA   Ports 1, 2, 3: 15 mA
Maximum total I_{OL} for all output pins: 71 mA
If I_{OL} exceeds the test condition, V_{OL} may exceed the related specification. Pins are not guaranteed to sink current greater than the listed test conditions.
2. Minimum V_{CC} for Power-down is 2V.

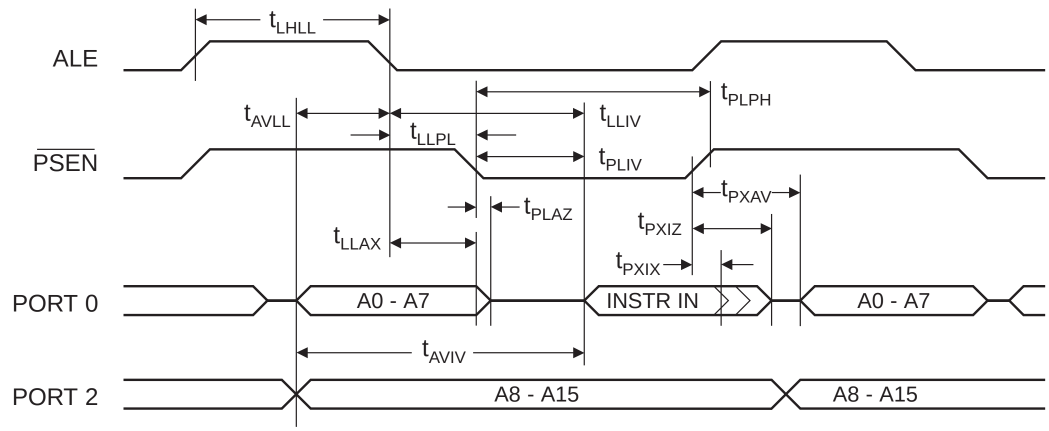
AC Characteristics

Under operating conditions, load capacitance for Port 0, ALE/$\overline{\text{PROG}}$, and $\overline{\text{PSEN}}$ = 100 pF; load capacitance for all other outputs = 80 pF.

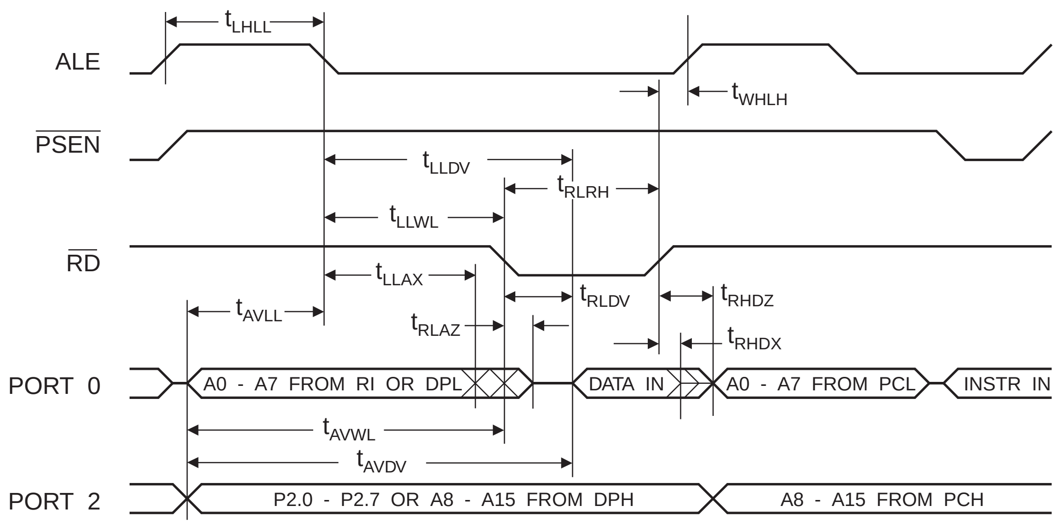
External Program and Data Memory Characteristics

Symbol	Parameter	12 MHz Oscillator		Variable Oscillator		Units
		Min	Max	Min	Max	
$1/t_{CLCL}$	Oscillator Frequency			0	33	MHz
t_{LHLL}	ALE Pulse Width	127		$2t_{CLCL}$-40		ns
t_{AVLL}	Address Valid to ALE Low	43		t_{CLCL}-25		ns
t_{LLAX}	Address Hold After ALE Low	48		t_{CLCL}-25		ns
t_{LLIV}	ALE Low to Valid Instruction In		233		$4t_{CLCL}$-65	ns
t_{LLPL}	ALE Low to $\overline{\text{PSEN}}$ Low	43		t_{CLCL}-25		ns
t_{PLPH}	$\overline{\text{PSEN}}$ Pulse Width	205		$3t_{CLCL}$-45		ns
t_{PLIV}	$\overline{\text{PSEN}}$ Low to Valid Instruction In		145		$3t_{CLCL}$-60	ns
t_{PXIX}	Input Instruction Hold After $\overline{\text{PSEN}}$	0		0		ns
t_{PXIZ}	Input Instruction Float After $\overline{\text{PSEN}}$		59		t_{CLCL}-25	ns
t_{PXAV}	$\overline{\text{PSEN}}$ to Address Valid	75		t_{CLCL}-8		ns
t_{AVIV}	Address to Valid Instruction In		312		$5t_{CLCL}$-80	ns
t_{PLAZ}	$\overline{\text{PSEN}}$ Low to Address Float		10		10	ns
t_{RLRH}	$\overline{\text{RD}}$ Pulse Width	400		$6t_{CLCL}$-100		ns
t_{WLWH}	$\overline{\text{WR}}$ Pulse Width	400		$6t_{CLCL}$-100		ns
t_{RLDV}	$\overline{\text{RD}}$ Low to Valid Data In		252		$5t_{CLCL}$-90	ns
t_{RHDX}	Data Hold After $\overline{\text{RD}}$	0		0		ns
t_{RHDZ}	Data Float After $\overline{\text{RD}}$		97		$2t_{CLCL}$-28	ns
t_{LLDV}	ALE Low to Valid Data In		517		$8t_{CLCL}$-150	ns
t_{AVDV}	Address to Valid Data In		585		$9t_{CLCL}$-165	ns
t_{LLWL}	ALE Low to $\overline{\text{RD}}$ or $\overline{\text{WR}}$ Low	200	300	$3t_{CLCL}$-50	$3t_{CLCL}$+50	ns
t_{AVWL}	Address to $\overline{\text{RD}}$ or $\overline{\text{WR}}$ Low	203		$4t_{CLCL}$-75		ns
t_{QVWX}	Data Valid to $\overline{\text{WR}}$ Transition	23		t_{CLCL}-30		ns
t_{QVWH}	Data Valid to $\overline{\text{WR}}$ High	433		$7t_{CLCL}$-130		ns
t_{WHQX}	Data Hold After $\overline{\text{WR}}$	33		t_{CLCL}-25		ns
t_{RLAZ}	$\overline{\text{RD}}$ Low to Address Float		0		0	ns
t_{WHLH}	$\overline{\text{RD}}$ or $\overline{\text{WR}}$ High to ALE High	43	123	t_{CLCL}-25	t_{CLCL}+25	ns

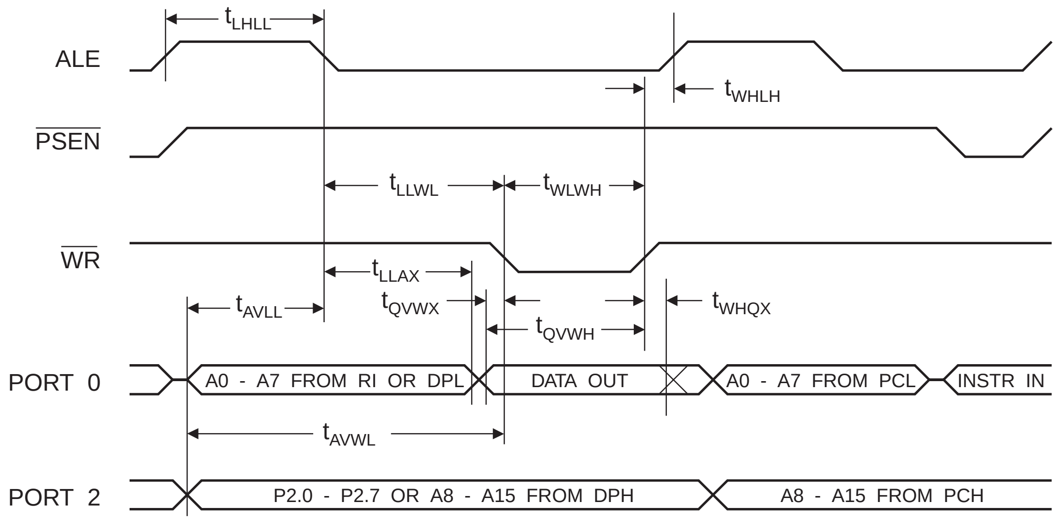
External Program Memory Read Cycle



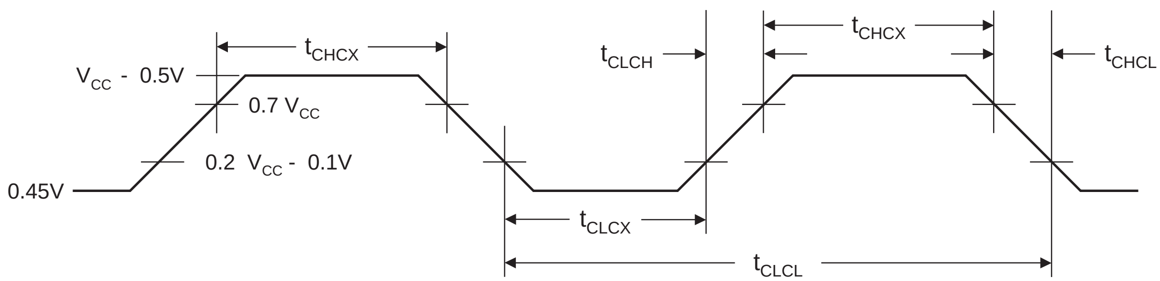
External Data Memory Read Cycle



External Data Memory Write Cycle



External Clock Drive Waveforms



External Clock Drive

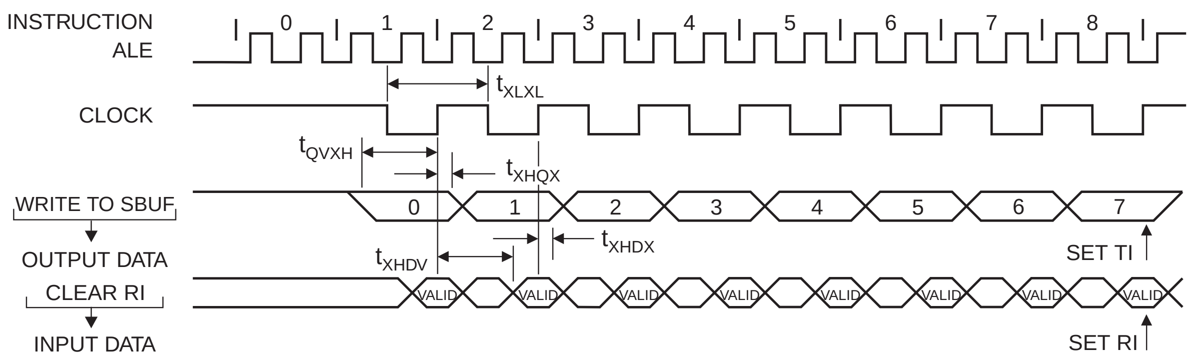
Symbol	Parameter	Min	Max	Units
$1/t_{CLCL}$	Oscillator Frequency	0	33	MHz
t_{CLCL}	Clock Period	30		ns
t_{CHCX}	High Time	12		ns
t_{CLCX}	Low Time	12		ns
t_{CLCH}	Rise Time		5	ns
t_{CHCL}	Fall Time		5	ns

Serial Port Timing: Shift Register Mode Test Conditions

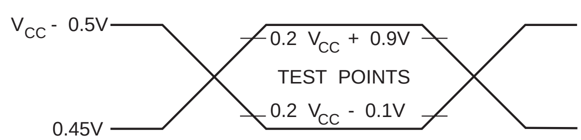
The values in this table are valid for V_{CC} = 4.0V to 5.5V and Load Capacitance = 80 pF.

		12 MHz Osc		Variable Oscillator		
Symbol	**Parameter**	**Min**	**Max**	**Min**	**Max**	**Units**
t_{XLXL}	Serial Port Clock Cycle Time	1.0		$12t_{CLCL}$		µs
t_{QVXH}	Output Data Setup to Clock Rising Edge	700		$10t_{CLCL}$-133		ns
t_{XHQX}	Output Data Hold After Clock Rising Edge	50		$2t_{CLCL}$-80		ns
t_{XHDX}	Input Data Hold After Clock Rising Edge	0		0		ns
t_{XHDV}	Clock Rising Edge to Input Data Valid		700		$10t_{CLCL}$-133	ns

Shift Register Mode Timing Waveforms

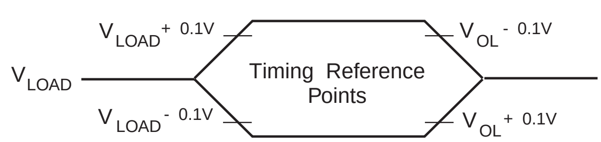


AC Testing Input/Output Waveforms[1]



Note: 1. AC Inputs during testing are driven at V_{CC} - 0.5V for a logic 1 and 0.45V for a logic 0. Timing measurements are made at V_{IH} min. for a logic 1 and V_{IL} max. for a logic 0.

Float Waveforms[1]



Note: 1. For timing purposes, a port pin is no longer floating when a 100 mV change from load voltage occurs. A port pin begins to float when a 100 mV change from the loaded V_{OH}/V_{OL} level occurs.

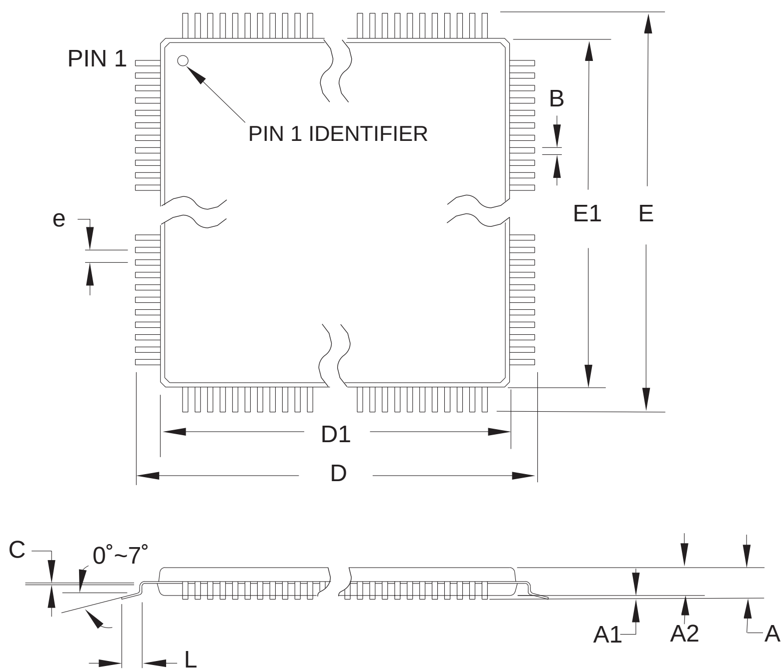
Ordering Information

Speed (MHz)	Power Supply	Ordering Code	Package	Operation Range
24	4.0V to 5.5V	AT89S51-24AC AT89S51-24JC AT89S51-24PC AT89S51-24SC	44A 44J 40P6 42PS6	Commercial (0° C to 70° C)
		AT89S51-24AI AT89S51-24JI AT89S51-24PI AT89S51-24SI	44A 44J 40P6 42PS6	Industrial (-40° C to 85° C)
33	4.5V to 5.5V	AT89S51-33AC AT89S51-33JC AT89S51-33PC AT89S51-33SC	44A 44J 40P6 42PS6	Commercial (0° C to 70° C)

Package Type	
44A	44-lead, Thin Plastic Gull Wing Quad Flatpack (TQFP)
44J	44-lead, Plastic J-leaded Chip Carrier (PLCC)
40P6	40-pin, 0.600" Wide, Plastic Dual Inline Package (PDIP)
42PS6	42-pin, 0.600" Wide, Plastic Dual Inline Package (PDIP)

Packaging Information

44A – TQFP



COMMON DIMENSIONS
(Unit of Measure = mm)

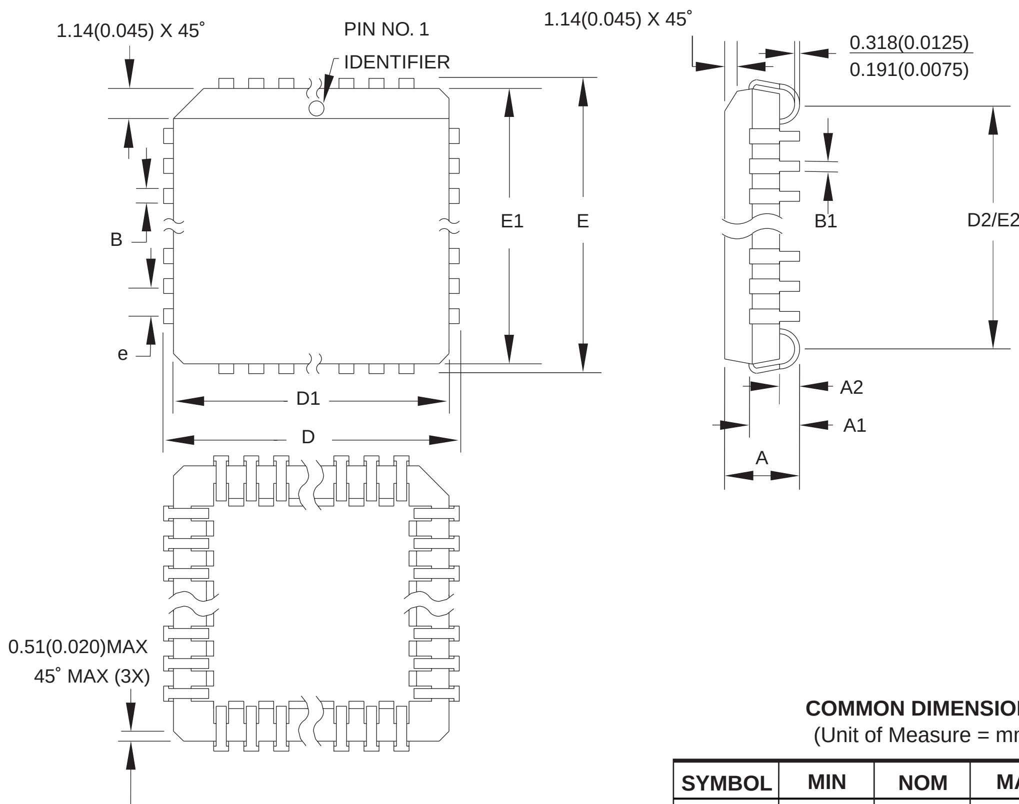
SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	1.20	
A1	0.05	–	0.15	
A2	0.95	1.00	1.05	
D	11.75	12.00	12.25	
D1	9.90	10.00	10.10	Note 2
E	11.75	12.00	12.25	
E1	9.90	10.00	10.10	Note 2
B	0.30	–	0.45	
C	0.09	–	0.20	
L	0.45	–	0.75	
e	0.80 TYP			

Notes:
1. This package conforms to JEDEC reference MS-026, Variation ACB.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25 mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10 mm maximum.

10/5/2001

	TITLE	DRAWING NO.	REV.
ATMEL 2325 Orchard Parkway San Jose, CA 95131	**44A,** 44-lead, 10 x 10 mm Body Size, 1.0 mm Body Thickness, 0.8 mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP)	44A	B

44J – PLCC



COMMON DIMENSIONS
(Unit of Measure = mm)

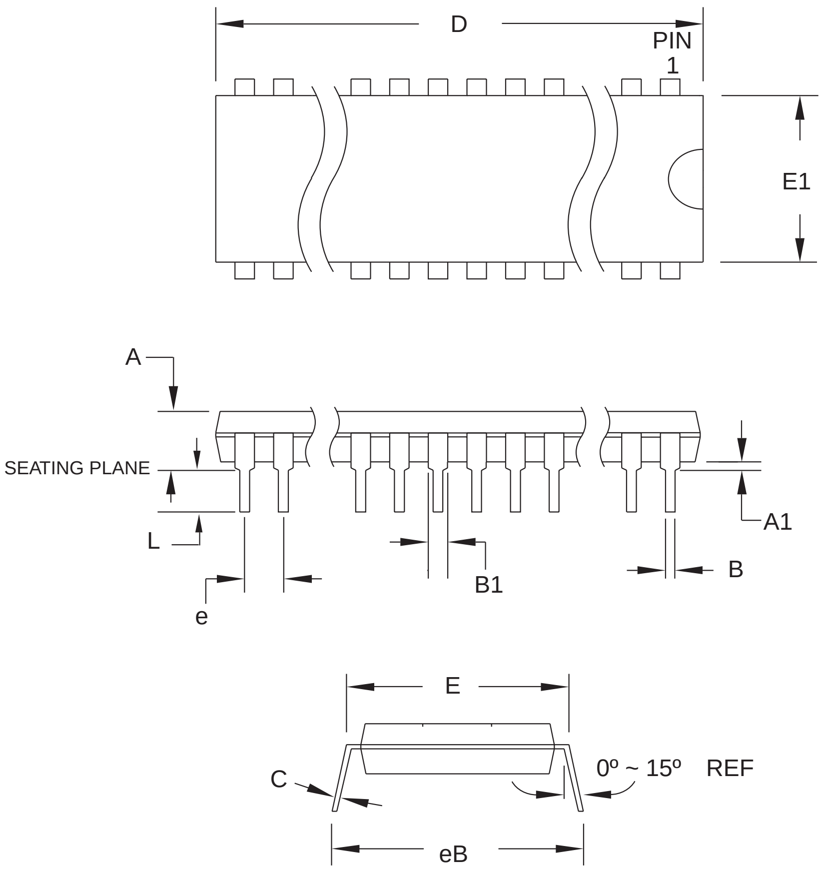
SYMBOL	MIN	NOM	MAX	NOTE
A	4.191	–	4.572	
A1	2.286	–	3.048	
A2	0.508	–	–	
D	17.399	–	17.653	
D1	16.510	–	16.662	Note 2
E	17.399	–	17.653	
E1	16.510	–	16.662	Note 2
D2/E2	14.986	–	16.002	
B	0.660	–	0.813	
B1	0.330	–	0.533	
e	1.270 TYP			

Notes:
1. This package conforms to JEDEC reference MS-018, Variation AC.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is .010"(0.254 mm) per side. Dimension D1 and E1 include mold mismatch and are measured at the extreme material condition at the upper or lower parting line.
3. Lead coplanarity is 0.004" (0.102 mm) maximum.

10/04/01

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**44J**, 44-lead, Plastic J-leaded Chip Carrier (PLCC)	44J	B

40P6 – PDIP



COMMON DIMENSIONS
(Unit of Measure = mm)

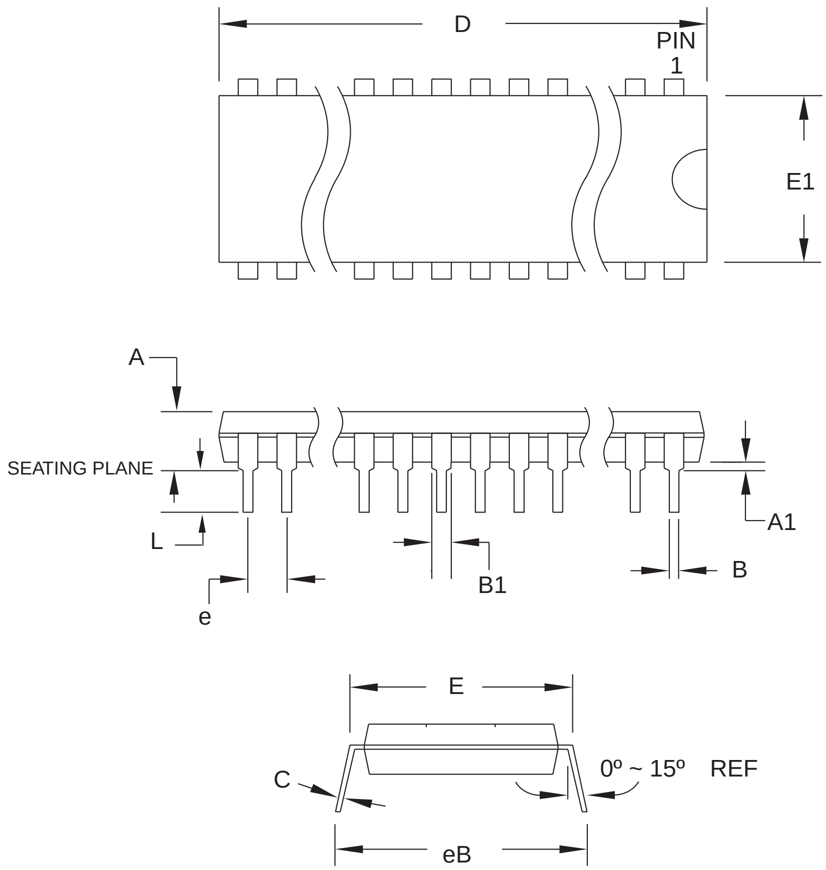
SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.826	
A1	0.381	–	–	
D	52.070	–	52.578	Note 2
E	15.240	–	15.875	
E1	13.462	–	13.970	Note 2
B	0.356	–	0.559	
B1	1.041	–	1.651	
L	3.048	–	3.556	
C	0.203	–	0.381	
eB	15.494	–	17.526	
e	2.540 TYP			

Notes:
1. This package conforms to JEDEC reference MS-011, Variation AC.
2. Dimensions D and E1 do not include mold Flash or Protrusion. Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

09/28/01

	TITLE	DRAWING NO.	REV.
ATMEL 2325 Orchard Parkway San Jose, CA 95131	**40P6**, 40-lead (0.600"/15.24 mm Wide) Plastic Dual Inline Package (PDIP)	40P6	B

42PS6 – PDIP



Notes: 1. This package conforms to JEDEC reference MS-011, Variation AC.
2. Dimensions D and E1 do not include mold Flash or Protrusion.
Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.83	
A1	0.51	–	–	
D	36.70	–	36.96	Note 2
E	15.24	–	15.88	
E1	13.46	–	13.97	Note 2
B	0.38	–	0.56	
B1	0.76	–	1.27	
L	3.05	–	3.43	
C	0.20	–	0.30	
eB	–	–	18.55	
e	1.78 TYP			

11/6/03

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**42PS6**, 42-lead (0.600"/15.24 mm Wide) Plastic Dual Inline Package (PDIP)	42PS6	A

Atmel Corporation

2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 487-2600

Regional Headquarters

Europe
Atmel Sarl
Route des Arsenaux 41
Case Postale 80
CH-1705 Fribourg
Switzerland
Tel: (41) 26-426-5555
Fax: (41) 26-426-5500

Asia
Room 1219
Chinachem Golden Plaza
77 Mody Road Tsimshatsui
East Kowloon
Hong Kong
Tel: (852) 2721-9778
Fax: (852) 2722-1369

Japan
9F, Tonetsu Shinkawa Bldg.
1-24-8 Shinkawa
Chuo-ku, Tokyo 104-0033
Japan
Tel: (81) 3-3523-3551
Fax: (81) 3-3523-7581

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Memory
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San Jose, CA 95131, USA
Tel: 1(408) 441-0311
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Tel: 1(408) 441-0311
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13106 Rousset Cedex, France
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Fax: (49) 71-31-67-2340

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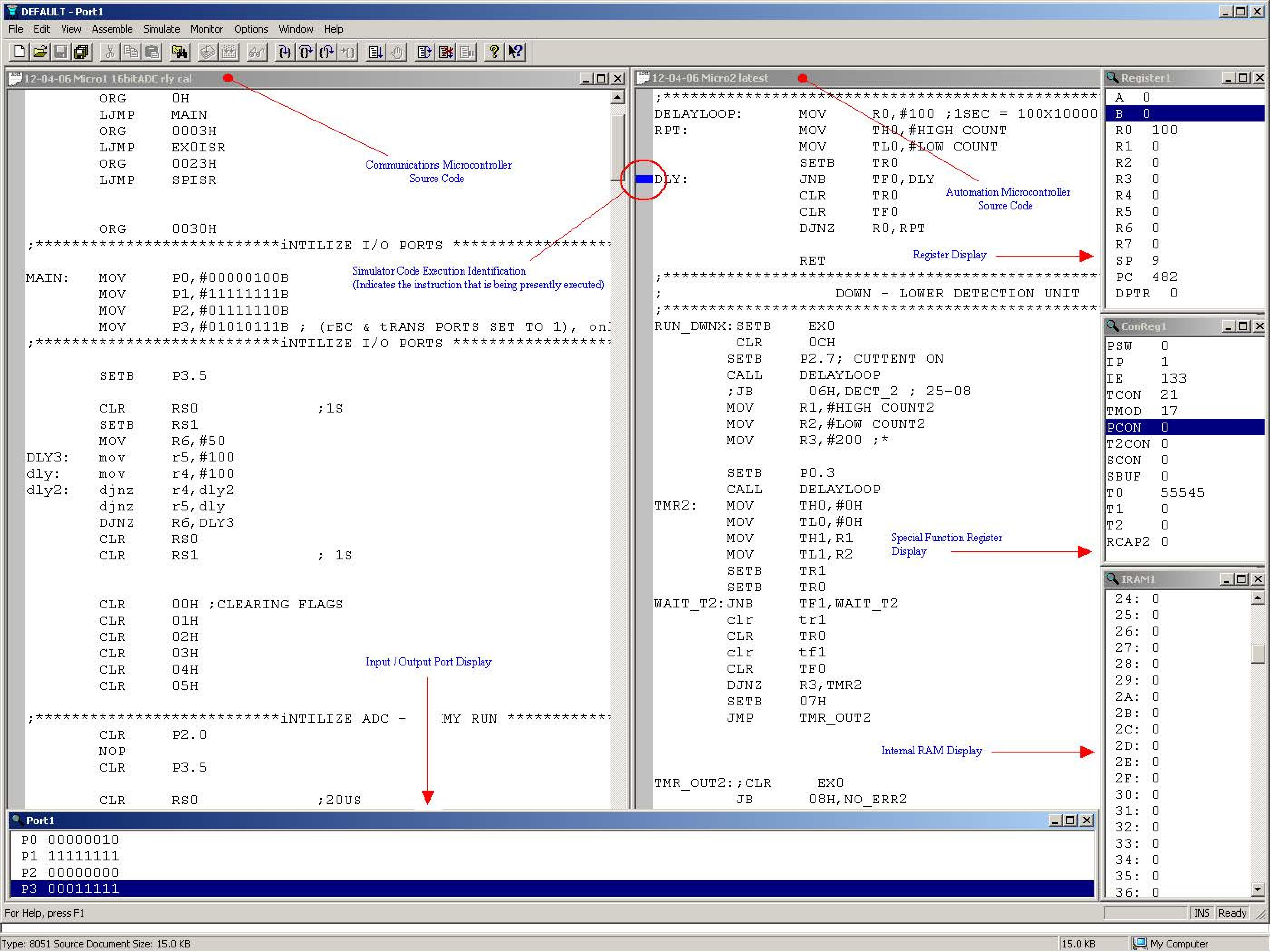
2487B–MICRO–12/03



DEFAULT - Port1
File Edit View Assemble Simulate Monitor Options Window Help
12-04-06 Micro1 16bitADC rly cal
ORG 0H
LJMP MAIN
ORG 0003H
LJMP EX0ISR
ORG 0023H
LJMP SPISR
ORG 0030H
;**************************iNTILIZE I/O PORTS *****************
MAIN: MOV P0,#00000100B
MOV P1,#11111111B
MOV P2,#01111110B
MOV P3,#01010111B ; (rEC & tRANS PORTS SET TO 1), onl
;**************************iNTILIZE I/O PORTS *****************
SETB P3.5
CLR RS0 ;1S
SETB RS1
MOV R6,#50
DLY3: mov r5,#100
dly: mov r4,#100
dly2: djnz r4,dly2
djnz r5,dly
DJNZ R6,DLY3
CLR RS0
CLR RS1 ; 1S
CLR 00H ;CLEARING FLAGS
CLR 01H
CLR 02H
CLR 03H
CLR 04H
CLR 05H
;**************************iNTILIZE ADC - MY RUN ***********
CLR P2.0
NOP
CLR P3.5
CLR RS0 ;20US
Communications Microcontroller Source Code
Simulator Code Execution Identification (Indicates the instruction that is being presently executed)
Input / Output Port Display
12-04-06 Micro2 latest
;***
DELAYLOOP: MOV R0,#100 ;1SEC = 100X10000
RPT: MOV TH0,#HIGH COUNT
MOV TL0,#LOW COUNT
SETB TR0
DLY: JNB TF0,DLY
CLR TR0
CLR TF0
DJNZ R0,RPT
RET
;***
; DOWN - LOWER DETECTION UNIT
;***
RUN_DWNX:SETB EX0
CLR 0CH
SETB P2.7; CUTTENT ON
CALL DELAYLOOP
;JB 06H,DECT_2 ; 25-08
MOV R1,#HIGH COUNT2
MOV R2,#LOW COUNT2
MOV R3,#200 ;*
SETB P0.3
CALL DELAYLOOP
TMR2: MOV TH0,#0H
MOV TL0,#0H
MOV TH1,R1
MOV TL1,R2
SETB TR1
SETB TR0
WAIT_T2:JNB TF1,WAIT_T2
clr tr1
CLR TR0
clr tf1
CLR TF0
DJNZ R3,TMR2
SETB 07H
JMP TMR_OUT2
TMR_OUT2:;CLR EX0
JB 08H,NO_ERR2
Automation Microcontroller Source Code
Register Display
Special Function Register Display
Internal RAM Display
Register1
A 0
B 0
R0 100
R1 0
R2 0
R3 0
R4 0
R5 0
R6 0
R7 0
SP 9
PC 482
DPTR 0
ConReg1
PSW 0
IP 1
IE 133
TCON 21
TMOD 17
PCON 0
T2CON 0
SCON 0
SBUF 0
T0 55545
T1 0
T2 0
RCAP2 0
IRAM1
24: 0
25: 0
26: 0
27: 0
28: 0
29: 0
2A: 0
2B: 0
2C: 0
2D: 0
2E: 0
2F: 0
30: 0
31: 0
32: 0
33: 0
34: 0
35: 0
36: 0
Port1
P0 00000010
P1 11111111
P2 00000000
P3 00011111
For Help, press F1
INS Ready
Type: 8051 Source Document Size: 15.0 KB
15.0 KB
My Computer

National Semiconductor

June 1989

54LS00/DM54LS00/DM74LS00 Quad 2-Input NAND Gates

General Description

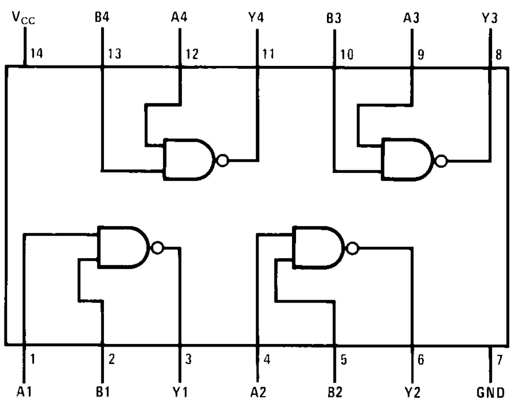
This device contains four independent gates each of which performs the logic NAND function.

Features

- Alternate Military/Aerospace device (54LS00) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6439–1

Order Number 54LS00DMQB, 54LS00FMQB, 54LS00LMQB, DM54LS00J, DM54LS00W, DM74LS00M or DM74LS00N
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

Y = $\overline{AB}$

Inputs		Output
A	**B**	**Y**
L	L	H
L	H	H
H	L	H
H	H	L

H = High Logic Level
L = Low Logic Level

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS00			DM74LS00			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max, V_{IL} = Max	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IH} = Min	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.36	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CCH}	Supply Current with Outputs High	V_{CC} = Max			0.8	1.6	mA
I_{CCL}	Supply Current with Outputs Low	V_{CC} = Max			2.4	4.4	mA

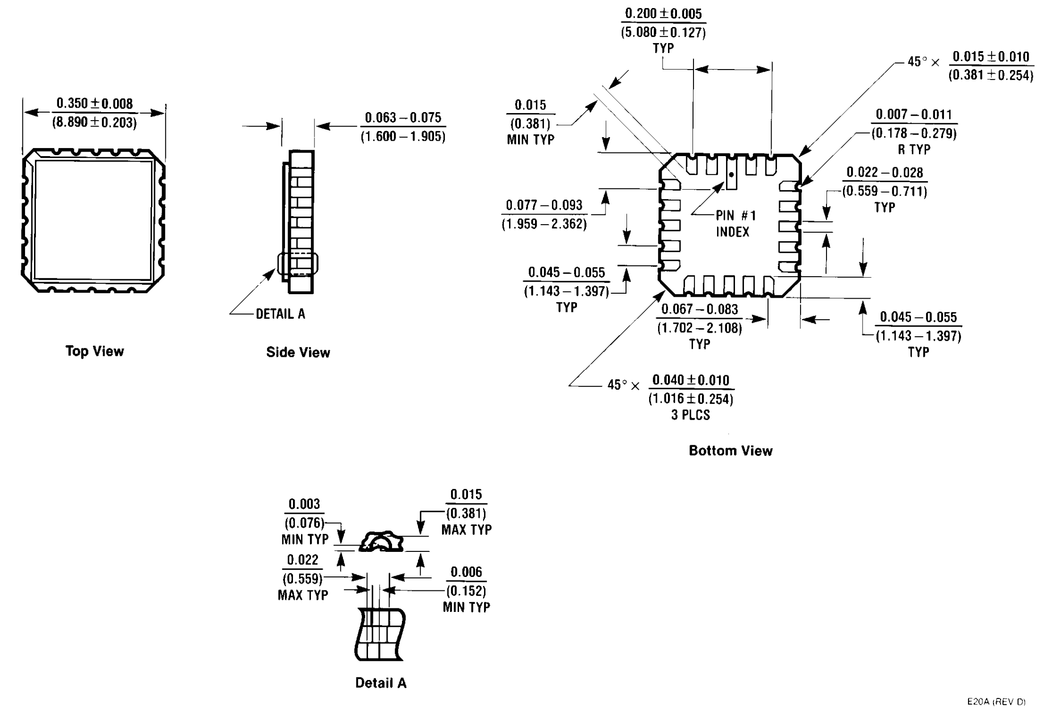
Switching Characteristics at V_{CC} = 5V and T_A = 25°C (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	3	10	4	15	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	3	10	4	15	ns

Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

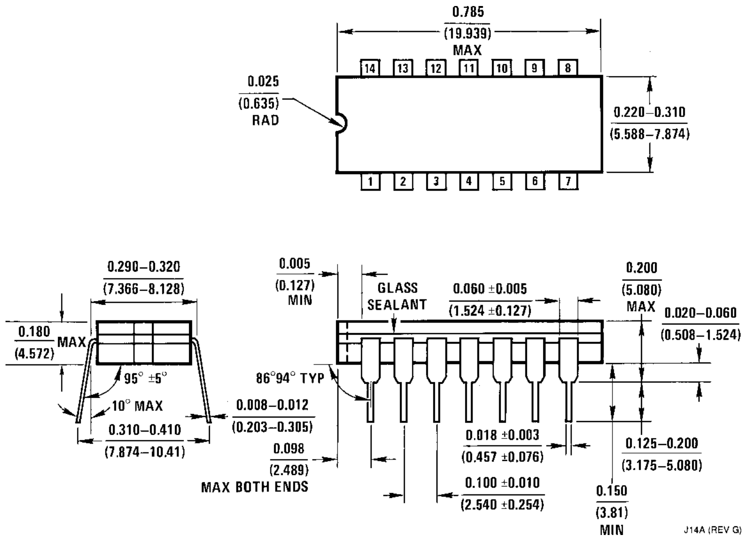
Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Physical Dimensions inches (millimeters)

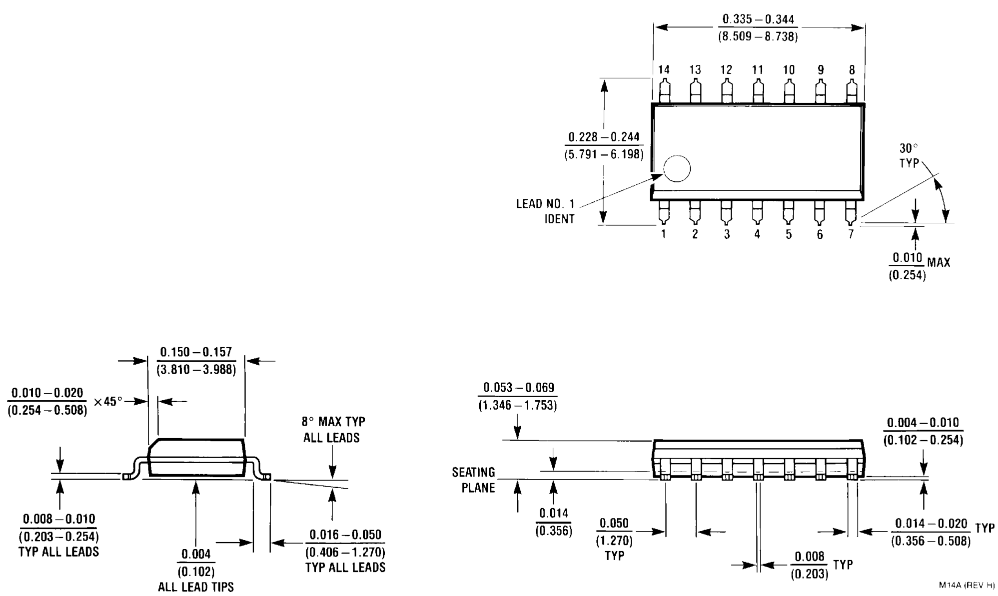


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS00LMQB
NS Package Number E20A

Physical Dimensions inches (millimeters)

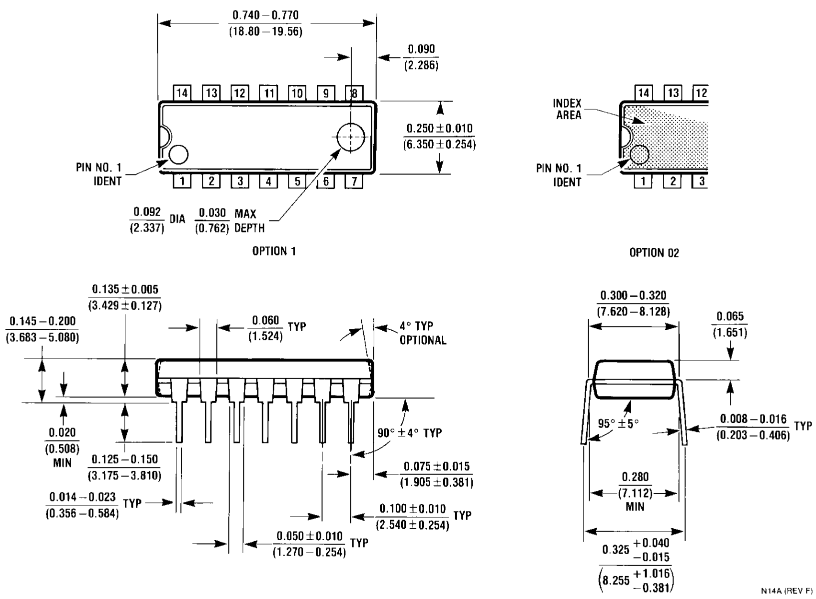


14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS00DMQB or DM54LS00J
NS Package Number J14A



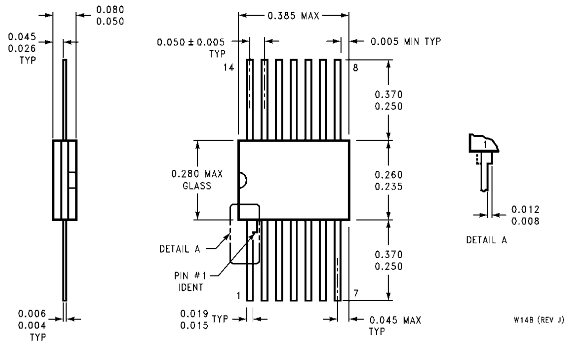
14-Lead Small Outline Molded Package (M)
Order Number DM74LS00M
NS Package Number M14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS00N
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS00FMQB or DM54LS00W
NS Package Number W14B

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
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SEMICONDUCTOR™

May 1986
Revised March 2000

DM74LS02
Quad 2-Input NOR Gate

General Description

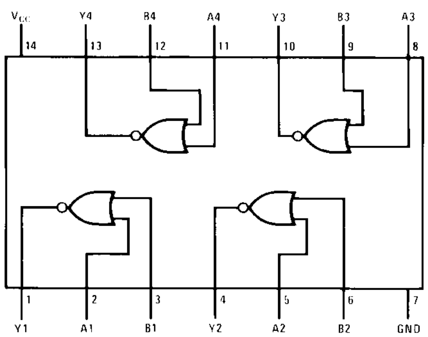
This device contains four independent gates each of which performs the logic NOR function.

Ordering Code:

Order Number	Package Number	Package Description
DM74LS02M	M14A	14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150 Narrow
DM74LS02SJ	M14D	14-Lead Small Outline Package (SOP), EIAJ TYPE II, 5.3mm Wide
DM74LS02N	N14A	14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300 Wide

Devices also available in Tape and Reel. Specify by appending the suffix letter “X” to the ordering code.

Connection Diagram



Function Table

$$Y = \overline{A + B}$$

Inputs		Output
A	**B**	**Y**
L	L	H
L	H	L
H	L	L
H	H	L

H = HIGH Logic Level
L = LOW Logic Level

Absolute Maximum Ratings(Note 1)

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	0°C to +70°C
Storage Temperature Range	–65°C to +150°C

Note 1: The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the Electrical Characteristics tables are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.

Recommended Operating Conditions

Symbol	Parameter	Min	Nom	Max	Units
V_{CC}	Supply Voltage	4.75	5	5.25	V
V_{IH}	HIGH Level Input Voltage	2			V
V_{IL}	LOW Level Input Voltage			0.8	V
I_{OH}	HIGH Level Output Current			–0.4	mA
I_{OL}	LOW Level Output Current			8	mA
T_A	Free Air Operating Temperature	0		70	°C

Electrical Characteristics

over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions	Min	Typ (Note 2)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = –18 mA			–1.5	V
V_{OH}	HIGH Level Output Voltage	V_{CC} = Min, I_{OH} = Max, V_{IL} = Max	2.7	3.4		V
V_{OL}	LOW Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IH} = Min		0.35	0.5	V
		I_{OL} = 4 mA, V_{CC} = Min		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V			0.1	mA
I_{IH}	HIGH Level Input Current	V_{CC} = Max, V_I = 2.7V			20	μA
I_{IL}	LOW Level Input Current	V_{CC} = Max, V_I = 0.4V			–0.40	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 3)	–20		–100	mA
I_{CCH}	Supply Current with Outputs HIGH	V_{CC} = Max		1.6	3.2	mA
I_{CCL}	Supply Current with Outputs LOW	V_{CC} = Max		2.8	5.4	mA

Note 2: All typicals are at V_{CC} = 5V, T_A = 25°C.

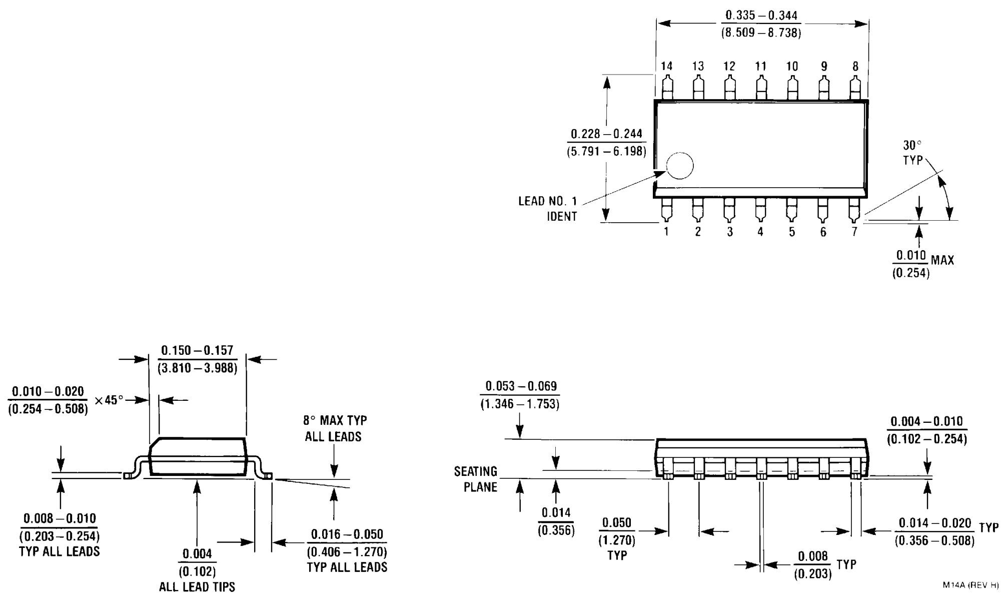
Note 3: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Switching Characteristics

at V_{CC} = 5V and T_A = 25°C

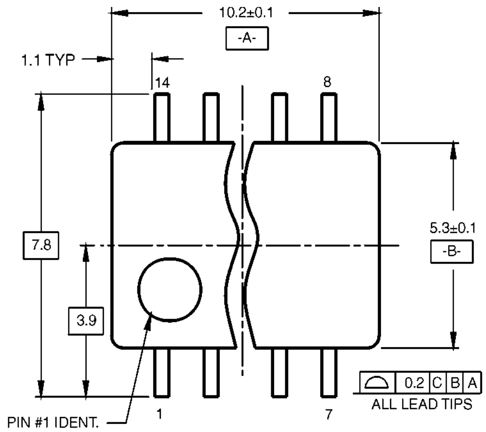
Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time LOW-to-HIGH Level Output		13		18	ns
t_{PHL}	Propagation Delay Time HIGH-to-LOW Level Output		10		15	ns

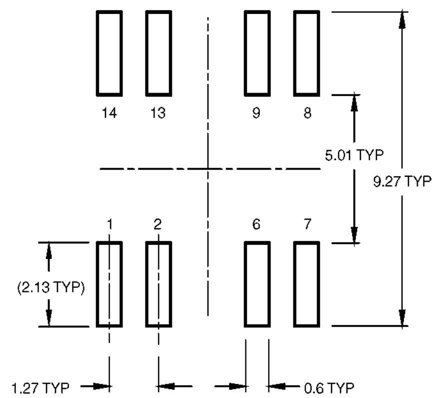
Physical Dimensions inches (millimeters) unless otherwise noted



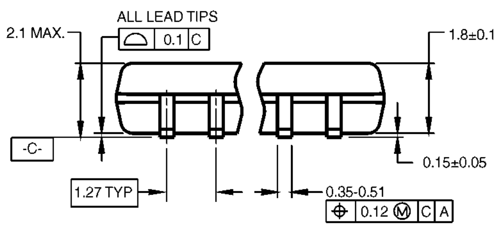
14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150 Narrow Package Number M14A

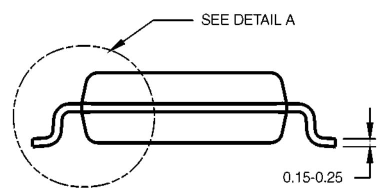
Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



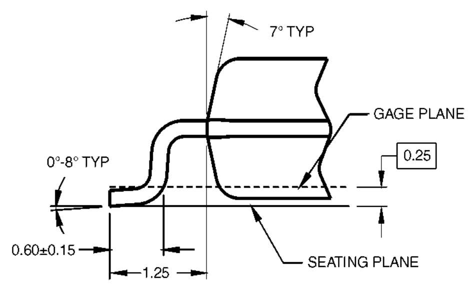


LAND PATTERN RECOMMENDATION





DIMENSIONS ARE IN MILLIMETERS



DETAIL A

NOTES:

A. CONFORMS TO EIAJ EDR-7320 REGISTRATION, ESTABLISHED IN DECEMBER, 1998.

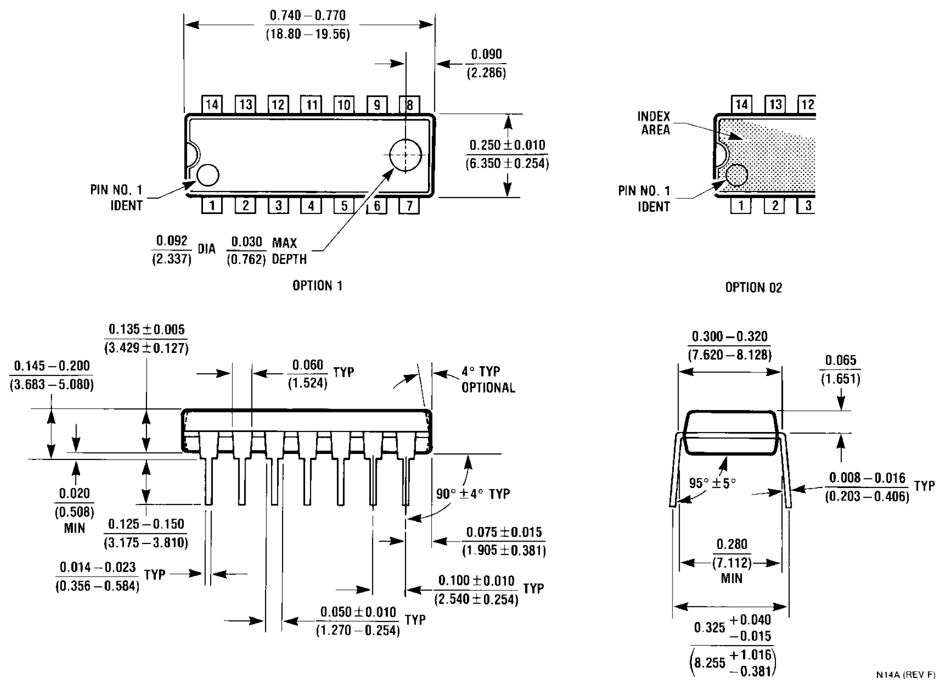
B. DIMENSIONS ARE IN MILLIMETERS.

C. DIMENSIONS ARE EXCLUSIVE OF BURRS, MOLD FLASH, AND TIE BAR EXTRUSIONS.

M14DRevB1

14-Lead Small Outline Package (SOP), EIAJ TYPE II, 5.3mm Wide
Package Number M14D

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300 Wide
Package Number N14A

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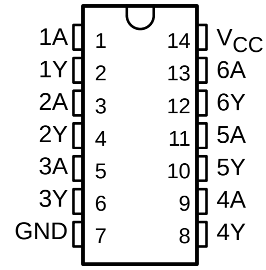
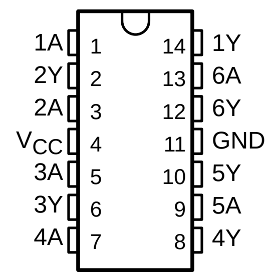
description

These devices contain six independent inverters.

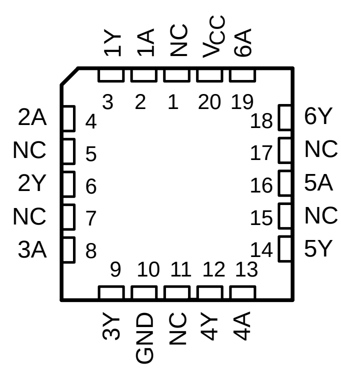
SN5404 . . . J PACKAGE
SN54LS04, SN54S04 . . . J OR W PACKAGE
SN7404 . . . D, N, OR NS PACKAGE
SN74LS04 . . . D, DB, N, OR NS PACKAGE
SN74S04 . . . D OR N PACKAGE
(TOP VIEW)



SN5404 . . . W PACKAGE
(TOP VIEW)



SN54LS04, SN54S04 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

ORDERING INFORMATION

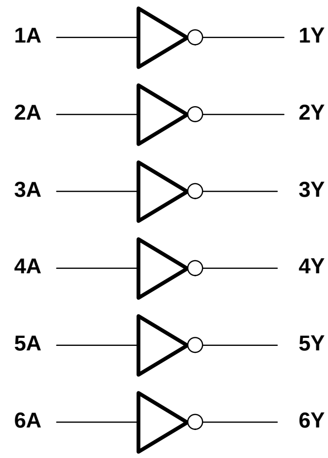
T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP – N	Tube	SN7404N	SN7404N
		Tube	SN74LS04N	SN74LS04N
		Tube	SN74S04N	SN74S04N
	SOIC – D	Tube	SN7404D	7404
		Tube	SN74LS04D	LS04
		Tape and reel	SN74LS04DR	
		Tube	SN74S04D	S04
		Tape and reel	SN74S04DR	
	SOP – NS	Tape and reel	SN7404NSR	SN7404
		Tape and reel	SN74LS04NSR	74LS04
	SSOP – DB	Tape and reel	SN74LS04DBR	LS04
–55°C to 125°C	CDIP – J	Tube	SN5404J	SN5404J
		Tube	SNJ5404J	SNJ5404J
		Tube	SN54LS04J	SN54LS04J
		Tube	SN54S04J	SN54S04J
		Tube	SNJ54LS04J	SNJ54LS04J
		Tube	SNJ54S04J	SNJ54S04J
	CFP – W	Tube	SNJ5404W	SNJ5404W
		Tube	SNJ54LS04W	SNJ54LS04W
		Tube	SNJ54S04W	SNJ54S04W
	LCCC – FK	Tube	SNJ54LS04FK	SNJ54LS04FK
		Tube	SNJ54S04FK	SNJ54S04FK

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

FUNCTION TABLE
(each inverter)

INPUT A	OUTPUT Y
H	L
L	H

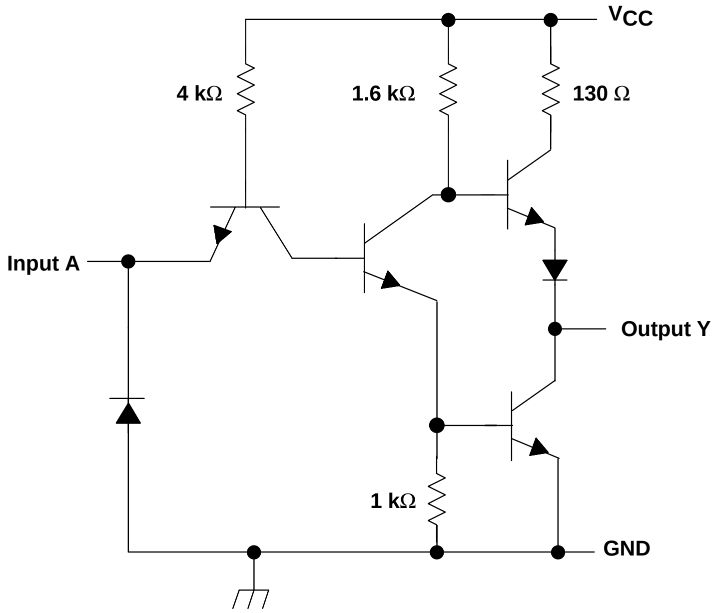
logic diagram (positive logic)



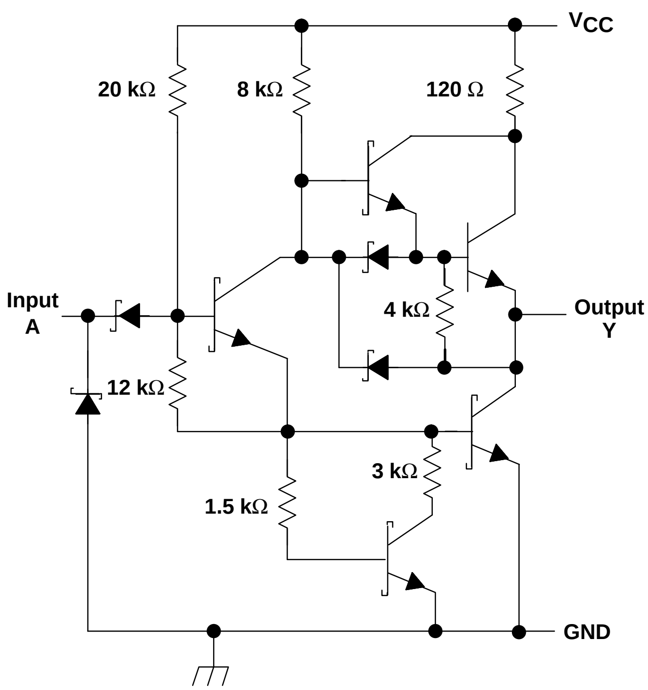
$Y = \overline{A}$

schematics (each gate)

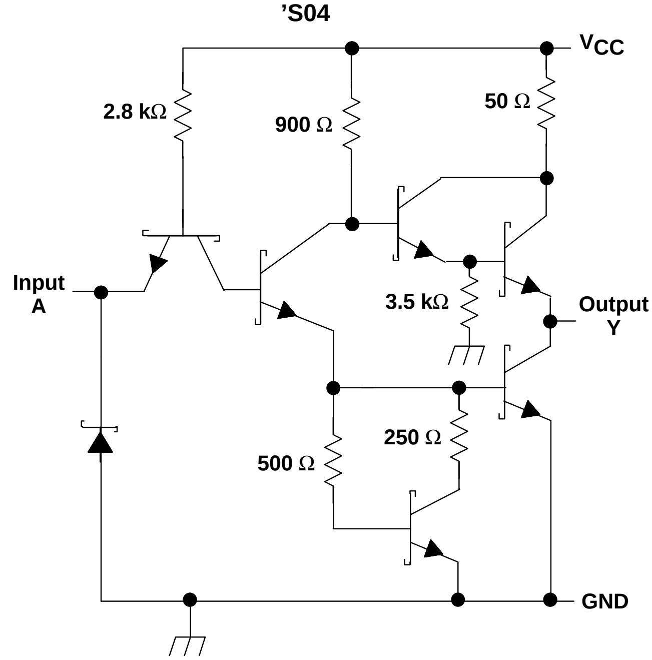
’04



’LS04



’S04



Resistor values shown are nominal.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{CC} (see Note 1) . . . . . 7 V
Input voltage, V_I: '04, 'S04 . . . . . 5.5 V
'LS04 . . . . . 7 V
Package thermal impedance, θ_{JA} (see Note 2): D package . . . . . 86°C/W
DB package . . . . . 96°C/W
N package . . . . . 80°C/W
NS package . . . . . 76°C/W
Storage temperature range, T_{stg} . . . . . –65°C to 150°C

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. This are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. Voltage values are with respect to network ground terminal.
2. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

		SN5404			SN7404			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.8			0.8	V
I_{OH}	High-level output current			–0.4			–0.4	mA
I_{OL}	Low-level output current			16			16	mA
T_A	Operating free-air temperature	–55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS‡			SN5404			SN7404			UNIT
				MIN	TYP§	MAX	MIN	TYP§	MAX	
V_{IK}	V_{CC} = MIN,	I_I = –12 mA				–1.5			–1.5	V
V_{OH}	V_{CC} = MIN,	V_{IL} = 0.8 V,	I_{OH} = –0.4 mA	2.4	3.4		2.4	3.4		V
V_{OL}	V_{CC} = MIN,	V_{IH} = 2 V,	I_{OL} = 16 mA		0.2	0.4		0.2	0.4	V
I_I	V_{CC} = MAX,	V_I = 5.5 V				1			1	mA
I_{IH}	V_{CC} = MAX,	V_I = 2.4 V				40			40	µA
I_{IL}	V_{CC} = MAX,	V_I = 0.4 V				–1.6			–1.6	mA
I_{OS}¶	V_{CC} = MAX			–20		–55	–18		–55	mA
I_{CCH}	V_{CC} = MAX,	V_I = 0 V			6	12		6	12	mA
I_{CCL}	V_{CC} = MAX,	V_I = 4.5 V			18	33		18	33	mA

‡ For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
§ All typical values are at V_{CC} = 5 V, T_A = 25°C.
¶ Not more than one output should be shorted at a time.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 1)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS		SN5404 SN7404			UNIT
					MIN	TYP	MAX	
t_{PLH}	A	Y	R_L = 400 Ω,	C_L = 15 pF		12	22	ns
t_{PHL}						8	15	

recommended operating conditions

		SN54LS04			SN74LS04			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.7			0.8	V
I_{OH}	High-level output current			–0.4			–0.4	mA
I_{OL}	Low-level output current			4			8	mA
T_A	Operating free-air temperature	–55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS†			SN54LS04			SN74LS04			UNIT
				MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IK}	V_{CC} = MIN,	I_I = –18 mA				–1.5			–1.5	V
V_{OH}	V_{CC} = MIN,	V_{IL} = MAX,	I_{OH} = –0.4 mA	2.5	3.4		2.7	3.4		V
V_{OL}	V_{CC} = MIN,	V_{IH} = 2 V	I_{OL} = 4 mA		0.25	0.4			0.4	V
			I_{OL} = 8 mA					0.25	0.5	
I_I	V_{CC} = MAX,	V_I = 7 V				0.1			0.1	mA
I_{IH}	V_{CC} = MAX,	V_I = 2.7 V				20			20	µA
I_{IL}	V_{CC} = MAX,	V_I = 0.4 V				–0.4			–0.4	mA
I_{OS}§	V_{CC} = MAX			–20		–100	–20		–100	mA
I_{CCH}	V_{CC} = MAX,	V_I = 0 V			1.2	2.4		1.2	2.4	mA
I_{CCL}	V_{CC} = MAX,	V_I = 4.5 V			3.6	6.6		3.6	6.6	mA

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡ All typical values are at V_{CC} = 5 V, T_A = 25°C.
§ Not more than one output should be shorted at a time and the duration of the short-circuit should not exceed one second.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 2)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS		SN54LS04 SN74LS04			UNIT
					MIN	TYP	MAX	
t_{PLH}	A	Y	R_L = 2 kΩ,	C_L = 15 pF		9	15	ns
t_{PHL}						10	15	

recommended operating conditions

		SN54S04			SN74S04			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.8			0.8	V
I_{OH}	High-level output current			–1			–1	mA
I_{OL}	Low-level output current			20			20	mA
T_A	Operating free-air temperature	–55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

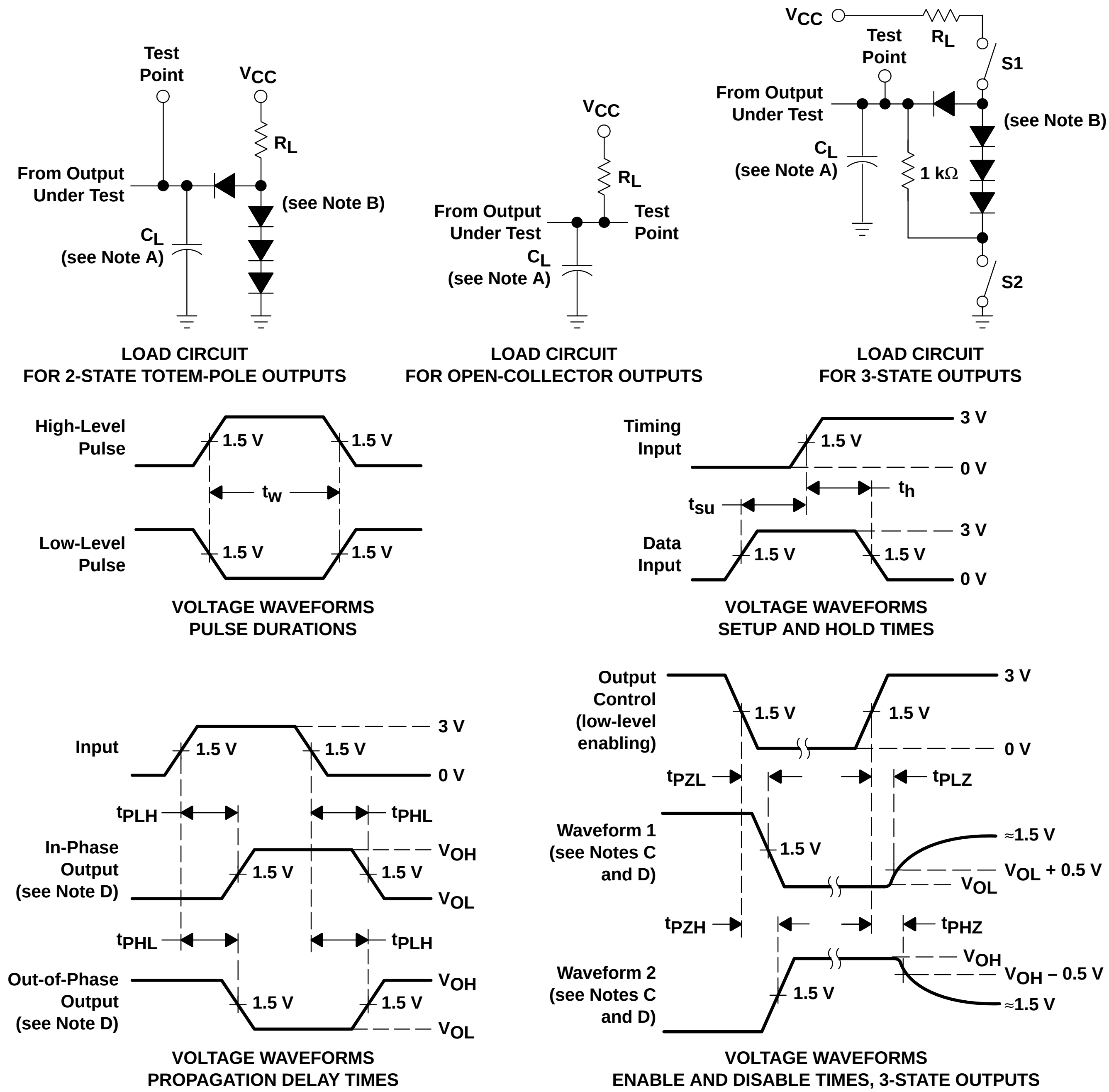
PARAMETER	TEST CONDITIONS†	SN54S04			SN74S04			UNIT
		MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IK}	V_{CC} = MIN, I_I = –18 mA			–1.2			–1.2	V
V_{OH}	V_{CC} = MIN, V_{IL} = 0.8 V, I_{OH} = –1 mA	2.5	3.4		2.7	3.4		V
V_{OL}	V_{CC} = MIN, V_{IH} = 2 V, I_{OL} = 20 mA			0.5			0.5	V
I_I	V_{CC} = MAX, V_I = 5.5 V			1			1	mA
I_{IH}	V_{CC} = MAX, V_I = 2.7 V			50			50	µA
I_{IL}	V_{CC} = MAX, V_I = 0.5 V			–2			–2	mA
I_{OS}§	V_{CC} = MAX	–40		–100	–40		–100	mA
I_{CCH}	V_{CC} = MAX, V_I = 0 V		15	24		15	24	mA
I_{CCL}	V_{CC} = MAX, V_I = 4.5 V		30	54		30	54	mA

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡ All typical values are at V_{CC} = 5 V, T_A = 25°C.
§ Not more than one output should be shorted at a time and the duration of the short-circuit should not exceed one second.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 1)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS	SN54S04 SN74S04			UNIT
				MIN	TYP	MAX	
t_{PLH}	A	Y	R_L = 280 Ω, C_L = 15 pF		3	4.5	ns
t_{PHL}					3	5	
t_{PLH}	A	Y	R_L = 280 Ω, C_L = 50 pF		4.5		ns
t_{PHL}					5		

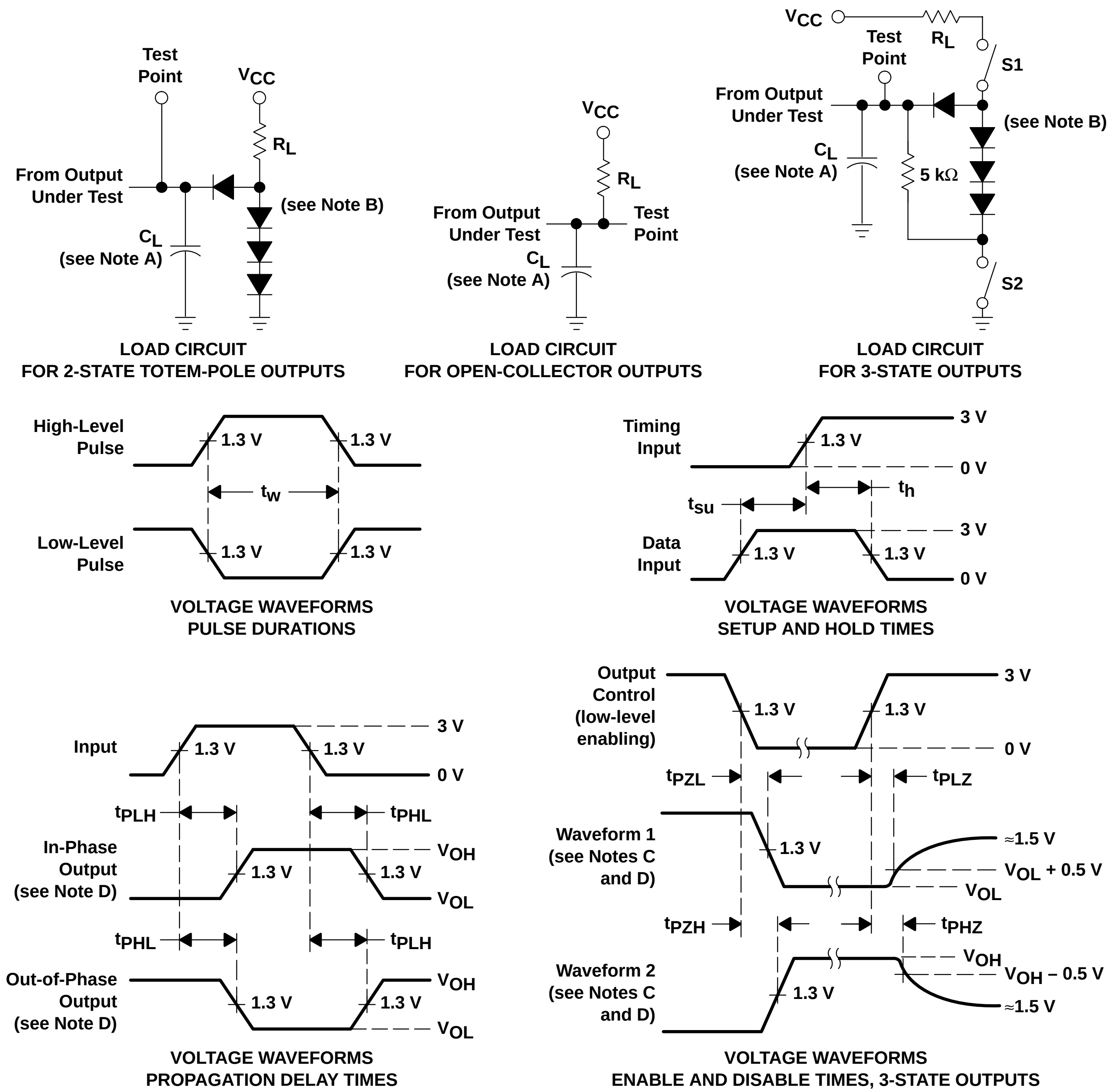
PARAMETER MEASUREMENT INFORMATION
SERIES 54/74 AND 54S/74S DEVICES



NOTES: A. C_L includes probe and jig capacitance.
B. All diodes are 1N3064 or equivalent.
C. Waveform 1 is for an output with internal conditions such that the output is low except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is high except when disabled by the output control.
D. S1 and S2 are closed for t_{PLH}, t_{PHL}, t_{PHZ}, and t_{PLZ}; S1 is open and S2 is closed for t_{PZH}; S1 is closed and S2 is open for t_{PZL}.
E. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, $Z_O \approx 50\ \Omega$; t_r and $t_f \le 7$ ns for Series 54/74 devices and t_r and $t_f \le 2.5$ ns for Series 54S/74S devices.
F. The outputs are measured one at a time with one input transition per measurement.

Figure 1. Load Circuits and Voltage Waveforms

PARAMETER MEASUREMENT INFORMATION
SERIES 54LS/74LS DEVICES



NOTES: A. C_L includes probe and jig capacitance.
B. All diodes are 1N3064 or equivalent.
C. Waveform 1 is for an output with internal conditions such that the output is low except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is high except when disabled by the output control.
D. S1 and S2 are closed for t_{PLH}, t_{PHL}, t_{PHZ}, and t_{PLZ}; S1 is open and S2 is closed for t_{PZH}; S1 is closed and S2 is open for t_{PZL}.
E. Phase relationships between inputs and outputs have been chosen arbitrarily for these examples.
F. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, Z_O ≈ 50 Ω, t_r ≤ 1.5 ns, t_f ≤ 2.6 ns.
G. The outputs are measured one at a time with one input transition per measurement.

Figure 2. Load Circuits and Voltage Waveforms

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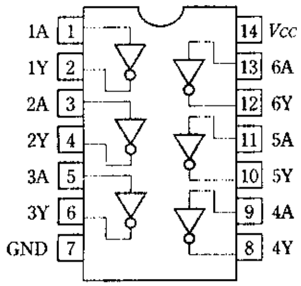
HD74LS06 ● Hex Inverter Buffers/Drivers (With Open Collector High-Voltage Outputs)

■ PIN ARRANGEMENT



(Top View)

■ ABSOLUTE MAXIMUM RATINGS

Item	Symbol	Ratings	Unit
Supply voltage	V_{CC}	7.0	V
Input voltage	V_{IN}	7.0	V
Output voltage	V_{out}	30	V
Operating temperature range	T_{opr}	–20 ~ +75	°C
Storage temperature range	T_{stg}	–65 ~ +150	°C

■ RECOMMENDED OPERATING CONDITIONS

Item	Symbol	min	typ	max	Unit
Supply voltage	V_{CC}	4.75	5.00	5.25	V
High level output voltage	V_{OH}	–	–	30	V
Low level output current	I_{OL}	–	–	48	mA
Operating temperature range	T_{opr}	–20	25	75	°C

■ ELECTRICAL CHARACTERISTICS (Ta = –20 ~ +75°C)

Item	Symbol	Test Conditions			min	typ*	max	Unit
Input voltage	V_{IH}				2.0	–	–	V
	V_{IL}				–	–	0.8	V
Output voltage	V_{OL}	V_{CC} = 4.75V,	V_{IH} = 2V	I_{OL} = 24mA	–	–	0.4	V
				I_{OL} = 48mA	–	–	0.5	V
Input current	I_{IH}	V_{CC} = 5.25V	V_I = 2.7V		–	–	20	µA
	I_{IL}	V_{CC} = 5.25V,	V_I = 0.4V		–	–	–0.4	mA
	I_I	V_{CC} = 5.25V,	V_I = 7V		–	–	0.1	mA
Output current	I_{OH}	V_{CC} = 4.75V,	V_{IL} = 0.8V,	V_{OH} = 30V	–	–	250	µA
Supply current	I_{CCH}	V_{CC} = 5.25V			–	23	48	mA
	I_{CCL}	V_{CC} = 5.25V			–	21	51	mA
Input clamp voltage	V_{IK}	V_{CC} = 4.75V,	I_{IN} = –18mA		–	–	–1.5	V

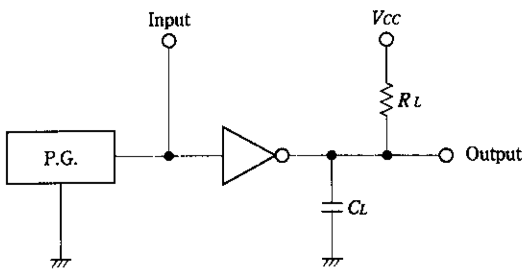
*V_{CC} = 5V, Ta = 25°C

■ SWITCHING CHARACTERISTICS (V_{CC} = 5V, Ta = 25°C)

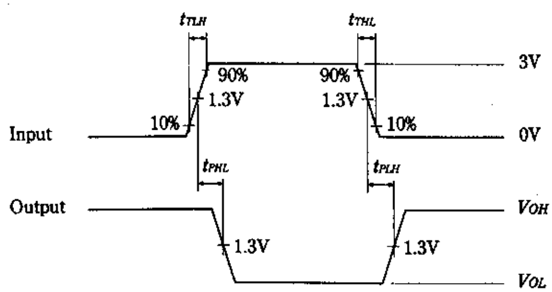
Item	Symbol	Test Conditions	min	typ	max	Unit
Propagation delay time	t_{PLH}	C_L = 15pF, R_L = 110Ω	–	10	15	ns
	t_{PHL}		–	15	23	ns

■ TESTING METHOD

Test Circuit

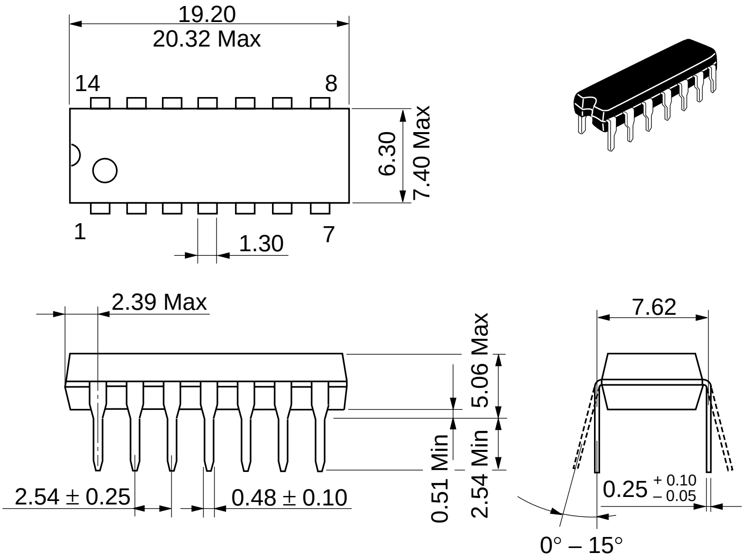


Waveform



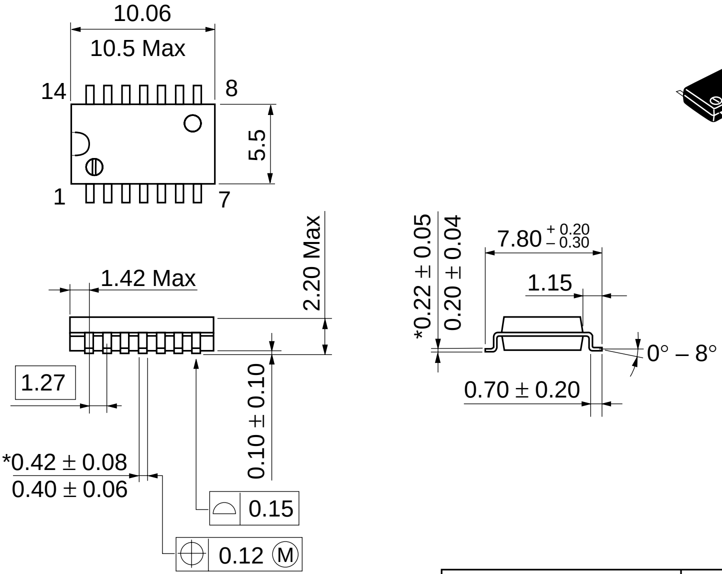
Notes) 1. Input pulse: PRR = 1MHz, duty cycle 50%, Zout = 50Ω, t_{TLH}≤15ns, t_{THL}≤6ns
2. C_L includes probe and jig capacitance.
3. All diodes are 1S2074(H)

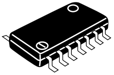
Unit: mm



Hitachi Code	DP-14
JEDEC	Conforms
EIAJ	Conforms
Weight (reference value)	0.97 g

Unit: mm

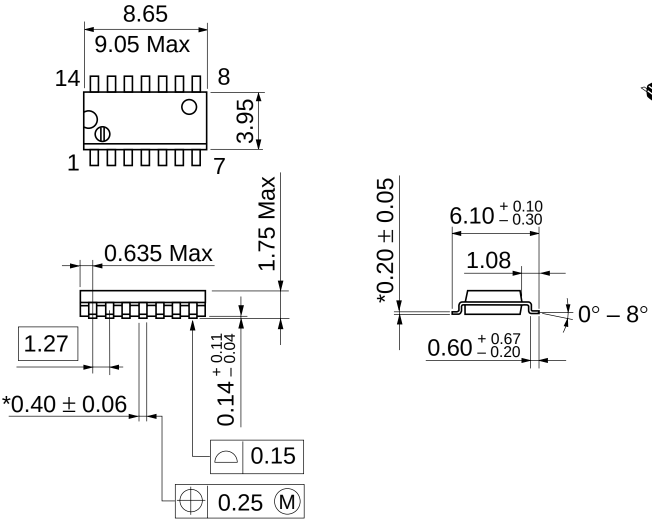


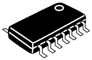


*Dimension including the plating thickness
Base material dimension

Hitachi Code	FP-14DA
JEDEC	—
EIAJ	Conforms
Weight (reference value)	0.23 g

Unit: mm





Hitachi Code	FP-14DN
JEDEC	Conforms
EIAJ	Conforms
Weight (reference value)	0.13 g

*Pd plating

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Hitachi Semiconductor
(America) Inc.
179 East Tasman Drive,
San Jose,CA 95134
Tel: <1> (408) 433-1990
Fax: <1>(408) 433-0223

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Dornacher Stra§e 3
D-85622 Feldkirchen, Munich
Germany
Tel: <49> (89) 9 9180-0
Fax: <49> (89) 9 29 30 00

Hitachi Europe Ltd.
Electronic Components Group.
Whitebrook Park
Lower Cookham Road
Maidenhead
Berkshire SL6 8YA, United Kingdom
Tel: <44> (1628) 585000
Fax: <44> (1628) 778322

Hitachi Asia Pte. Ltd.
16 Collyer Quay #20-00
Hitachi Tower
Singapore 049318
Tel: 535-2100
Fax: 535-1533

Hitachi Asia Ltd.
Taipei Branch Office
3F, Hung Kuo Building. No.167,
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Group III (Electronic Components)
7/F., North Tower, World Finance Centre,
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National Semiconductor

June 1989

54LS08/DM54LS08/DM74LS08 Quad 2-Input AND Gates

General Description

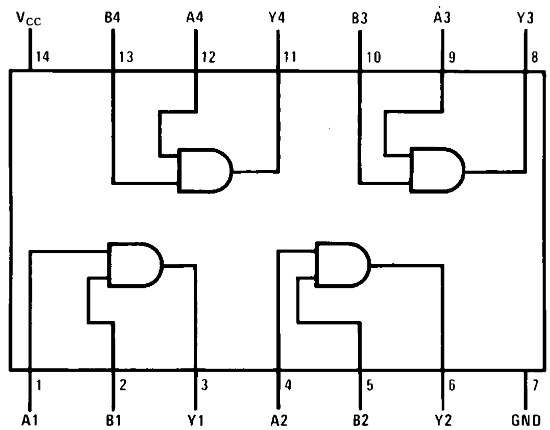
This device contains four independent gates each of which performs the logic AND function.

Features

- Alternate Military/Aerospace device (54LS08) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6347–1

Order Number 54LS08DMQB, 54LS08FMQB, 54LS08LMQB, DM54LS08J, DM54LS08W, DM74LS08M or DM74LS08N
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

Y = AB

Inputs		Output
A	B	Y
L	L	L
L	H	L
H	L	L
H	H	H

H = High Logic Level
L = Low Logic Level

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS08			DM74LS08			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max, V_{IH} = Min	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IL} = Max	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.36	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CCH}	Supply Current with Outputs High	V_{CC} = Max			2.4	4.8	mA
I_{CCL}	Supply Current with Outputs Low	V_{CC} = Max			4.4	8.8	mA

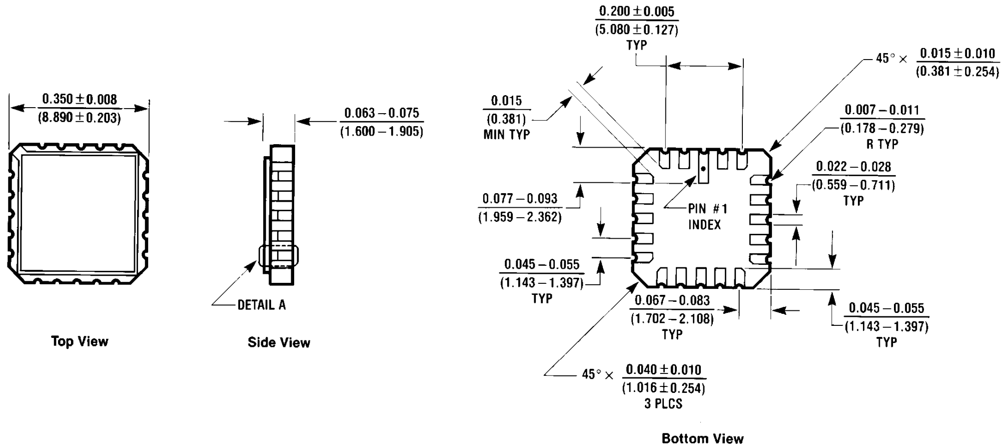
Switching Characteristics at V_{CC} = 5V and T_A = 25°C (See Section 1 for Test Waveforms and Output Load)

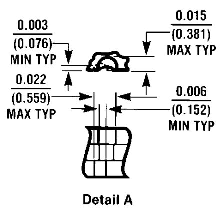
Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	4	13	6	18	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	3	11	5	18	ns

Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

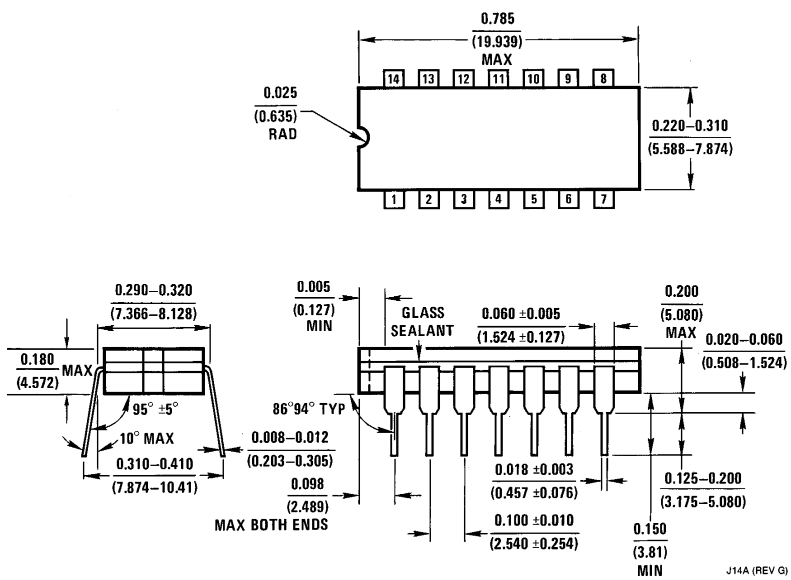
Physical Dimensions inches (millimeters)





E20A (REV D)

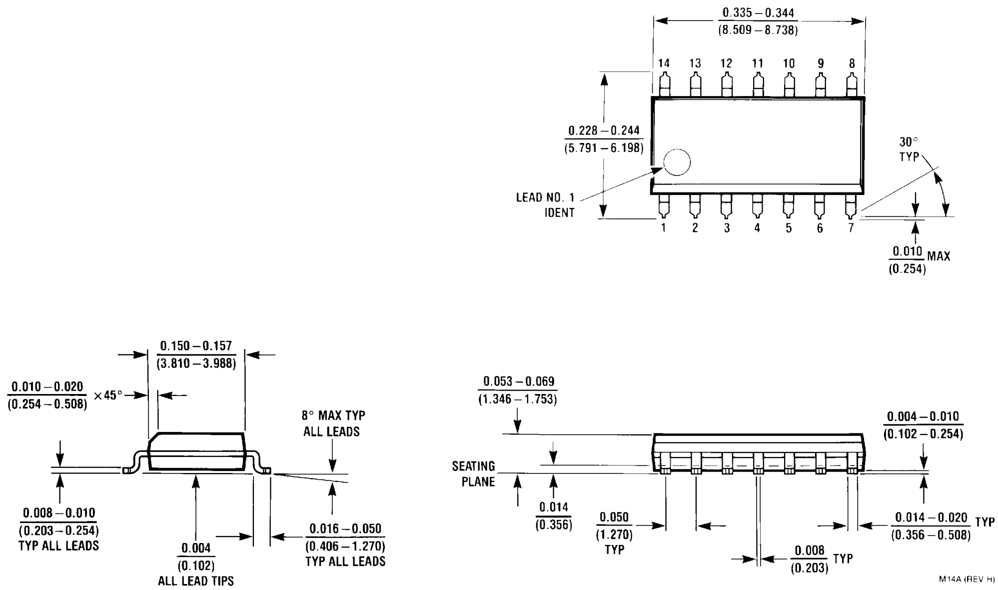
Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS08LMQB
NS Package Number E20A



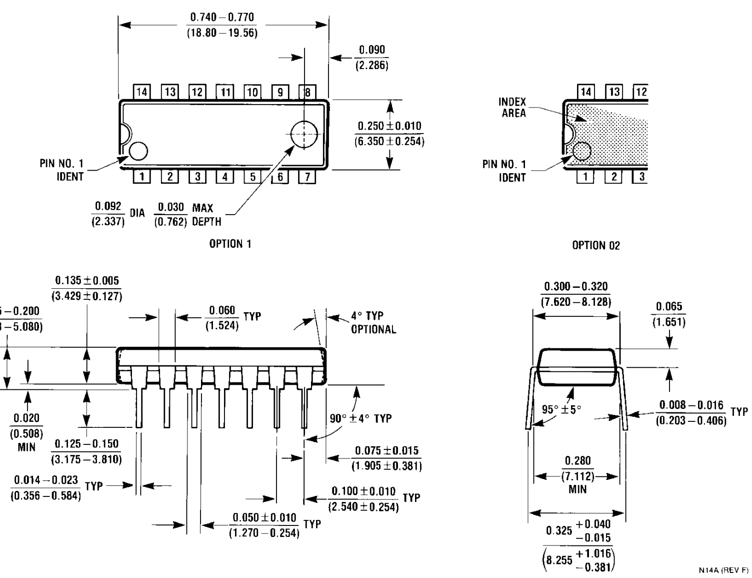
J14A (REV G)

14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS08DMQB or DM54LS08J
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

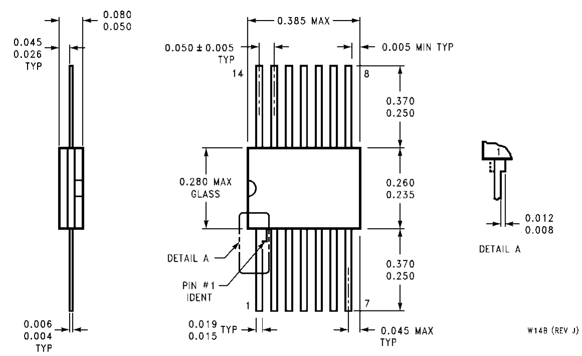


14-Lead Small Outline Molded Package (M)
Order Number DM74LS08M
NS Package Number M14A



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS08N
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS08FMQB or DM54LS08W
NS Package Number W14B

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

National Semiconductor

May 1989

54LS32/DM54LS32/DM74LS32 Quad 2-Input OR Gates

General Description

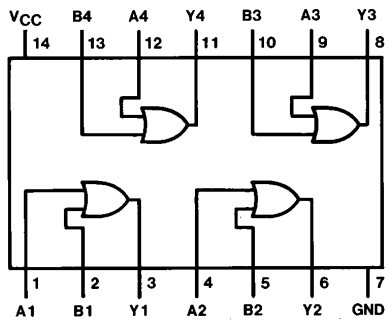
This device contains four independent gates each of which performs the logic OR function.

Features

- Alternate Military/Aerospace device (54LS32) is available. Contact a National Semiconductor Sales Office/ Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6361–1

Order Number 54LS32DMQB, 54LS32FMQB, 54LS32LMQB, DM54LS32J, DM54LS32W, DM74LS32M or DM74LS32N
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

$Y = A + B$

Inputs		Output
A	B	Y
L	L	L
L	H	H
H	L	H
H	H	H

H = High Logic Level
L = Low Logic Level

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage 7V

Input Voltage 7V

Operating Free Air Temperature Range

DM54LS and 54LS −55°C to +125°C

DM74LS 0°C to +70°C

Storage Temperature Range −65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS32			DM74LS32			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max V_{IH} = Min	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max V_{IL} = Max	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.36	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CCH}	Supply Current with Outputs High	V_{CC} = Max			3.1	6.2	mA
I_{CCL}	Supply Current with Outputs Low	V_{CC} = Max			4.9	9.8	mA

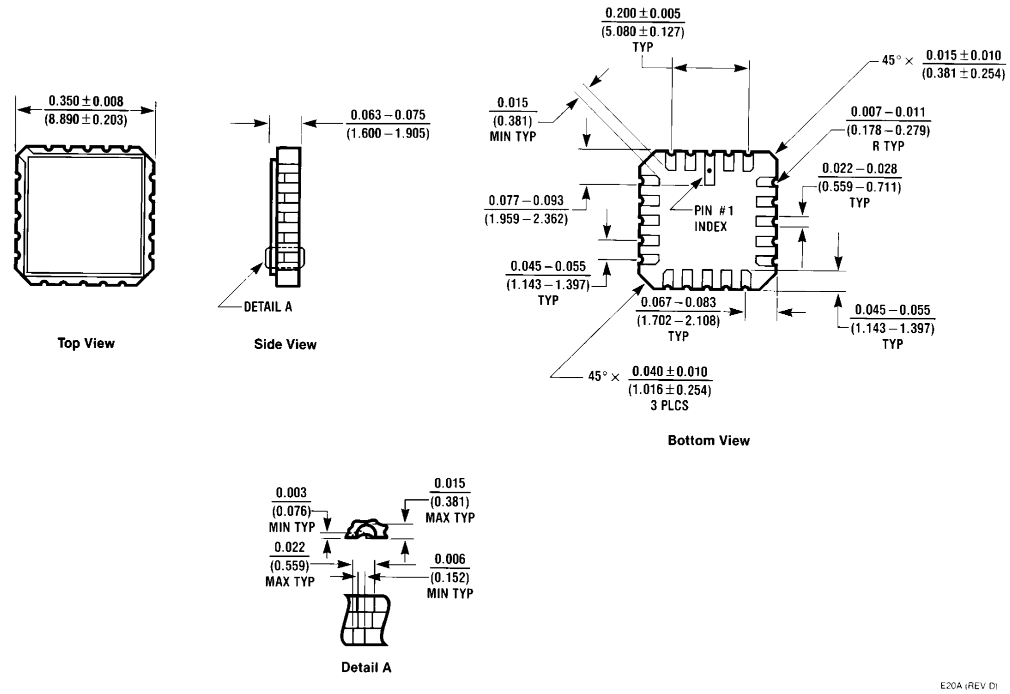
Switching Characteristics at V_{CC} = 5V and T_A = 25°C (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	3	11	4	15	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	3	11	4	15	ns

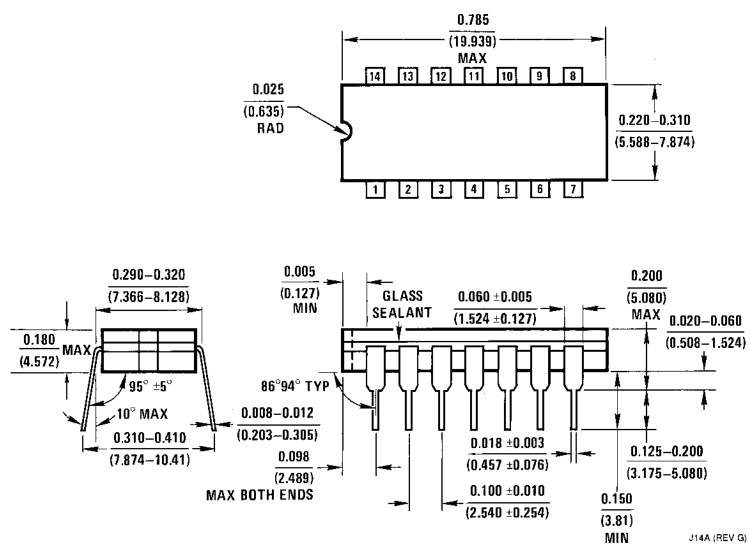
Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Physical Dimensions inches (millimeters)

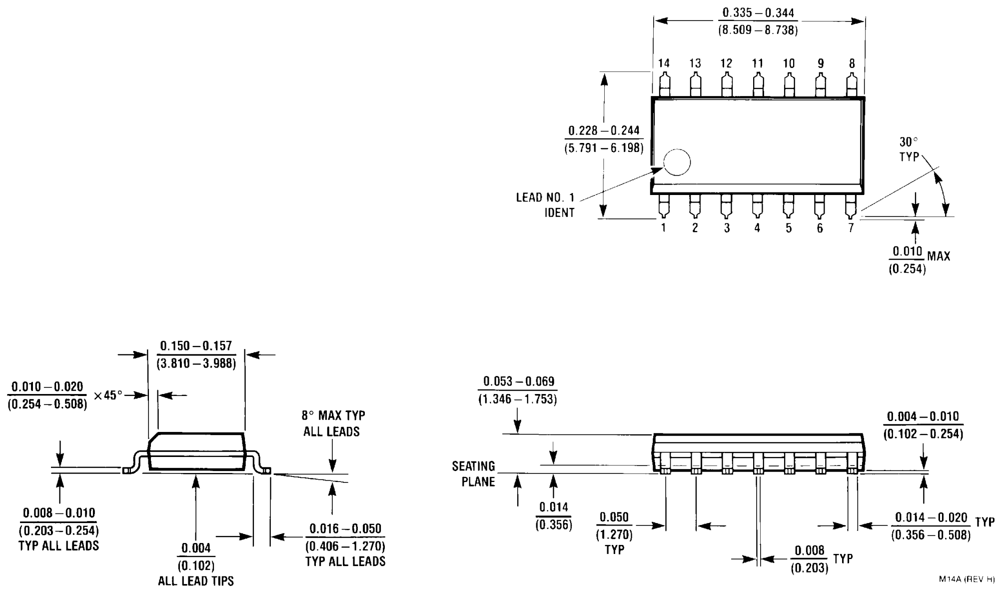


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS32LMQB
NS Package Number E20A

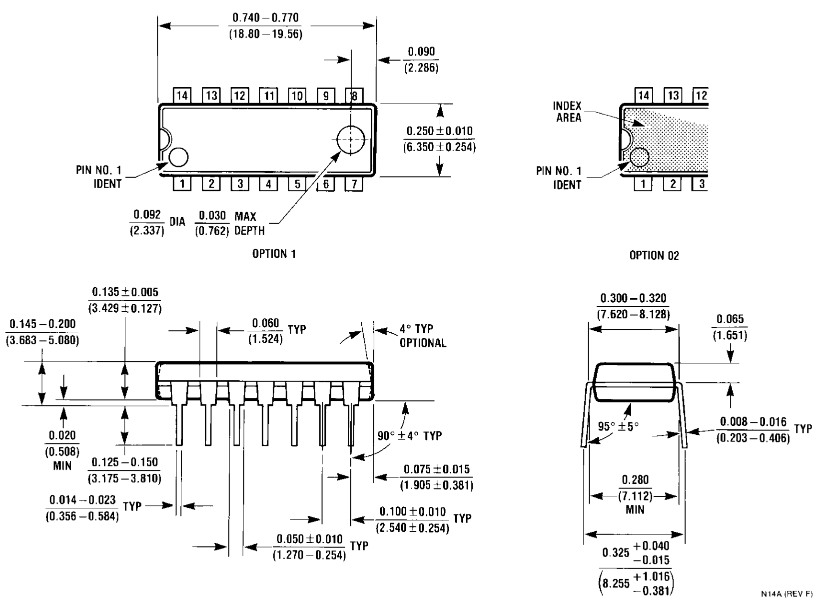


14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS32DMQB or DM54LS32J
NS Package Number J14A

Physical Dimensions inches (millimeters)

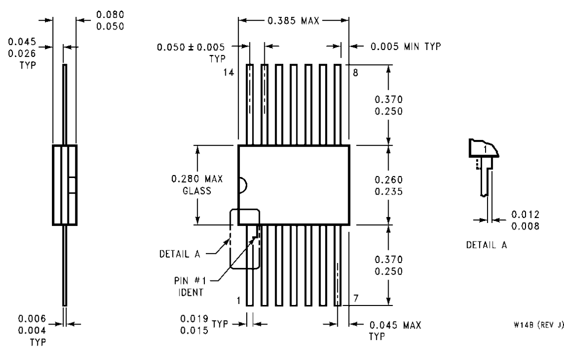


14-Lead Small Outline Molded Package (M)
Order Number DM74LS32M
NS Package Number M14A



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS32N
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS32FMQB or DM54LS32W
NS Package Number W14B

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
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National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
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National Semiconductor

May 1989

54LS279/DM54LS279/DM74LS279 Quad $\overline{S}$-$\overline{R}$ Latches

General Description

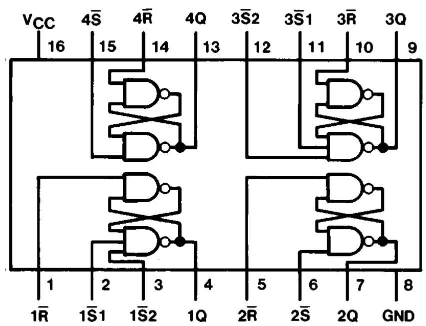
The 'LS279 consists of four individual and independent Set-Reset Latches with active low inputs. Two of the four latches have an additonal $\overline{S}$ input ANDed with the primary $\overline{S}$ input. A low on any $\overline{S}$ input while the $\overline{R}$ input is high will be stored in the latch and appear on the corresponding Q output as a high. A low on the $\overline{R}$ input while the $\overline{S}$ input is high will clear the Q output to a low. Simultaneous transistion of the $\overline{R}$ and $\overline{S}$ inputs from low to high will cause the Q output to be indeterminate. Both inputs are voltage level triggered and are not affected by transition time of the input data.

Features

- Alternate military/aerospace device (54LS279) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6420–1

Order Number 54LS279DMQB, 54LS279FMQB, 54LS279LMQB, DM54LS279J, DM74LS279M or DM74LS279N
See NS Package Number E20A, J16A, M16A, N16E or W16A

Function Table

Inputs		Output
$\overline{S}$(1)	$\overline{R}$	Q
L	L	H*
L	H	H
H	L	L
H	H	Q_0

H = High Level

L = Low Level

Q_0 = The Level of Q before the indicated input conditions were established.

*This output level is pseudo stable; that is, it may not persist when the $\overline{S}$ and $\overline{R}$ inputs return to their inactive (high) level.

Note 1: For latches with double $\overline{S}$ inputs:

H = both $\overline{S}$ inputs high

L = one or both $\overline{S}$ inputs low

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS279			DM74LS279			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max	DM54	2.5	3.5		V
		V_{IL} = Max, V_{IH} = Min	DM74	2.7	3.5		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max V_{IL} = Max, V_{IH} = Min	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.4	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CC}	Supply Current	V_{CC} = Max (Note 3)			3.8	7	mA

Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

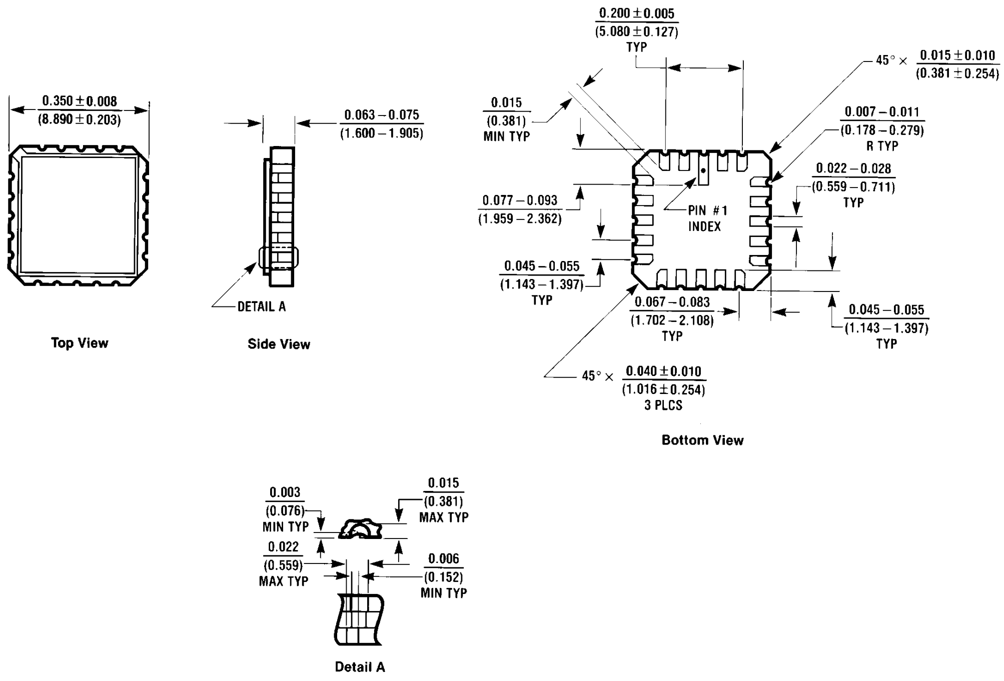
Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Note 3: I_{CC} is measured with all $\overline{R}$ inputs grounded, all $\overline{S}$ inputs at 4.5V and all outputs open.

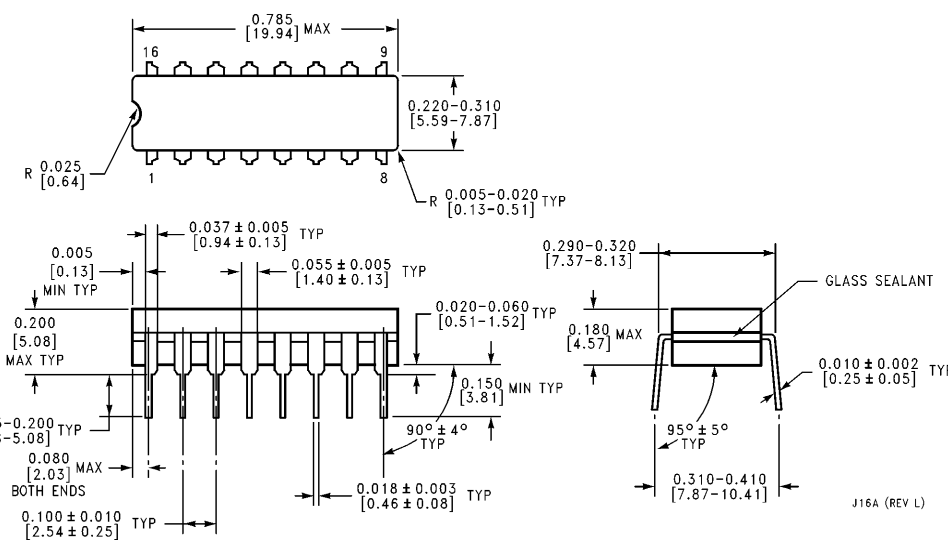
Switching Characteristics at $V_{CC} = 5V$ and $T_A = 25°C$ (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	From (Input) To (Output)	$R_L = 2\ k\Omega$				Units
			$C_L = 15\ pF$		$C_L = 50\ pF$		
			Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	$\overline{S}$ to Q		22		25	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	$\overline{S}$ to Q		15		23	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	$\overline{R}$ to Q		27		33	ns

Physical Dimensions inches (millimeters)

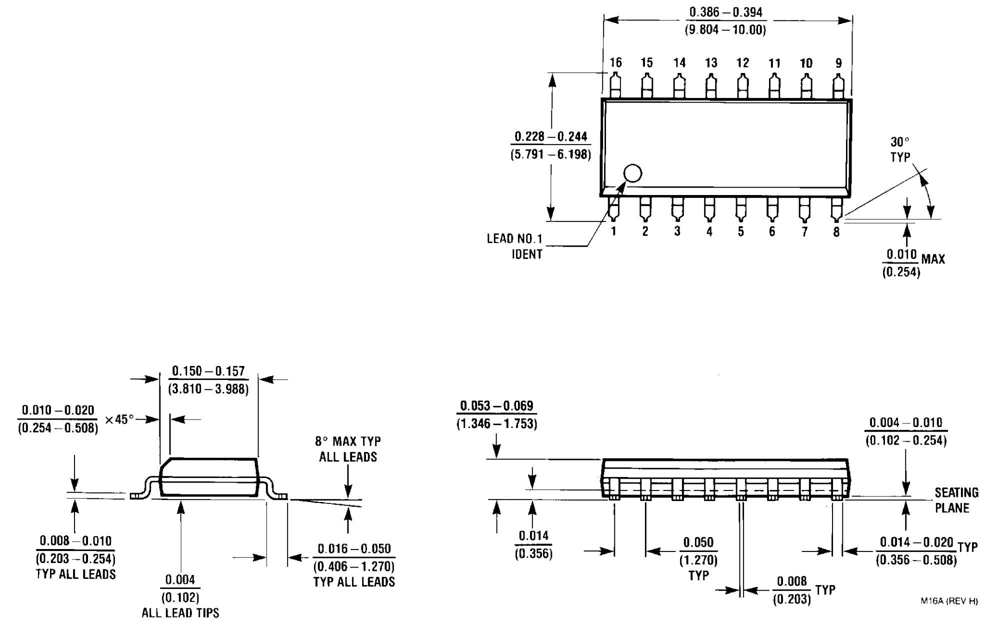


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS279LMQB
NS Package Number E20A

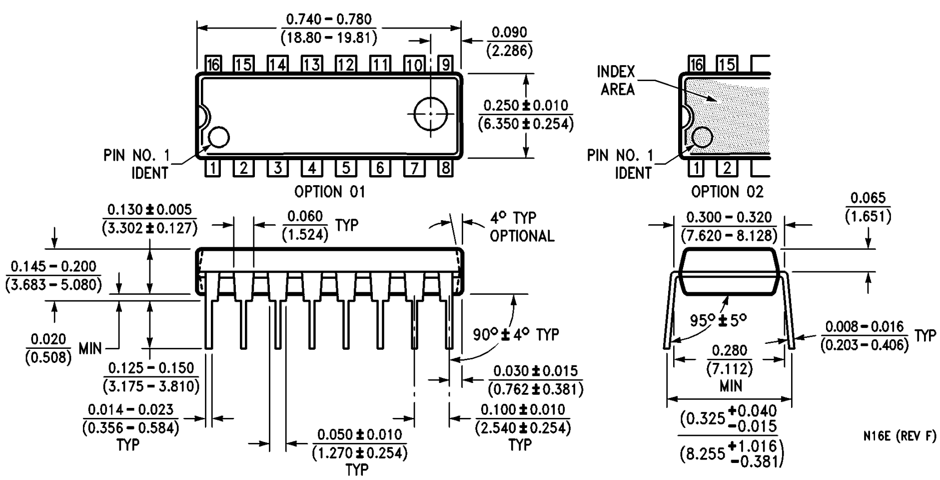


16-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS279DMQB or DM54LS279J
NS Package Number J16A

Physical Dimensions inches (millimeters) (Continued)

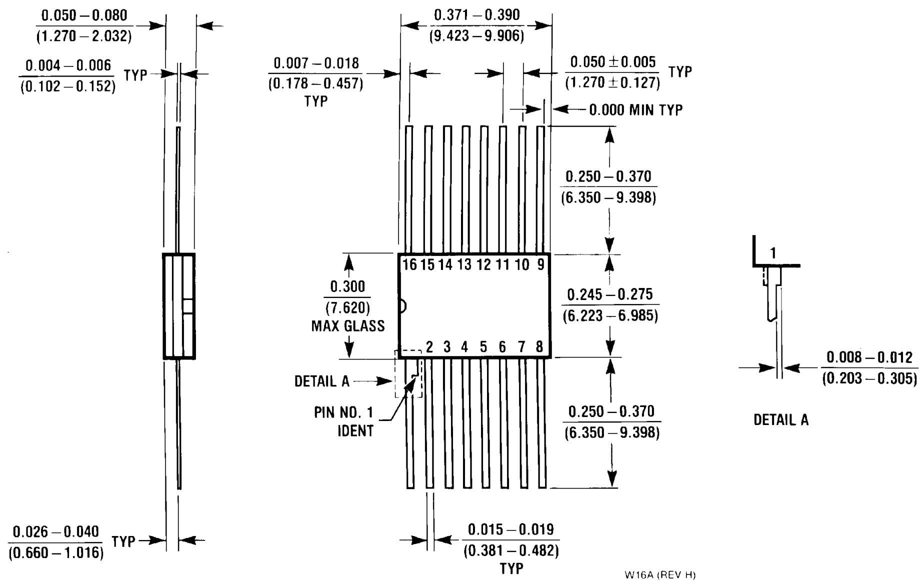


16-Lead Small Outline Molded Package (M)
Order Number DM74LS279M
NS Package Number M16A



16-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS279N
NS Package Number N16E

Physical Dimensions inches (millimeters) (Continued)



16-Lead Ceramic Flat Package (W)
Order Number 54LS279FMQB or DM54LS279W
NS Package Number W16A

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
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National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
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Features

- Compatible with MCS®-51 Products
- 4K Bytes of In-System Programmable (ISP) Flash Memory
  - Endurance: 1000 Write/Erase Cycles
- 4.0V to 5.5V Operating Range
- Fully Static Operation: 0 Hz to 33 MHz
- Three-level Program Memory Lock
- 128 x 8-bit Internal RAM
- 32 Programmable I/O Lines
- Two 16-bit Timer/Counters
- Six Interrupt Sources
- Full Duplex UART Serial Channel
- Low-power Idle and Power-down Modes
- Interrupt Recovery from Power-down Mode
- Watchdog Timer
- Dual Data Pointer
- Power-off Flag
- Fast Programming Time
- Flexible ISP Programming (Byte and Page Mode)

Description

The AT89S51 is a low-power, high-performance CMOS 8-bit microcontroller with 4K bytes of In-System Programmable Flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology and is compatible with the industry-standard 80C51 instruction set and pinout. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with In-System Programmable Flash on a monolithic chip, the Atmel AT89S51 is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications.

The AT89S51 provides the following standard features: 4K bytes of Flash, 128 bytes of RAM, 32 I/O lines, Watchdog timer, two data pointers, two 16-bit timer/counters, a five-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry. In addition, the AT89S51 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port, and interrupt system to continue functioning. The Power-down mode saves the RAM contents but freezes the oscillator, disabling all other chip functions until the next external interrupt or hardware reset.

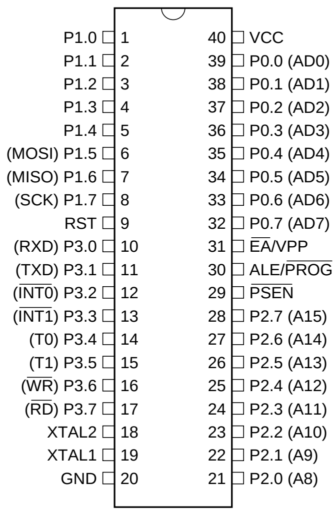
8-bit Microcontroller with 4K Bytes In-System Programmable Flash

AT89S51

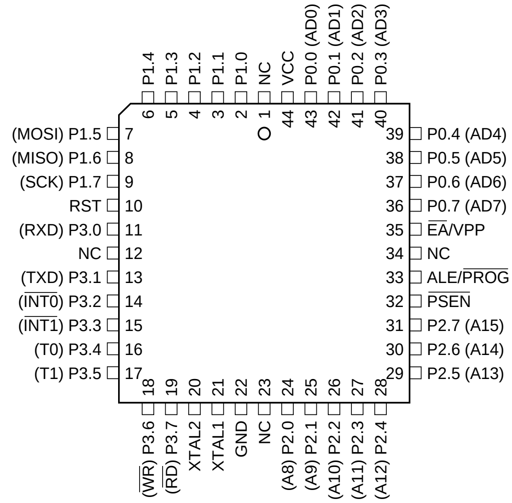
2487B–MICRO–12/03

Pin Configurations

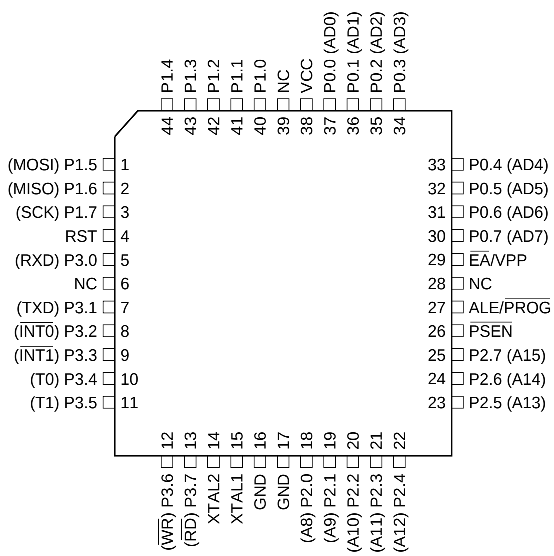
PDIP



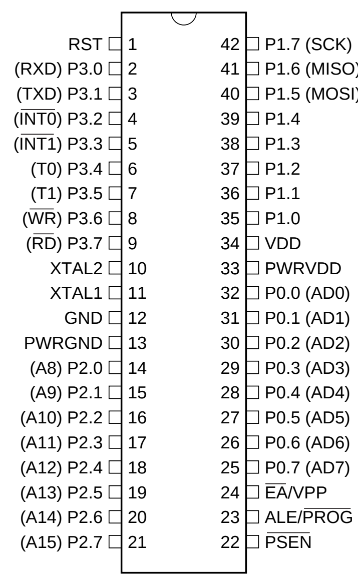
PLCC



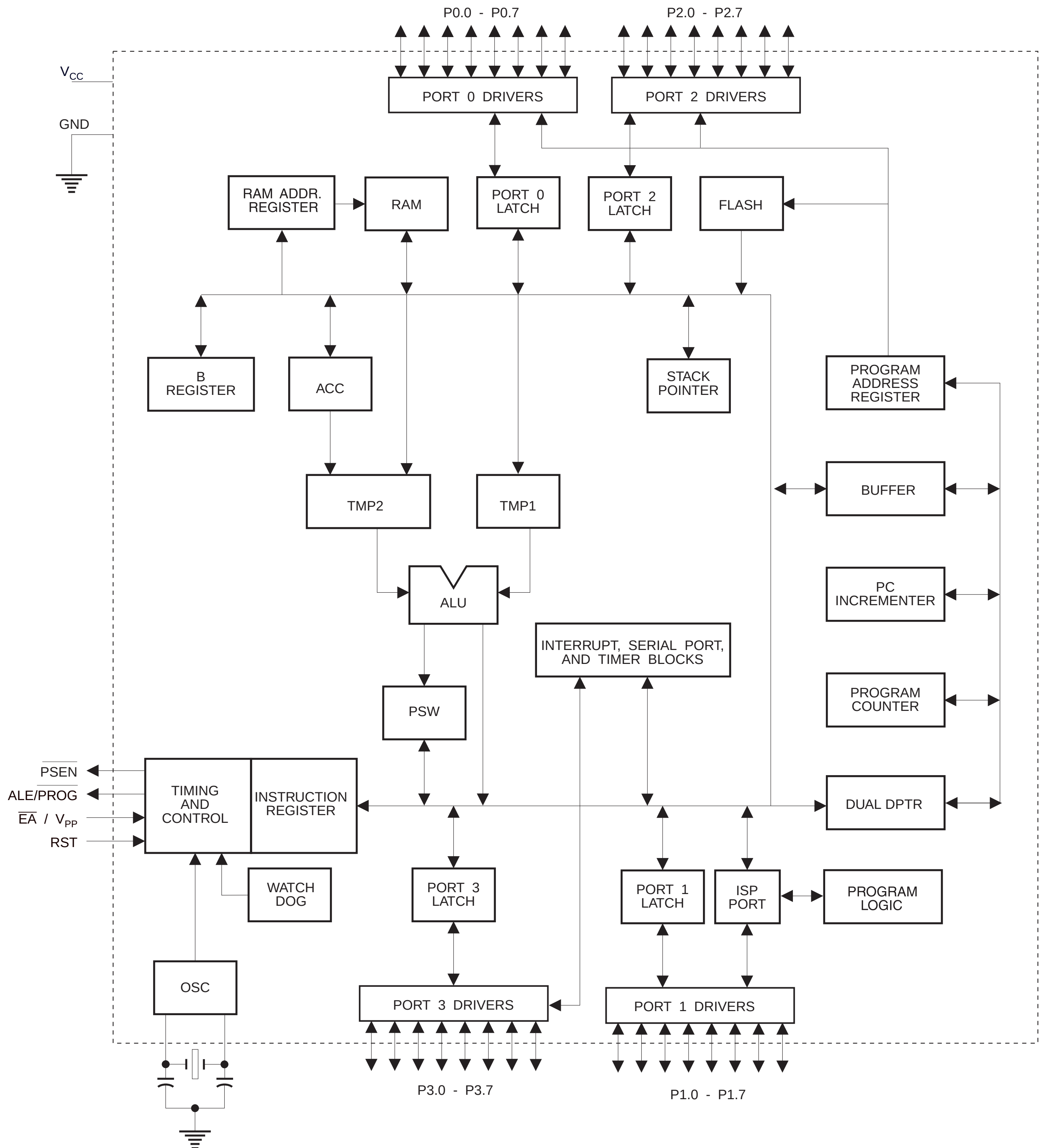
TQFP



PDIP



Block Diagram



Pin Description

VCC

Supply voltage (all packages except 42-PDIP).

GND

Ground (all packages except 42-PDIP; for 42-PDIP GND connects only the logic core and the embedded program memory).

VDD

Supply voltage for the 42-PDIP which connects only the logic core and the embedded program memory.

PWRVDD

Supply voltage for the 42-PDIP which connects only the I/O Pad Drivers. The application board **MUST** connect both VDD and PWRVDD to the board supply voltage.

PWRGND

Ground for the 42-PDIP which connects only the I/O Pad Drivers. PWRGND and GND are weakly connected through the common silicon substrate, but not through any metal link. The application board **MUST** connect both GND and PWRGND to the board ground.

Port 0

Port 0 is an 8-bit open drain bi-directional I/O port. As an output port, each pin can sink eight TTL inputs. When 1s are written to port 0 pins, the pins can be used as high-impedance inputs.

Port 0 can also be configured to be the multiplexed low-order address/data bus during accesses to external program and data memory. In this mode, P0 has internal pull-ups.

Port 0 also receives the code bytes during Flash programming and outputs the code bytes during program verification. **External pull-ups are required during program verification**.

Port 1

Port 1 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 1 output buffers can sink/source four TTL inputs. When 1s are written to Port 1 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 1 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

Port 1 also receives the low-order address bytes during Flash programming and verification.

Port Pin	Alternate Functions
P1.5	MOSI (used for In-System Programming)
P1.6	MISO (used for In-System Programming)
P1.7	SCK (used for In-System Programming)

Port 2

Port 2 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 2 output buffers can sink/source four TTL inputs. When 1s are written to Port 2 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 2 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

Port 2 emits the high-order address byte during fetches from external program memory and during accesses to external data memory that use 16-bit addresses (MOVX @ DPTR). In this application, Port 2 uses strong internal pull-ups when emitting 1s. During accesses to external data memory that use 8-bit addresses (MOVX @ RI), Port 2 emits the contents of the P2 Special Function Register.

Port 2 also receives the high-order address bits and some control signals during Flash programming and verification.

Port 3

Port 3 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 3 output buffers can sink/source four TTL inputs. When 1s are written to Port 3 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 3 pins that are externally being pulled low will source current (I_{IL}) because of the pull-ups.

Port 3 receives some control signals for Flash programming and verification.

Port 3 also serves the functions of various special features of the AT89S51, as shown in the following table.

Port Pin	Alternate Functions
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{\text{INT0}}$ (external interrupt 0)
P3.3	$\overline{\text{INT1}}$ (external interrupt 1)
P3.4	T0 (timer 0 external input)
P3.5	T1 (timer 1 external input)
P3.6	$\overline{\text{WR}}$ (external data memory write strobe)
P3.7	$\overline{\text{RD}}$ (external data memory read strobe)

RST

Reset input. A high on this pin for two machine cycles while the oscillator is running resets the device. This pin drives High for 98 oscillator periods after the Watchdog times out. The DISRTO bit in SFR AUXR (address 8EH) can be used to disable this feature. In the default state of bit DISRTO, the RESET HIGH out feature is enabled.

ALE/$\overline{\text{PROG}}$

Address Latch Enable (ALE) is an output pulse for latching the low byte of the address during accesses to external memory. This pin is also the program pulse input ($\overline{\text{PROG}}$) during Flash programming.

In normal operation, ALE is emitted at a constant rate of 1/6 the oscillator frequency and may be used for external timing or clocking purposes. Note, however, that one ALE pulse is skipped during each access to external data memory.

If desired, ALE operation can be disabled by setting bit 0 of SFR location 8EH. With the bit set, ALE is active only during a MOVX or MOVC instruction. Otherwise, the pin is weakly pulled high. Setting the ALE-disable bit has no effect if the microcontroller is in external execution mode.

$\overline{\text{PSEN}}$

Program Store Enable ($\overline{\text{PSEN}}$) is the read strobe to external program memory.

When the AT89S51 is executing code from external program memory, $\overline{\text{PSEN}}$ is activated twice each machine cycle, except that two $\overline{\text{PSEN}}$ activations are skipped during each access to external data memory.

$\overline{\text{EA}}$/VPP

External Access Enable. $\overline{\text{EA}}$ must be strapped to GND in order to enable the device to fetch code from external program memory locations starting at 0000H up to FFFFH. Note, however, that if lock bit 1 is programmed, $\overline{\text{EA}}$ will be internally latched on reset.

$\overline{\text{EA}}$ should be strapped to V_{CC} for internal program executions.

This pin also receives the 12-volt programming enable voltage (V_{PP}) during Flash programming.

XTAL1

Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the inverting oscillator amplifier

Special Function Registers

A map of the on-chip memory area called the Special Function Register (SFR) space is shown in Table 1.

Note that not all of the addresses are occupied, and unoccupied addresses may not be implemented on the chip. Read accesses to these addresses will in general return random data, and write accesses will have an indeterminate effect.

Table 1. AT89S51 SFR Map and Reset Values

0F8H									0FFH
0F0H	B 00000000								0F7H
0E8H									0EFH
0E0H	ACC 00000000								0E7H
0D8H									0DFH
0D0H	PSW 00000000								0D7H
0C8H									0CFH
0C0H									0C7H
0B8H	IP XX000000								0BFH
0B0H	P3 11111111								0B7H
0A8H	IE 0X000000								0AFH
0A0H	P2 11111111		AUXR1 XXXXXXX0				WDTRST XXXXXXXX		0A7H
98H	SCON 00000000	SBUF XXXXXXXX							9FH
90H	P1 11111111								97H
88H	TCON 00000000	TMOD 00000000	TL0 00000000	TL1 00000000	TH0 00000000	TH1 00000000	AUXR XXX00XX0		8FH
80H	P0 11111111	SP 00000111	DP0L 00000000	DP0H 00000000	DP1L 00000000	DP1H 00000000		PCON 0XXX0000	87H

User software should not write 1s to these unlisted locations, since they may be used in future products to invoke new features. In that case, the reset or inactive values of the new bits will always be 0.

Interrupt Registers: The individual interrupt enable bits are in the IE register. Two priorities can be set for each of the five interrupt sources in the IP register.

Table 2. AUXR: Auxiliary Register

AUXR Address = 8EH Reset Value = XXX00XX0B

Not Bit Addressable

	–	–	–	WDIDLE	DISRTO	–	–	DISALE
Bit	7	6	5	4	3	2	1	0

– Reserved for future expansion

DISALE Disable/Enable ALE

DISALE
Operating Mode

0 ALE is emitted at a constant rate of 1/6 the oscillator frequency

1 ALE is active only during a MOVX or MOVC instruction

DISRTO Disable/Enable Reset-out

DISRTO

0 Reset pin is driven High after WDT times out

1 Reset pin is input only

WDIDLE Disable/Enable WDT in IDLE mode

WDIDLE

0 WDT continues to count in IDLE mode

1 WDT halts counting in IDLE mode

Dual Data Pointer Registers: To facilitate accessing both internal and external data memory, two banks of 16-bit Data Pointer Registers are provided: DP0 at SFR address locations 82H-83H and DP1 at 84H-85H. Bit DPS = 0 in SFR AUXR1 selects DP0 and DPS = 1 selects DP1. The user should **ALWAYS** initialize the DPS bit to the appropriate value before accessing the respective Data Pointer Register.

Power Off Flag: The Power Off Flag (POF) is located at bit 4 (PCON.4) in the PCON SFR. POF is set to “1” during power up. It can be set and rest under software control and is not affected by reset.

Table 3. AUXR1: Auxiliary Register 1

AUXR1	Address = A2H						Reset Value = XXXXXXX0B	
Not Bit Addressable								
	–	–	–	–	–	–	–	DPS
Bit	7	6	5	4	3	2	1	0

–	Reserved for future expansion	
DPS	Data Pointer Register Select	
	DPS	
	0	Selects DPTR Registers DP0L, DP0H
	1	Selects DPTR Registers DP1L, DP1H

Memory Organization

MCS-51 devices have a separate address space for Program and Data Memory. Up to 64K bytes each of external Program and Data Memory can be addressed.

Program Memory

If the $\overline{EA}$ pin is connected to GND, all program fetches are directed to external memory.

On the AT89S51, if $\overline{EA}$ is connected to V_{CC}, program fetches to addresses 0000H through FFFH are directed to internal memory and fetches to addresses 1000H through FFFFH are directed to external memory.

Data Memory

The AT89S51 implements 128 bytes of on-chip RAM. The 128 bytes are accessible via direct and indirect addressing modes. Stack operations are examples of indirect addressing, so the 128 bytes of data RAM are available as stack space.

Watchdog Timer (One-time Enabled with Reset-out)

The WDT is intended as a recovery method in situations where the CPU may be subjected to software upsets. The WDT consists of a 14-bit counter and the Watchdog Timer Reset (WDTRST) SFR. The WDT is defaulted to disable from exiting reset. To enable the WDT, a user must write 01EH and 0E1H in sequence to the WDTRST register (SFR location 0A6H). When the WDT is enabled, it will increment every machine cycle while the oscillator is running. The WDT timeout period is dependent on the external clock frequency. There is no way to disable the WDT except through reset (either hardware reset or WDT overflow reset). When WDT overflows, it will drive an output RESET HIGH pulse at the RST pin.

Using the WDT

To enable the WDT, a user must write 01EH and 0E1H in sequence to the WDTRST register (SFR location 0A6H). When the WDT is enabled, the user needs to service it by writing 01EH and 0E1H to WDTRST to avoid a WDT overflow. The 14-bit counter overflows when it reaches 16383 (3FFFH), and this will reset the device. When the WDT is enabled, it will increment every machine cycle while the oscillator is running. This means the user must reset the WDT at least every 16383 machine cycles. To reset the WDT the user must write 01EH and 0E1H to WDTRST. WDTRST is a write-only register. The WDT counter cannot be read or written. When WDT overflows, it will generate an output RESET pulse at the RST pin. The RESET pulse duration is 98xTOSC, where TOSC = 1/FOSC. To make the best use of the WDT, it should be serviced in those sections of code that will periodically be executed within the time required to prevent a WDT reset.

WDT During Power-down and Idle

In Power-down mode the oscillator stops, which means the WDT also stops. While in Power-down mode, the user does not need to service the WDT. There are two methods of exiting Power-down mode: by a hardware reset or via a level-activated external interrupt, which is enabled prior to entering Power-down mode. When Power-down is exited with hardware reset, servicing the WDT should occur as it normally does whenever the AT89S51 is reset. Exiting Power-down with an interrupt is significantly different. The interrupt is held low long enough for the oscillator to stabilize. When the interrupt is brought high, the interrupt is serviced. To prevent the WDT from resetting the device while the interrupt pin is held low, the WDT is not started until the interrupt is pulled high. It is suggested that the WDT be reset during the interrupt service for the interrupt used to exit Power-down mode.

To ensure that the WDT does not overflow within a few states of exiting Power-down, it is best to reset the WDT just before entering Power-down mode.

Before going into the IDLE mode, the WDIDLE bit in SFR AUXR is used to determine whether the WDT continues to count if enabled. The WDT keeps counting during IDLE (WDIDLE bit = 0) as the default state. To prevent the WDT from resetting the AT89S51 while in IDLE mode, the user should always set up a timer that will periodically exit IDLE, service the WDT, and reenter IDLE mode.

With WDIDLE bit enabled, the WDT will stop to count in IDLE mode and resumes the count upon exit from IDLE.

UART

The UART in the AT89S51 operates the same way as the UART in the AT89C51. For further information on the UART operation, refer to the Atmel Web site (http://www.atmel.com). From the home page, select “Products”, then “Microcontrollers”, then “8051-Architecture”, then “Documentation”, and “Other Documents”. Open the Adobe® Acrobat® file “AT89 Series Hardware Description”.

Timer 0 and 1

Timer 0 and Timer 1 in the AT89S51 operate the same way as Timer 0 and Timer 1 in the AT89C51. For further information on the timers’ operation, refer to the Atmel Web site (http://www.atmel.com). From the home page, select “Products”, then “Microcontrollers”, then “8051-Architecture”, then “Documentation”, and “Other Documents”. Open the Adobe Acrobat file “AT89 Series Hardware Description”.

Interrupts

The AT89S51 has a total of five interrupt vectors: two external interrupts ($\overline{\text{INT0}}$ and $\overline{\text{INT1}}$), two timer interrupts (Timers 0 and 1), and the serial port interrupt. These interrupts are all shown in Figure 1.

Each of these interrupt sources can be individually enabled or disabled by setting or clearing a bit in Special Function Register IE. IE also contains a global disable bit, EA, which disables all interrupts at once.

Note that Table 4 shows that bit positions IE.6 and IE.5 are unimplemented. User software should not write 1s to these bit positions, since they may be used in future AT89 products.

The Timer 0 and Timer 1 flags, TF0 and TF1, are set at S5P2 of the cycle in which the timers overflow. The values are then polled by the circuitry in the next cycle.

Table 4. Interrupt Enable (IE) Register

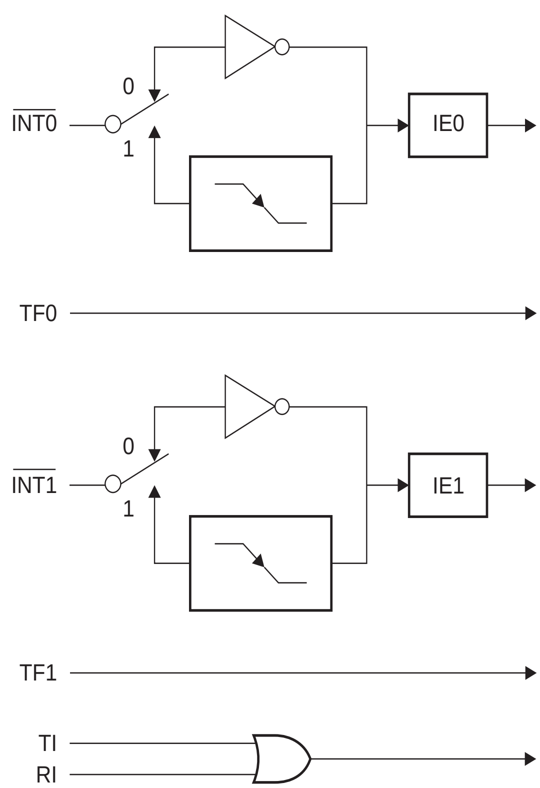
(MSB)							(LSB)
EA	–	–	ES	ET1	EX1	ET0	EX0

Enable Bit = 1 enables the interrupt.

Enable Bit = 0 disables the interrupt.

Symbol	Position	Function
EA	IE.7	Disables all interrupts. If EA = 0, no interrupt is acknowledged. If EA = 1, each interrupt source is individually enabled or disabled by setting or clearing its enable bit.
–	IE.6	Reserved
–	IE.5	Reserved
ES	IE.4	Serial Port interrupt enable bit
ET1	IE.3	Timer 1 interrupt enable bit
EX1	IE.2	External interrupt 1 enable bit
ET0	IE.1	Timer 0 interrupt enable bit
EX0	IE.0	External interrupt 0 enable bit
User software should never write 1s to reserved bits, because they may be used in future AT89 products.		

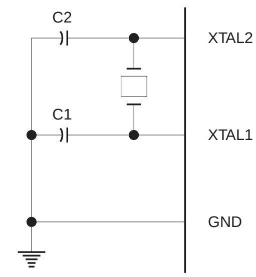
Figure 1. Interrupt Sources



Oscillator Characteristics

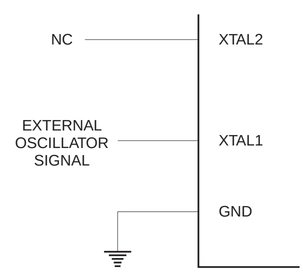
XTAL1 and XTAL2 are the input and output, respectively, of an inverting amplifier that can be configured for use as an on-chip oscillator, as shown in Figure 2. Either a quartz crystal or ceramic resonator may be used. To drive the device from an external clock source, XTAL2 should be left unconnected while XTAL1 is driven, as shown in Figure 3. There are no requirements on the duty cycle of the external clock signal, since the input to the internal clocking circuitry is through a divide-by-two flip-flop, but minimum and maximum voltage high and low time specifications must be observed.

Figure 2. Oscillator Connections



Note: C1, C2 = 30 pF ± 10 pF for Crystals
= 40 pF ± 10 pF for Ceramic Resonators

Figure 3. External Clock Drive Configuration



Idle Mode

In idle mode, the CPU puts itself to sleep while all the on-chip peripherals remain active. The mode is invoked by software. The content of the on-chip RAM and all the special function registers remain unchanged during this mode. The idle mode can be terminated by any enabled interrupt or by a hardware reset.

Note that when idle mode is terminated by a hardware reset, the device normally resumes program execution from where it left off, up to two machine cycles before the internal reset algorithm takes control. On-chip hardware inhibits access to internal RAM in this event, but access to the port pins is not inhibited. To eliminate the possibility of an unexpected write to a port pin when idle mode is terminated by a reset, the instruction following the one that invokes idle mode should not write to a port pin or to external memory.

Power-down Mode

In the Power-down mode, the oscillator is stopped, and the instruction that invokes Power-down is the last instruction executed. The on-chip RAM and Special Function Registers retain their values until the Power-down mode is terminated. Exit from Power-down mode can be initiated either by a hardware reset or by activation of an enabled external interrupt ($\overline{\text{INT0}}$ or $\overline{\text{INT1}}$). Reset redefines the SFRs but does not change the on-chip RAM. The reset should not be activated before V_{CC} is restored to its normal operating level and must be held active long enough to allow the oscillator to restart and stabilize.

Table 5. Status of External Pins During Idle and Power-down Modes

Mode	Program Memory	ALE	$\overline{PSEN}$	PORT0	PORT1	PORT2	PORT3
Idle	Internal	1	1	Data	Data	Data	Data
Idle	External	1	1	Float	Data	Address	Data
Power-down	Internal	0	0	Data	Data	Data	Data
Power-down	External	0	0	Float	Data	Data	Data

Program Memory Lock Bits

The AT89S51 has three lock bits that can be left unprogrammed (U) or can be programmed (P) to obtain the additional features listed in the following table.

Table 6. Lock Bit Protection Modes

Program Lock Bits	LB1	LB2	LB3	Protection Type
1	U	U	U	No program lock features
2	P	U	U	MOVC instructions executed from external program memory are disabled from fetching code bytes from internal memory, $\overline{EA}$ is sampled and latched on reset, and further programming of the Flash memory is disabled
3	P	P	U	Same as mode 2, but verify is also disabled
4	P	P	P	Same as mode 3, but external execution is also disabled

When lock bit 1 is programmed, the logic level at the $\overline{EA}$ pin is sampled and latched during reset. If the device is powered up without a reset, the latch initializes to a random value and holds that value until reset is activated. The latched value of $\overline{EA}$ must agree with the current logic level at that pin in order for the device to function properly.

Programming the Flash – Parallel Mode

The AT89S51 is shipped with the on-chip Flash memory array ready to be programmed. The programming interface needs a high-voltage (12-volt) program enable signal and is compatible with conventional third-party Flash or EPROM programmers.

The AT89S51 code memory array is programmed byte-by-byte.

Programming Algorithm: Before programming the AT89S51, the address, data, and control signals should be set up according to the Flash Programming Modes table (Table 7) and Figures 4 and 5. To program the AT89S51, take the following steps:

1. Input the desired memory location on the address lines.
2. Input the appropriate data byte on the data lines.
3. Activate the correct combination of control signals.
4. Raise $\overline{EA}/V_{PP}$ to 12V.
5. Pulse ALE/$\overline{PROG}$ once to program a byte in the Flash array or the lock bits. The byte-write cycle is self-timed and typically takes no more than 50 µs. Repeat steps 1 through 5, changing the address and data for the entire array or until the end of the object file is reached.

$\overline{\text{Data}}$ Polling: The AT89S51 features $\overline{\text{Data}}$ Polling to indicate the end of a byte write cycle. During a write cycle, an attempted read of the last byte written will result in the complement of the written data on P0.7. Once the write cycle has been completed, true data is valid on all outputs, and the next cycle may begin. $\overline{\text{Data}}$ Polling may begin any time after a write cycle has been initiated.

Ready/$\overline{\text{Busy}}$: The progress of byte programming can also be monitored by the RDY/$\overline{\text{BSY}}$ output signal. P3.0 is pulled low after ALE goes high during programming to indicate $\overline{\text{BUSY}}$. P3.0 is pulled high again when programming is done to indicate READY.

Program Verify: If lock bits LB1 and LB2 have not been programmed, the programmed code data can be read back via the address and data lines for verification. **The status of the individual lock bits can be verified directly by reading them back.**

Reading the Signature Bytes: The signature bytes are read by the same procedure as a normal verification of locations 000H, 100H, and 200H, except that P3.6 and P3.7 must be pulled to a logic low. The values returned are as follows.

(000H) = 1EH indicates manufactured by Atmel
(100H) = 51H indicates AT89S51
(200H) = 06H

Chip Erase: In the parallel programming mode, a chip erase operation is initiated by using the proper combination of control signals and by pulsing ALE/$\overline{\text{PROG}}$ low for a duration of 200 ns - 500 ns.

In the serial programming mode, a chip erase operation is initiated by issuing the Chip Erase instruction. In this mode, chip erase is self-timed and takes about 500 ms.

During chip erase, a serial read from any address location will return 00H at the data output.

Programming the Flash – Serial Mode

The Code memory array can be programmed using the serial ISP interface while RST is pulled to V_{CC}. The serial interface consists of pins SCK, MOSI (input) and MISO (output). After RST is set high, the Programming Enable instruction needs to be executed first before other operations can be executed. Before a reprogramming sequence can occur, a Chip Erase operation is required.

The Chip Erase operation turns the content of every memory location in the Code array into FFH.

Either an external system clock can be supplied at pin XTAL1 or a crystal needs to be connected across pins XTAL1 and XTAL2. The maximum serial clock (SCK) frequency should be less than 1/16 of the crystal frequency. With a 33 MHz oscillator clock, the maximum SCK frequency is 2 MHz.

Serial Programming Algorithm

To program and verify the AT89S51 in the serial programming mode, the following sequence is recommended:

1. Power-up sequence:

   Apply power between VCC and GND pins.

   Set RST pin to “H”.

   If a crystal is not connected across pins XTAL1 and XTAL2, apply a 3 MHz to 33 MHz clock to XTAL1 pin and wait for at least 10 milliseconds.
2. Enable serial programming by sending the Programming Enable serial instruction to pin MOSI/P1.5. The frequency of the shift clock supplied at pin SCK/P1.7 needs to be less than the CPU clock at XTAL1 divided by 16.
3. The Code array is programmed one byte at a time in either the Byte or Page mode. The write cycle is self-timed and typically takes less than 0.5 ms at 5V.
4. Any memory location can be verified by using the Read instruction that returns the content at the selected address at serial output MISO/P1.6.
5. At the end of a programming session, RST can be set low to commence normal device operation.

Power-off sequence (if needed):

Set XTAL1 to “L” (if a crystal is not used).

Set RST to “L”.

Turn V_{CC} power off.

$\overline{\text{Data}}$ Polling: The $\overline{\text{Data}}$ Polling feature is also available in the serial mode. In this mode, during a write cycle an attempted read of the last byte written will result in the complement of the MSB of the serial output byte on MISO.

Serial Programming Instruction Set

The Instruction Set for Serial Programming follows a 4-byte protocol and is shown in Table 8.

Programming Interface – Parallel Mode

Every code byte in the Flash array can be programmed by using the appropriate combination of control signals. The write operation cycle is self-timed and once initiated, will automatically time itself to completion.

Most major worldwide programming vendors offer worldwide support for the Atmel AT89 microcontroller series. Please contact your local programming vendor for the appropriate software revision.

Table 7. Flash Programming Modes

Mode	V_{CC}	RST	$\overline{PSEN}$	ALE/ $\overline{PROG}$	$\overline{EA}$/ V_{PP}	P2.6	P2.7	P3.3	P3.6	P3.7	P0.7-0 Data	P2.3-0 Address	P1.7-0 Address
Write Code Data	5V	H	L	(2)	12V	L	H	H	H	H	D_{IN}	A11-8	A7-0
Read Code Data	5V	H	L	H	H	L	L	L	H	H	D_{OUT}	A11-8	A7-0
Write Lock Bit 1	5V	H	L	(3)	12V	H	H	H	H	H	X	X	X
Write Lock Bit 2	5V	H	L	(3)	12V	H	H	H	L	L	X	X	X
Write Lock Bit 3	5V	H	L	(3)	12V	H	L	H	H	L	X	X	X
Read Lock Bits 1, 2, 3	5V	H	L	H	H	H	H	L	H	L	P0.2, P0.3, P0.4	X	X
Chip Erase	5V	H	L	(1)	12V	H	L	H	L	L	X	X	X
Read Atmel ID	5V	H	L	H	H	L	L	L	L	L	1EH	0000	00H
Read Device ID	5V	H	L	H	H	L	L	L	L	L	51H	0001	00H
Read Device ID	5V	H	L	H	H	L	L	L	L	L	06H	0010	00H

Notes:
1. Each $\overline{PROG}$ pulse is 200 ns - 500 ns for Chip Erase.
2. Each $\overline{PROG}$ pulse is 200 ns - 500 ns for Write Code Data.
3. Each $\overline{PROG}$ pulse is 200 ns - 500 ns for Write Lock Bits.
4. RDY/$\overline{BSY}$ signal is output on P3.0 during programming.
5. X = don’t care.

Figure 4. Programming the Flash Memory (Parallel Mode)

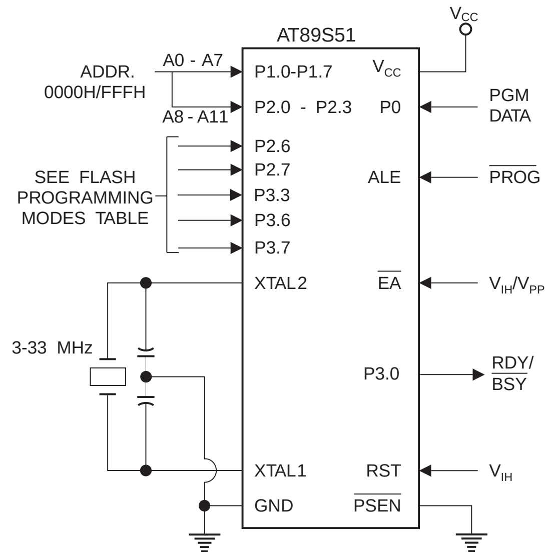
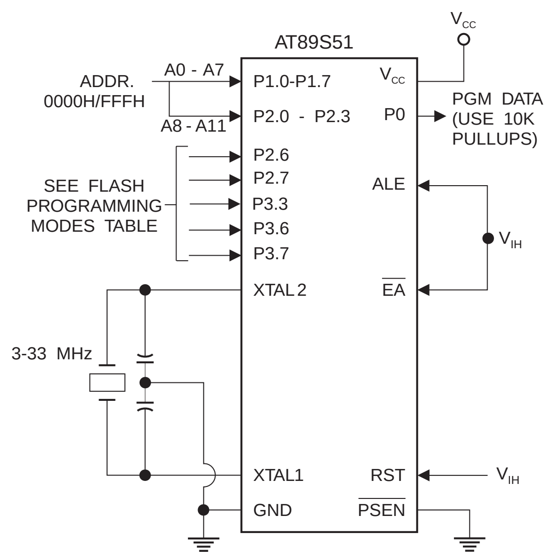


Figure 5. Verifying the Flash Memory (Parallel Mode)



Flash Programming and Verification Characteristics (Parallel Mode)

T_A = 20°C to 30°C, V_{CC} = 4.5 to 5.5V

Symbol	Parameter	Min	Max	Units
V_{PP}	Programming Supply Voltage	11.5	12.5	V
I_{PP}	Programming Supply Current		10	mA
I_{CC}	V_{CC} Supply Current		30	mA
$1/t_{CLCL}$	Oscillator Frequency	3	33	MHz
t_{AVGL}	Address Setup to $\overline{\text{PROG}}$ Low	$48t_{CLCL}$		
t_{GHAX}	Address Hold After $\overline{\text{PROG}}$	$48t_{CLCL}$		
t_{DVGL}	Data Setup to $\overline{\text{PROG}}$ Low	$48t_{CLCL}$		
t_{GHDX}	Data Hold After $\overline{\text{PROG}}$	$48t_{CLCL}$		
t_{EHSH}	P2.7 ($\overline{\text{ENABLE}}$) High to V_{PP}	$48t_{CLCL}$		
t_{SHGL}	V_{PP} Setup to $\overline{\text{PROG}}$ Low	10		µs
t_{GHSL}	V_{PP} Hold After $\overline{\text{PROG}}$	10		µs
t_{GLGH}	$\overline{\text{PROG}}$ Width	0.2	1	µs
t_{AVQV}	Address to Data Valid		$48t_{CLCL}$	
t_{ELQV}	$\overline{\text{ENABLE}}$ Low to Data Valid		$48t_{CLCL}$	
t_{EHQZ}	Data Float After $\overline{\text{ENABLE}}$	0	$48t_{CLCL}$	
t_{GHBL}	$\overline{\text{PROG}}$ High to $\overline{\text{BUSY}}$ Low		1.0	µs
t_{WC}	Byte Write Cycle Time		50	µs

Figure 6. Flash Programming and Verification Waveforms – Parallel Mode

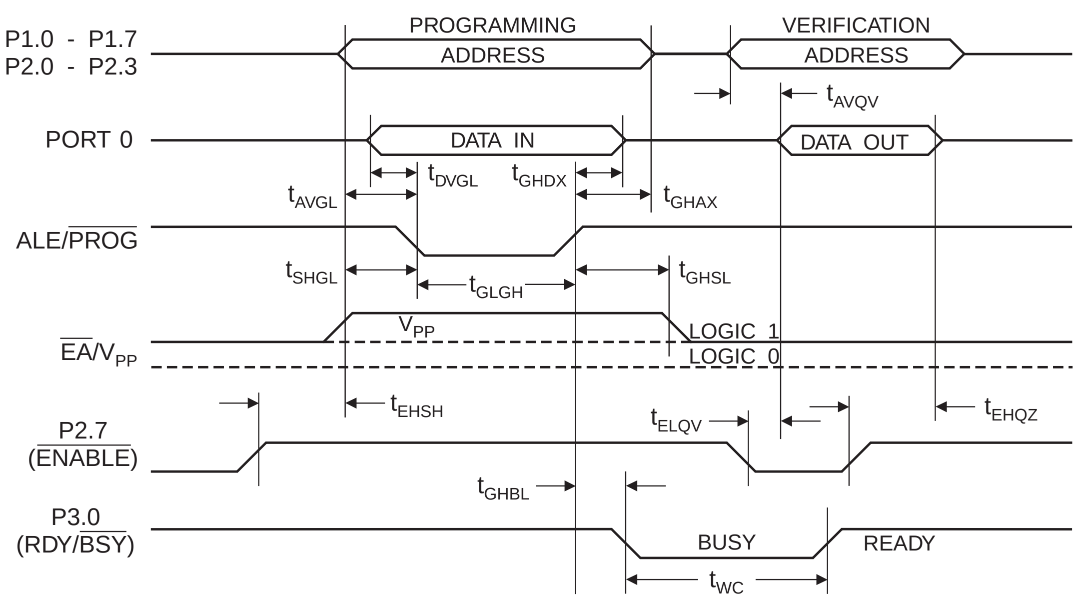
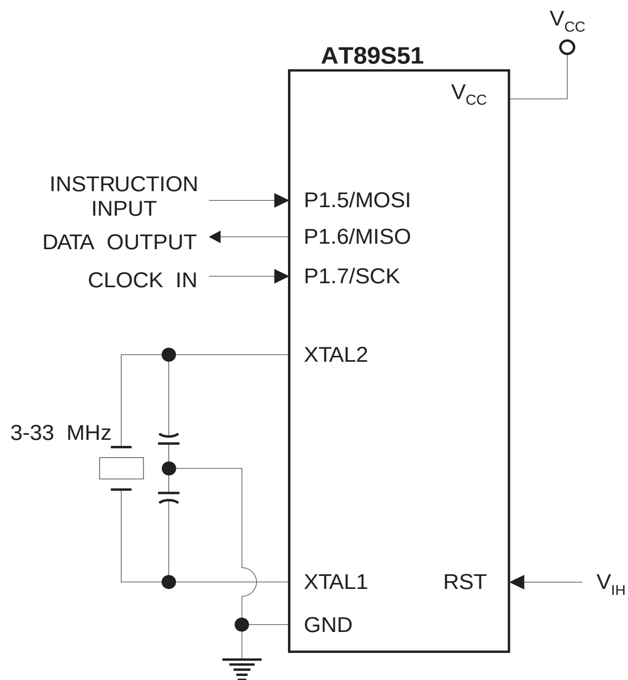


Figure 7. Flash Memory Serial Downloading



Flash Programming and Verification Waveforms – Serial Mode

Figure 8. Serial Programming Waveforms

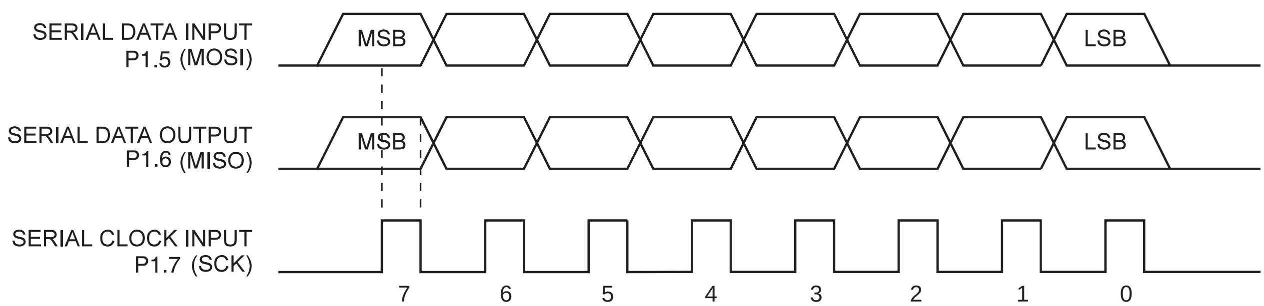


Table 8. Serial Programming Instruction Set

Instruction	Instruction Format Byte 1	Byte 2	Byte 3	Byte 4	Operation
Programming Enable	1010 1100	0101 0011	xxxx xxxx	xxxx xxxx 0110 1001 (Output on MISO)	Enable Serial Programming while RST is high
Chip Erase	1010 1100	100x xxxx	xxxx xxxx	xxxx xxxx	Chip Erase Flash memory array
Read Program Memory (Byte Mode)	0010 0000	xxxx A11 A10 A9 A8	A7 A6 A5 A4 A3 A2 A1 A0	D7 D6 D5 D4 D3 D2 D1 D0	Read data from Program memory in the byte mode
Write Program Memory (Byte Mode)	0100 0000	xxxx A11 A10 A9 A8	A7 A6 A5 A4 A3 A2 A1 A0	D7 D6 D5 D4 D3 D2 D1 D0	Write data to Program memory in the byte mode
Write Lock Bits(1)	1010 1100	1110 00 B1 B2	xxxx xxxx	xxxx xxxx	Write Lock bits. See Note (1).
Read Lock Bits	0010 0100	xxxx xxxx	xxxx xxxx	xxx LB3 LB2 LB1 xx	Read back current status of the lock bits (a programmed lock bit reads back as a "1")
Read Signature Bytes	0010 1000	xxxx A11 A10 A9 A8	A7 xxx xxx0	Signature Byte	Read Signature Byte
Read Program Memory (Page Mode)	0011 0000	xxxx A11 A10 A9 A8	Byte 0	Byte 1... Byte 255	Read data from Program memory in the Page Mode (256 bytes)
Write Program Memory (Page Mode)	0101 0000	xxxx A11 A10 A9 A8	Byte 0	Byte 1... Byte 255	Write data to Program memory in the Page Mode (256 bytes)

Note: 1. B1 = 0, B2 = 0 → Mode 1, no lock protection
B1 = 0, B2 = 1 → Mode 2, lock bit 1 activated
B1 = 1, B2 = 0 → Mode 3, lock bit 2 activated
B1 = 1, B2 = 1 → Mode 4, lock bit 3 activated

}Each of the lock bit modes need to be activated sequentially before Mode 4 can be executed.

After Reset signal is high, SCK should be low for at least 64 system clocks before it goes high to clock in the enable data bytes. No pulsing of Reset signal is necessary. SCK should be no faster than 1/16 of the system clock at XTAL1.

For Page Read/Write, the data always starts from byte 0 to 255. After the command byte and upper address byte are latched, each byte thereafter is treated as data until all 256 bytes are shifted in/out. Then the next instruction will be ready to be decoded.

Serial Programming Characteristics

Figure 9. Serial Programming Timing

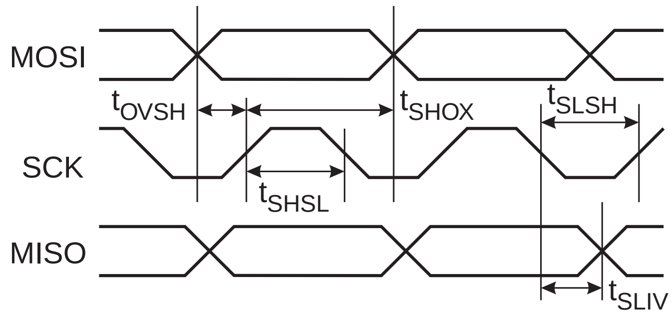


Table 9. Serial Programming Characteristics, T_A = -40° C to 85° C, V_{CC} = 4.0 - 5.5V (Unless Otherwise Noted)

Symbol	Parameter	Min	Typ	Max	Units
$1/t_{CLCL}$	Oscillator Frequency	3		33	MHz
t_{CLCL}	Oscillator Period	30			ns
t_{SHSL}	SCK Pulse Width High	8 t_{CLCL}			ns
t_{SLSH}	SCK Pulse Width Low	8 t_{CLCL}			ns
t_{OVSH}	MOSI Setup to SCK High	t_{CLCL}			ns
t_{SHOX}	MOSI Hold after SCK High	2 t_{CLCL}			ns
t_{SLIV}	SCK Low to MISO Valid	10	16	32	ns
t_{ERASE}	Chip Erase Instruction Cycle Time			500	ms
t_{SWC}	Serial Byte Write Cycle Time			64 t_{CLCL} + 400	µs

Absolute Maximum Ratings*

Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C
Voltage on Any Pin with Respect to Ground	-1.0V to +7.0V
Maximum Operating Voltage	6.6V
DC Output Current	15.0 mA

*NOTICE: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC Characteristics

The values shown in this table are valid for T_A = -40°C to 85°C and V_{CC} = 4.0V to 5.5V, unless otherwise noted.

Symbol	Parameter	Condition	Min	Max	Units
V_{IL}	Input Low Voltage	(Except $\overline{EA}$)	-0.5	0.2 V_{CC}-0.1	V
V_{IL1}	Input Low Voltage ($\overline{EA}$)		-0.5	0.2 V_{CC}-0.3	V
V_{IH}	Input High Voltage	(Except XTAL1, RST)	0.2 V_{CC}+0.9	V_{CC}+0.5	V
V_{IH1}	Input High Voltage	(XTAL1, RST)	0.7 V_{CC}	V_{CC}+0.5	V
V_{OL}	Output Low Voltage(1) (Ports 1,2,3)	I_{OL} = 1.6 mA		0.45	V
V_{OL1}	Output Low Voltage(1) (Port 0, ALE, $\overline{PSEN}$)	I_{OL} = 3.2 mA		0.45	V
V_{OH}	Output High Voltage (Ports 1,2,3, ALE, $\overline{PSEN}$)	I_{OH} = -60 µA, V_{CC} = 5V ±10%	2.4		V
		I_{OH} = -25 µA	0.75 V_{CC}		V
		I_{OH} = -10 µA	0.9 V_{CC}		V
V_{OH1}	Output High Voltage (Port 0 in External Bus Mode)	I_{OH} = -800 µA, V_{CC} = 5V ±10%	2.4		V
		I_{OH} = -300 µA	0.75 V_{CC}		V
		I_{OH} = -80 µA	0.9 V_{CC}		V
I_{IL}	Logical 0 Input Current (Ports 1,2,3)	V_{IN} = 0.45V		-50	µA
I_{TL}	Logical 1 to 0 Transition Current (Ports 1,2,3)	V_{IN} = 2V, V_{CC} = 5V ±10%		-650	µA
I_{LI}	Input Leakage Current (Port 0, $\overline{EA}$)	0.45 < V_{IN} < V_{CC}		±10	µA
RRST	Reset Pulldown Resistor		50	300	KΩ
C_{IO}	Pin Capacitance	Test Freq. = 1 MHz, T_A = 25°C		10	pF
I_{CC}	Power Supply Current	Active Mode, 12 MHz		25	mA
		Idle Mode, 12 MHz		6.5	mA
	Power-down Mode(2)	V_{CC} = 5.5V		50	µA

Notes: 1. Under steady state (non-transient) conditions, I_{OL} must be externally limited as follows:
Maximum I_{OL} per port pin: 10 mA
Maximum I_{OL} per 8-bit port:
Port 0: 26 mA Ports 1, 2, 3: 15 mA
Maximum total I_{OL} for all output pins: 71 mA
If I_{OL} exceeds the test condition, V_{OL} may exceed the related specification. Pins are not guaranteed to sink current greater than the listed test conditions.
2. Minimum V_{CC} for Power-down is 2V.

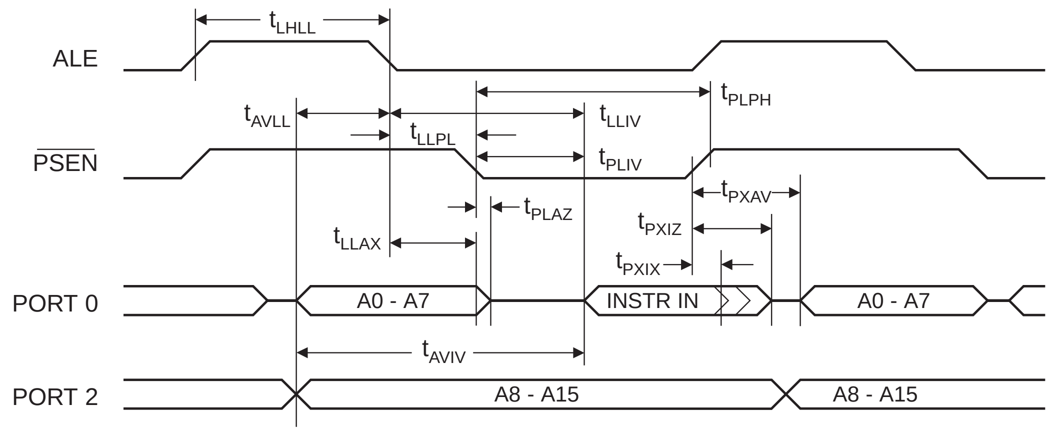
AC Characteristics

Under operating conditions, load capacitance for Port 0, ALE/$\overline{PROG}$, and $\overline{PSEN}$ = 100 pF; load capacitance for all other outputs = 80 pF.

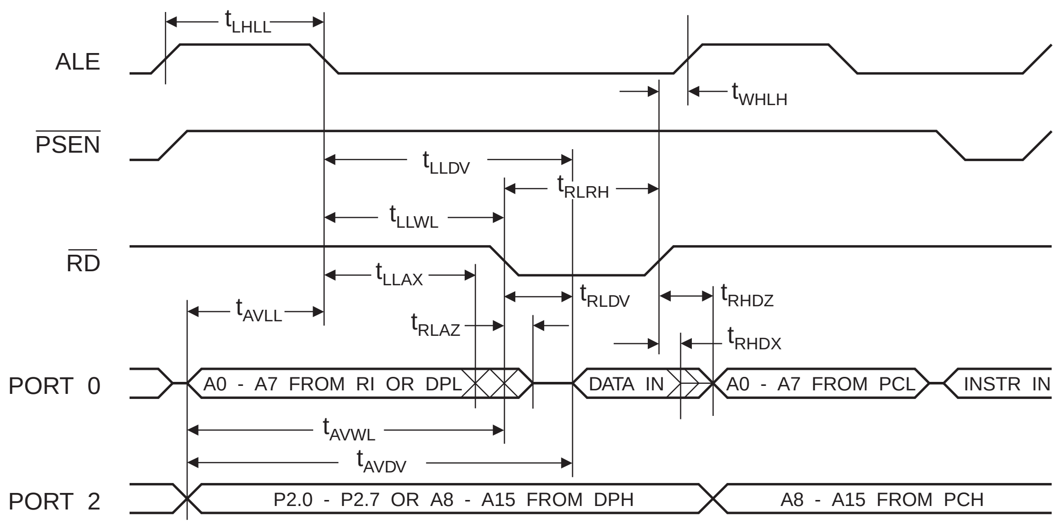
External Program and Data Memory Characteristics

Symbol	Parameter	12 MHz Oscillator		Variable Oscillator		Units
		Min	Max	Min	Max	
$1/t_{CLCL}$	Oscillator Frequency			0	33	MHz
t_{LHLL}	ALE Pulse Width	127		$2t_{CLCL}$-40		ns
t_{AVLL}	Address Valid to ALE Low	43		t_{CLCL}-25		ns
t_{LLAX}	Address Hold After ALE Low	48		t_{CLCL}-25		ns
t_{LLIV}	ALE Low to Valid Instruction In		233		$4t_{CLCL}$-65	ns
t_{LLPL}	ALE Low to $\overline{PSEN}$ Low	43		t_{CLCL}-25		ns
t_{PLPH}	$\overline{PSEN}$ Pulse Width	205		$3t_{CLCL}$-45		ns
t_{PLIV}	$\overline{PSEN}$ Low to Valid Instruction In		145		$3t_{CLCL}$-60	ns
t_{PXIX}	Input Instruction Hold After $\overline{PSEN}$	0		0		ns
t_{PXIZ}	Input Instruction Float After $\overline{PSEN}$		59		t_{CLCL}-25	ns
t_{PXAV}	$\overline{PSEN}$ to Address Valid	75		t_{CLCL}-8		ns
t_{AVIV}	Address to Valid Instruction In		312		$5t_{CLCL}$-80	ns
t_{PLAZ}	$\overline{PSEN}$ Low to Address Float		10		10	ns
t_{RLRH}	$\overline{RD}$ Pulse Width	400		$6t_{CLCL}$-100		ns
t_{WLWH}	$\overline{WR}$ Pulse Width	400		$6t_{CLCL}$-100		ns
t_{RLDV}	$\overline{RD}$ Low to Valid Data In		252		$5t_{CLCL}$-90	ns
t_{RHDX}	Data Hold After $\overline{RD}$	0		0		ns
t_{RHDZ}	Data Float After $\overline{RD}$		97		$2t_{CLCL}$-28	ns
t_{LLDV}	ALE Low to Valid Data In		517		$8t_{CLCL}$-150	ns
t_{AVDV}	Address to Valid Data In		585		$9t_{CLCL}$-165	ns
t_{LLWL}	ALE Low to $\overline{RD}$ or $\overline{WR}$ Low	200	300	$3t_{CLCL}$-50	$3t_{CLCL}$+50	ns
t_{AVWL}	Address to $\overline{RD}$ or $\overline{WR}$ Low	203		$4t_{CLCL}$-75		ns
t_{QVWX}	Data Valid to $\overline{WR}$ Transition	23		t_{CLCL}-30		ns
t_{QVWH}	Data Valid to $\overline{WR}$ High	433		$7t_{CLCL}$-130		ns
t_{WHQX}	Data Hold After $\overline{WR}$	33		t_{CLCL}-25		ns
t_{RLAZ}	$\overline{RD}$ Low to Address Float		0		0	ns
t_{WHLH}	$\overline{RD}$ or $\overline{WR}$ High to ALE High	43	123	t_{CLCL}-25	t_{CLCL}+25	ns

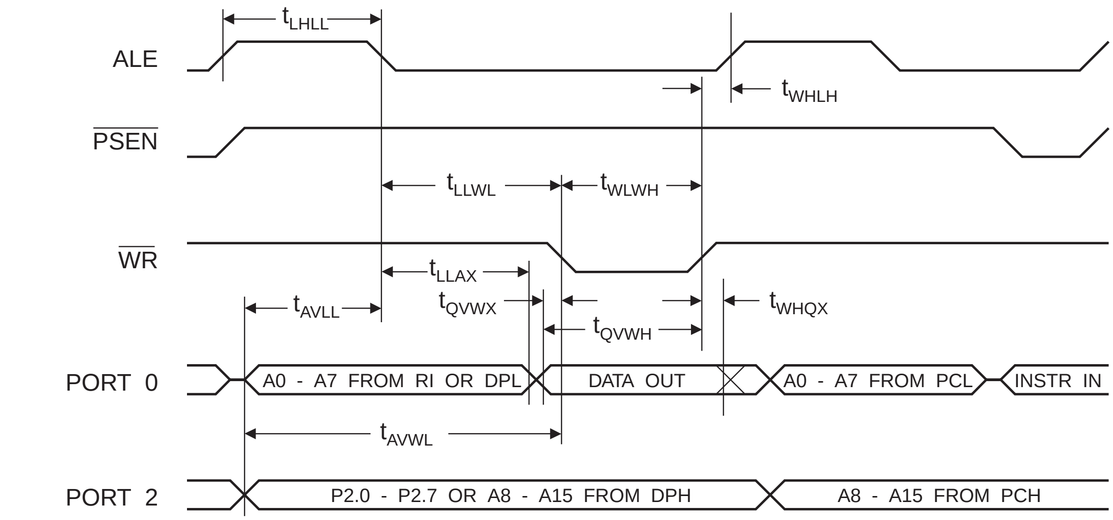
External Program Memory Read Cycle



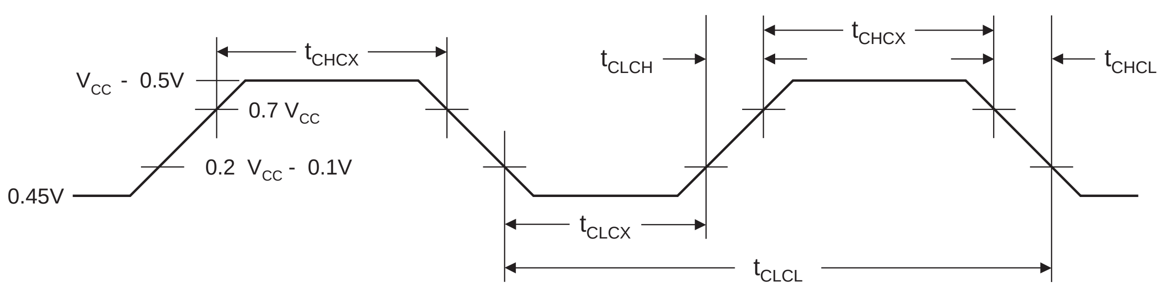
External Data Memory Read Cycle



External Data Memory Write Cycle



External Clock Drive Waveforms



External Clock Drive

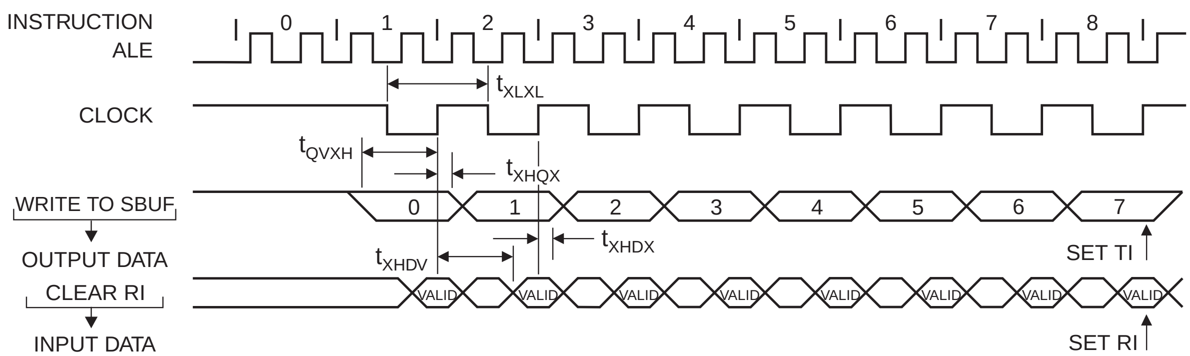
Symbol	Parameter	Min	Max	Units
$1/t_{CLCL}$	Oscillator Frequency	0	33	MHz
t_{CLCL}	Clock Period	30		ns
t_{CHCX}	High Time	12		ns
t_{CLCX}	Low Time	12		ns
t_{CLCH}	Rise Time		5	ns
t_{CHCL}	Fall Time		5	ns

Serial Port Timing: Shift Register Mode Test Conditions

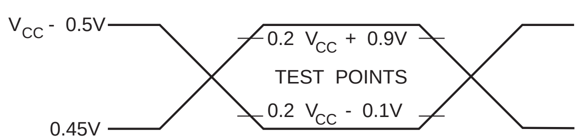
The values in this table are valid for V_{CC} = 4.0V to 5.5V and Load Capacitance = 80 pF.

Symbol	Parameter	12 MHz Osc Min	12 MHz Osc Max	Variable Oscillator Min	Variable Oscillator Max	Units
t_{XLXL}	Serial Port Clock Cycle Time	1.0		$12t_{CLCL}$		µs
t_{QVXH}	Output Data Setup to Clock Rising Edge	700		$10t_{CLCL}$-133		ns
t_{XHQX}	Output Data Hold After Clock Rising Edge	50		$2t_{CLCL}$-80		ns
t_{XHDX}	Input Data Hold After Clock Rising Edge	0		0		ns
t_{XHDV}	Clock Rising Edge to Input Data Valid		700		$10t_{CLCL}$-133	ns

Shift Register Mode Timing Waveforms

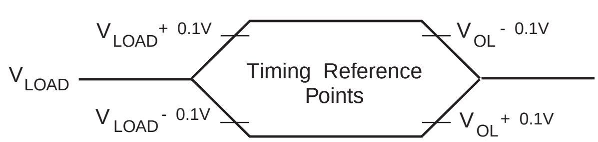


AC Testing Input/Output Waveforms[1]



Note: 1. AC Inputs during testing are driven at V_{CC} - 0.5V for a logic 1 and 0.45V for a logic 0. Timing measurements are made at V_{IH} min. for a logic 1 and V_{IL} max. for a logic 0.

Float Waveforms[1]



Note: 1. For timing purposes, a port pin is no longer floating when a 100 mV change from load voltage occurs. A port pin begins to float when a 100 mV change from the loaded V_{OH}/V_{OL} level occurs.

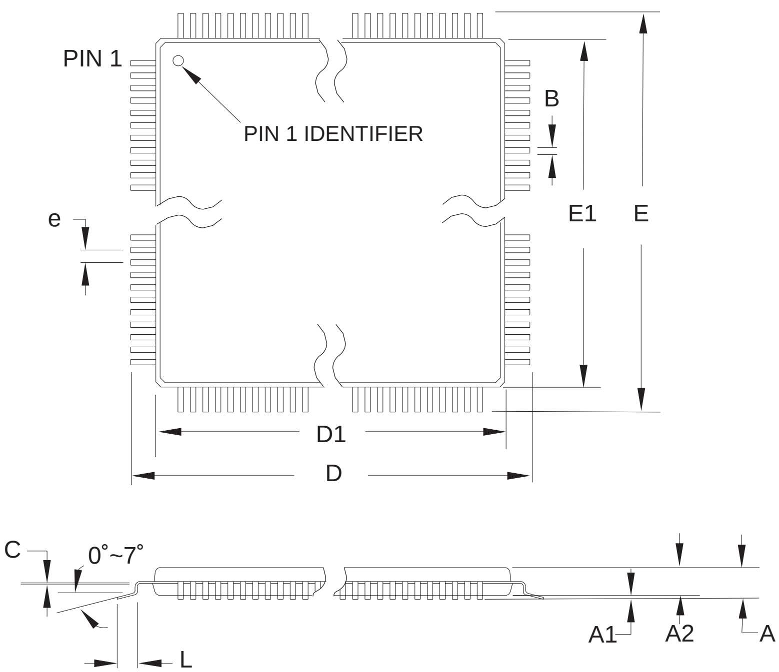
Ordering Information

Speed (MHz)	Power Supply	Ordering Code	Package	Operation Range
24	4.0V to 5.5V	AT89S51-24AC AT89S51-24JC AT89S51-24PC AT89S51-24SC	44A 44J 40P6 42PS6	Commercial (0° C to 70° C)
		AT89S51-24AI AT89S51-24JI AT89S51-24PI AT89S51-24SI	44A 44J 40P6 42PS6	Industrial (-40° C to 85° C)
33	4.5V to 5.5V	AT89S51-33AC AT89S51-33JC AT89S51-33PC AT89S51-33SC	44A 44J 40P6 42PS6	Commercial (0° C to 70° C)

Package Type	
44A	44-lead, Thin Plastic Gull Wing Quad Flatpack (TQFP)
44J	44-lead, Plastic J-leaded Chip Carrier (PLCC)
40P6	40-pin, 0.600" Wide, Plastic Dual Inline Package (PDIP)
42PS6	42-pin, 0.600" Wide, Plastic Dual Inline Package (PDIP)

Packaging Information

44A – TQFP



COMMON DIMENSIONS
(Unit of Measure = mm)

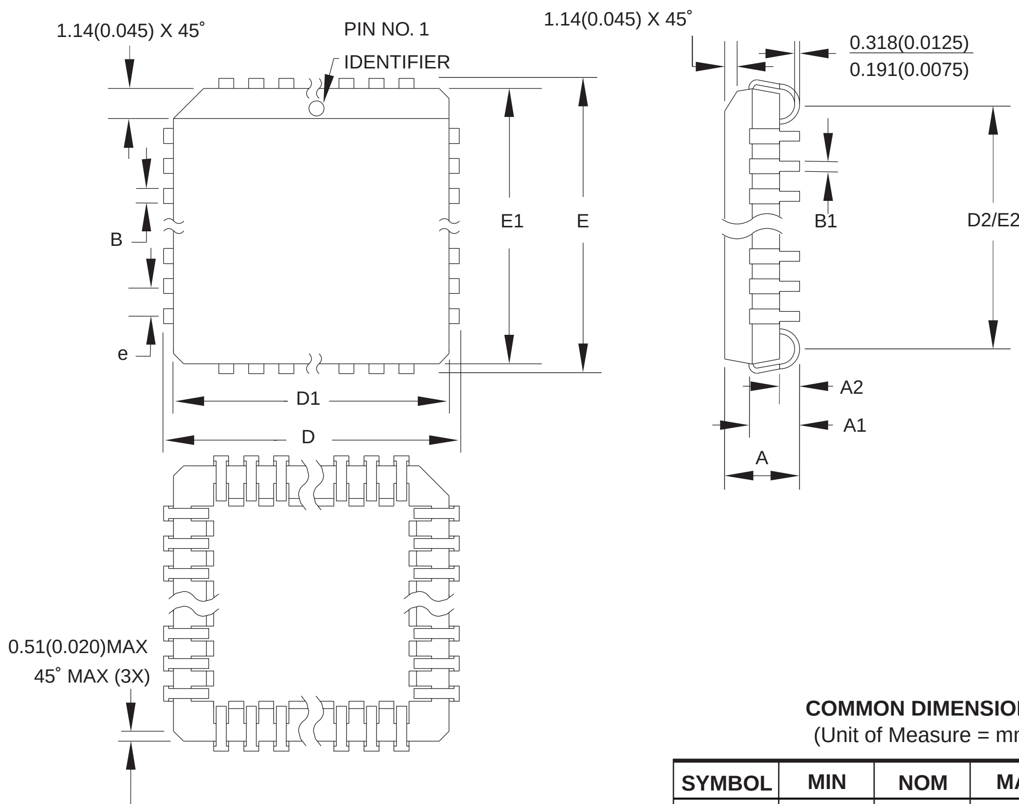
SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	1.20	
A1	0.05	–	0.15	
A2	0.95	1.00	1.05	
D	11.75	12.00	12.25	
D1	9.90	10.00	10.10	Note 2
E	11.75	12.00	12.25	
E1	9.90	10.00	10.10	Note 2
B	0.30	–	0.45	
C	0.09	–	0.20	
L	0.45	–	0.75	
e	0.80 TYP			

Notes:
1. This package conforms to JEDEC reference MS-026, Variation ACB.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25 mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10 mm maximum.

10/5/2001

	TITLE	DRAWING NO.	REV.
ATMEL 2325 Orchard Parkway San Jose, CA 95131	**44A,** 44-lead, 10 x 10 mm Body Size, 1.0 mm Body Thickness, 0.8 mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP)	44A	B

44J – PLCC



COMMON DIMENSIONS
(Unit of Measure = mm)

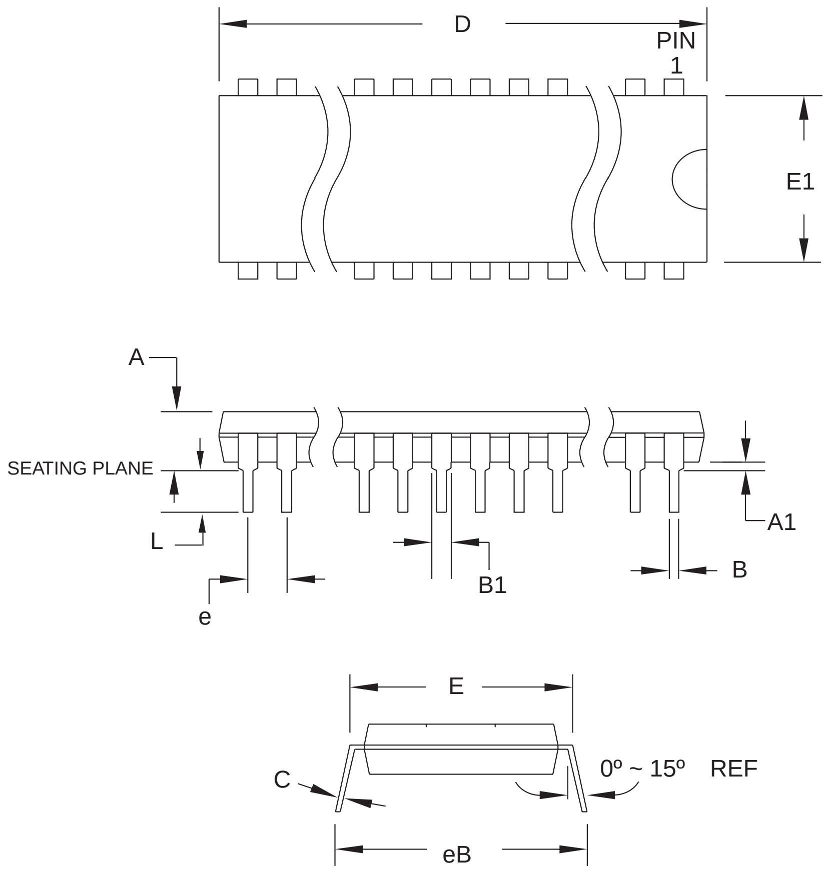
SYMBOL	MIN	NOM	MAX	NOTE
A	4.191	–	4.572	
A1	2.286	–	3.048	
A2	0.508	–	–	
D	17.399	–	17.653	
D1	16.510	–	16.662	Note 2
E	17.399	–	17.653	
E1	16.510	–	16.662	Note 2
D2/E2	14.986	–	16.002	
B	0.660	–	0.813	
B1	0.330	–	0.533	
e	1.270 TYP			

Notes:
1. This package conforms to JEDEC reference MS-018, Variation AC.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is .010"(0.254 mm) per side. Dimension D1 and E1 include mold mismatch and are measured at the extreme material condition at the upper or lower parting line.
3. Lead coplanarity is 0.004" (0.102 mm) maximum.

10/04/01

	TITLE	DRAWING NO.	REV.
ATMEL 2325 Orchard Parkway San Jose, CA 95131	**44J**, 44-lead, Plastic J-leaded Chip Carrier (PLCC)	44J	B

40P6 – PDIP



COMMON DIMENSIONS
(Unit of Measure = mm)

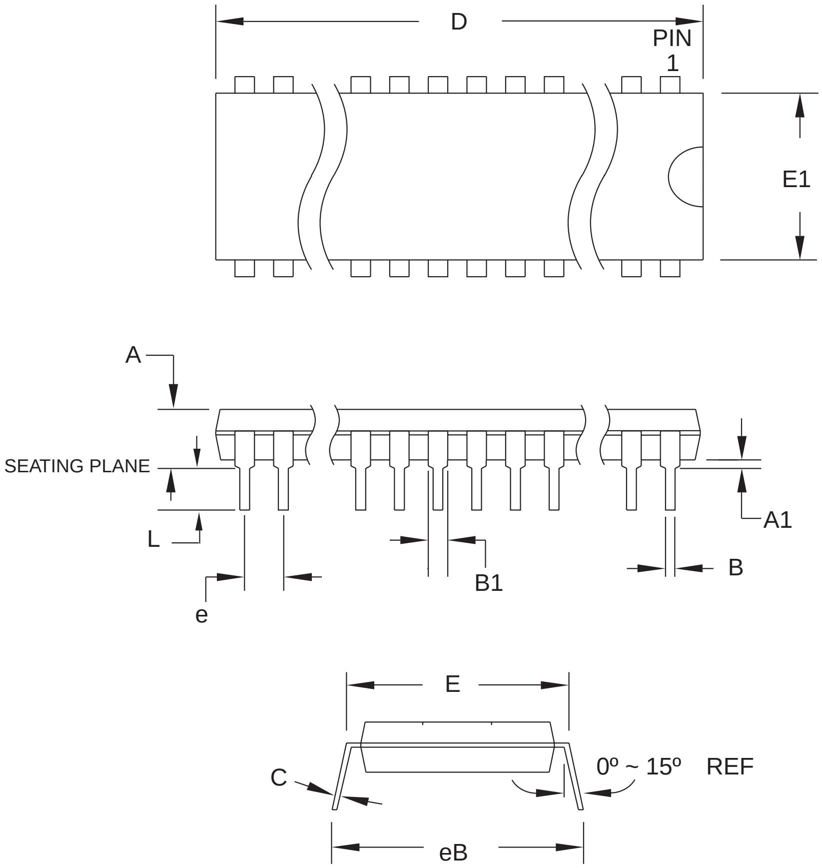
SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.826	
A1	0.381	–	–	
D	52.070	–	52.578	Note 2
E	15.240	–	15.875	
E1	13.462	–	13.970	Note 2
B	0.356	–	0.559	
B1	1.041	–	1.651	
L	3.048	–	3.556	
C	0.203	–	0.381	
eB	15.494	–	17.526	
e	2.540 TYP			

Notes:
1. This package conforms to JEDEC reference MS-011, Variation AC.
2. Dimensions D and E1 do not include mold Flash or Protrusion. Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

09/28/01

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**40P6**, 40-lead (0.600"/15.24 mm Wide) Plastic Dual Inline Package (PDIP)	40P6	B

42PS6 – PDIP



COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.83	
A1	0.51	–	–	
D	36.70	–	36.96	Note 2
E	15.24	–	15.88	
E1	13.46	–	13.97	Note 2
B	0.38	–	0.56	
B1	0.76	–	1.27	
L	3.05	–	3.43	
C	0.20	–	0.30	
eB	–	–	18.55	
e	1.78 TYP			

Notes: 1. This package conforms to JEDEC reference MS-011, Variation AC.
2. Dimensions D and E1 do not include mold Flash or Protrusion. Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

11/6/03

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**42PS6**, 42-lead (0.600"/15.24 mm Wide) Plastic Dual Inline Package (PDIP)	42PS6	A

Atmel Corporation

2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 487-2600

Regional Headquarters

Europe
Atmel Sarl
Route des Arsenaux 41
Case Postale 80
CH-1705 Fribourg
Switzerland
Tel: (41) 26-426-5555
Fax: (41) 26-426-5500

Asia
Room 1219
Chinachem Golden Plaza
77 Mody Road Tsimshatsui
East Kowloon
Hong Kong
Tel: (852) 2721-9778
Fax: (852) 2722-1369

Japan
9F, Tonetsu Shinkawa Bldg.
1-24-8 Shinkawa
Chuo-ku, Tokyo 104-0033
Japan
Tel: (81) 3-3523-3551
Fax: (81) 3-3523-7581

Atmel Operations

Memory
2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

Microcontrollers
2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

La Chantrerie
BP 70602
44306 Nantes Cedex 3, France
Tel: (33) 2-40-18-18-18
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ASIC/ASSP/Smart Cards
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13106 Rousset Cedex, France
Tel: (33) 4-42-53-60-00
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Colorado Springs, CO 80906, USA
Tel: 1(719) 576-3300
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Scottish Enterprise Technology Park
Maxwell Building
East Kilbride G75 0QR, Scotland
Tel: (44) 1355-803-000
Fax: (44) 1355-242-743

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74025 Heilbronn, Germany
Tel: (49) 71-31-67-0
Fax: (49) 71-31-67-2340

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2487B–MICRO–12/03

National Semiconductor

February 1995

LM555/LM555C Timer

General Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200 mA or drive TTL circuits.

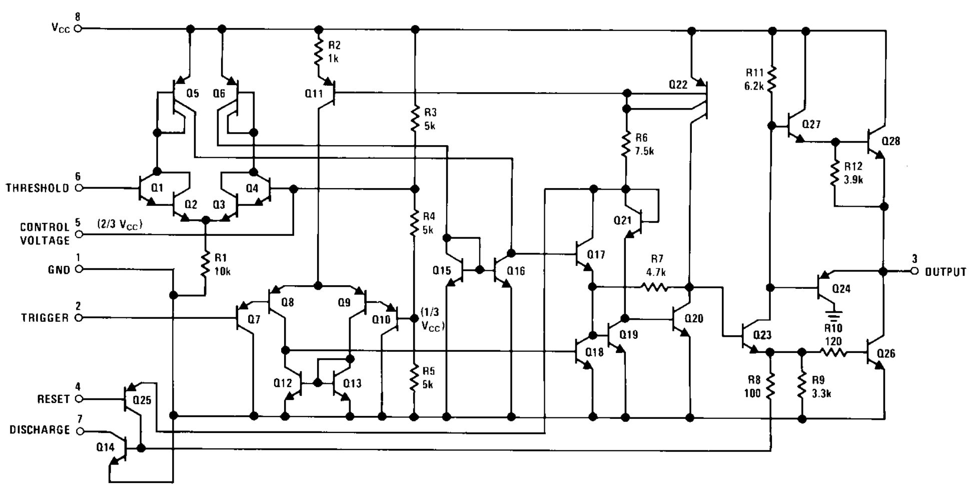
Features

- Direct replacement for SE555/NE555
- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- Output can source or sink 200 mA
- Output and supply TTL compatible
- Temperature stability better than 0.005% per °C
- Normally on and normally off output

Applications

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation
- Pulse position modulation
- Linear ramp generator

Schematic Diagram



TL/H/7851–1

RRD-B30M115/Printed in U. S. A.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	+18V
Power Dissipation (Note 1)	
LM555H, LM555CH	760 mW
LM555, LM555CN	1180 mW
Operating Temperature Ranges	
LM555C	0°C to +70°C
LM555	−55°C to + 125°C
Storage Temperature Range	−65°C to +150°C
Soldering Information	
Dual-In-Line Package	
Soldering (10 Seconds)	260°C
Small Outline Package	
Vapor Phase (60 Seconds)	215°C
Infrared (15 Seconds)	220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

Electrical Characteristics (T_A = 25°C, V_{CC} = +5V to +15V, unless othewise specified)

Parameter	Conditions	Limits						Units
		LM555			LM555C			
		Min	Typ	Max	Min	Typ	Max	
Supply Voltage		4.5		18	4.5		16	V
Supply Current	V_{CC} = 5V, R_L = ∞ V_{CC} = 15V, R_L = ∞ (Low State) (Note 2)		3 10	5 12		3 10	6 15	mA mA
Timing Error, Monostable Initial Accuracy Drift with Temperature Accuracy over Temperature Drift with Supply	 R_A = 1k to 100 kΩ, C = 0.1 μF, (Note 3)		 0.5 30 1.5 0.05			 1 50 1.5 0.1		 % ppm/°C % %/V
Timing Error, Astable Initial Accuracy Drift with Temperature Accuracy over Temperature Drift with Supply	 R_A, R_B = 1k to 100 kΩ, C = 0.1 μF, (Note 3)		 1.5 90 2.5 0.15			 2.25 150 3.0 0.30		 % ppm/°C % %/V
Threshold Voltage			0.667			0.667		x V_{CC}
Trigger Voltage	V_{CC} = 15V V_{CC} = 5V	4.8 1.45	5 1.67	5.2 1.9		5 1.67		V V
Trigger Current			0.01	0.5		0.5	0.9	μA
Reset Voltage		0.4	0.5	1	0.4	0.5	1	V
Reset Current			0.1	0.4		0.1	0.4	mA
Threshold Current	(Note 4)		0.1	0.25		0.1	0.25	μA
Control Voltage Level	V_{CC} = 15V V_{CC} = 5V	9.6 2.9	10 3.33	10.4 3.8	9 2.6	10 3.33	11 4	V V
Pin 7 Leakage Output High			1	100		1	100	nA
Pin 7 Sat (Note 5) Output Low Output Low	 V_{CC} = 15V, I_7 = 15 mA V_{CC} = 4.5V, I_7 = 4.5 mA		 150 70	 100		 180 80	 200	 mV mV

Electrical Characteristics $T_A = 25°C$, $V_{CC} = +5V$ to $+15V$, (unless othewise specified) (Continued)

Parameter	Conditions	Limits						Units
		LM555			LM555C			
		Min	Typ	Max	Min	Typ	Max	
Output Voltage Drop (Low)	$V_{CC} = 15V$							
	$I_{SINK} = 10$ mA		0.1	0.15		0.1	0.25	V
	$I_{SINK} = 50$ mA		0.4	0.5		0.4	0.75	V
	$I_{SINK} = 100$ mA		2	2.2		2	2.5	V
	$I_{SINK} = 200$ mA		2.5			2.5		V
	$V_{CC} = 5V$							
	$I_{SINK} = 8$ mA		0.1	0.25				V
	$I_{SINK} = 5$ mA					0.25	0.35	V
Output Voltage Drop (High)	$I_{SOURCE} = 200$ mA, $V_{CC} = 15V$		12.5			12.5		V
	$I_{SOURCE} = 100$ mA, $V_{CC} = 15V$	13	13.3		12.75	13.3		V
	$V_{CC} = 5V$	3	3.3		2.75	3.3		V
Rise Time of Output			100			100		ns
Fall Time of Output			100			100		ns

Note 1: For operating at elevated temperatures the device must be derated above 25°C based on a +150°C maximum junction temperature and a thermal resistance of 164°c/w (T0-5), 106°c/w (DIP) and 170°c/w (S0-8) junction to ambient.

Note 2: Supply current when output high typically 1 mA less at $V_{CC} = 5V$.

Note 3: Tested at $V_{CC} = 5V$ and $V_{CC} = 15V$.

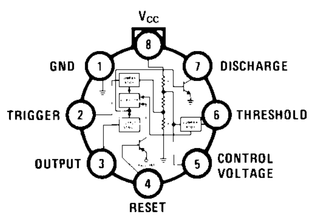
Note 4: This will determine the maximum value of $R_A + R_B$ for 15V operation. The maximum total $(R_A + R_B)$ is 20 MΩ.

Note 5: No protection against excessive pin 7 current is necessary providing the package dissipation rating will not be exceeded.

Note 6: Refer to RETS555X drawing of military LM555H and LM555J versions for specifications.

Connection Diagrams

Metal Can Package

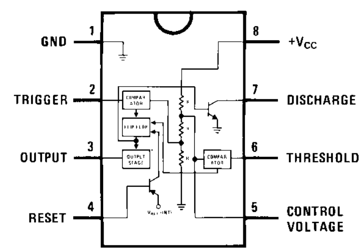


TL/H/7851–2

Top View

Order Number LM555H or LM555CH
See NS Package Number H08C

Dual-In-Line and Small Outline Packages



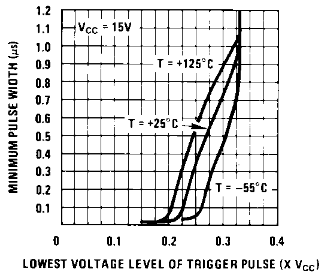
TL/H/7851–3

Top View

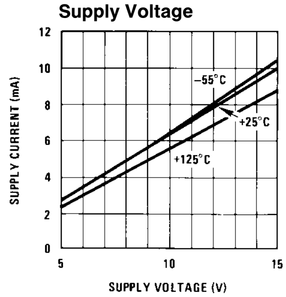
Order Number LM555J, LM555CJ,
LM555CM or LM555CN
See NS Package Number J08A, M08A or N08E

Typical Performance Characteristics

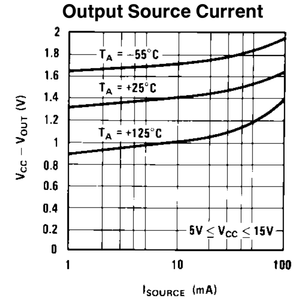
Minimuim Pulse Width Required for Triggering



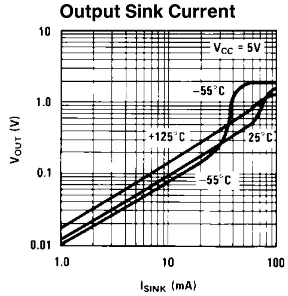
Supply Current vs Supply Voltage



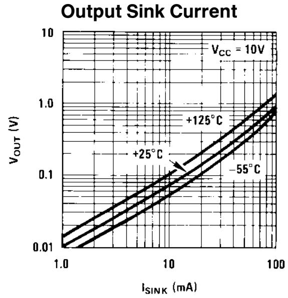
High Output Voltage vs Output Source Current



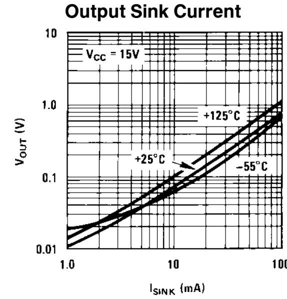
Low Output Voltage vs Output Sink Current



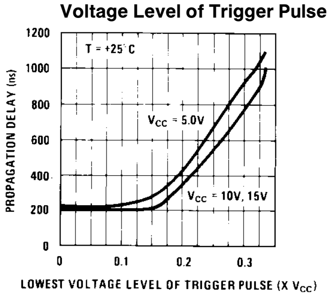
Low Output Voltage vs Output Sink Current



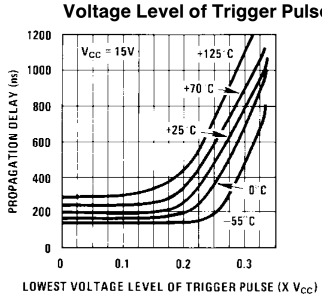
Low Output Voltage vs Output Sink Current



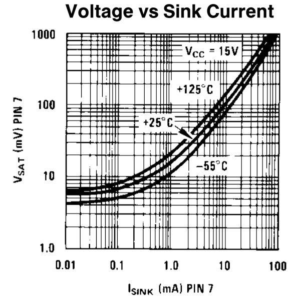
Output Propagation Delay vs Voltage Level of Trigger Pulse



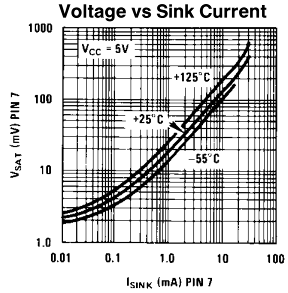
Output Propagation Delay vs Voltage Level of Trigger Pulse



Discharge Transistor (Pin 7) Voltage vs Sink Current



Discharge Transistor (Pin 7) Voltage vs Sink Current

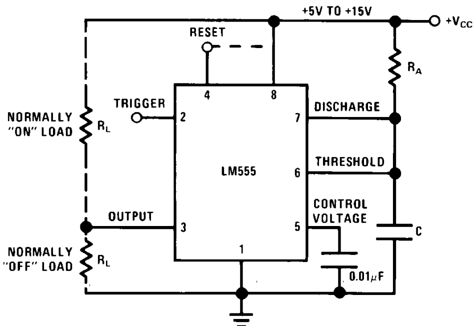


TL/H/7851–4

Applications Information

MONOSTABLE OPERATION

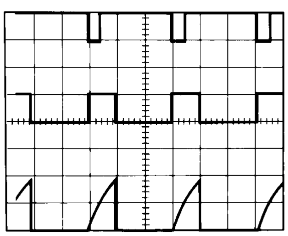
In this mode of operation, the timer functions as a one-shot *(Figure 1).* The external capacitor is initially held discharged by a transistor inside the timer. Upon application of a negative trigger pulse of less than 1/3 V_{CC} to pin 2, the flip-flop is set which both releases the short circuit across the capacitor and drives the output high.



TL/H/7851–5

FIGURE 1. Monostable

The voltage across the capacitor then increases exponentially for a period of $t = 1.1\ R_A\ C$, at the end of which time the voltage equals 2/3 V_{CC}. The comparator then resets the flip-flop which in turn discharges the capacitor and drives the output to its low state. *Figure 2* shows the waveforms generated in this mode of operation. Since the charge and the threshold level of the comparator are both directly proportional to supply voltage, the timing internal is independent of supply.



TL/H/7851–6

$V_{CC} = 5V$	Top Trace: Input 5V/Div.
TIME = 0.1 ms/DIV.	Middle Trace: Output 5V/Div.
$R_A = 9.1\ k\Omega$	Bottom Trace: Capacitor Voltage 2V/Div.
$C = 0.01\ \mu F$	

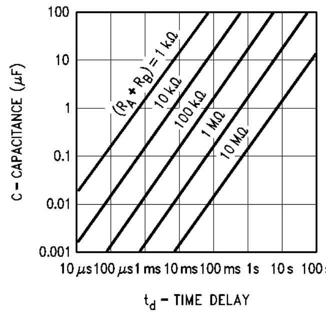
FIGURE 2. Monostable Waveforms

During the timing cycle when the output is high, the further application of a trigger pulse will not effect the circuit so long as the trigger input is returned high at least 10 μs before the end of the timing interval. However the circuit can be reset during this time by the application of a negative pulse to the reset terminal (pin 4). The output will then remain in the low state until a trigger pulse is again applied.

When the reset function is not in use, it is recommended that it be connected to V_{CC} to avoid any possibility of false triggering.

Figure 3 is a nomograph for easy determination of R, C values for various time delays.

NOTE: In monostable operation, the trigger should be driven high before the end of timing cycle.

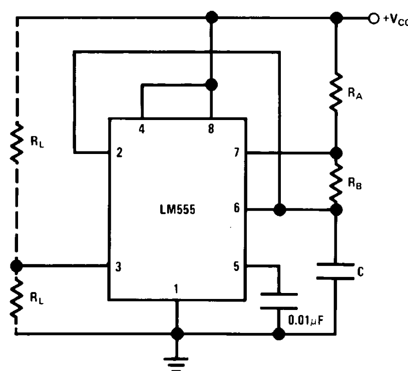


TL/H/7851–7

FIGURE 3. Time Delay

ASTABLE OPERATION

If the circuit is connected as shown in *Figure 4* (pins 2 and 6 connected) it will trigger itself and free run as a multivibrator. The external capacitor charges through $R_A + R_B$ and discharges through R_B. Thus the duty cycle may be precisely set by the ratio of these two resistors.



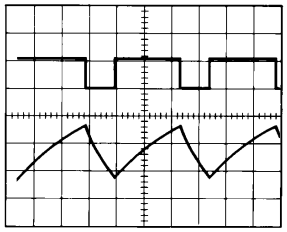
TL/H/7851–8

FIGURE 4. Astable

In this mode of operation, the capacitor charges and discharges between 1/3 V_{CC} and 2/3 V_{CC}. As in the triggered mode, the charge and discharge times, and therefore the frequency are independent of the supply voltage.

Applications Information (Continued)

Figure 5 shows the waveforms generated in this mode of operation.



TL/H/7851–9

V_{CC} = 5V
TIME = 20 μs/DIV.
R_A = 3.9 kΩ
R_B = 3 kΩ
C = 0.01 μF

Top Trace: Output 5V/Div.
Bottom Trace: Capacitor Voltage 1V/Div.

FIGURE 5. Astable Waveforms

The charge time (output high) is given by:

$$t_1 = 0.693\,(R_A + R_B)\,C$$

And the discharge time (output low) by:

$$t_2 = 0.693\,(R_B)\,C$$

Thus the total period is:

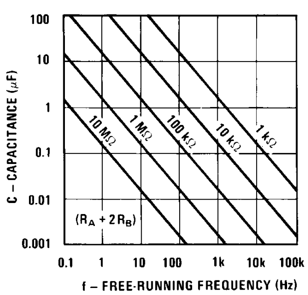
$$T = t_1 + t_2 = 0.693\,(R_A + 2R_B)\,C$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2\,R_B)\,C}$$

Figure 6 may be used for quick determination of these RC values.

The duty cycle is: $D = \dfrac{R_B}{R_A + 2R_B}$

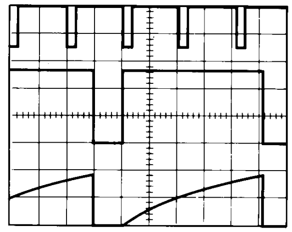


TL/H/7851–10

FIGURE 6. Free Running Frequency

FREQUENCY DIVIDER

The monostable circuit of *Figure 1* can be used as a frequency divider by adjusting the length of the timing cycle. *Figure 7* shows the waveforms generated in a divide by three circuit.



TL/H/7851–11

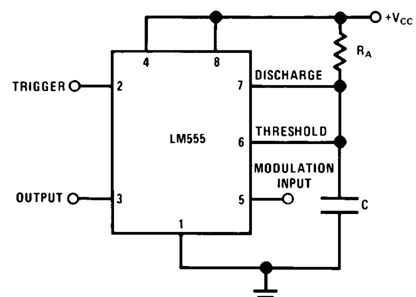
V_{CC} = 5V
TIME = 20 μs/DIV.
R_A = 9.1 kΩ
C = 0.01 μF

Top Trace: Input 4V/Div.
Middle Trace: Output 2V/Div.
Bottom Trace: Capacitor 2V/Div.

FIGURE 7. Frequency Divider

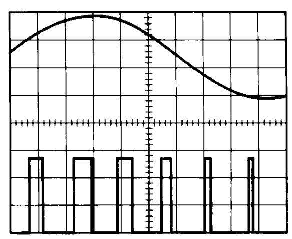
PULSE WIDTH MODULATOR

When the timer is connected in the monostable mode and triggered with a continuous pulse train, the output pulse width can be modulated by a signal applied to pin 5. *Figure 8* shows the circuit, and in *Figure 9* are some waveform examples.



TL/H/7851–12

FIGURE 8. Pulse Width Modulator



TL/H/7851–13

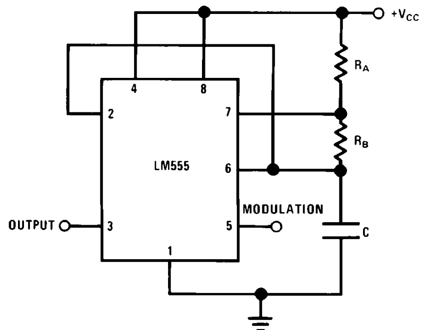
V_{CC} = 5V
TIME = 0.2 ms/DIV.
R_A = 9.1 kΩ
C = 0.01 μF

Top Trace: Modulation 1V/Div.
Bottom Trace: Output Voltage 2V/Div.

FIGURE 9. Pulse Width Modulator

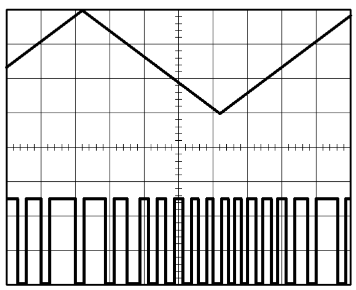
PULSE POSITION MODULATOR

This application uses the timer connected for astable operation, as in *Figure 10,* with a modulating signal again applied to the control voltage terminal. The pulse position varies with the modulating signal, since the threshold voltage and hence the time delay is varied. *Figure 11* shows the waveforms generated for a triangle wave modulation signal.



TL/H/7851–14

FIGURE 10. Pulse Position Modulator



TL/H/7851–15

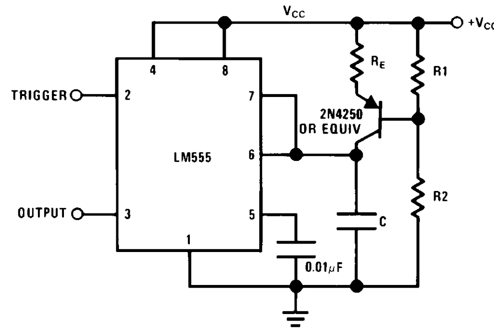
$V_{CC} = 5V$
TIME = 0.1 ms/DIV.
$R_A = 3.9\ k\Omega$
$R_B = 3\ k\Omega$
$C = 0.01\ \mu F$

Top Trace: Modulation Input 1V/Div.
Bottom Trace: Output 2V/Div.

FIGURE 11. Pulse Position Modulator

LINEAR RAMP

When the pullup resistor, R_A, in the monostable circuit is replaced by a constant current source, a linear ramp is generated. *Figure 12* shows a circuit configuration that will perform this function.



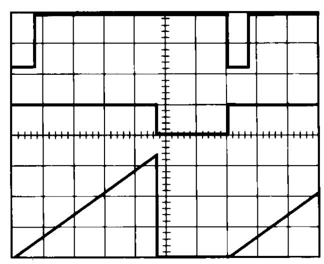
TL/H/7851–16

FIGURE 12

Figure 13 shows waveforms generated by the linear ramp. The time interval is given by:

$$T = \frac{2/3\, V_{CC}\, R_E\, (R_1 + R_2)\, C}{R_1\, V_{CC} - V_{BE}\, (R_1 + R_2)}$$

$$V_{BE} \cong 0.6V$$



TL/H/7851–17

$V_{CC} = 5V$
TIME = 20 μs/DIV.
$R_1 = 47\ k\Omega$
$R_2 = 100\ k\Omega$
$R_E = 2.7\ k\Omega$
$C = 0.01\ \mu F$

Top Trace: Input 3V/Div.
Middle Trace: Output 5V/Div.
Bottom Trace: Capacitor Voltage 1V/Div.

FIGURE 13. Linear Ramp

50% DUTY CYCLE OSCILLATOR

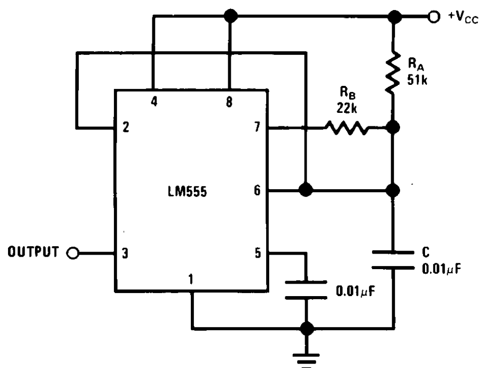
For a 50% duty cycle, the resistors R_A and R_B may be connected as in *Figure 14.* The time period for the out-

Applications Information (Continued)

put high is the same as previous, $t_1 = 0.693\ R_A\ C$. For the output low it is $t_2 =$

$$\left[(R_A R_B)/(R_A + R_B)\right] C\ \ell n \left[\frac{R_B - 2R_A}{2R_B - R_A}\right]$$

Thus the frequency of oscillation is $f = \dfrac{1}{t_1 + t_2}$



TL/H/7851–18

FIGURE 14. 50% Duty Cycle Oscillator

Note that this circuit will not oscillate if R_B is greater than 1/2 R_A because the junction of R_A and R_B cannot bring pin 2 down to 1/3 V_{CC} and trigger the lower comparator.

ADDITIONAL INFORMATION

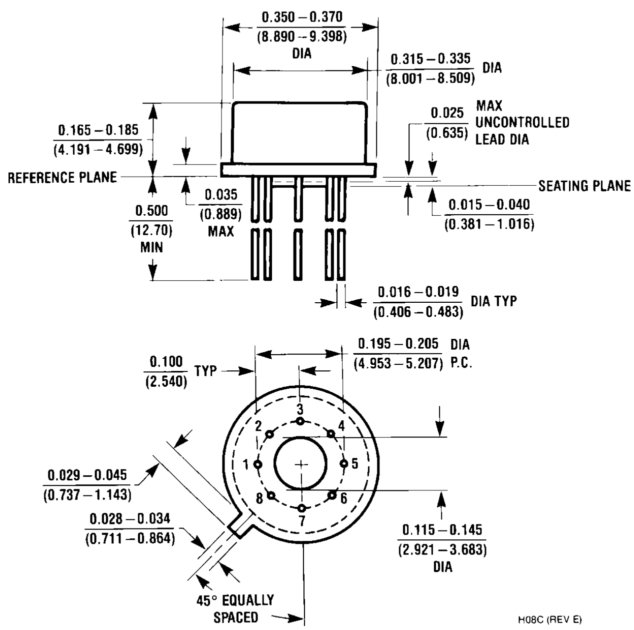
Adequate power supply bypassing is necessary to protect associated circuitry. Minimum recommended is 0.1 μF in parallel with 1 μF electrolytic.

Lower comparator storage time can be as long as 10 μs when pin 2 is driven fully to ground for triggering. This limits the monostable pulse width to 10 μs minimum.

Delay time reset to output is 0.47 μs typical. Minimum reset pulse width must be 0.3 μs, typical.

Pin 7 current switches within 30 ns of the output (pin 3) voltage.

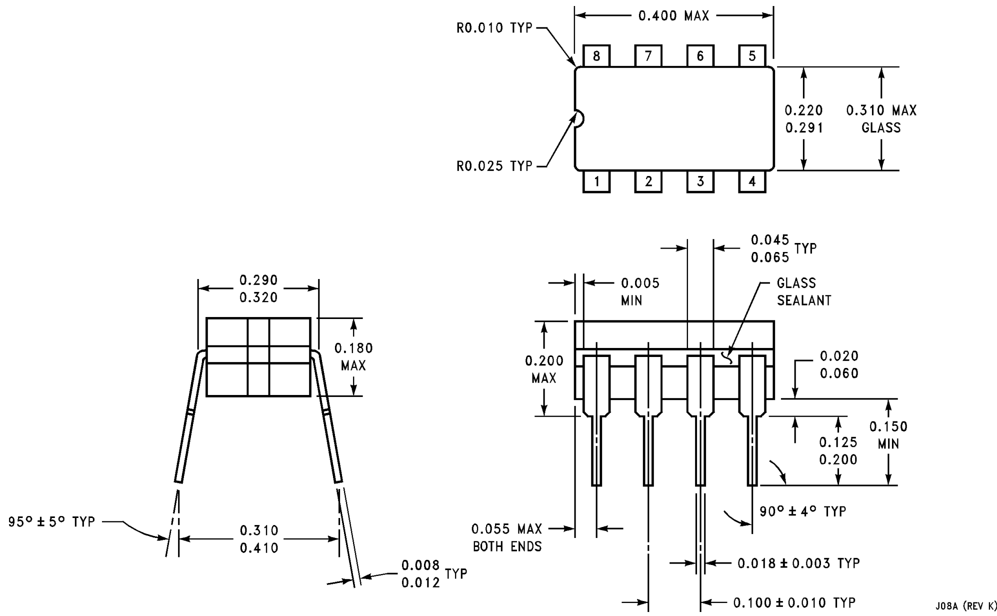
Physical Dimensions inches (millimeters)



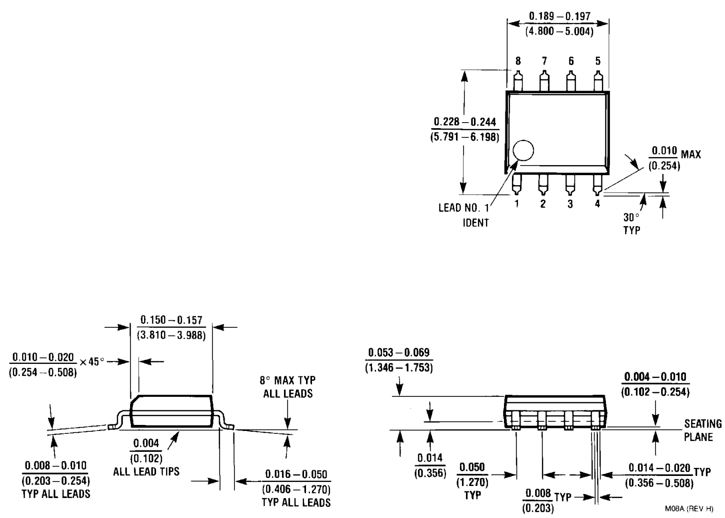
H08C (REV E)

Metal Can Package (H)
Order Number LM555H or LM555CH
NS Package Number H08C

Physical Dimensions inches (millimeters) (Continued)

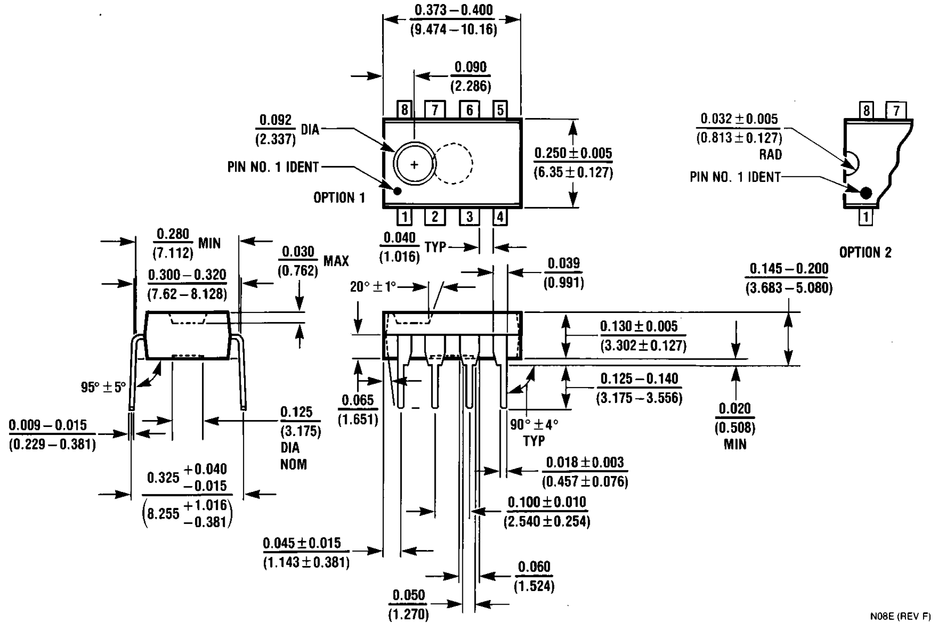


Ceramic Dual-In-Line Package (J)
Order Number LM555J or LM555CJ
NS Package Number J08A



Small Outline Package (M)
Order Number LM555CM
NS Package Number M08A

Physical Dimensions inches (millimeters) (Continued)



Molded Dual-In-Line Package (N)
Order Number LM555CN
NS Package Number N08E

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National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

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Fax: 81-043-299-2408

National Semiconductor

June 1989

54LS74/DM54LS74A/DM74LS74A Dual Positive-Edge-Triggered D Flip-Flops with Preset, Clear and Complementary Outputs

General Description

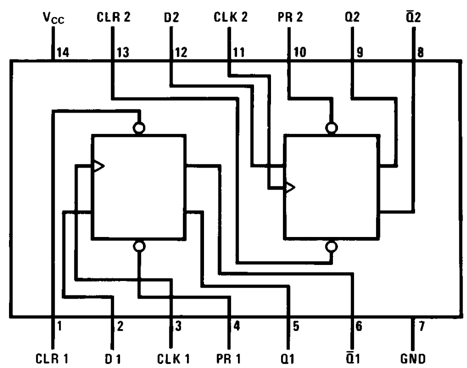
This device contains two independent positive-edge-triggered D flip-flops with complementary outputs. The information on the D input is accepted by the flip-flops on the positive going edge of the clock pulse. The triggering occurs at a voltage level and is not directly related to the transition time of the rising edge of the clock. The data on the D input may be changed while the clock is low or high without affecting the outputs as long as the data setup and hold times are not violated. A low logic level on the preset or clear inputs will set or reset the outputs regardless of the logic levels of the other inputs.

Features

- Alternate military/aerospace device (54LS74) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6373–1

Order Number 54LS74DMQB, 54LS74FMQB, 54LS74LMQB, DM54LS74AJ, DM54LS74AW, DM74LS74AM or DM74LS74AN
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

Inputs				Outputs	
PR	CLR	CLK	D	Q	$\overline{Q}$
L	H	X	X	H	L
H	L	X	X	L	H
L	L	X	X	H*	H*
H	H	↑	H	H	L
H	H	↑	L	L	H
H	H	L	X	Q_0	$\overline{Q}_0$

H = High Logic Level

X = Either Low or High Logic Level

L = Low Logic Level

↑ = Positive-going Transition

* = This configuration is nonstable; that is, it will not persist when either the preset and/or clear inputs return to their inactive (high) level.

Q_0 = The output logic level of Q before the indicated input conditions were established.

RRD-B30M105/Printed in U. S. A.

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter		DM54LS74A			DM74LS74A			Units
			Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage		4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage		2			2			V
V_{IL}	Low Level Input Voltage				0.7			0.8	V
I_{OH}	High Level Output Current				−0.4			−0.4	mA
I_{OL}	Low Level Output Current				4			8	mA
f_{CLK}	Clock Frequency (Note 2)		0		25	0		25	MHz
f_{CLK}	Clock Frequency (Note 3)		0		20	0		20	MHz
t_W	Pulse Width (Note 2)	Clock High	18			18			ns
		Preset Low	15			15			
		Clear Low	15			15			
t_W	Pulse Width (Note 3)	Clock High	25			25			ns
		Preset Low	20			20			
		Clear Low	20			20			
t_{SU}	Setup Time (Notes 1 and 2)		20 ↑			20 ↑			ns
t_{SU}	Setup Time (Notes 1 and 3)		25 ↑			25 ↑			ns
t_H	Hold Time (Note 1 and 4)		0 ↑			0 ↑			ns
T_A	Free Air Operating Temperature		−55		125	0		70	°C

Note 1: The symbol (↑) indicates the rising edge of the clock pulse is used for reference.

Note 2: $C_L = 15$ pF, $R_L = 2$ kΩ, $T_A = 25°C$, and $V_{CC} = 5V$.

Note 3: $C_L = 50$ pF, $R_L = 2$ kΩ, $T_A = 25°C$, and $V_{CC} = 5V$.

Note 4: $T_A = 25°C$ and $V_{CC} = 5V$.

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	$V_{CC} = $ Min, $I_I = -18$ mA				−1.5	V
V_{OH}	High Level Output Voltage	$V_{CC} = $ Min, $I_{OH} = $ Max $V_{IL} = $ Max, $V_{IH} = $ Min	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	$V_{CC} = $ Min, $I_{OL} = $ Max $V_{IL} = $ Max, $V_{IH} = $ Min	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		$I_{OL} = 4$ mA, $V_{CC} = $ Min	DM74		0.25	0.4	
I_I	Input Current @Max Input Voltage	$V_{CC} = $ Max $V_I = 7V$	Data			0.1	mA
			Clock			0.1	
			Preset			0.2	
			Clear			0.2	
I_{IH}	High Level Input Current	$V_{CC} = $ Max $V_I = 2.7V$	Data			20	μA
			Clock			20	
			Clear			40	
			Preset			40	
I_{IL}	Low Level Input Current	$V_{CC} = $ Max $V_I = 0.4V$	Data			−0.4	mA
			Clock			−0.4	
			Preset			−0.8	
			Clear			−0.8	
I_{OS}	Short Circuit Output Current	$V_{CC} = $ Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CC}	Supply Current	$V_{CC} = $ Max (Note 3)			4	8	mA

Note 1: All typicals are at $V_{CC} = 5V$, $T_A = 25°C$.

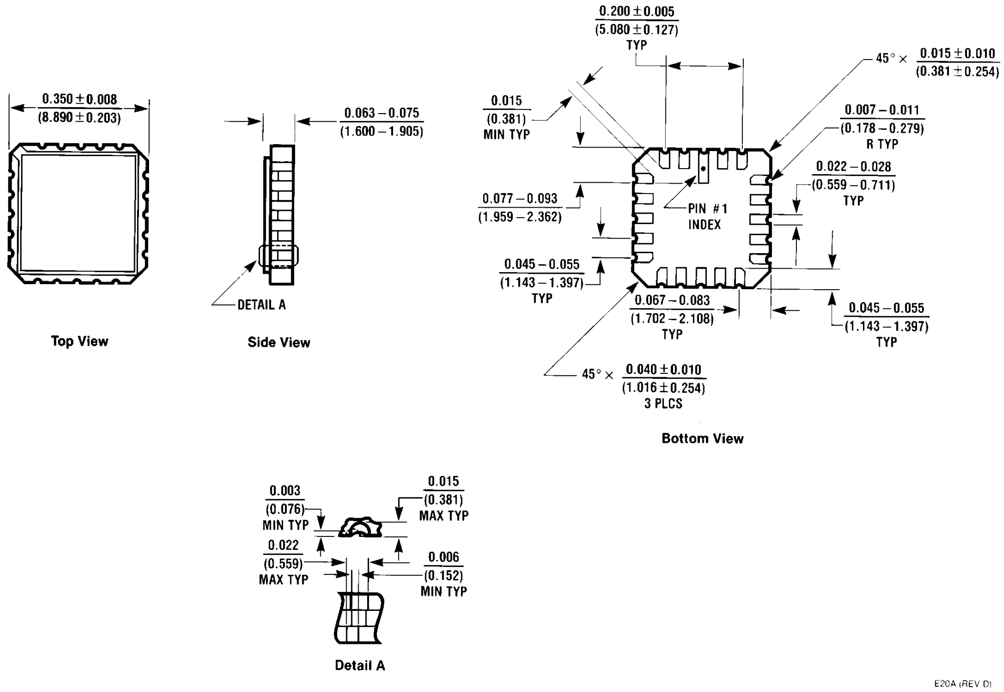
Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second. For devices, with feedback from the outputs, where shorting the outputs to ground may cause the outputs to change logic state an equivalent test may be performed where $V_O = 2.25V$ and 2.125V for DM54 and DM74 series, respectively, with the minimum and maximum limits reduced by one half from their stated values. This is very useful when using automatic test equipment.

Note 3: With all outputs open, I_{CC} is measured with CLOCK grounded after setting the Q and $\overline{Q}$ outputs high in turn.

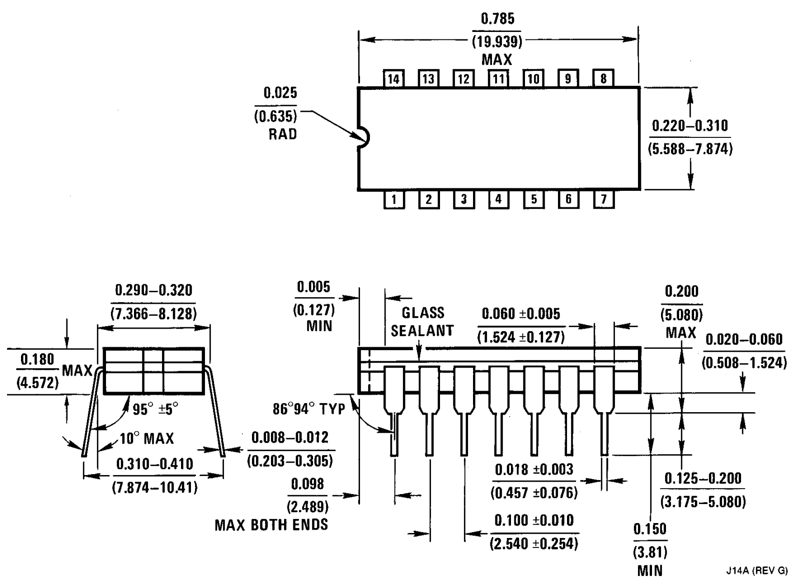
Switching Characteristics at $V_{CC} = 5V$ and $T_A = 25°C$ (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	From (Input) To (Output)	$R_L = 2\ k\Omega$				Units
			$C_L = 15$ pF		$C_L = 50$ pF		
			Min	Max	Min	Max	
f_{MAX}	Maximum Clock Frequency		25		20		MHz
t_{PLH}	Propagation Delay Time Low to High Level Output	Clock to Q or $\overline{Q}$		25		35	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	Clock to Q or $\overline{Q}$		30		35	ns
t_{PLH}	Propagation Delay Time Low to High Level Output	Preset to Q		25		35	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	Preset to $\overline{Q}$		30		35	ns
t_{PLH}	Propagation Delay Time Low to High Level Output	Clear to $\overline{Q}$		25		35	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	Clear to Q		30		35	ns

Physical Dimensions inches (millimeters)

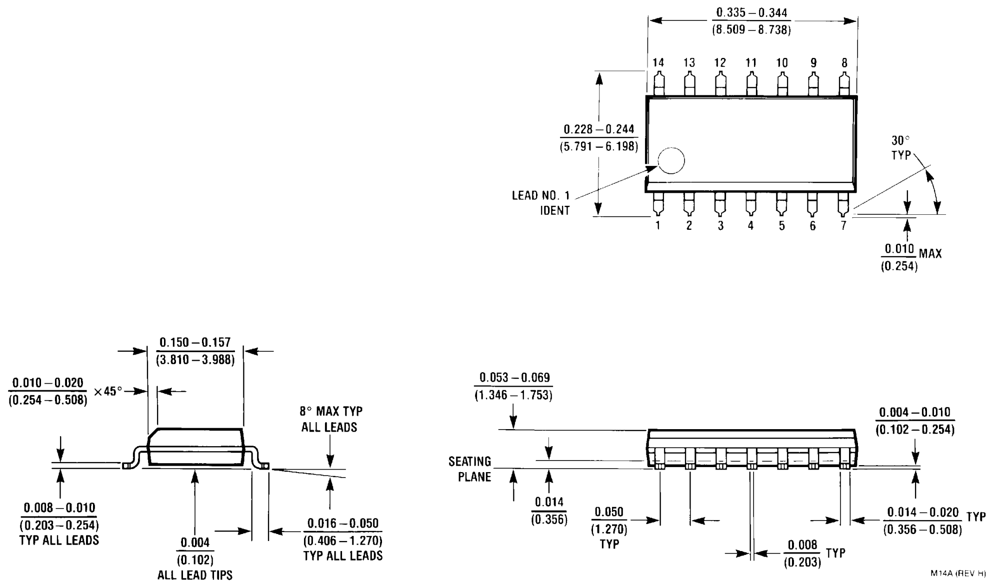


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS74LMQB
NS Package Number E20A

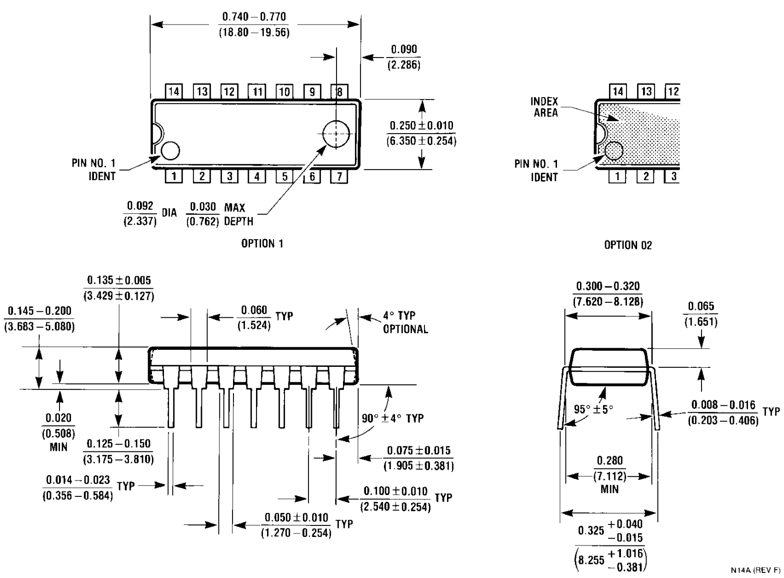


14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS74DMQB or DM54LS74AJ
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

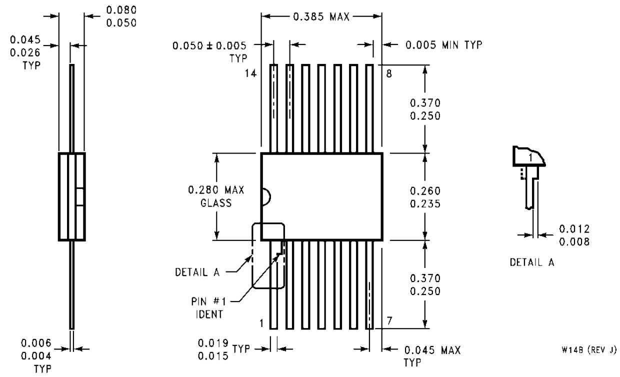


14-Lead Small Outline Molded Package (M)
Order Number DM74LS74AM
NS Package Number M14A



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS74AN
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS74FMQB or DM54LS74AW
NS Package Number W14B

LIFE SUPPORT POLICY

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

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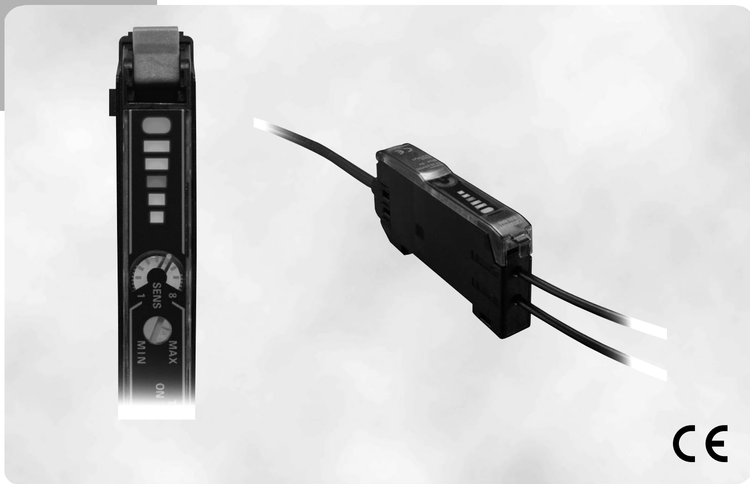
Tel: 81-043-299-2309
Fax: 81-043-299-2408

E3X-NA

Super Manual Fiber Amplifier

Sense the Difference, Make a Difference!



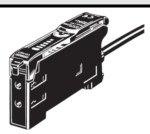
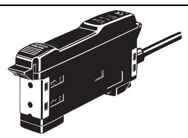
Simple and Easy

- Easy operation.
- LED display for incident level.
- Long sensing distance (200 mm with reflective models) - double that of standard E3X-NA models.
- High resolution - 7 times that of previous models (e.g., E3X-NA11).
- “Easy wiring” connector.
- Same design as E3X-DA-N Digital Fiber Amplifier.

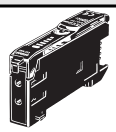
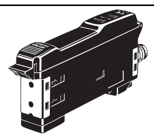
Ordering Information: Amplifier Units, Connectors and Accessories

■ Amplifier Units

Amplifier Units with Cables

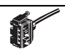
Item	Appearance	Control output	Model	
			NPN output	PNP output
Standard models		ON/OFF output	E3X-NA11	E3X-NA41
High-speed detection models			E3X-NA11F	E3X-NA41F
Mark-detecting models			E3X-NAG11	E3X-NAG41
Water-resistant models			E3X-NA11V	E3X-NA41V

Amplifier Units with Connectors

Item	Appearance	Applicable Connector (order separately)		Control output	Model	
					NPN output	PNP output
Standard models		Master	E3X-CN11	ON/OFF output	E3X-NA6	E3X-NA8
		Slave	E3X-CN12			
Water-resistant models (M8 connectors)		XS3F-M421-40□-A XS3F-M422-40□-A			E3X-NA14V	E3X-NA44V

■ Amplifier Unit Connectors (Order Separately)

Note Stickers for Connectors are included as accessories.

Item	Appearance	Cable length	No. of conductors	Model
Master Connector		2 m	3	E3X-CN11
Slave Connector			1	E3X-CN12

■ Combining Amplifier Units and Connectors

Refer to the following tables when placing an order. Basically, Amplifier Units and Connectors are sold separately.

Amplifier Units		
Type	NPN	PNP
Standard models	E3X-NA6	E3X-NA8

+

Applicable Connectors (Order Separately)	
Master Connector	Slave Connector
E3X-CN11 (3-wire)	E3X-CN12 (1-wire)

When Using 5 Amplifier Units

Amplifier Units (5 Units)

+

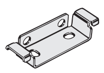
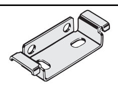
1 Master Connector + 4 Slave Connectors

■ Sensor I/O Connectors (Order Separately)

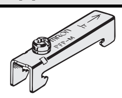
Size	Cable specifications	Appearance	Cable type		Model
M8	Standard cable	Straight connector 	2 m	Four-core cable	XS3F-M421-402-A
			5 m		XS3F-M421-405-A
		L-shaped connector 	2 m		XS3F-M422-402-A
			5 m		XS3F-M422-405-A

■ Accessories (Order Separately)

Mounting Brackets

Appearance	Applicable models	Model	Quantity
	E3X-NA☐ E3X-NA☐F E3X-NAG☐	E39-L143	1
	E3X-NA☐V	E39-L148	

End Plate

Appearance	Model	Quantity
	**PFP-M**	1

Specifications: Amplifier Units

■ Ratings/Characteristics

Item		Amplifier Units with Cables				Amplifier Units with Connectors	
		Standard models	High-speed detection models	Mark-detecting models	Water-resistant models	Standard models	Water-resistant models (M8 connectors)
Output type	NPN output	E3X-NA11	E3X-NA11F	E3X-NAG11	E3X-NA11V	E3X-NA6	E3X-NA14V
	PNP output	E3X-NA41	E3X-NA41F	E3X-NAG41	E3X-NA41V	E3X-NA8	E3X-NA44V
Light source (wavelength)		Red LED (680 nm)		Green LED (520 nm)	Red LED (680 nm)		
Supply voltage		12 to 24 VDC ±10%, ripple (p-p): 10% max.					
Current consumption		35 mA max.	35 mA max. (for 24-VDC power supply)	35 mA max.			
Control output		NPN/PNP (depends on model) open collector; load current: 50 mA max.; residual voltage: 1 V max.; Light ON/Dark ON mode selector					
Response time		200 μs max. for operation and reset respectively (See note.)	Operation: 20 μs max. Reset: 30 μs max.	200 μs max. for operation and reset respectively (See note.)			
Sensitivity adjustment		8-turn sensitivity adjuster (with indicator)					
Circuit protection		Reverse polarity, output short-circuit, mutual interference prevention (optically synchronized)	Reverse polarity, output short-circuit	Reverse polarity, output short-circuit, mutual interference prevention (optically synchronized)			
Timer function		OFF-delay timer: 40 ms (fixed)					
Ambient illumination (receiver side)		Incandescent lamp: 10,000 lux max. Sunlight: 20,000 lux max.					
Ambient temperature		Operating: Groups of 1 to 3 Amplifiers: −25°C to 55°C Groups of 4 to11 Amplifiers: −25°C to 50°C Groups of 12 to16 Amplifiers: −25°C to 45°C (with no icing or condensation) Storage: −30°C to 70°C (with no icing or condensation)					
Ambient humidity		Operating and storage: 35% to 85% (with no condensation)					
Insulation resistance		20 MΩ min. (at 500 VDC)					
Dielectric strength (destruction)		1,000 VAC at 50/60 Hz for 1 minute					500 VAC at 50/60 Hz for 1 minute
Vibration resistance (destruction)		10 to 55 Hz with a 1.5-mm double amplitude for 2 hrs each in X, Y and Z directions					
Shock resistance (destruction)		500 m/s^2, for 3 times each in X, Y and Z directions					
Enclosure rating		IEC60529 IP50 (with Protective Cover attached)			IEC60529 IP66 (with Protective Cover attached)	IEC60529 IP50 (with Protective Cover attached)	IEC60529 IP66 (with Protective Cover attached)
Connection method		Pre-wired (standard cable length: 2 m)				Connector	M8 connector
Weight (packed state)		Approx. 100 g			Approx. 110 g	Approx. 55 g	Approx. 65 g
Material	Case	Polybutylene terephthalate (PBT)					
	Cover	Polycarbonate			Polyethersulfone (PES)	Polycarbonate	Polyethersulfone (PES)
Accessories		Instruction Sheet					

Note When there are 8 or more Units mounted side-by-side, the response time will be 350 μs max.

■ Amplifier Unit Connectors

Item		E3X-CN11	E3X-CN12
Rated current		2.5 A	
Rated voltage		50 V	
Contact resistance		20 mΩ max. (20 mVDC max., 100 mA max.) (The above figure is for connection to the Amplifier Unit and the adjacent Connector. It does not include the conductor resistance of the cable.)	
Number of insertions (destruction)		50 times (for connection to the Amplifier Unit and the adjacent Connector)	
Material	Housing	Polybutylene terephthalate (PBT)	
	Contact	Phosphor bronze/gold-plated nickel	
Weight (packed state)		Approx. 55 g	Approx. 25 g

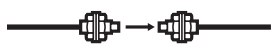
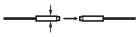
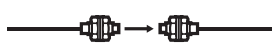
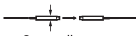
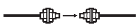
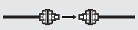
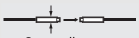
Ordering Information: Fiber Units

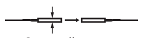
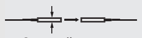
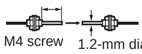
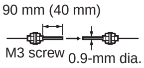
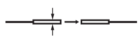
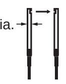
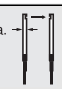
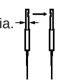
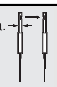
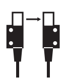
■ Through-beam Fiber Units

Refer to the end of the following table for notes and precautions.

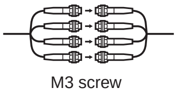
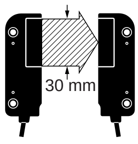
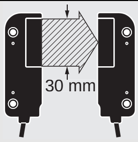
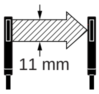
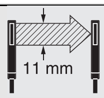
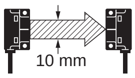
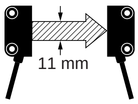
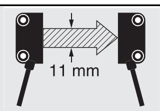
(Free-cut) Indicates models that allow free cutting. Models without this mark do not allow free cutting.

▬ : Red light ▭ : Green light

Applica-tion	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) (Values in parentheses: when using the E39-F1 Lens Unit)	Standard object (see notes) (min. sensing object: opaque)	Model	Permissi-ble bend-ing radius
Long distance	**M4** (Free-cut)	 M4 screw	E3X-NA□ (V)	700 (2,000)	1.4-mm dia. (0.03-mm dia.)	**E32-T11L**	25 mm
			E3X-NAG□	130 (370)			
			E3X-NA□F	210 (600)	1.4-mm dia. (0.5-mm dia.)		
	3-mm dia. (Free-cut)	 3-mm dia.	E3X-NA□ (V)	700	1.4-mm dia. (0.03-mm dia.)	**E32-T12L**	
			E3X-NAG□	130			
			E3X-NA□F	210	1.4-mm dia. (0.5-mm dia.)		
	M3 (Free-cut)	 M3 screw	E3X-NA□ (V)	200	0.9-mm dia. (0.03-mm dia.)	**E32-T21L**	10 mm
			E3X-NAG□	40			
			E3X-NA□F	60	0.9-mm dia. (0.2-mm dia.)		
	2-mm dia.; small diameter (Free-cut)	 2-mm dia.	E3X-NA□ (V)	200	0.9-mm dia. (0.03-mm dia.)	**E32-T22L**	
			E3X-NAG□	40			
			E3X-NA□F	60	0.9-mm dia. (0.2-mm dia.)		
	M14; with lens; ideal for explo-sion-proof appli-cations (Free-cut)	 M14 screw	E3X-NA□ (V)	14,000	10-mm dia. (0.1-mm dia.)	**E32-T17L**	25 mm
			E3X-NA□F	4,200	10-mm dia. (1.5-mm dia.)		
General-purpose	**M4** (Free-cut)	 M4 screw	E3X-NA□ (V)	400 (3,000)	1.0-mm dia. (0.03-mm dia.)	**E32-TC200**	25 mm
			E3X-NAG□	75 (550)			
			E3X-NA□F	120 (900)	1.0-mm dia. (0.2-mm dia.)		
	M4 (Free-cut)	 M4 screw	E3X-NA□ (V)	280 (2,100)	1.0-mm dia. (0.03-mm dia.)	**E32-T11R**	1 mm
			E3X-NAG□	50 (375)			
			E3X-NA□F	80 (600)	1.0-mm dia. (0.2-mm dia.)		
	3-mm dia. (Free-cut)	 3-mm dia.	E3X-NA□ (V)	280	1.0-mm dia. (0.03-mm dia.)	**E32-T12R**	
			E3X-NAG□	50			
			E3X-NA□F	80	1.0-mm dia. (0.2-mm dia.)		
	M3; possible to mount the reflec-tive side-view conversion attachment E39-F5 (Free-cut)	M3 screw	E3X-NA□ (V)	360	1.0-mm dia. (0.03-mm dia.)	**E32-TC200A**	25 mm
			E3X-NAG□	65			
			E3X-NA□F	100	1.0-mm dia. (0.2-mm dia.)		
	M3; for detecting minute sensing objects (Free-cut)	M3 screw	E3X-NA□ (V)	100	0.5-mm dia. (0.03-mm dia.)	**E32-TC200E**	10 mm
			E3X-NAG□	20			
			E3X-NA□F	30	0.5-mm dia. (0.1-mm dia.)		
	M3; small diame-ter (Free-cut)	M3 screw	E3X-NA□ (V)	60	0.5-mm dia. (0.03-mm dia.)	**E32-T21R**	1 mm
			E3X-NAG□	12			
			E3X-NA□F	18	1.0-mm dia. (0.1-mm dia.)		

Application	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) (Values in parentheses: when using the E39-F1 Lens Unit)	Standard object (see notes) (min. sensing object: opaque)	Model	Permissible bending radius
Thin fiber	2-mm dia.; for detecting minute sensing objects (Free-cut)	 2-mm dia.	E3X-NA□ (V)	100	0.5-mm dia. (0.03-mm dia.)	E32-T22	10 mm
			E3X-NAG□	20			
			E3X-NA□F	30	0.5-mm dia. (0.1-mm dia.)		
	2-mm dia.; small diameter (Free-cut)	 2-mm dia.	E3X-NA□ (V)	60	0.5-mm dia. (0.03-mm dia.)	E32-T22R	1 mm
			E3X-NA□F	18	0.5-mm dia. (0.1-mm dia.)		
	1.2-mm dia.; with sleeve (Free-cut)	90 mm (40 mm)  M4 screw 1.2-mm dia. ( ): E32-TC200B4	E3X-NA□ (V)	400	1.0-mm dia. (0.03-mm dia.)	E32-TC200B E32-TC200B4	25 mm
			E3X-NAG□	75			
			E3X-NA□F	120	1.0-mm dia. (0.2-mm dia.)		
	0.9-mm dia.; with sleeve (Free-cut)	90 mm (40 mm)  M3 screw 0.9-mm dia. ( ): E32-TC200F4	E3X-NA□ (V)	100	0.5-mm dia. (0.03-mm dia.)	E32-TC200F E32-TC200F4	10 mm
			E3X-NAG□	20			
			E3X-NA□F	30	0.5-mm dia. (0.1-mm dia.)		
Flexible (resists breaking) (R4)	Ideal for mounting on moving sections (R4) (Free-cut)	 M4 screw	E3X-NA□ (V)	360	1.0-mm dia. (0.03-mm dia.)	E32-T11	4 mm
			E3X-NAG□	65			
			E3X-NA□F	100	1.0-mm dia. (0.2-mm dia.)		
		M3 screw	E3X-NA□ (V)	100	0.5-mm dia. (0.03-mm dia.)	E32-T21	
			E3X-NAG□	18			
			E3X-NA□F	30	0.5-mm dia. (0.1-mm dia.)		
		 1.5-mm dia.	E3X-NA□ (V)	100	0.5-mm dia. (0.03-mm dia.)	E32-T22B	
			E3X-NAG□	18			
			E3X-NA□F	30	0.5-mm dia. (0.1-mm dia.)		
Side-view	Long distance; space-saving (Free-cut)	3-mm dia. 	E3X-NA□ (V)	240	1.0-mm dia. (0.03-mm dia.)	E32-T14L	25 mm
			E3X-NAG□	45			
			E3X-NA□F	70	1.0-mm dia. (0.2-mm dia.)		
	Space-saving (Free-cut)	3-mm dia. 	E3X-NA□ (V)	110	1.0-mm dia. (0.03-mm dia.)	E32-T14LR	1 mm
			E3X-NA□F	33	1.0-mm dia. (0.2-mm dia.)		
	Suitable for detecting minute sensing objects (Free-cut)	1-mm dia. 	E3X-NA□ (V)	90	0.5-mm dia. (0.03-mm dia.)	E32-T24	10 mm
			E3X-NAG□	12			
			E3X-NA□F	27	0.5-mm dia. (0.3-mm dia.)		
	Suitable for detecting minute sensing objects (small diameter) (Free-cut)	1-mm dia. 	E3X-NA□ (V)	30	0.5-mm dia. (0.03-mm dia.)	E32-T24R	1 mm
			E3X-NA□F	9	0.5-mm dia. (0.3-mm dia.)		
	Screw-mounting type (Free-cut)		E3X-NA□ (V)	1,800	4.0-mm dia. (0.03-mm dia.)	E32-T14	25 mm
			E3X-NAG□	330			
			E3X-NA□F	540	4.0-mm dia. (0.2-mm dia.)		

Application	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) (Values in parentheses: when using the E39-F1 Lens Unit)	Standard object (see notes) (min. sensing object: opaque)	Model	Permissible bending radius
Chemical-resistant	Free-cut Teflon-covered *1; withstands chemicals and harsh environments (operating ambient temperature: −30°C to 70°C)	5-mm dia.	E3X-NA☐ (V)	1,600	4.0-mm dia. (0.2-mm dia.)	E32-T12F	40 mm
			E3X-NAG☐	300			
			E3X-NA☐F	480	4.0-mm dia. (0.7-mm dia.)		
	Free-cut Teflon-covered *1; side-view; withstands chemicals and harsh environments (operating ambient temperature: −30°C to 70°C)	5-mm dia.	E3X-NA☐ (V)	200	3.0-mm dia. (0.2-mm dia.)	E32-T14F	
			E3X-NAG☐	37			
			E3X-NA☐F	60	3.0-mm dia. (0.7-mm dia.)		
	Teflon *1; withstands chemicals and harsh environments (operating ambient temperature: −40°C to 200°C)	6-mm dia.	E3X-NA☐ (V)	350	1.0-mm dia. (0.2-mm dia.)	E32-T81F	10 mm
			E3X-NA☐F	100	1.0-mm dia. (0.5-mm dia.)		
Heat-resistant	Resists 200°C; flexible (R10); fiber sheath material: Teflon *1 (operating ambient temperature: −40°C to 200°C)	M4 screw	E3X-NA☐ (V)	180	1.0-mm dia. (0.2-mm dia.)	E32-T81R	10 mm
			E3X-NA☐F	50	1.0-mm dia. (0.5-mm dia.)		
	Free-cut Resists 150°C *2; fiber sheath material: fluororesin (operating ambient temperature: −40°C to 150°C)	M4 screw	E3X-NA☐ (V)	400	1.5-mm dia. (0.03-mm dia.)	E32-T51	35 mm
			E3X-NA☐F	120	1.5-mm dia. (1.0-mm dia.)		
	Resists 300°C *3, with spiral tube; high mechanical strength; fiber sheath material: stainless steel (operating ambient temperature: −40°C to 300°C)	M4 screw	E3X-NA☐ (V)	300 (3,000)	1.0-mm dia. (0.03-mm dia.)	E32-T61	25 mm
			E3X-NA☐F	90	1.0-mm dia. (0.5-mm dia.)		
	Free-cut Side-view; resists 150°C *2; suitable for detecting minute sensing objects; fiber sheath material: fluororesin (operating ambient temperature: −40°C to 150°C)	2-mm dia.	E3X-NA☐ (V)	130	1.0-mm dia. (0.03-mm dia.)	E32-T54	35 mm
			E3X-NA☐F	35	1.0-mm dia. (0.3-mm dia.)		
	Resists 200°C *3; L-shaped; fiber sheath material: stainless steel	3-mm dia.	E3X-NA☐ (V)	700	1.7-mm dia. (0.03-mm dia.)	E32-T84S	25 mm
			E3X-NA☐F	210	1.7-mm dia. (0.4-mm dia.)		
Slot sensor	Free-cut Suitable for film sheet detection; no optical axis adjustment required; easy to mount		E3X-NA☐ (V)	10	4.0-mm dia. (0.1-mm dia.)	E32-G14	25 mm
			E3X-NAG☐	10			
			E3X-NA☐F	10	4.0-mm dia. (1.0-mm dia.)		
Narrow vision field	Free-cut Suitable for detecting wafers	3-mm dia.	E3X-NA☐ (V)	1,000	1.7-mm dia. (0.5-mm dia.)	E32-T22S	10 mm
			E3X-NA☐F	300			
	Free-cut Side-view; suitable for detecting wafers	3.5 mm dia. x 3	E3X-NA☐ (V)	700	2.0-mm dia. (0.03-mm dia.)	E32-T24S	
			E3X-NA☐F	210	2.0-mm dia. (0.5-mm dia.)		

Application	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) (Values in parentheses: when using the E39-F1 Lens Unit)	Standard object (see notes) (min. sensing object: opaque)	Model	Permissible bending radius
Area sensing	Multi-point detection (4-head)	 M3 screw	E3X-NA☐ (V)	300	2.0-mm dia. (0.03-mm dia.)	**E32-M21**	25 mm
			E3X-NA☐F	90	2.0-mm dia. (0.3-mm dia.)		
	Detects in a 30-mm area Free-cut		E3X-NA☐ (V)	920	(0.5-mm dia.) *4	**E32-T16W**	10 mm
			E3X-NAG☐	170			
			E3X-NA☐F	270	(4.0-mm dia.) *4		
	Detects in a 30-mm area Free-cut		E3X-NA☐ (V)	690	(0.5-mm dia.) *4	**E32-T16WR**	1 mm
			E3X-NA☐F	200	(4.0-mm dia.) *4		
	Side-view; suitable for applications with limited spatial depth Free-cut		E3X-NA☐ (V)	520	(0.3-mm dia.) *4	**E32-T16J**	10 mm
			E3X-NAG☐	95			
			E3X-NA☐F	150	(2.0-mm dia.) *4		
	Side-view; suitable for applications with limited spatial depth Free-cut		E3X-NA☐ (V)	390	(0.3-mm dia.) *4	**E32-T16JR**	1 mm
			E3X-NA☐F	110	(2.0-mm dia.) *4		
	Suitable for detecting over a 10-mm area; long distance Free-cut		E3X-NA☐ (V)	1,500	(0.9-mm dia.) *4	**E32-T16**	25 mm
			E3X-NAG☐	275			
			E3X-NA☐F	450	(1.5-mm dia.) *4		
	Stable for detecting minute sensing objects in a wide area; degree of protection: IEC 60529 IP50 Free-cut		E3X-NA☐ (V)	600	(0.3-mm dia.) *4	**E32-T16P**	10 mm
			E3X-NAG☐	110			
			E3X-NA☐F	180	(2.0-mm dia.) *4		
	Stable for detecting minute sensing objects in a wide area; degree of protection: IEC60529 IP50 Free-cut		E3X-NA☐ (V)	450	(0.3-mm dia.) *4	**E32-T16PR**	1 mm
			E3X-NA☐F	130	(2.0-mm dia.) *4		

*1 Teflon is a registered trademark of the Dupont Company and the Mitsui Dupont Chemical Company for their fluoride resin.

*2 For continuous operation, use the products within a temperature range of −40°C to 130°C.

*3 Indicates the heat-resistant temperature at the fiber tip.

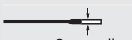
*4 These figures are for a sensing distance of 100 mm. (Diameters of sensing objects are ones at a stationary state.)

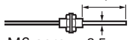
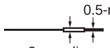
Note:
1. The size of standard sensing object is the same as the fiber core diameter (lens diameter for models with lens).
2. The values of the minimum sensing object for E3X-NA☐ (V) and E3X-NAG☐ through-beam models indicate those obtained where the sensing distance and sensitivity are set to optimum values.
3. The value of the minimum sensing object for E3X-NA☐F through-beam models indicates that obtained at the rated sensing distance with the sensitivity set to the optimum value.

■ Fiber Units with Reflective Sensors

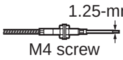
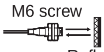
Refer to the end of the following table for notes and precautions.

(Free-cut) Indicates models that allow free cutting. Models without this mark do not allow free cutting. ■ : Red light □ : Green light

Application	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) *1	Standard object (see note) (min. sensing object: Gold wire)	Model	Permissible bending radius
Long distance	M6 (Free-cut)	 M6 screw	E3X-NA□ (V)	200	250×250 (0.01-mm dia.)	E32-D11L	25 mm
			E3X-NAG□	35	50×50 (0.1-mm dia.)		
			E3X-NA□F	65	100×100 (0.015-mm dia.)		
	3-mm dia.; small diameter (Free-cut)	 3-mm dia.	E3X-NA□ (V)	120	150×150 (0.01-mm dia.)	E32-D12	
			E3X-NAG□	20	25×25 (0.1-mm dia.)		
			E3X-NA□F	40	50×50 (0.015-mm dia.)		
	M4 (Free-cut)	 M4 screw	E3X-NA□ (V)	50	100×100 (0.01-mm dia.)	E32-D21L	10 mm
			E3X-NAG□	10	25×25 (0.1-mm dia.)		
			E3X-NA□F	17	25×25 (0.015-mm dia.)		
	3-mm dia.; small diameter (Free-cut)	 3-mm dia.	E3X-NA□ (V)	50	100×100 (0.01-mm dia.)	E32-D22L	
			E3X-NAG□	10	25×25 (0.1-mm dia.)		
			E3X-NA□F	17	25×25 (0.015-mm dia.)		
General-purpose	M6 (Free-cut)	 M6 screw	E3X-NA□ (V)	150	200×200 (0.01-mm dia.)	E32-DC200	25 mm
			E3X-NAG□	25	50×50 (0.1-mm dia.)		
			E3X-NA□F	50	75×75 (0.015-mm dia.)		
	M6 (Free-cut)	 M6 screw	E3X-NA□ (V)	90	150×150 (0.01-mm dia.)	E32-D11R	1 mm
			E3X-NAG□	15	25×25 (0.1-mm dia.)		
			E3X-NA□F	30	50×50 (0.02-mm dia.)		
	3-mm dia. (Free-cut)	 3-mm dia.	E3X-NA□ (V)	90	150×150 (0.01-mm dia.)	E32-D12R	
			E3X-NAG□	15	25×25 (0.1-mm dia.)		
			E3X-NA□F	30	50×50 (0.02-mm dia.)		
	M3; small diameter (Free-cut)	M3 screw	E3X-NA□ (V)	36	50×50 (0.01-mm dia.)	E32-DC200E	10 mm
			E3X-NAG□	6	25×25 (0.1-mm dia.)		
			E3X-NA□F	12	25×25 (0.02-mm dia.)		
	M3; small diameter (Free-cut)	M3 screw	E3X-NA□ (V)	15	25×25 (0.01-mm dia.)	E32-D21R	1 mm
			E3X-NA□F	5	25×25 (0.03-mm dia.)		
	3-mm dia.; small diameter (Free-cut)	 3-mm dia.	E3X-NA□ (V)	15	25×25 (0.01-mm dia.)	E32-D22R	
			E3X-NA□F	5	25×25 (0.03-mm dia.)		

Application	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) *1	Standard object (see note) (min. sensing object: Gold wire)	Model	Permissible bending radius
Thin fiber	**2.5-mm dia.; with sleeve** Free-cut	90 mm (40 mm)  M6 screw 2.5-mm dia. ( ): E32-DC200B4	E3X-NA☐ (V)	150	200×200 (0.01-mm dia.)	**E32-DC200B E32-DC200B4**	25 mm
			E3X-NAG☐	25	50×50 (0.1-mm dia.)		
			E3X-NA☐F	50	75×75 (0.015-mm dia.)		
	1.2-mm dia.; with sleeve Free-cut	90 mm (40 mm)  M3 screw 1.2-mm dia. ( ): E32-DC200F4	E3X-NA☐ (V)	36	50×50 (0.01-mm dia.)	**E32-DC200F E32-DC200F4**	10 mm
			E3X-NAG☐	6	25×25 (0.1-mm dia.)		
			E3X-NA☐F	12	25×25 (0.02-mm dia.)		
	0.8-mm dia.; for detecting minute sensing objects Free-cut	3-mm dia.  0.8-mm dia.	E3X-NA☐ (V)	10	25×25 (0.01-mm dia.)	**E32-D33**	4 mm
			E3X-NA☐F	3.3	25×25 (0.03-mm dia.)		
	0.5-mm dia.; for detecting minute sensing objects	0.5-mm dia.  2-mm dia.	E3X-NA☐	1.5	25×25 (0.01-mm dia.)	**E32-D331**	4 mm
			E3X-NA☐F	0.5	25×25 (0.05-mm dia.)		
Flexible (resists breaking) (R4)	**Ideal for mounting on moving sections (R4)** Free-cut	 M6 screw	E3X-NA☐ (V)	90	150×150 (0.01-mm dia.)	**E32-D11**	4 mm
			E3X-NAG☐	15	25×25 (0.1-mm dia.)		
			E3X-NA☐F	30	50×50 (0.015-mm dia.)		
	Free-cut	M3 screw	E3X-NA☐ (V)	15	25×25 (0.01-mm dia.)	**E32-D21**	
			E3X-NA☐F	5	25×25 (0.02-mm dia.)		
	Free-cut	 M4 screw	E3X-NA☐ (V)	15	25×25 (0.01-mm dia.)	**E32-D21B**	
			E3X-NAG☐	2.4	25×25 (0.1-mm dia.)		
			E3X-NA☐F	5	25×25 (0.02-mm dia.)		
		 1.5-mm dia.	E3X-NA☐ (V)	7	25×25 (0.01-mm dia.)	**E32-D22B**	
			E3X-NA☐F	2.3	25×25 (0.02-mm dia.)		

Application	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) *1	Standard object (see note) (min. sensing object: Gold wire)	Model	Permissible bending radius
Coaxial	**M6 coaxial; high-precision positioning** (Free-cut)	M6 screw	E3X-NA□ (V)	150	200×200 (0.01-mm dia.)	**E32-CC200**	25 mm
			E3X-NAG□	25	50×50 (0.1-mm dia.)		
			E3X-NA□F	50	75×75 (0.015-mm dia.)		
	3-mm dia. coaxial; small diameter; high-precision positioning (Free-cut)	3-mm dia.	E3X-NA□ (V)	80	100×100 (0.01-mm dia.)	**E32-D32L**	
			E3X-NAG□	12	25×25 (0.1-mm dia.)		
			E3X-NA□F	25	50×50 (0.02-mm dia.)		
	M3 coaxial; high-precision positioning; possible to mount small-spot lens (E39-F3A-5/F3B/F3C) (Free-cut)	M3 screw	E3X-NA□ (V)	40	50×50 (0.01-mm dia.)	**E32-C31**	
			E3X-NAG□	6	25×25 (0.1-mm dia.)		
			E3X-NA□F	13	25×25 (0.02-mm dia.)		
	M3 coaxial; high-precision positioning; possible to mount small–spot lens (E39-F3A-5/F3B/F3C)	M3 screw	E3X-NA□ (V)	15	25×25 (0.01-mm dia.)	**E32-C41**	
			E3X-NA□F	5	25×25 (0.02-mm dia.)		
	2-mm dia. coaxial; high-precision positioning; possible to mount small-spot (0.1 to 0.6 dia.) lens (E39-F3A)	2-mm dia.	E3X-NA□ (V)	15	25×25 (0.01-mm dia.)	**E32-C42**	
			E3X-NA□F	5	25×25 (0.02-mm dia.)		
	2-mm dia. coaxial; high-precision positioning; possible to mount small-spot (0.5 to 1 dia.) lens (E39-F3A) (Free-cut)	2-mm dia.	E3X-NA□ (V)	40	50×50 (0.01-mm dia.)	**E32-D32**	
			E3X-NAG□	6	25×25 (0.1-mm dia.)		
			E3X-NA□F	13	25×25 (0.02-mm dia.)		
Side-view	**6-mm dia.; long distance** (Free-cut)	6-mm dia.	E3X-NA□ (V)	40	50×50 (0.03-mm dia.)	**E32-D14L**	25 mm
			E3X-NAG□	10	25×25 (0.3-mm dia.)		
			E3X-NA□F	13	25×25 (0.03-mm dia.)		
	6-mm dia. (Free-cut)	6-mm dia.	E3X-NA□ (V)	16	25×25 (0.03-mm dia.)	**E32-D14LR**	1 mm
			E3X-NA□F	5			
	2-mm dia.; small diameter space-saving (Free-cut)	2-mm dia.	E3X-NA□ (V)	15	25×25 (0.03-mm dia.)	**E32-D24**	10 mm
			E3X-NAG□	2.4	25×25 (0.3-mm dia.)		
			E3X-NA□F	5	25×25 (0.03-mm dia.)		
	2-mm dia.; small diameter space-saving (Free-cut)	2-mm dia.	E3X-NA□ (V)	7	25×25 (0.03-mm dia.)	**E32-D24R**	1 mm
			E3X-NA□F	2.3			
Chemical-resistant	**Teflon-covered *3; withstands chemicals and harsh environments (operating ambient temperature: −30°C to 70°C)** (Free-cut)	6-mm dia.	E3X-NA□ (V)	50	100×100 (0.03-mm dia.)	**E32-D12F**	40 mm
			E3X-NAG□	8	25×25 (0.3-mm dia.)		
			E3X-NA□F	16	25×25 (0.03-mm dia.)		

Applica-tion	Features	Appearance	Applicable Amplifier Unit	Sensing distance (mm) *1	Standard object (see note) (min. sensing object: Gold wire)	Model	Permis-sible bending radius
Heat-re-sistant	**Resists 150°C *2; fiber sheath material: fluo-roresin (operating ambi-ent temperature: −40°C to 150°C)** Free-cut	 M6 screw	E3X-NA☐ (V)	120	150×150 (0.03-mm dia.)	**E32-D51**	35 mm
			E3X-NA☐F	40	50×50 (0.03-mm dia.)		
	Resists 300°C *4; fiber sheath material: stainless steel (operating ambient temperature: −40°C to 300°C)	 M6 screw	E3X-NA☐ (V)	45	100×100 (0.03-mm dia.)	**E32-D61**	25 mm
			E3X-NA☐F	15	25×25 (0.03-mm dia.)		
	Resists 400°C *4; fiber sheath material: stainless steel (operating ambient temperature: −40°C to 400°C)	 1.25-mm dia. M4 screw	E3X-NA☐ (V)	30	50×50 (0.03-mm dia.)	**E32-D73**	
			E3X-NA☐F	10	25×25 (0.03-mm dia.)		
Area sensing	**Side-view; de-tection over wide areas** Free-cut		E3X-NA☐ (V)	75	100×100 (0.03-mm dia.)	**E32-D36P1**	25 mm
			E3X-NA☐F	25	50×50 (0.03-mm dia.)		
Retrore-flective	**Transparent ob-ject detection** Free-cut	 M6 screw Reflector E39-R3	E3X-NA☐ (V)	10 to 250	35-mm dia. (0.3-mm dia.)	**E32-R21 +E39-R3 (Attachment)**	10 mm
			E3X-NA☐F	10 to 250	35-mm dia. (0.5-mm dia.)		
	Transparent ob-ject detection (operating ambi-ent temperature: −25°C to 55°C); degree of protection: IEC 60529 IP66 Free-cut	 Reflector E39-R1	E3X-NA☐ (V)	150 to 1,500	35-mm dia. (0.6-mm dia.)	**E32-R16 +E39-R1 (Attachment)**	25 mm
			E3X-NA☐F	150 to 1,000	35-mm dia. (4.0-mm dia.)		
Limited reflec-tive	**Suitable for po-sitioning crystal glass** Free-cut		E3X-NA☐ (V)	4 to12	---	**E32-L56E1 E32-L56E2**	35 mm
			E3X-NA☐F	4 to12			
	Detects wafers and small differ-ences in height; (operating ambient tem-perature: −40°C to 105°C); degree of protection: IEC 60529 IP50 Free-cut		E3X-NA☐ (V)	4±2	25×25 (0.015-mm dia.)	**E32-L24L**	10 mm
			E3X-NA☐F	4±2	25×25 (0.03-mm dia.)		
			E3X-NA☐ (V)	7.2±1.8	25×25 (0.015-mm dia.)	**E32-L25L**	
			E3X-NA☐F	7.2±1.8	25×25 (0.03-mm dia.)		
	Detects wafers and small differ-ences in height; degree of protection: IEC 60529 IP50 Free-cut		E3X-NA☐ (V)	3.3	25×25 (0.015-mm dia.)	**E32-L25**	25 mm
			E3X-NA☐F	3.3	25×25 (0.03-mm dia.)		
			E3X-NA☐ (V)	3.3	25×25 (0.015-mm dia.)	**E32-L25A**	
			E3X-NA☐F	3.3	25×25 (0.03-mm dia.)		
Fluid-level de-tection	**Fluid contact type: un-bendable section L=150 mm, 350 mm (two types)**	 L	E3X-NA☐ (V)	---	---	**E32-D82F1 E32-D82F2**	40 mm
			E3X-NA☐F		---		
	Tube-mounting type Free-cut		E3X-NA☐ (V)	---	---	**E32-L25T**	10 mm
			E3X-NA☐F		---		

*1 Sensing distance indicates values for white paper.

*2 For continuous operation, use the products within a temperature range of −40°C to 130°C.

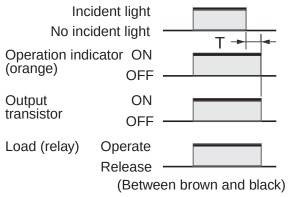
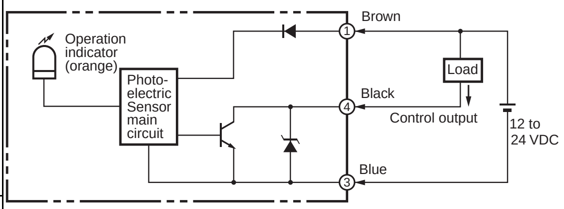
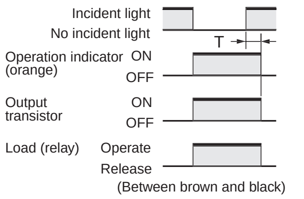
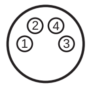
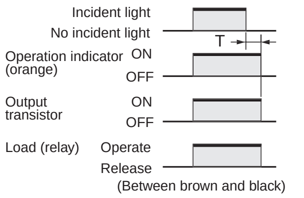
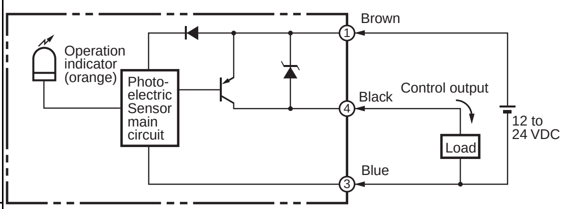
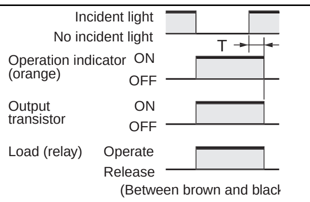
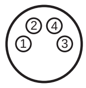
*3 Teflon is a registered trademark of the Dupont Company and the Mitsui Dupont Chemical Company for their fluoride resin.

*4 Indicates the heat-resistant temperature at the fiber tip.

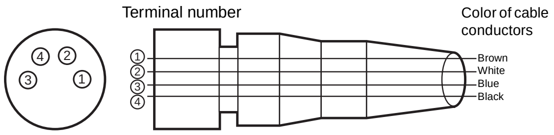
Note The values of the minimum sensing object indicate those obtained at a distance where the smallest object can be sensed with the Reflective Fiber Unit.

Operation

■ Output Circuits

Output	Model	Mode selector	Timing chart	State of output transistor	Output circuit
NPN	E3X-NA11 E3X-NA6 E3X-NAG11 E3X-NA11F E3X-NA11V E3X-NA14V	LIGHT ON (L/ON)		Light ON	
		DARK ON (D/ON)		Dark ON	**M8 Connector Pin Arrangement**  **Note** Pin 2 is not used.
PNP	E3X-NA41 E3X-NA8 E3X-NAG41 E3X-NA41F E3X-NA41V E3X-NA44V	LIGHT ON (L/ON)		Light ON	
		DARK ON (D/ON)		Dark ON	**M8 Connector Pin Arrangement**  **Note** Pin 2 is not used.

Connectors (Sensor I/O Connectors)



XS3F-M421-402-A, XS3F-M422-402-A
XS3F-M421-405-A, XS3F-M422-405-A

Classification	Color of cable conductors	Connection pin number	Application
DC	Brown	1	Power supply (+V)
	White	2	---
	Blue	3	Power supply (0 V)
	Black	4	Output

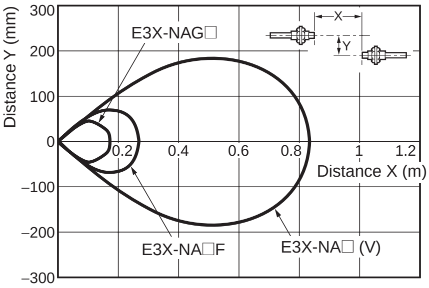
Note Pin 2 is not used.

Engineering Data (Typical)

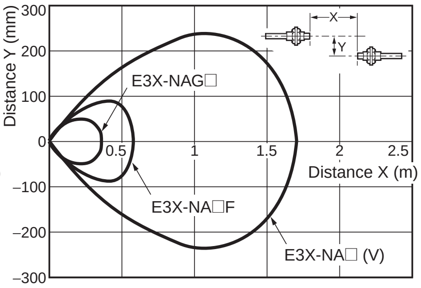
Parallel Operating Range

At max. sensitivity. (Use for optical axis adjustment at installation.)

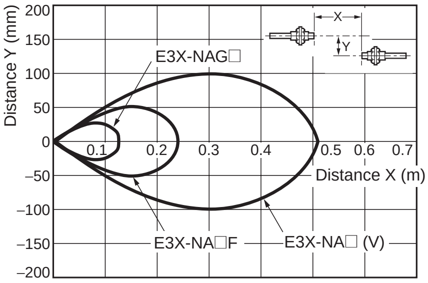
E32-TC200



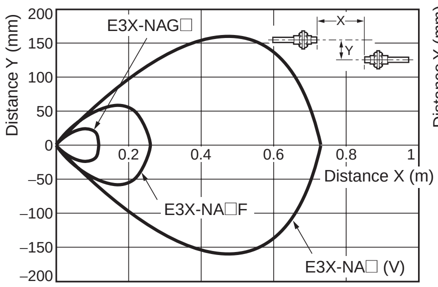
E32-T11L/T12L



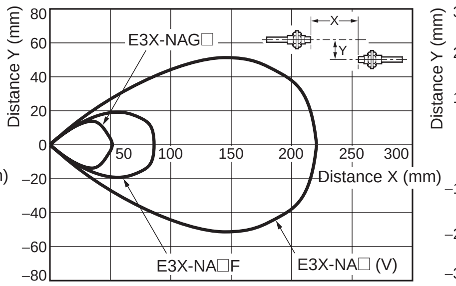
E32-T11R



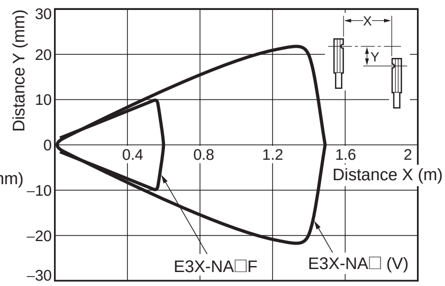
E32-T11



E32-TC200E



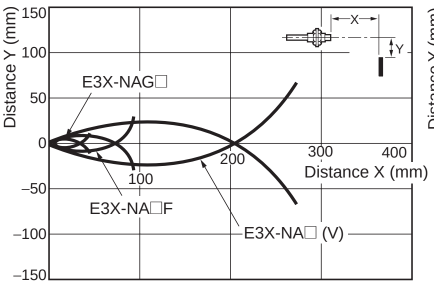
E32-T24S



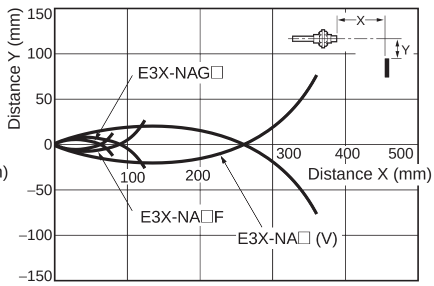
Operating Range

With standard sensing object at max. sensitivity. (Use for the positioning of the object and Sensor.)

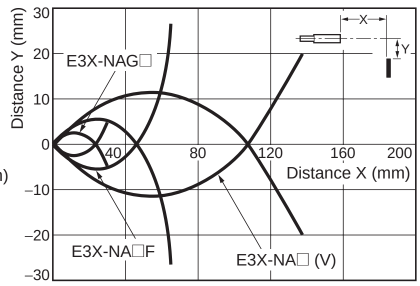
E32-DC200



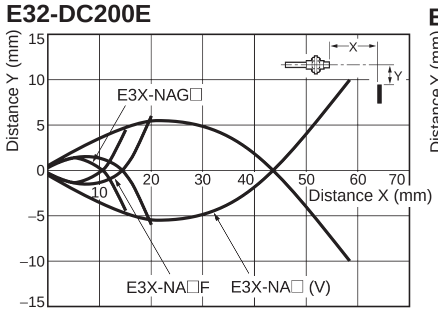
E32-D11L



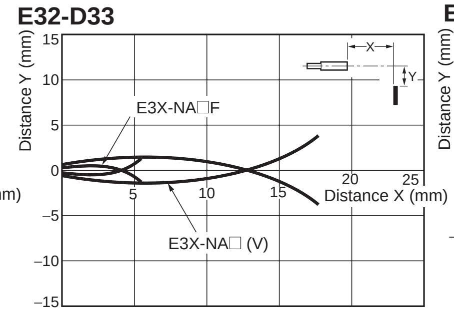
E32-D11R/D12R



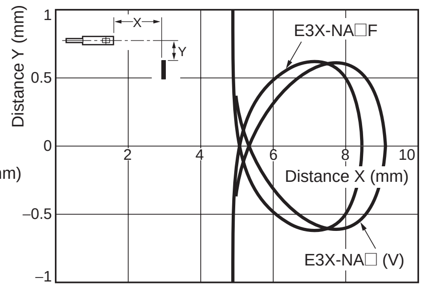
E32-DC200E



E32-D33

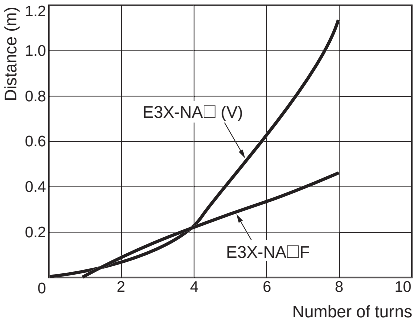


E32-L25L

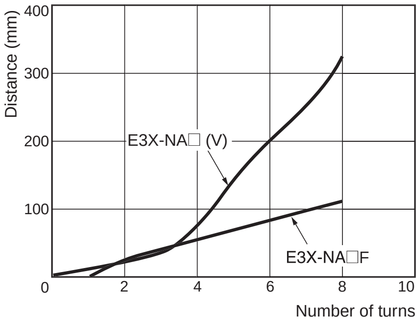


Number of Turns of Sensitivity Adjuster vs. Sensing Distance

E32-T11L

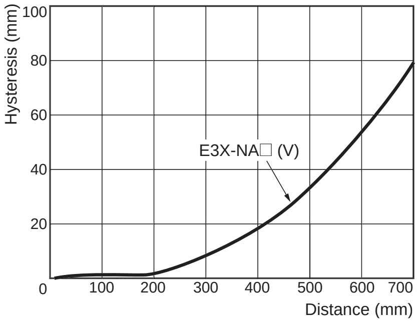


E32-D11L

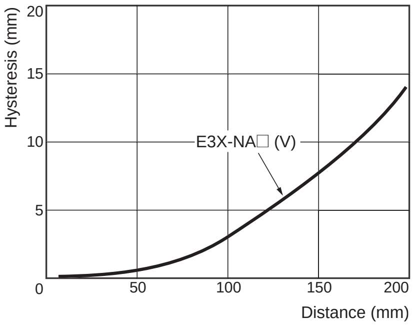


Sensing Distance vs. Hysteresis

E32-T11L



E32-D11L



Application

■ Wiring Precautions

Read the following before using the Amplifier Unit and Sensor to ensure safety.

Power Supply Voltage

Do not impose any voltage exceeding the rated voltage on the E3X-NA. Do not impose AC power (100 VAC) on models that operate with DC. In both cases, the E3X-NA may rupture or burn.

Load Short-circuits

Do not short-circuit the load connected to the E3X-NA, otherwise the E3X-NA may rupture or burn.

Polarity

When supplying power to the E3X-NA, make sure that the polarity of the power is correct, otherwise the E3X-NA may rupture or burn.

No-load Operation

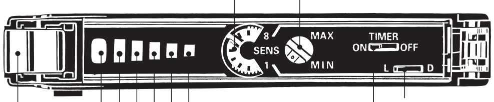
A load must be connected to the E3X-NA during operation, otherwise internal elements may rupture or burn. Always wire through a load.

Operating Environment

- Do not use the Amplifier Unit or Sensor in places with flammable or explosive gas.
- Do not use the Amplifier Unit or Sensor underwater.
- Do not disassemble, repair, or modify the Amplifier Unit or Sensor.

■ Amplifier Units

Nomenclature



Installation

Turning Power ON

The Sensor is ready to operate within 100 ms after the power supply is turned ON. If the Sensor and load are connected to power supplies separately, be sure to turn ON the power supply to the Sensor first.

Turning Power OFF

Pulses may be output when the power is turned OFF. Always turn OFF the power to the load or the load line first.

Power Supply Type

A full or half-wave rectifying power supply without a smoothing circuit cannot be used.

Communications Hole

The hole on the side of the Amplifier Unit is a communications hole for preventing mutual interference when Amplifier Units are mounted side-by-side. The E3X-MC11 Mobile Console (sold separately) cannot be used.
If an excessive amount of light is received via the Sensor, the mutual interference prevention function may not work. In this case, make the appropriate adjustments using the sensitivity adjuster.
The mutual interference prevention function will not operate when the E3X-NA is used side-by-side with E3X-DA-N models.

Wiring

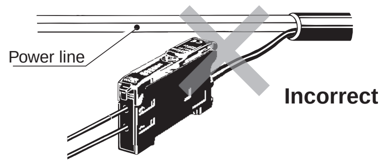
Cable

The cable can be extended, provided that the extension wire applied is at least 0.3 mm^2 thick and the total distance no more than 100 m.

Do not pull the cable with a force exceeding 30N.

Separation from Power or High-tension Lines

Do not wire power lines or high-tension lines alongside the lines of the Amplifier Unit in the same conduit, otherwise the Amplifier Unit may be damaged or malfunction due to induction. Be sure to wire the lines of the Amplifier Unit separated as far as possible from power lines or high-tension lines or laid in an exclusive, shielded conduit.



Power Supply

If a standard switching regulator is used as a power supply, the frame ground (FG) terminal and the ground (G) terminal must be grounded, otherwise faulty operation may result from the switching noise of the power supply.

M8 Metal Connectors (Water-resistant Models)

Turn OFF the power before inserting or removing the connector.

Hold the connector cover when inserting or removing the connector.

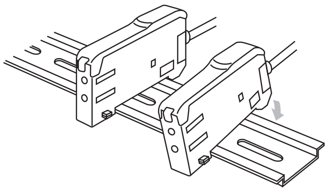
Tighten the fixing screws by hand. Using tools such as pliers may cause damage.

The applicable tightening torque range is 0.3 to 0.4 N·m. If tightening is insufficient, the enclosure rating may not be maintained, and vibrations may cause the connector to come loose.

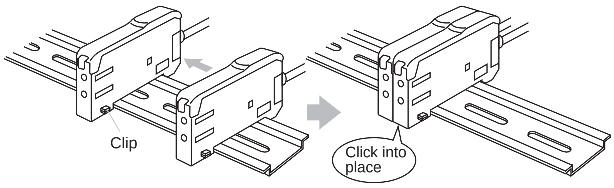
Mounting

Joining Amplifier Units

1. Mount the Amplifier Units one at a time onto the DIN track.



2. Slide the Amplifier Units together, line up the clips, and press the Amplifier Units together until they click into place.



Separating Amplifier Units

Slide Amplifier Units away from each other, and remove from the DIN track one at a time. (Do not attempt to remove Amplifier Units from the DIN track without separating them first.)

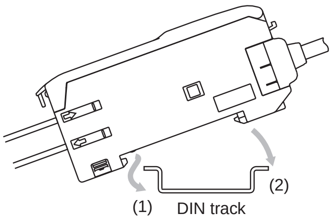
Note: **1.** The specifications for ambient temperature will vary according to the number of Amplifier Units used together. For details, refer to *Ratings/Characteristics*.

2. Always turn OFF the power supply before joining or separating Amplifier Units.

Mounting

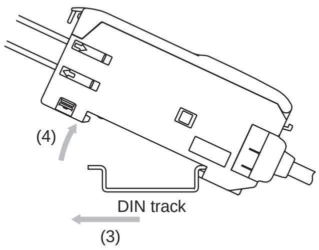
1. Mount the front part on the mounting bracket (ordered separately) or a DIN track.
2. Press the back part onto the mounting bracket or the DIN track.

Note Do not mount the back of the Amplifier Unit onto the mounting bracket or the DIN track first, otherwise the mounting strength of the Amplifier Unit may be reduced. Always mount the front of the Amplifier Unit first.

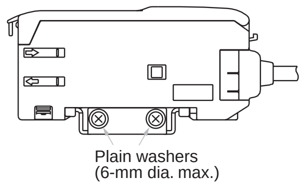


Dismounting

By pressing the Amplifier Unit in direction (3) and lifting the fiber insertion part in direction (4) as shown in the following diagram, the Amplifier Unit can be dismounted with ease.



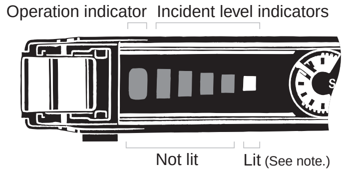
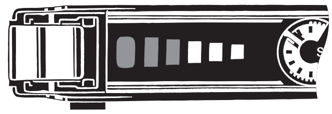
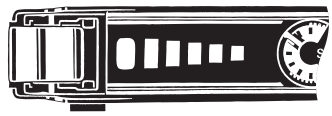
When side-mounting using a mounting bracket, secure the mounting bracket to the Amplifier Unit and then mount using M3 screws. Use plain washers of diameter 6 mm or less when mounting.



Adjustment

Indicators

In addition to an operation indicator (orange), the E3X-NA also has incident level indicators (4 green and 1 red). Use these indicators for optical axis adjustments and maintenance.

Status of indicators (in L/ON mode)	Operation indicator (in L/ON mode)	Incident level
	Not lit	Approx. 80% max. of operating level
	Not lit	Approx. 80% to 90% of operating level
	Not lit or lit	Approx. 90% to 110% of operating level
	Lit	Approx. 110% to 120% of operating level
	Lit	Approx. 120% min. of operating level

Note The rightmost indicator will be lit even if the incident level is 0.

Operating Environment

Ambient Conditions

If dust or dirt adhere to the hole for optical communications, it may prevent normal communications. Be sure to remove any dust or dirt before using the Units.

Miscellaneous

Ratings and Specifications

The ratings and performance specifications for items such as the minimum sensing object and characteristics are based on products taken at random from certain production lots. Use this data as reference only.

Protective Cover

Be sure to mount the Protective Cover before use.

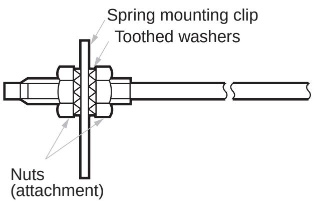
■ Fiber Unit

Mounting

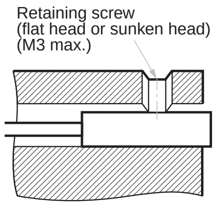
Tightening Force

The tightening force applied to the Fiber Unit should be as follows:

Screw-mounting Model

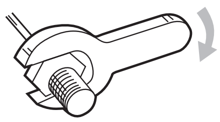


Cylindrical Model



Fiber Units	Clamping torque
M3/M4 screw	0.78 N·m max.
M6 screw/ 6-mm dia. cylinder	0.98 N·m max.
1.5-mm dia. cylinder	0.2 N·m max.
2-mm dia./3-mm dia. cylinder	0.29 N·m max.
E32-T12F 5-mm dia. Teflon model	0.78 N·m max.
E32-D12F 6-mm dia. Teflon model	
E32-T16	0.49 N·m max.
E32-R21	0.59 N·m max.
E32-M21	Up to 5 mm to the tip: 0.49 N·m max. More than 5 mm from the tip: 0.78 N·m max.
E32-L25A	0.78 N·m max.
E32-T16P E32-T16PR E32-T24S E32-L24L E32-L25L E32-T16J E32-T16JR	0.29 N·m max.
E32-T16W E32-T16WR	0.3 N·m max.

Use a proper-sized wrench.

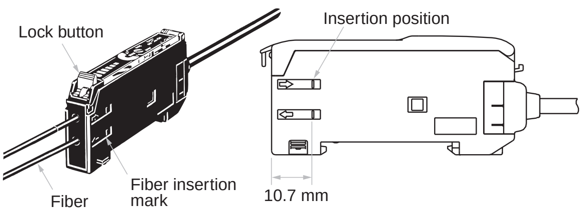


Fiber Connection and Disconnection

The E3X Amplifier Unit has a lock button. Connect or disconnect the fibers to or from the E3X Amplifier Unit using the following procedures:

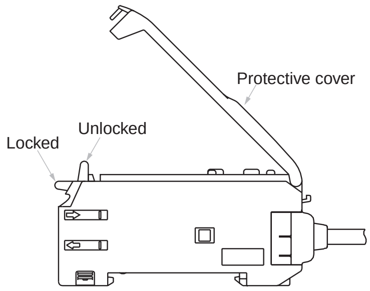
1. Connection

   Open the protective cover, insert the fibers according to the fiber insertion marks on the side of the Amplifier Unit, and lower the lock button.



2. Disconnection

   Remove the protective cover and raise the lock button to pull out the fiber.



Note To maintain the fiber properties, confirm that the lock is released before removing the fiber.

3. Precautions for Fiber Connection/Disconnection

Be sure to lock or unlock the lock button within an ambient temperature range between −10°C and 40°C.

Cutting Fiber

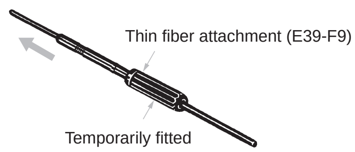
Insert a fiber into the Fiber Cutter and determine the length of the fiber to be cut.

Press down the Fiber Cutter in a single stroke to cut the fiber.

The cutting holes cannot be used twice. If the same hole is used twice, the cutting face of the fiber will be rough and the sensing distance will be reduced. Always use an unused hole.

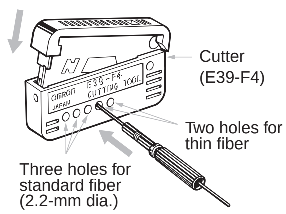
Cut a thin fiber as follows:

1. An attachment is temporarily fitted to a thin fiber before shipment.

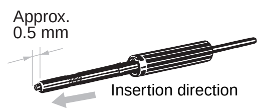


2. Secure the attachment after adjusting the position of it in the direction indicated by the arrow.

3. Insert the fiber to be cut into the E39-F4.



4. Finished state (proper cutting state)



Note Insert the fiber in the direction indicated by the arrow.

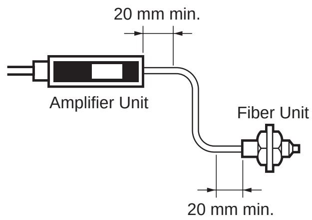
Connection

Do not pull or press the Fiber Units. The Fiber Units have a withstand force of 9.8 N or 29.4 N maximum (pay utmost attention because the fibers are thin).

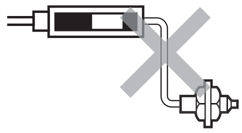
Do not bend the Fiber Unit beyond the permissible bending radius given under *Specifications: Amplifier Units* on page 3.

Do not bend the edge of the Fiber Units (excluding the E32-T☐R and E32-D☐R).

Correct

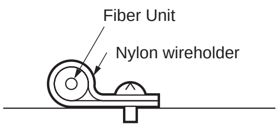


Incorrect

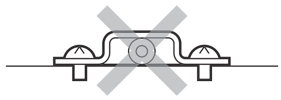


Do not apply excess force on the Fiber Units.

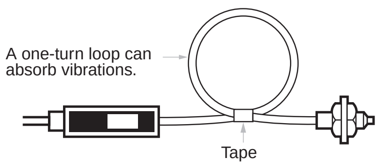
Correct



Incorrect



The Fiber Head could be broken by excessive vibration. To prevent this, the following is effective:

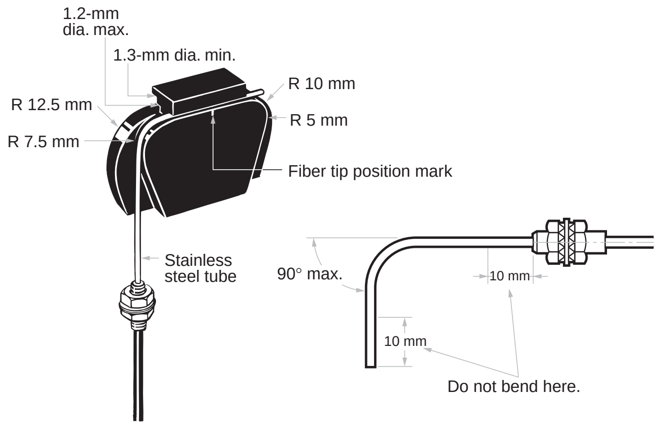


Bending Radius

E39-F11 Sleeve Bender

The bending radius of the stainless steel tube should be as large as possible. The smaller the bending radius becomes, the shorter the sensing distance will be.

Insert the tip of the stainless steel tube to the Sleeve Bender and bend the stainless steel tube slowly along the curve of the Sleeve Bender (refer to the figure).

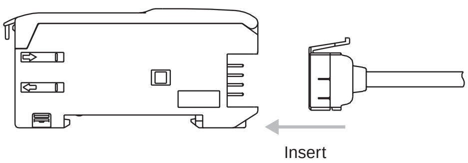


■ Amplifier Units with Connectors

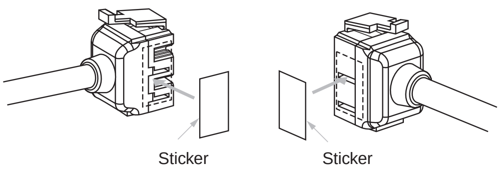
Mounting

Mounting Connectors

1. Insert the Master or Slave Connector into the Amplifier Unit until it clicks into place.



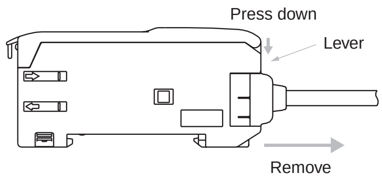
2. Join Amplifier Units together as required after all the Master and Slave Connectors have been inserted.
3. Attach the stickers (provided as accessories) to the sides of Master and Slave Connectors that are not connected to other Connectors.



Note Attach the stickers to the sides with grooves.

Removing Connectors

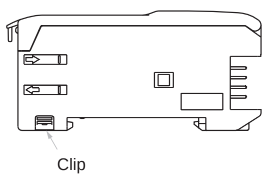
1. Slide the slave Amplifier Unit for which the Connector is to be removed away from the rest of the group.
2. After the Amplifier Unit has been separated, press down on the lever on the Connector and remove it. (Do not attempt to remove Connectors without separating them from other Amplifier Units first.)



Mounting End Plate (PFP-M)

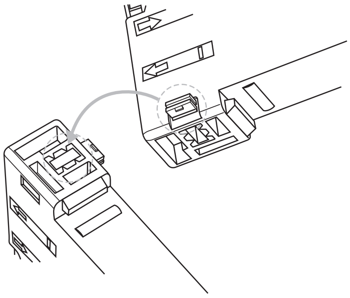
Depending on how it is mounted, an Amplifier Unit may move during operation. In this case, use an End Plate.

Before mounting an End Plate, remove the clip from the master Amplifier Unit using a nipper or similar tool.

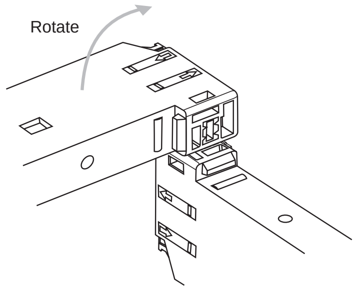


The clip can also be removed using the following mechanism, which is incorporated in the construction of the section underneath the clip.

1. Insert the clip to be removed into the slit underneath the clip on another Amplifier Unit.



2. Remove the clip by rotating the Amplifier Unit.



Pull Strengths for Connectors (Including Cables)

E3X-CN11: 30 N max.
E3X-CN12: 12 N max.

■ Reflector

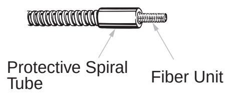
Use of E39-R3 Reflector

Use detergent, etc., to remove any dust or oil from the surfaces where tape is applied. Adhesive tape will not be attached properly if oil or dust remains on the surface.

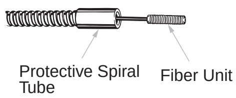
The E39-R3 cannot be used in places where it is exposed to oil or chemicals.

E39-F32□ Protective Spiral Tubes

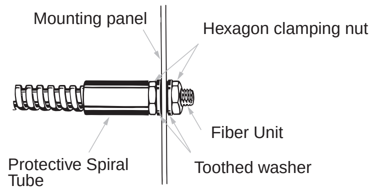
Insert a fiber to the Protective Spiral Tube from the head connector side (screwed) of the tube.



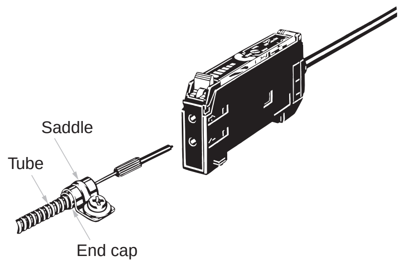
Push the fiber into the Protective Spiral Tube. The tube should be straight so that the fiber is not twisted when inserted. Then turn the end cap of the spiral tube.



Secure the Protective Spiral Tube on a suitable place with the attached nut.

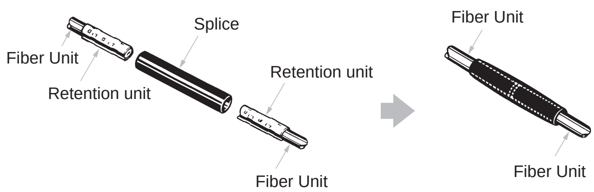


Use the attached saddle to secure the end cap of the Protective Spiral Tube. To secure the Protective Spiral Tube at a position other than the end cap, apply tape to the tube so that the portion becomes thicker in diameter.



E39-F10 Fiber Connector

Mount the Fiber Connector as shown in the following illustrations.



The Fiber Units should be as close as possible when they are connected.

Sensing distance will be reduced by approximately 25% when fibers are connected.

Only 2.2-mm-dia. fibers can be connected.

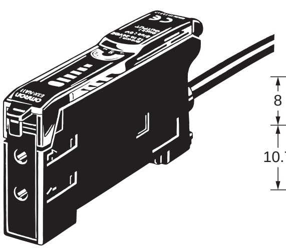
Dimensions

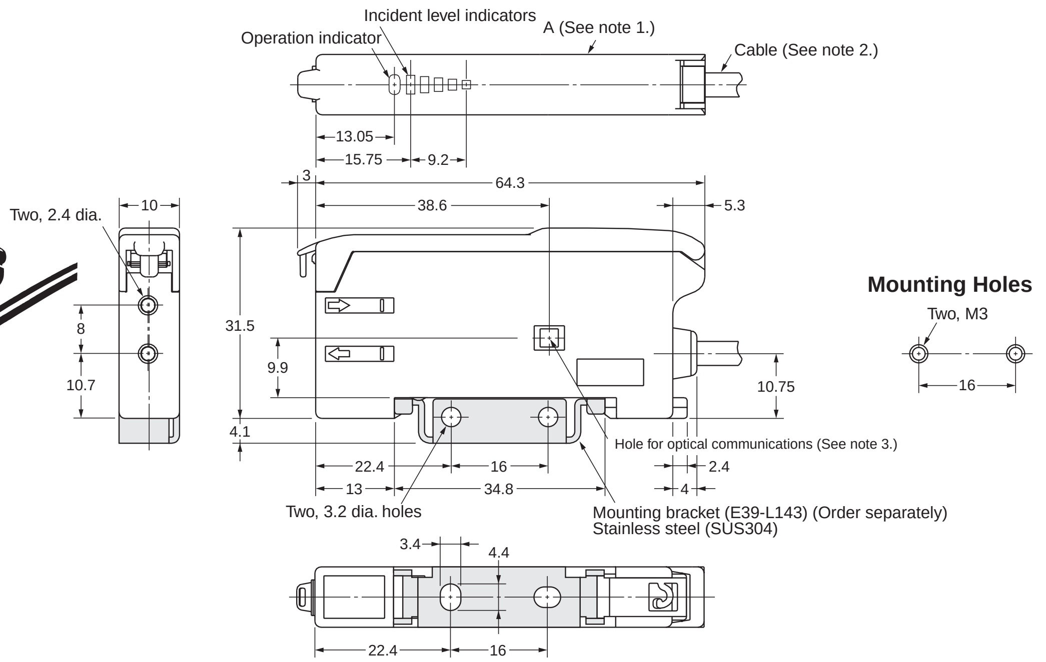
Note All units are in millimeters unless otherwise indicated.

■ Amplifier Units

Amplifier Units with Cables (with Mounting Bracket Attached)

E3X-NA11
E3X-NA11F
E3X-NA41
E3X-NA41F
E3X-NAG11
E3X-NAG41

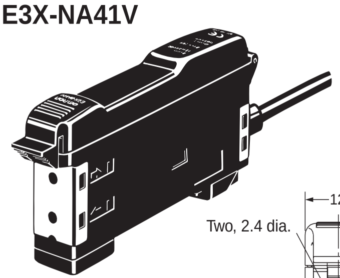


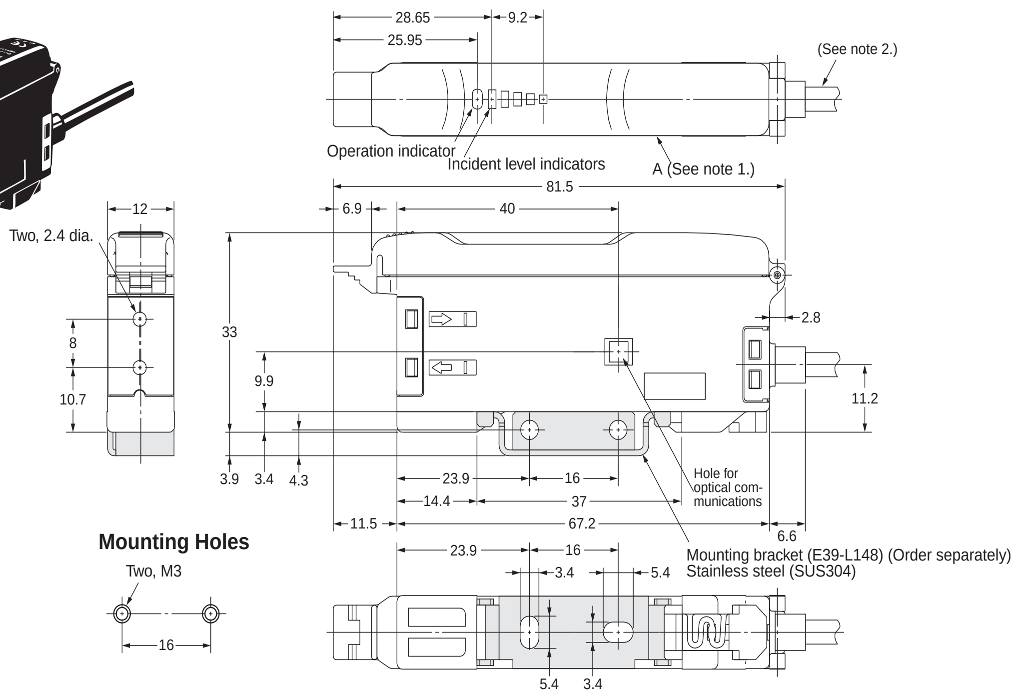


Note:
1. The mounting bracket can also be used on side A.
2. With these models, a 4-dia., 3-conductor, vinyl-insulated round cable (conductor cross-sectional area: 0.2 mm^2; insulation diameter: 1.1 mm) is used.
   Standard length: 2 m.
3. The hole for optical communications is for preventing mutual interference. There is no hole for E3X-NA□F models.

Amplifier Units with Cables, Water-resistant Models (with Mounting Bracket Attached)

E3X-NA11V
E3X-NA41V

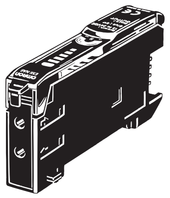


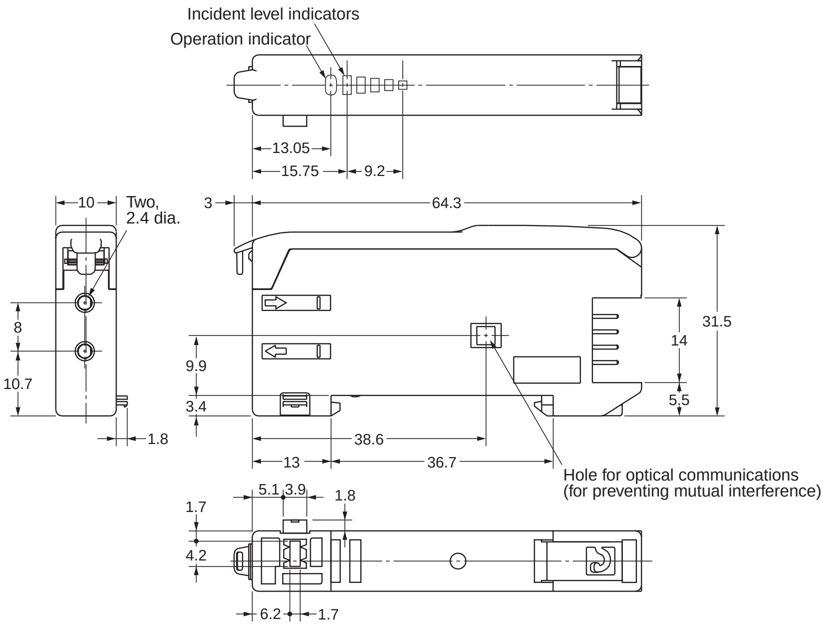


Note:
1. The mounting bracket can also be used on side A.
2. With these models, a 4-dia., 3-conductor, vinyl-insulated round cable (conductor cross-sectional area: 0.2 mm^2; insulation diameter: 1.1 mm) is used.
   Standard length: 2 m.

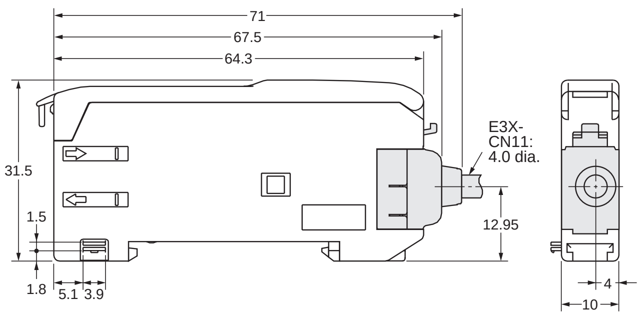
Amplifier Units with Connectors

E3X-NA6
E3X-NA8

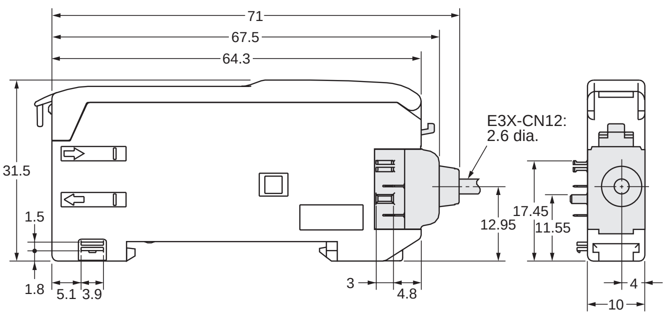




Dimensions with Master Connector Connected

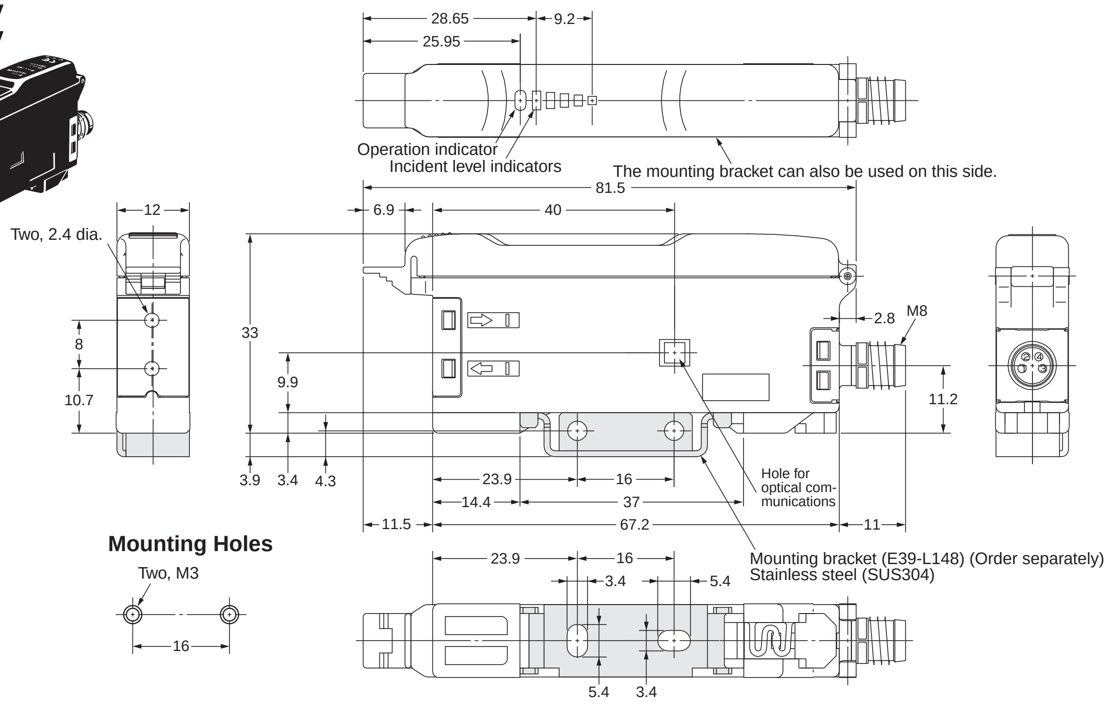


Dimensions with Slave Connector Connected



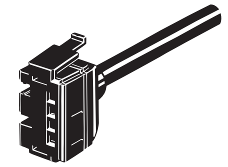
Amplifier Units with Connectors, Water-resistant Models (with Mounting Bracket Attached)

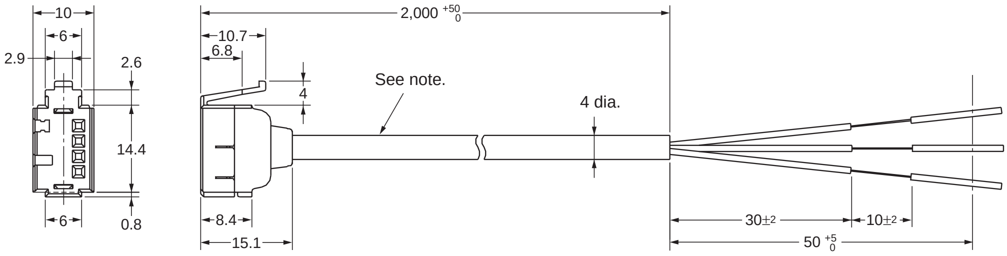
E3X-NA14V
E3X-NA44V



■ Amplifier Unit Connectors

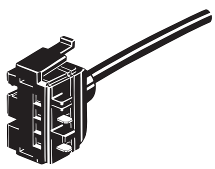
Master Connectors
E3X-CN11

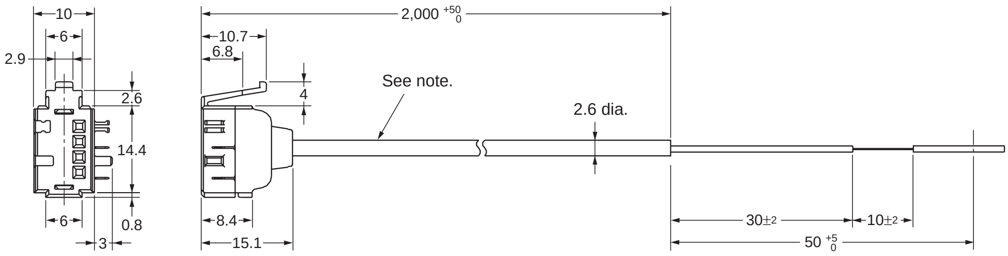




Note: A 4-dia., 3-conductor, vinyl-insulated round cable (conductor cross-sectional area: 0.2 mm^2; insulation diameter: 1.1 mm) is used.

Slave Connectors
E3X-CN12

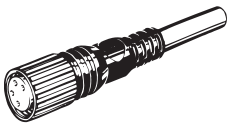


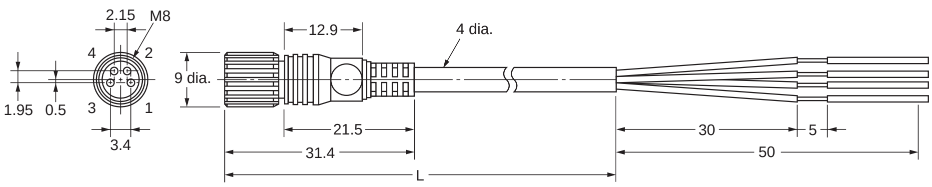


Note: A 2.6-dia., single-conductor, vinyl-insulated round cable (conductor cross-sectional area: 0.2 mm^2; insulation diameter: 1.1 mm) is used.

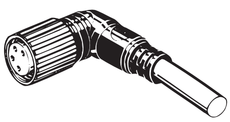
■ Sensor I/O Connectors

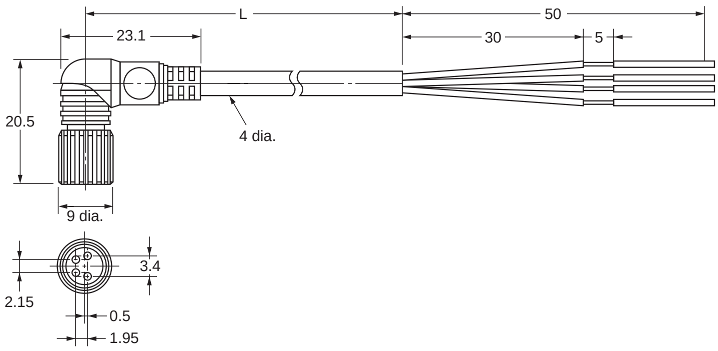
Straight Connector (at One End of Cable)
XS3F-M421-402-A (L=2 m)
XS3F-M421-405-A (L=5 m)





L-shaped Connector (at One End of Cable)
XS3F-M422-402-A (L=2 m)
XS3F-M422-405-A (L=5 m)

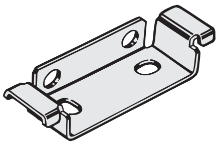




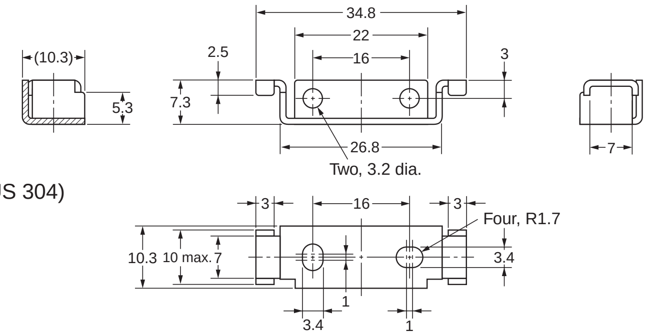
■ Accessories (Order Separately)

Mounting Bracket for E3X-NA□, E3X-NA□F, and E3X-NAG□ Models

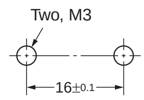
E39-L143



Material: Stainless steel (SUS 304)

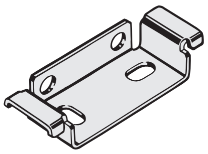


Mounting Holes

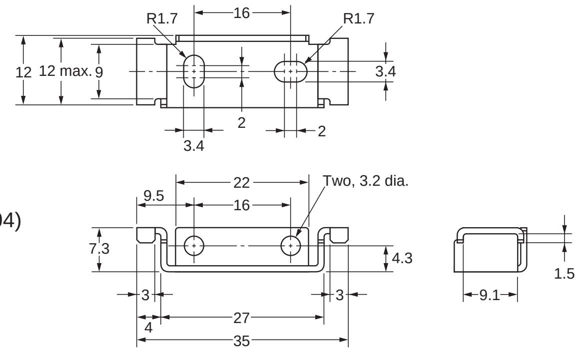


Mounting Bracket for E3X-NA□V Models

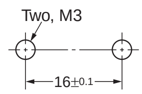
E39-L148



Material: Stainless steel (SUS 304)

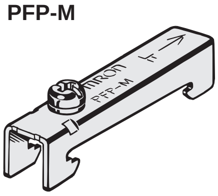


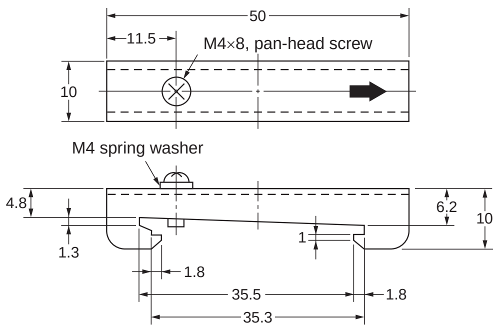
Mounting Holes



End Plate

PFP-M





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ALL DIMENSIONS SHOWN ARE IN MILLIMETERS.
To convert millimeters into inches, multiply by 0.03937. To convert grams into ounces, multiply by 0.03527.

Cat. No. E318-E1-02A

In the interest of product improvement, specifications are subject to change without notice.

OMRON Corporation

Industrial Automation Company

Application Sensors Division
Sensing Devices and Components Division H.Q.
Shiokoji Horikawa, Shimogyo-ku,
Kyoto, 600-8530 Japan
Tel: (81)75-344-7068/Fax: (81)75-344-7107

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0102-2M (0601) (A)

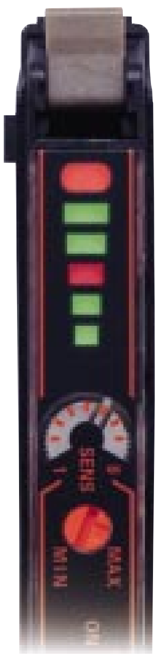
OMRON

Sense Different,
Make Difference!

E3X-NA SERIES

Simple to Use

Just Open It!



You don't need a manual anymore.
Super Manual Fiber Amplifiers
The E3X-NA Series

The E3X-NA debut!
Following on from our best-seller E3X-A/F Amplifiers, OMRON now presents the ultimate in ease and simplicity.

We were highly praised for the simplicity of the E3X-A / F Fiber Amplifiers when they were released in the ’90’s. Now, at the beginning of 21st century, we present the E3X-NA Series of Super Manual Fiber Amplifiers. Based on the concept that anyone should be able to use the amplifiers without an instruction manual, we pursued the bare essentials required of manual fiber amplifiers. Removing all unnecessary functions, we achieved simplicity in an amplifier that could be used immediately by anyone. The Millennium Sensor.

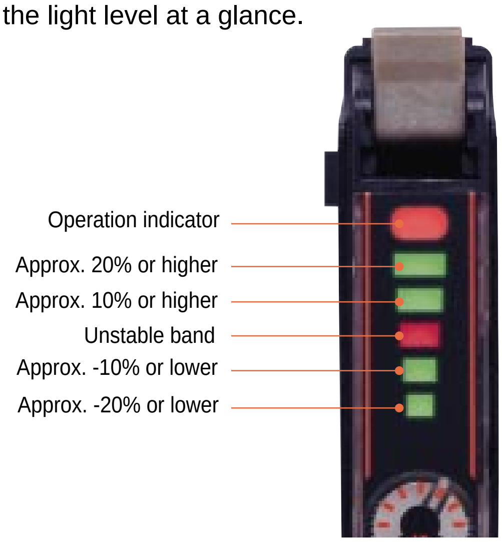

2000
E3X-NA
SENS
MAX
MIN
TIMER
ON
OFF

Instinctively Simple

1. Instinctive LED Bar Displays of Light Levels

E3X-NA: LED Bar Display

The vertical movement of the LED light level and operation display shows the light level at a glance.



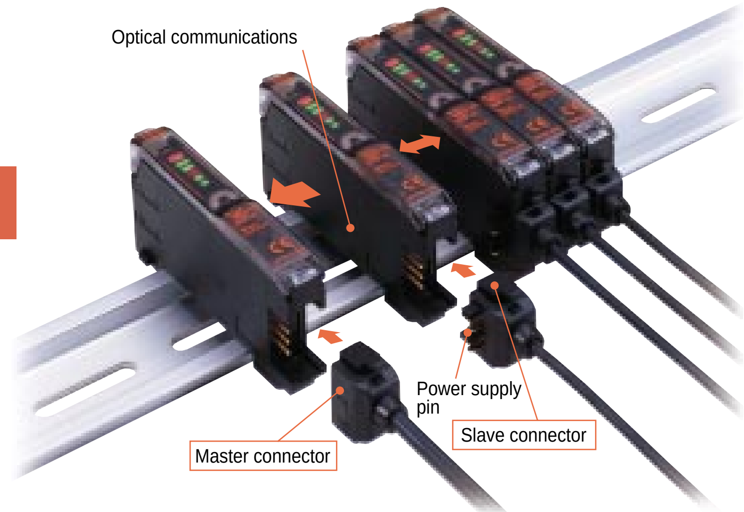
Previous Manual Amplifier: Stability and Light Reception Indicators

This method makes the light level far less obvious.

2. The Same "Save-wiring" Connector as the E3X-DA-N

New Type of Connector

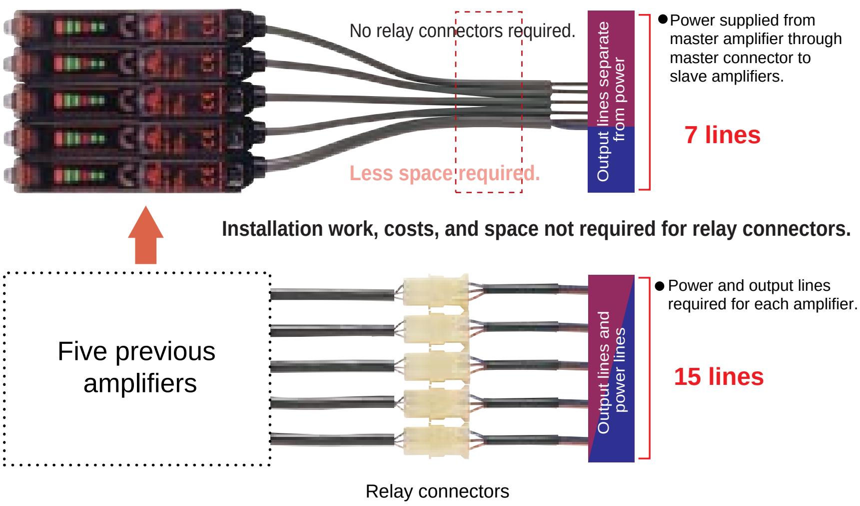
Gang-mount up to 16 Amplifiers



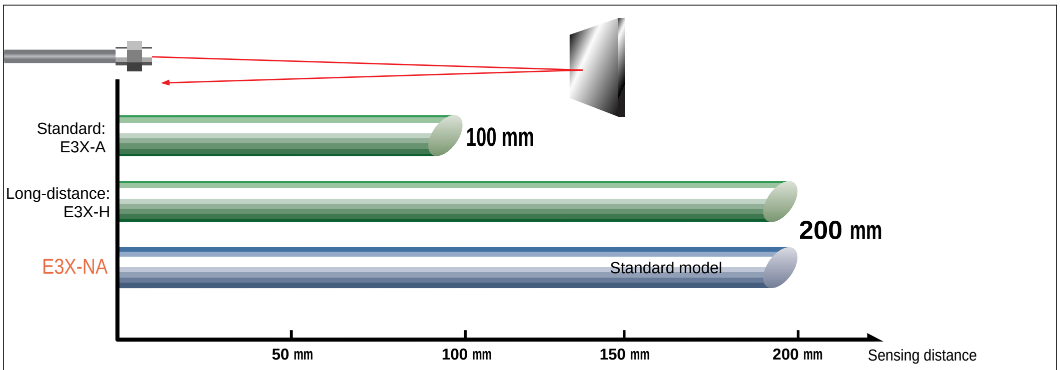
Reduced Wiring and Space Requirements for Power Lines

Example for 5 Amplifiers

E3X-NA Series



3. Same Sensing Distance as Previous Long-distance Models (200-mm Reflective Models)



The above characteristics are ensured with the E32-D11L Reflective Sensor (long-distance model).
The E3X-NA Series does not have a long-distance model.

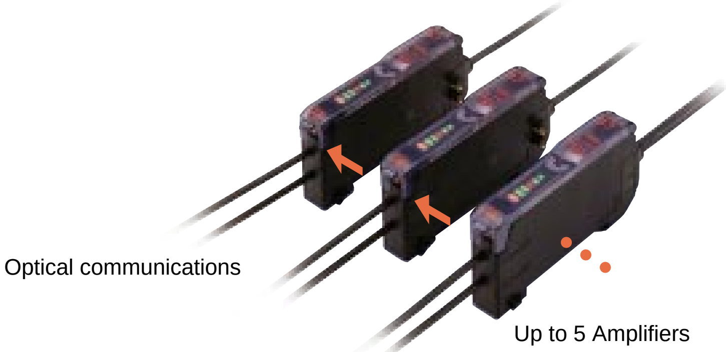
4. Approximately Seven Times the Detection Accuracy

Applied Fiber: E32-T16P (screen fiber) set at 100 mm.

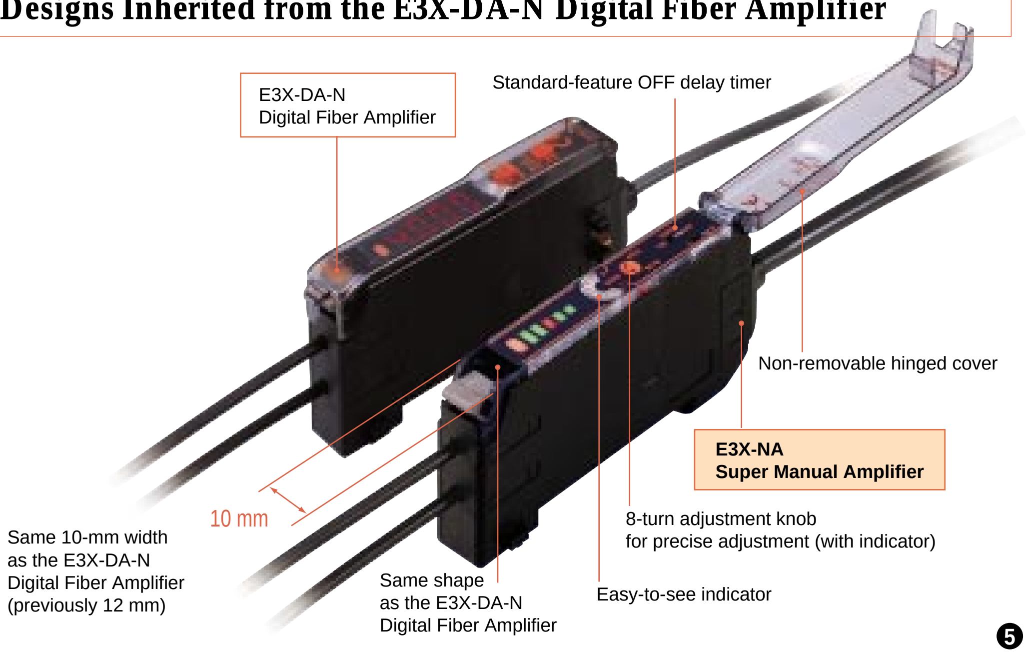
E3X-A11 (previous model) — 7 times — E3X-NA

Minimum detection object: 2.0 mm dia. ➔ 0.3 mm dia.

5. Optical Communications to Prevent Mutual Interference for Up to 5 Amplifiers



6. Dimensions and Designs Inherited from the E3X-DA-N Digital Fiber Amplifier



Selecting State-of-the-Art Fiber Amplifiers

Select the E3X-NA Series of Super Manual Fiber Amplifiers for the Ultimate in Simplicity.

E3X-NA SERIES

● Standard Models

(Representative model: E3X-NA11)

● Models with "Save-wiring" Connector

(Representative model: E3X-NA6)

● Mark-detecting Models
(green light source)

(Representative model: E3X-NAG11)

● High-speed Models

(Representative model: E3X-NA11F)

● Water-resistant Models
(M8 connectors)

(Representative model: E3X-NA14V)

For Complete Functionality, select the E3X-DA-N Series of Digital Fiber Amplifiers

E3X-DA-N SERIES

● Mobile Console

● Standard Models

(Representative model: E3X-DA11-N)

● Models with "Save-wiring" Connector

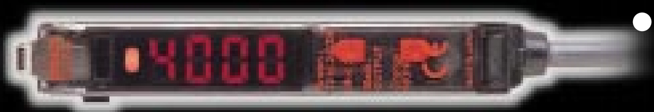
(Representative model: E3X-DA6)

● Mark-detecting Models with Blue Light Source

(Representative model: E3X-DAB11-N)

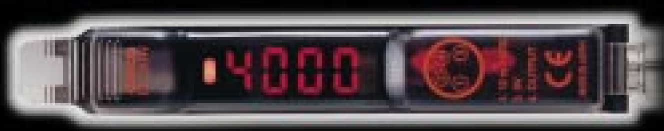
● Infrared Light Models

(Representative model: E3X-DAH11-N)



● Mark-detecting Models with Green Light Source

(Representative model: E3X-DAG11-N)



● Water-resistant Models (M8 connectors)

(Representative model: E3X-DA14V)

A New Series Addition:

E3X-DA□□TW

- Twin Output Models with Two Threshold Settings
- Supports zone outputs with OK/NG judgements

● Twin Output Models

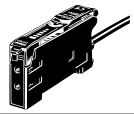
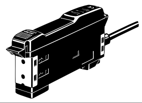
(Representative models:
Cord pull-out: E3X-DA11TW
Connector: E3X-DA6TW)

The E3X-NA Series - a new lineup of Fiber Amplifiers that enable simple manual operation.

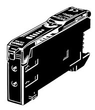
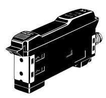
Ordering Information

Amplifier Units

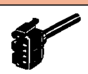
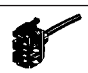
Amplifier Units with Cables

Item	Appearance	Control output	Model	
			NPN output	PNP output
Standard models		ON/OFF output	E3X-NA11	E3X-NA41
High-speed detection models			E3X-NA11F	E3X-NA41F
Mark-detecting models			E3X-NAG11	E3X-NAG41
Water-resistant models			E3X-NA11V	E3X-NA41V

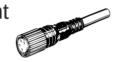
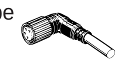
Amplifier Units with Connectors

Item	Appearance	Applicable Connector (order separately)		Control output	Model	
					NPN output	PNP output
Standard models		Master	E3X-CN11	ON/OFF output	E3X-NA6	E3X-NA8
		Slave	E3X-CN12			
Water-resistant models (M8 connectors)		XS3F-M421-40□-A XS3F-M422-40□-A			E3X-NA14V	E3X-NA44V

Amplifier Unit Connectors (Order Separately)

Item	Appearance	Cable length	No. of conductors	Model
Master Connector		2 m	3	E3X-CN11
Slave Connector			1	E3X-CN12

Sensor I/O Connectors (Order Separately)

Cable specifications	Appearance		Type of cable		Model
Standard cable	Straight		2 m	Four-core cable	XS3F-M421-402-A
			5 m		XS3F-M421-405-A
	L-shape		2 m		XS3F-M422-402-A
			5 m		XS3F-M422-405-A

Combining Amplifier Units and Connectors

When ordering Connector-type Amplifier Units, refer to the following tables. Basically, Amplifier Units and Connectors are sold separately.

Amplifier Units		
Type	NPN	PNP
Standard models	E3X-NA6	E3X-NA8

+

Applicable Connectors (Order Separately)	
Master Connector	Slave Connector
E3X-CN11 (3-wire)	E3X-CN21 (1-wire)

When Using 5 Amplifier Units

Amplifier Units (5 Units)

+

1 Master Connector + 4 Slave Connectors

OMRON Corporation
Industrial Automation Company

Industrial Sensors Division
Sensing Devices and Components Division H.Q.
Shiokoji Horikawa, Shimogyo-ku, Kyoto, 600-8530 Japan
Tel: (81)75-344-7068/Fax: (81)75-344-7107

Regional Headquarters

OMRON EUROPE B.V.
Sensor Business Unit, Carl-Benz-Str. 4, D-71154 Nufringen, Germany
Tel: (49)7032-811-0/Fax: (49)7032-811-199

OMRON ELECTRONICS LLC
1 East Commerce Drive, Schaumburg, IL 60173 U.S.A.
Tel: (1)847-843-7900/Fax: (1)847-843-8568

OMRON ASIA PACIFIC PTE. LTD.
83 Clemenceau Avenue,
#11-01, UE Square, 239920 Singapore
Tel: (65)835-3011/Fax: (65)835-2711

OMRON CHINA CO., LTD.
BEIJING OFFICE
Room 1028, Office Building, Beijing Capital Times Square,
No. 88 West Chang'an Road, Beijing, 100031 China
Tel: (86)10-8391-3005/Fax: (86)10-8391-3688

Authorized Distributor:

Cat. No. E317-E1-2
Printed in Japan
0601-2M (A)

OMRON

Photoelectric Sensor with Built-in Amplifier

E3Z

- Photoelectric Sensor with built-in amplifier is applicable to a wide variety of lines and ensures a longer sensing distance than any other model.
- User-friendly Sensor takes all installation and on-site conditions into consideration.
- Eliminates the influence of installation and on-site conditions, thus increasing the reliability of the line.
- OMRON has been making efforts towards environmental protection by adopting user and environment-friendly measures.
- Greatly saves energy and resources. The economy-oriented age has evolved into the ecology-oriented age.
- Meets a variety of international standards, thus allowing use in any country.

Ordering Information

List of Models

Red light   Infrared light

Sensing method	Appearance	Connection method	Sensing distance	Model	
				NPN output	PNP output
Through-beam		Pre-wired (see note 3)	15 m	E3Z-T61	E3Z-T81
		Connector		E3Z-T66	E3Z-T86
Retroreflective (with MSR function)	(see note 1)	Pre-wired (see note 3)	4 m (100 mm) (see note 2)	E3Z-R61	E3Z-R81
		Connector		E3Z-R66	E3Z-R86
Diffuse-reflective		Pre-wired (see note 3)	5 to 100 mm (wide view)	E3Z-D61	E3Z-D81
		Connector		E3Z-D66	E3Z-D86
		Pre-wired (see note 3)	1 m	E3Z-D62	E3Z-D82
		Connector		E3Z-D67	E3Z-D87

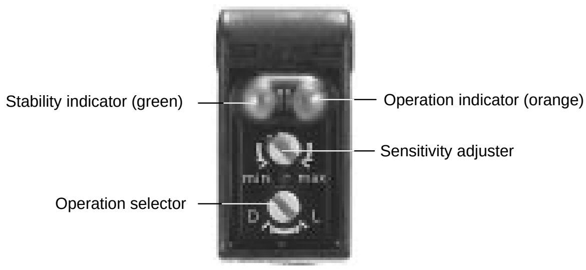
Note:
1. The Reflector is sold separately. Select the Reflector model most suited to the application.
2. The sensing distance specified is possible when the E39-R1S used. Figure in parentheses indicate the minimum required distance between the Sensor and Reflector.
3. Models provided with a 0.5-m cable are available. When ordering, specify the cable length by adding the code “0.5M” to the model number (e.g., E3Z-T61 0.5M).

Nomenclature

Through-beam Models
E3Z-T6□ Receiver

Retroreflective Models
E3Z-R6□

Diffuse-reflective Models
E3Z-D6□



■ Accessories (Order Separately)

Slit for Through-beam Models

Slit width	Sensing distance (typical)	Minimum sensing object (typical)	Model	Quantity required	Remarks
0.5 mm dia.	50 mm	0.5 mm dia.	E39-S65A	One each for the emitter and receiver.	These Slits are available for the E3Z-T□□.
1 mm dia.	200 mm	1 mm dia.	E39-S65B		
2 mm dia.	800 mm	2 mm dia.	E39-S65C		
0.5 × 10 mm	1 m	0.7 mm dia.	E39-S65D		
1 × 10 mm	2.2 m	1.2 mm dia.	E39-S65E		
2 × 10 mm	5 m	2.4 mm dia.	E39-S65F		

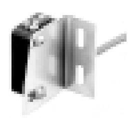
Reflectors for Retroreflective Models

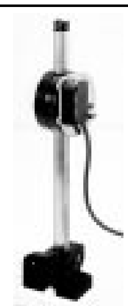
Name	Sensing distance (typical)	Model	Remarks
Reflector	3 m (100 mm)	E39-R1	Retroreflective models are not provided with Reflectors. The MSR function is available.
	4 m (100 mm)	E39-R1S	
	5 m (100 mm) (see note 2)	E39-R2	
Miniature Reflector	1.5 m (50 mm) (see note 2)	E39-R3	
Tape Reflector	700 mm (150 mm) (see note 2)	E39-RS1	
	1.1 m (150 mm) (see note 2)	E39-RS2	
	1.4 m (150 mm) (see note 2)	E39-RS3	

Note: 1. Figure in parentheses indicates the minimum required distance between the Sensor and Reflector.

2. The actual sensing distance may be reduced to approximately 70% of the typical sensing distance when using a Reflector other than E39-R1 or E39-R1S.

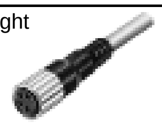
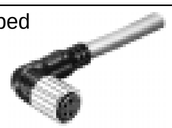
Mounting Brackets

Appearance	Model
	E39-L104
	E39-L43
	E39-L44

Appearance	Model	Remarks
	E39-L93	For Sensor adjustment use. Mounted to the aluminum frame rails of conveyors and adjustable with ease.
	E39-L98	Vertical protective cover bracket

Note: If a through-beam model is used, order two Mounting Brackets for the emitter and receiver respectively.

Sensor I/O Connectors

Cable	Appearance	Cable type		Model
Standard	Straight 	2 m	Four-wire type	XS3F-M421-402-A
		5 m		XS3F-M421-405-A
	L-shaped 	2 m		XS3F-M422-402-A
		5 m		XS3F-M422-405-A

Specifications

■ Ratings/Characteristics

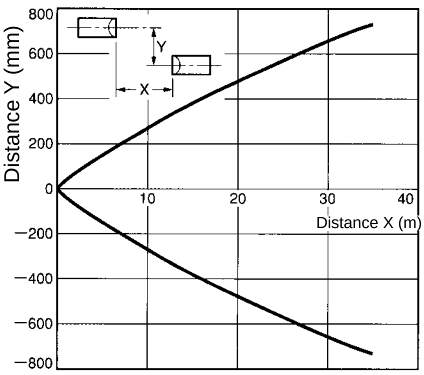
Item	Sensing method	Through-beam	Retroreflective with MSR function	Diffuse-reflective	
	NPN output	E3Z-T61/T66	E3Z-R61/R66	E3Z-D61/D66	E3Z-D62/D67
	PNP output (see note 3)	E3Z-T81/T86	E3Z-R81/R86	E3Z-D81/D86	E3Z-D82/D87
Sensing distance		15 m	4 m (100 mm)* (when using E39-R1S) 3 m (100 mm)* (when using E39-R1)	White paper (100 × 100 mm): 100 mm	White paper (300 × 300 mm): 1 m
Standard sensing object		Opaque: 12-mm dia. min.	Opaque: 75-mm dia. min.	---	
Hysteresis		---		20% max. of setting distance	
Directional angle		Both emitter and receiver: 3 to 15°	2 to 10°	---	
Light source (wave length)		Infrared LED (860 nm)	Red LED (680 nm)	Infrared LED (860 nm)	
Power supply voltage		12 to 24 VDC ±10% including 10% (p-p) max. ripple			
Current consumption		Emitter: 15 mA Receiver: 20 mA	30 mA max.		
Control output		Load power supply voltage: 26.4 V max. Load current: 100 mA max. (Residual voltage: 1 V max.) Open collector output (NPN or PNP depending on model) L-ON/D-ON selectable			
Circuit protection		Protection from load short-circuit and reversed power supply connection	Protection from reversed power supply connection, output short-circuit, and mutual interference protection		
Response time		Operation or reset: 1 ms max.			
Sensitivity adjustment		One-turn adjuster			
Ambient illumination (receiver side)		Incandescent lamp: 3,000 ℓx max. Sunlight: 10,000 ℓx max.			
Ambient temperature		Operating: –25°C to 55°C/Storage: –40°C to 70°C (with no icing or condensation)			
Ambient humidity		Operating: 35% to 85%/Storage: 35% to 95% (with no condensation)			
Insulation resistance		20 MΩ min. at 500 VDC			
Dielectric strength		1,000 VAC, 50/60 Hz for 1 min			
Vibration resistance		10 to 55 Hz, 1.5-mm double amplitude or 300 m/s^2 for 2 hours each in X, Y, and Z directions			
Shock resistance		Destruction: 500 m/s^2 3 times each in X, Y, and Z directions			
Degree of protection		IP67 (IEC60529)			
Connection method		500-mm-thick pre-wired cable (standard length: 2 m) with M8 connector			
Indicator		Operation indicator (orange) Stability indicator (green) Emitter has power indicator (orange) only.			
Weight (packed state)	**Pre-wired cable (2 m)**	Approx. 120 g	Approx. 65 g		
	Connector	Approx. 30 g	Approx. 20 g		
Material	**Case**	PBT (polybutylene terephthalate)			
	Lens	Methacrylate resin			
Accessories		Instruction manual (The Reflector or Mounting Bracket is not provided with any of the above models.)			

Note: *Figures in parentheses indicate the minimum required distances between the Sensors and Reflectors.

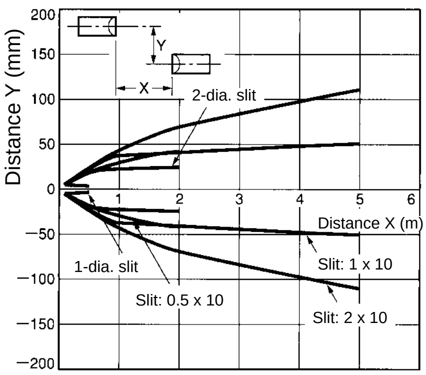
Engineering Data

■ Parallel Operating Range (Typical)

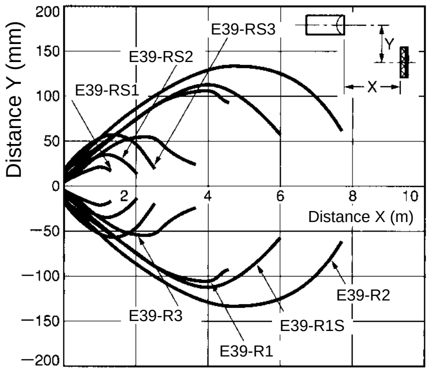
Through-beam Models
E3Z-T□1 (T□6)



Through-beam Models
E3Z-T□1 (T□6) and Slit

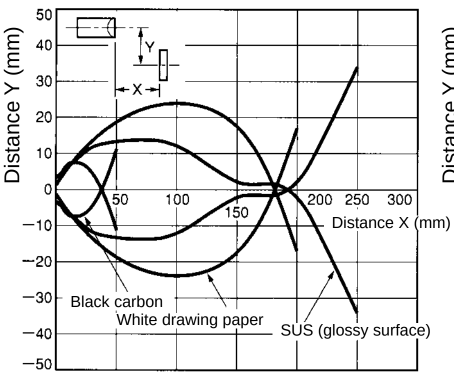


Retroreflective Models
E3Z-R□1 (R□6) and Reflector

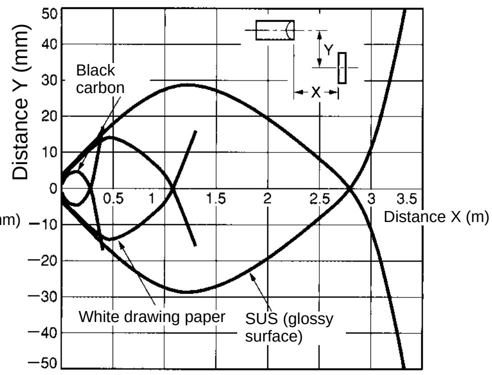


■ Operating Range (Typical)

Diffuse-reflective Models
E3Z-D□1 (D□6)

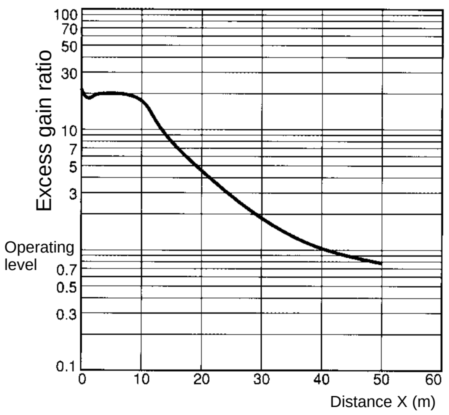


Diffuse-reflective Models
E3Z-D□2 (D□7)

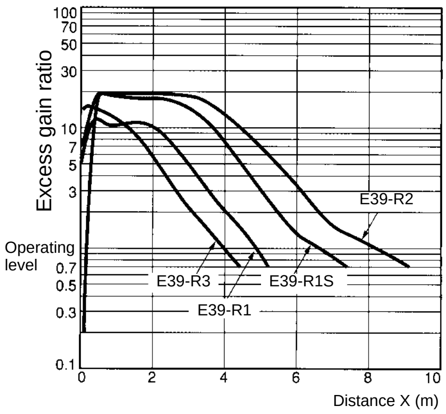


■ Excess Gain Ratio vs. Distance (Typical)

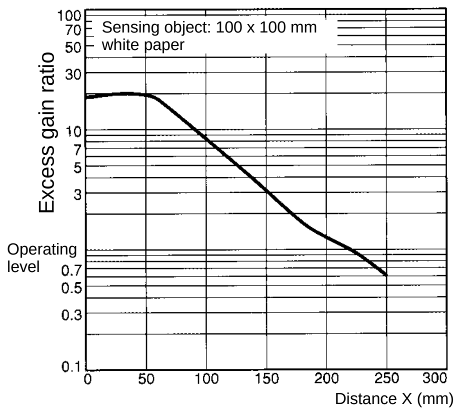
Through-beam Models
E3Z-T□1 (T□6)



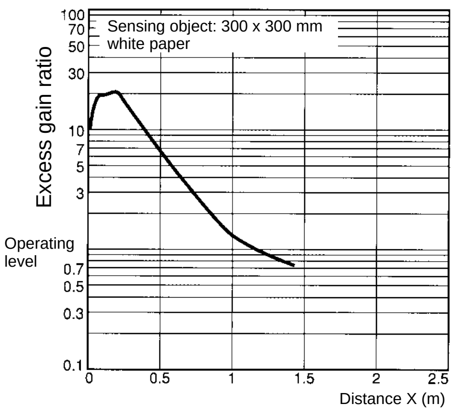
Retroreflective Models
E3Z-R□1 (R□6) and Reflector



Diffuse-reflective Models
E3Z-D□1 (D□6)

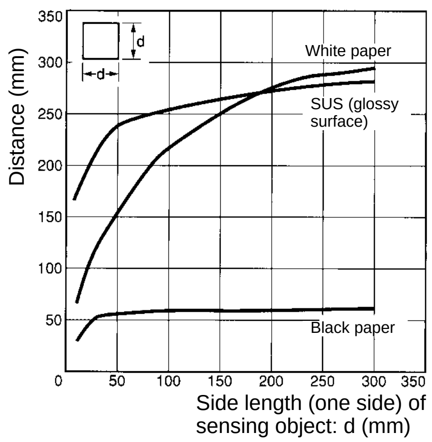


Diffuse-reflective Model
E3Z-D□2 (D□7)

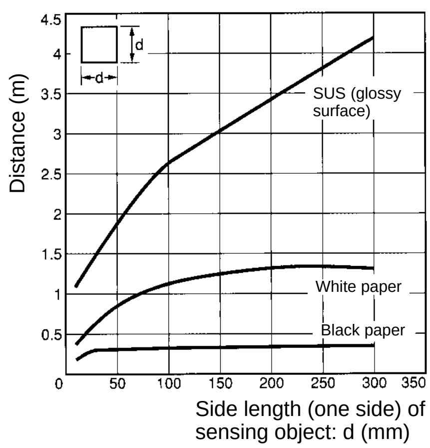


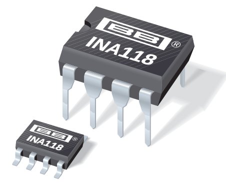
■ Sensing Object Size vs. Sensing Distance (Typical)

Diffuse-reflective Models
E3Z-D□1 (D□6)



Diffuse-reflective Models
E3Z-D□2 (D□7)





INA118

Precision, Low Power INSTRUMENTATION AMPLIFIER

FEATURES

- LOW OFFSET VOLTAGE: 50µV max
- LOW DRIFT: 0.5µV/°C max
- LOW INPUT BIAS CURRENT: 5nA max
- HIGH CMR: 110dB min
- INPUTS PROTECTED TO ±40V
- WIDE SUPPLY RANGE: ±1.35 to ±18V
- LOW QUIESCENT CURRENT: 350µA
- 8-PIN PLASTIC DIP, SO-8

APPLICATIONS

- BRIDGE AMPLIFIER
- THERMOCOUPLE AMPLIFIER
- RTD SENSOR AMPLIFIER
- MEDICAL INSTRUMENTATION
- DATA ACQUISITION

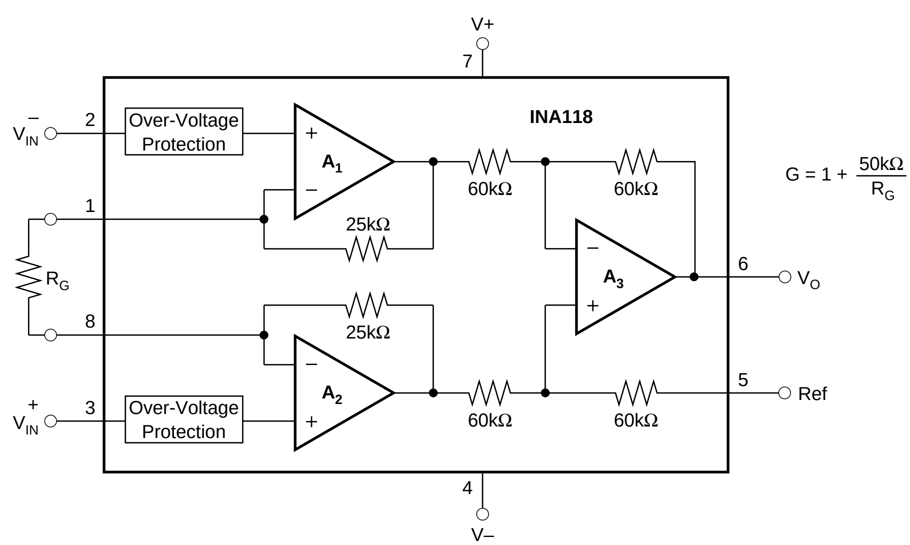
DESCRIPTION

The INA118 is a low power, general purpose instrumentation amplifier offering excellent accuracy. Its versatile 3-op amp design and small size make it ideal for a wide range of applications. Current-feedback input circuitry provides wide bandwidth even at high gain (70kHz at G = 100).

A single external resistor sets any gain from 1 to 10,000. Internal input protection can withstand up to ±40V without damage.

The INA118 is laser trimmed for very low offset voltage (50µV), drift (0.5µV/°C) and high common-mode rejection (110dB at G = 1000). It operates with power supplies as low as ±1.35V, and quiescent current is only 350µA—ideal for battery operated systems.

The INA118 is available in 8-pin plastic DIP, and SO-8 surface-mount packages, specified for the –40°C to +85°C temperature range.



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Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

 PDS-1199D Printed in U.S.A. April, 1998

SPECIFICATIONS

ELECTRICAL

At T_A = +25°C, V_S = ±15V, R_L = 10kΩ unless otherwise noted.

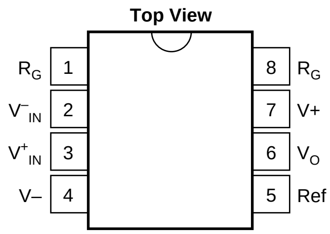
PARAMETER	CONDITIONS	INA118PB, UB			INA118P, U			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
INPUT								
Offset Voltage, RTI								
Initial	T_A = +25°C		±10 ± 50/G	±50 ± 500/G		±25 ±100/G	±125±1000/G	μV
vs Temperature	$T_A = T_{MIN}$ to T_{MAX}		±0.2 ± 2/G	±0.5 ± 20/G		±0.2 ± 5/G	±1 ± 20/G	μV/°C
vs Power Supply	V_S = ±1.35V to ±18V		±1 ±10/G	±5 ± 100/G		*	±10 ±100/G	μV/V
Long-Term Stability			±0.4 ±5/G			*		μV/mo
Impedance, Differential			$10^{10} \parallel 1$			*		Ω ∥ pF
Common-Mode			$10^{10} \parallel 4$			*		Ω ∥ pF
Linear Input Voltage Range		(V+) – 1	(V+) – 0.65		*	*		V
		(V–) + 1.1	(V–) + 0.95		*	*		V
Safe Input Voltage				±40			*	V
Common-Mode Rejection	V_{CM} = ±10V, ΔR_S = 1kΩ							
	G = 1	80	90		73	*		dB
	G = 10	97	110		89	*		dB
	G = 100	107	120		98	*		dB
	G = 1000	110	125		100	*		dB
BIAS CURRENT			±1	±5		*	±10	nA
vs Temperature			±40			*		pA/°C
OFFSET CURRENT			±1	±5		*	±10	nA
vs Temperature			±40			*		pA/°C
NOISE VOLTAGE, RTI	G = 1000, R_S = 0Ω							
f = 10Hz			11			*		nV/√Hz
f = 100Hz			10			*		nV/√Hz
f = 1kHz			10			*		nV/√Hz
f_B = 0.1Hz to 10Hz			0.28			*		μVp-p
Noise Current								
f=10Hz			2.0			*		pA/√Hz
f=1kHz			0.3			*		pA/√Hz
f_B = 0.1Hz to 10Hz			80			*		pAp-p
GAIN								
Gain Equation			1 + (50kΩ/R_G)			*		V/V
Range of Gain		1		10000	*		*	V/V
Gain Error	G = 1		±0.01	±0.024		*	±0.1	%
	G = 10		±0.02	±0.4		*	±0.5	%
	G = 100		±0.05	±0.5		*	±0.7	%
	G = 1000		±0.5	±1		*	±2	%
Gain vs Temperature	G = 1		±1	±10		*	±10	ppm/°C
50kΩ Resistance(1)			±25	±100		*	*	ppm/°C
Nonlinearity	G = 1		±0.0003	±0.001		*	±0.002	% of FSR
	G = 10		±0.0005	±0.002		*	±0.004	% of FSR
	G = 100		±0.0005	±0.002		*	±0.004	% of FSR
	G = 1000		±0.002	±0.01		*	±0.02	% of FSR
OUTPUT								
Voltage: Positive	R_L = 10kΩ	(V+) – 1	(V+) – 0.8		*	*		V
Negative	R_L = 10kΩ	(V–) + 0.35	(V–) + 0.2		*	*		V
Single Supply High	V_S = +2.7V/0V(2), R_L = 10kΩ	1.8	2.0		*	*		V
Single Supply Low	V_S = +2.7V/0V(2), R_L = 10kΩ	60	35		*	*		mV
Load Capacitance Stability			1000			*		pF
Short Circuit Current			+5/–12			*		mA
FREQUENCY RESPONSE								
Bandwidth, –3dB	G = 1		800			*		kHz
	G = 10		500			*		kHz
	G = 100		70			*		kHz
	G = 1000		7			*		kHz
Slew Rate	V_O = ±10V, G = 10		0.9			*		V/μs
Settling Time, 0.01%	G = 1		15			*		μs
	G = 10		15			*		μs
	G = 100		21			*		μs
	G = 1000		210			*		μs
Overload Recovery	50% Overdrive		20			*		μs
POWER SUPPLY								
Voltage Range		±1.35	±15	±18	*	*	*	V
Current	V_{IN} = 0V		±350	±385		*	*	μA
TEMPERATURE RANGE								
Specification		–40		85	*		*	°C
Operating		–40		125	*		*	°C
θ_{JA}			80			*		°C/W

* Specification same as INA118PB, UB.

NOTE: (1) Temperature coefficient of the "50kΩ" term in the gain equation. (2) Common-mode input voltage range is limited. See text for discussion of low power supply and single power supply operation.

PIN CONFIGURATION

8-Pin DIP and SO-8



ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±18V
Analog Input Voltage Range	±40V
Output Short-Circuit (to ground)	Continuous
Operating Temperature	–40°C to +125°C
Storage Temperature	–40°C to +125°C
Junction Temperature	+150°C
Lead Temperature (soldering, 10s)	+300°C

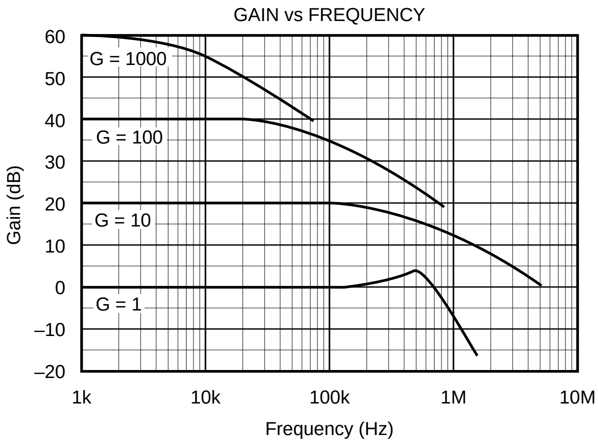
ORDERING INFORMATION

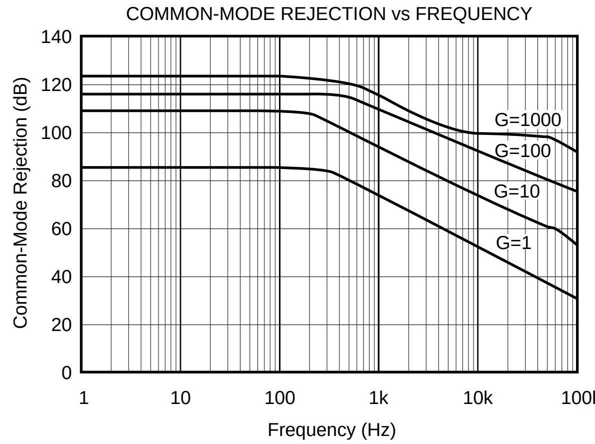
PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER(1)	TEMPERATURE RANGE
INA118P	8-Pin Plastic DIP	006	–40°C to +85°C
INA118PB	8-Pin Plastic DIP	006	–40°C to +85°C
INA118U	SO-8 Surface-Mount	182	–40°C to +85°C
INA118UB	SO-8 Surface-Mount	182	–40°C to +85°C

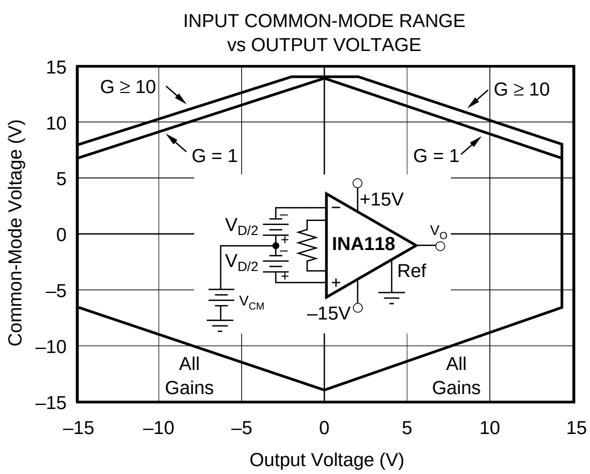
NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

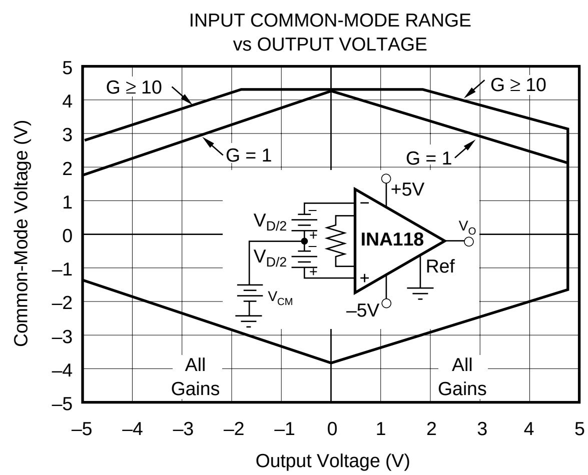
TYPICAL PERFORMANCE CURVES

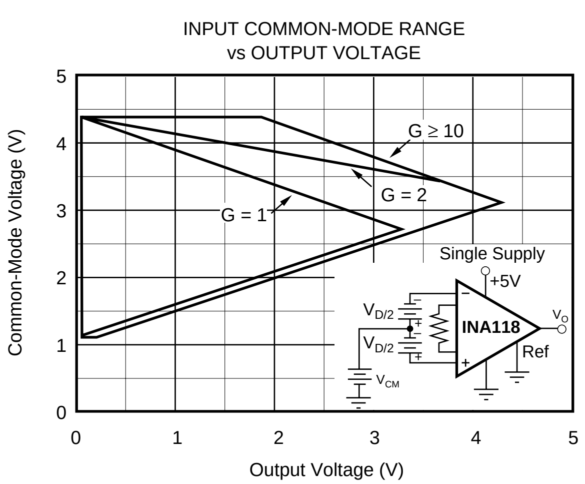
At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.

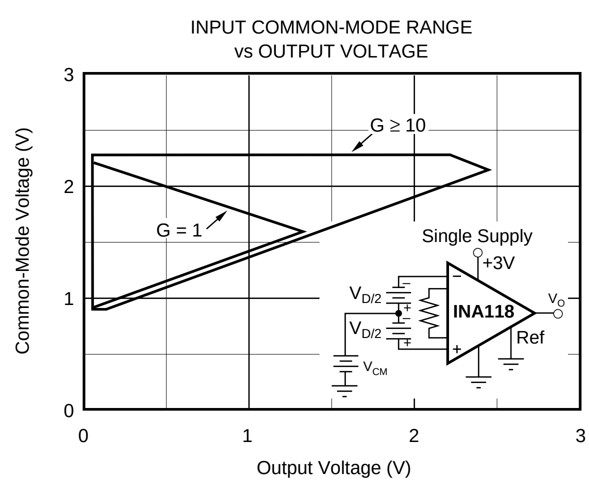












TYPICAL PERFORMANCE CURVES (CONT)

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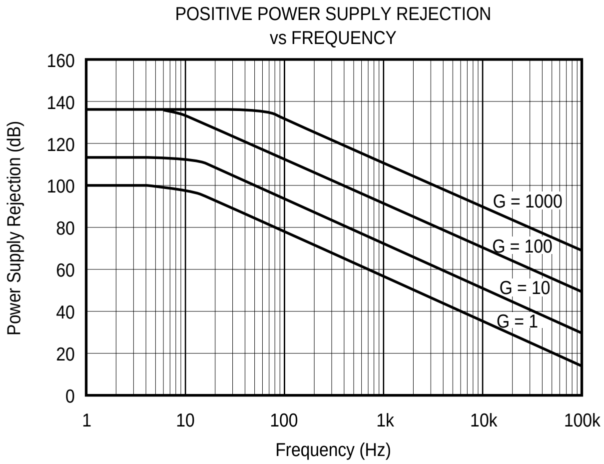
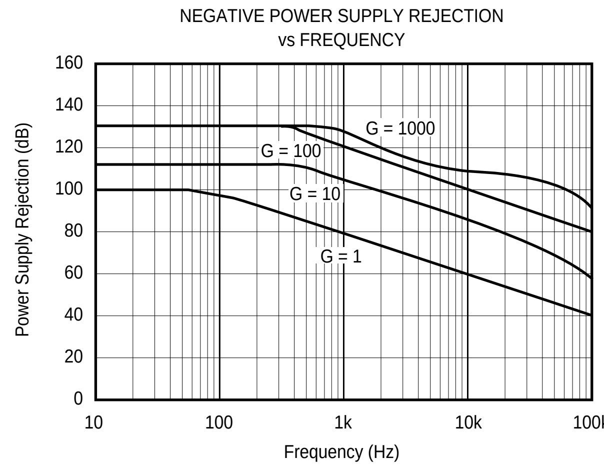
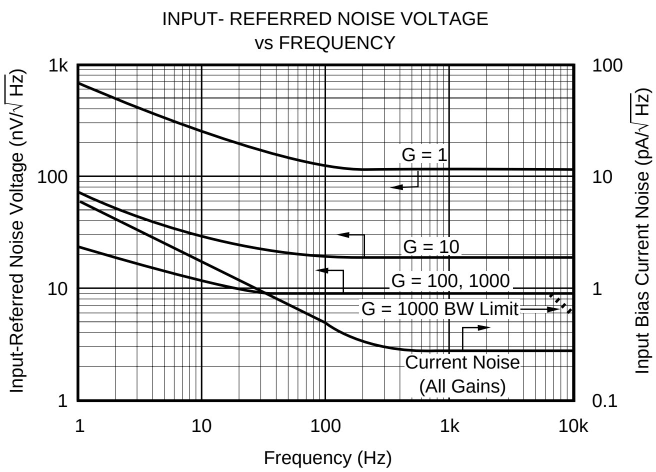
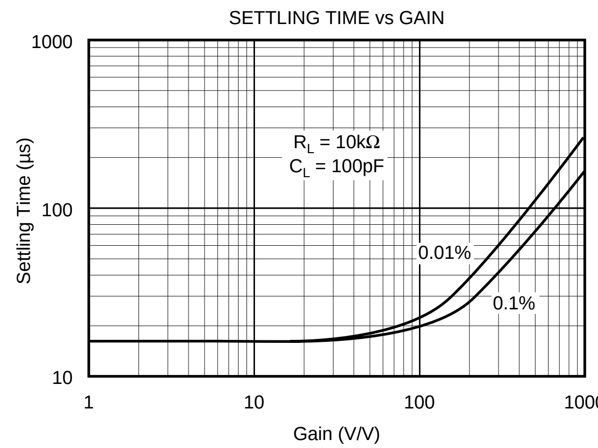
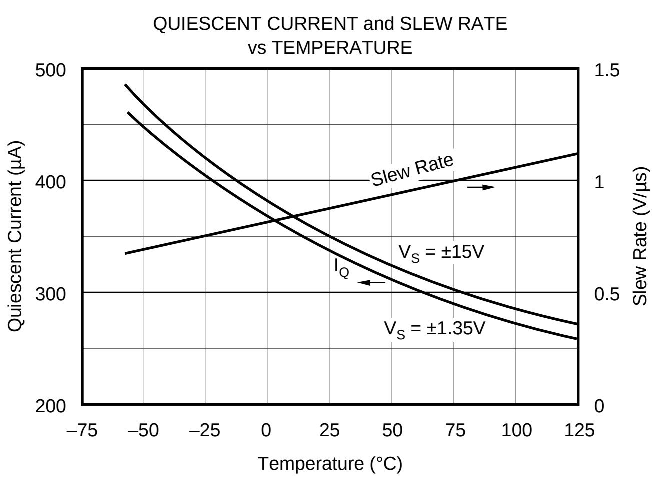
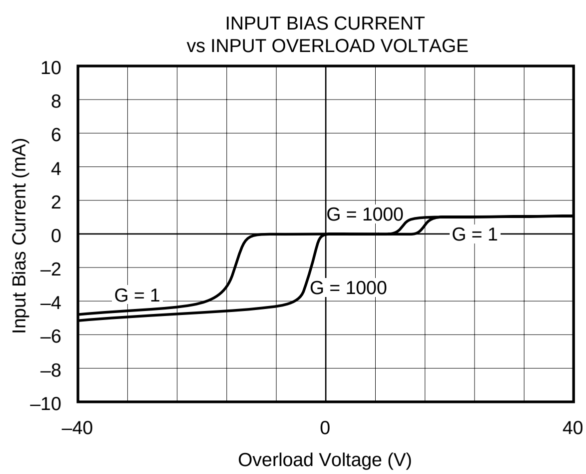






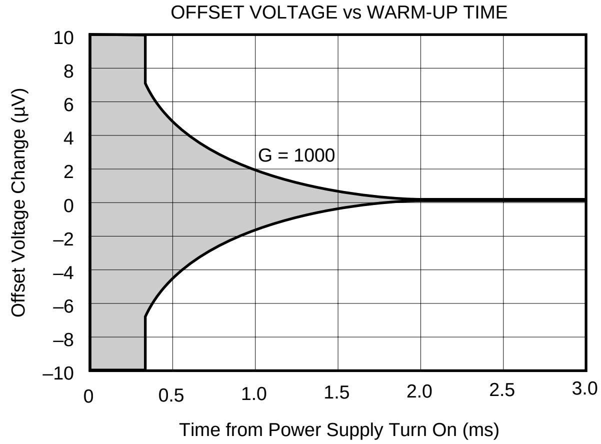


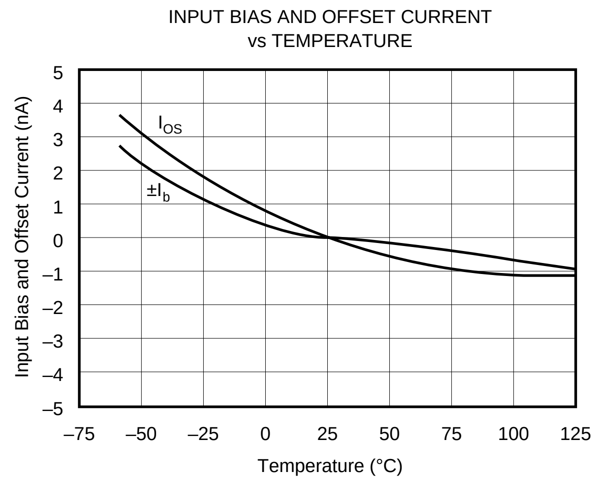


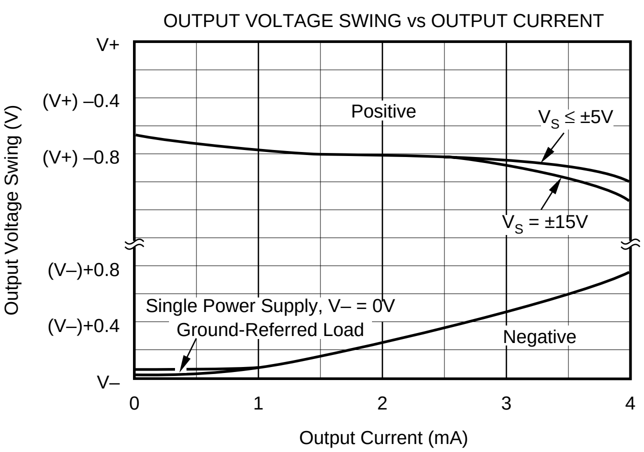


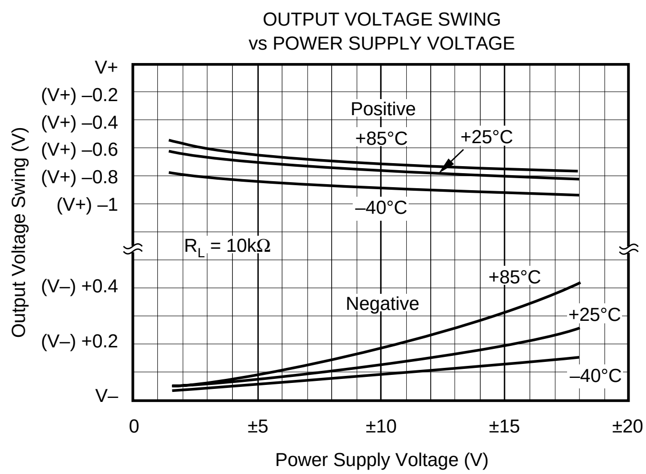
TYPICAL PERFORMANCE CURVES (CONT)

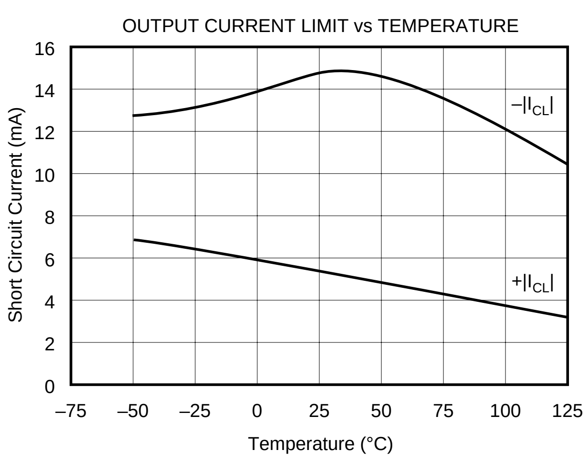
At T_A = +25°C, V_S = ±15V, unless otherwise noted.

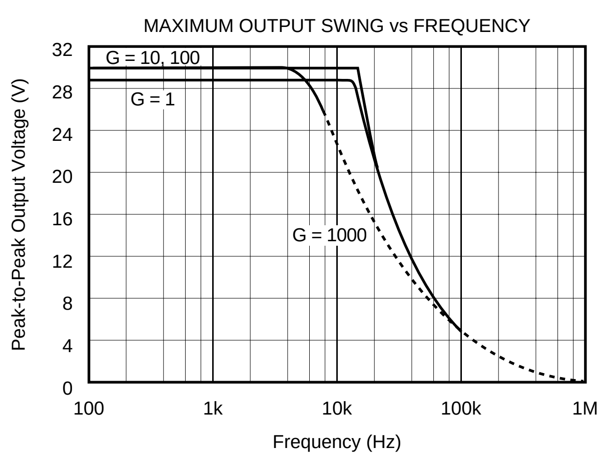








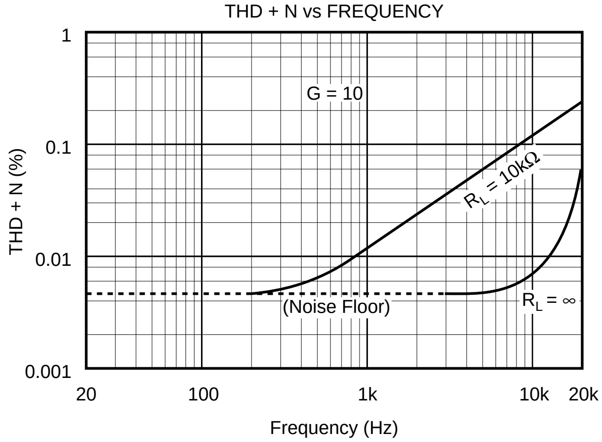




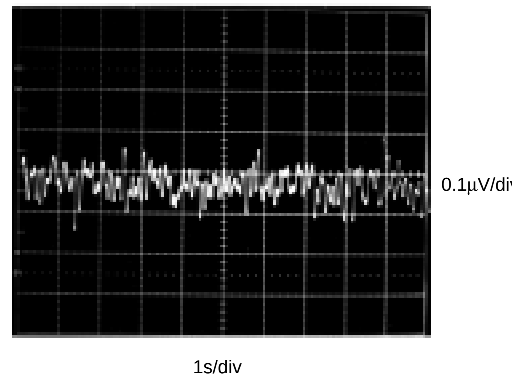
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25°C$, $V_S = \pm15V$, unless otherwise noted.

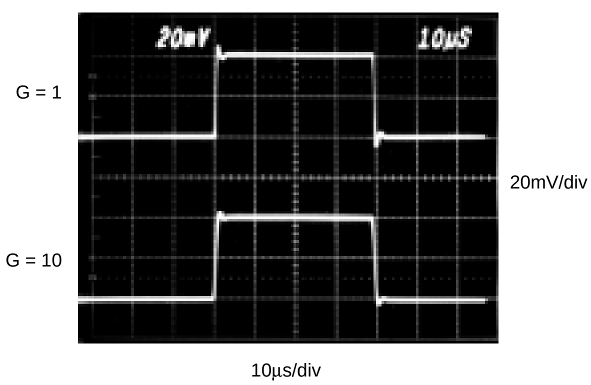
THD + N vs FREQUENCY



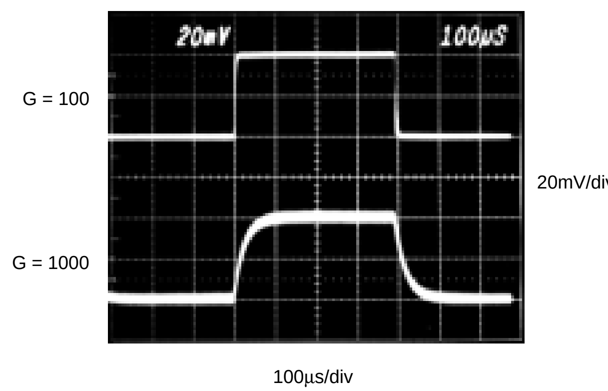
INPUT-REFERRED NOISE, 0.1Hz to 10Hz



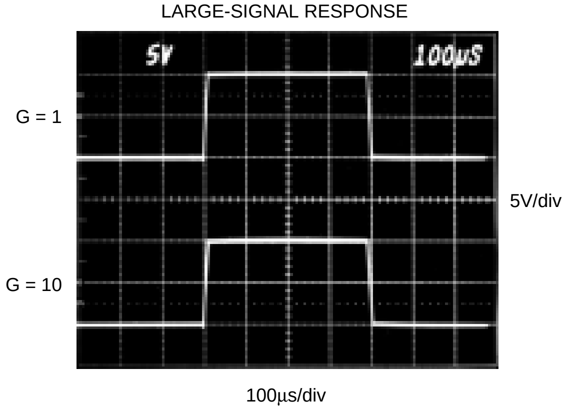
SMALL-SIGNAL RESPONSE



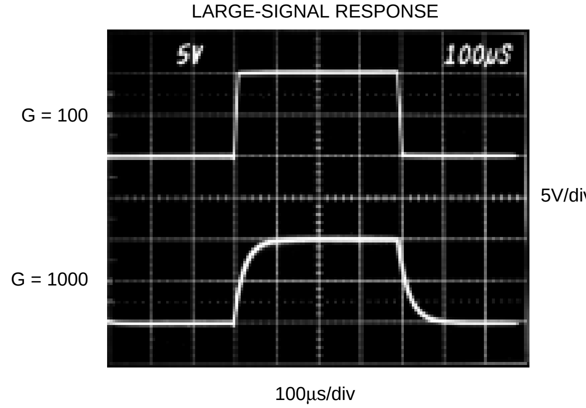
SMALL-SIGNAL RESPONSE



LARGE-SIGNAL RESPONSE



LARGE-SIGNAL RESPONSE



APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA118. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins as shown.

The output is referred to the output reference (Ref) terminal which is normally grounded. This must be a low-impedance connection to assure good common-mode rejection. A resistance of 12Ω in series with the Ref pin will cause a typical device to degrade to approximately 80dB CMR (G = 1).

SETTING THE GAIN

Gain of the INA118 is set by connecting a single external resistor, R_G, connected between pins 1 and 8:

$$G = 1 + \frac{50\,k\Omega}{R_G} \tag{1}$$

Commonly used gains and resistor values are shown in Figure 1.

The 50kΩ term in Equation 1 comes from the sum of the two internal feedback resistors of A_1 and A_2. These on-chip metal film resistors are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these resistors are included in the gain accuracy and drift specifications of the INA118.

The stability and temperature drift of the external gain setting resistor, R_G, also affects gain. R_G's contribution to gain accuracy and drift can be directly inferred from the gain equation (1). Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance which will contribute additional gain error (possibly an unstable gain error) in gains of approximately 100 or greater.

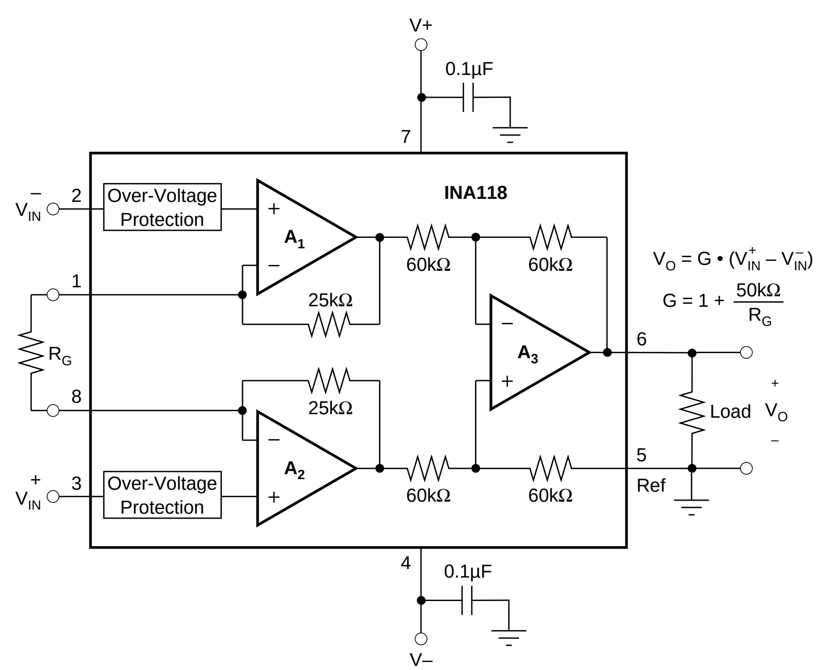
DYNAMIC PERFORMANCE

The typical performance curve “Gain vs Frequency” shows that, despite its low quiescent current, the INA118 achieves wide bandwidth, even at high gain. This is due to the current-feedback topology of the INA118. Settling time also remains excellent at high gain.

The INA118 exhibits approximately 3dB peaking at 500kHz in unity gain. This is a result of its current-feedback topology and is not an indication of instability. Unlike an op amp with poor phase margin, the rise in response is a predictable +6dB/octave due to a response zero. A simple pole at 300kHz or lower will produce a flat passband unity gain response.

DESIRED GAIN	R_G (Ω)	NEAREST 1% R_G (Ω)
1	NC	NC
2	50.00k	49.9k
5	12.50k	12.4k
10	5.556k	5.62k
20	2.632k	2.61k
50	1.02k	1.02k
100	505.1	511
200	251.3	249
500	100.2	100
1000	50.05	49.9
2000	25.01	24.9
5000	10.00	10
10000	5.001	4.99

NC: No Connection.



Also drawn in simplified form:

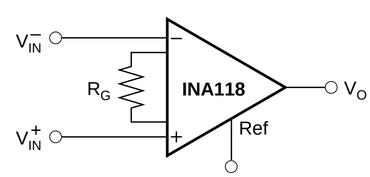


FIGURE 1. Basic Connections.

NOISE PERFORMANCE

The INA118 provides very low noise in most applications. For differential source impedances less than 1kΩ, the INA103 may provide lower noise. For source impedances greater than 50kΩ, the INA111 FET-Input Instrumentation Amplifier may provide lower noise.

Low frequency noise of the INA118 is approximately 0.28µVp-p measured from 0.1 to 10Hz (G≥100). This provides dramatically improved noise when compared to state-of-the-art chopper-stabilized amplifiers.

OFFSET TRIMMING

The INA118 is laser trimmed for low offset voltage and drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to Ref terminal is summed at the output. The op amp buffer provides low impedance at the Ref terminal to preserve good common-mode rejection.

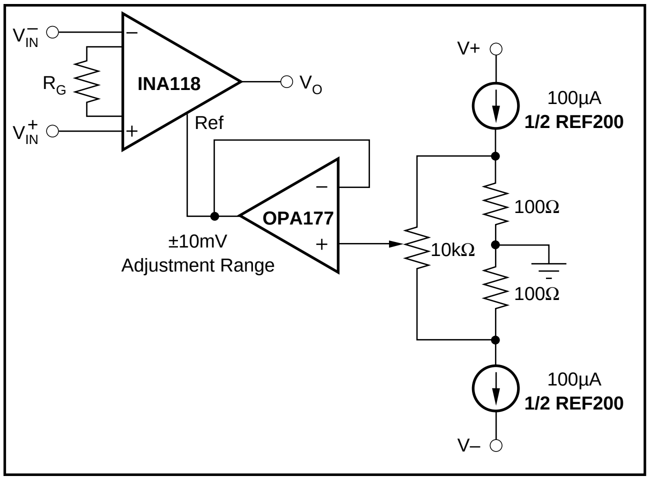


FIGURE 2. Optional Trimming of Output Offset Voltage.

INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA118 is extremely high—approximately 10^{10}Ω. However, a path must be provided for the input bias current of both inputs. This input bias current is approximately ±5nA. High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. Figure 3 shows various provisions for an input bias current path. Without a bias current path, the inputs will float to a potential which exceeds the common-mode range of the INA118 and the input amplifiers will saturate.

If the differential source resistance is low, the bias current return path can be connected to one input (see the thermocouple example in Figure 3). With higher source impedance, using two equal resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better high-frequency common-mode rejection.

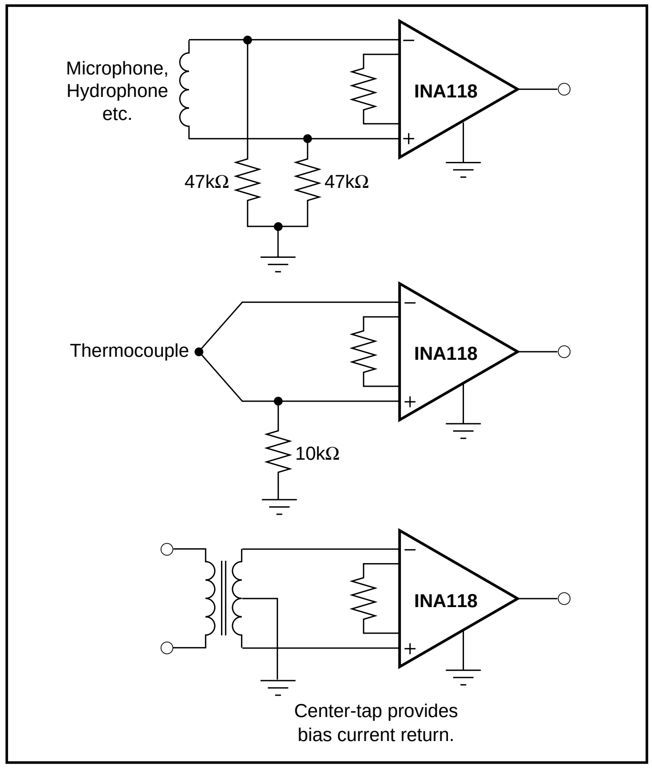


FIGURE 3. Providing an Input Common-Mode Current Path.

INPUT COMMON-MODE RANGE

The linear input voltage range of the input circuitry of the INA118 is from approximately 0.6V below the positive supply voltage to 1V above the negative supply. As a differential input voltage causes the output voltage to increase, however, the linear input range will be limited by the output voltage swing of amplifiers A_1 and A_2. Thus, the linear common-mode input range is related to the output voltage of the complete amplifier. This behavior also depends on supply voltage—see performance curves “Input Common-Mode Range vs Output Voltage”.

Input-overload can produce an output voltage that appears normal. For example, if an input overload condition drives both input amplifiers to their positive output swing limit, the difference voltage measured by the output amplifier will be near zero. The output of the INA118 will be near 0V even though both inputs are overloaded.

LOW VOLTAGE OPERATION

The INA118 can be operated on power supplies as low as ±1.35V. Performance of the INA118 remains excellent with power supplies ranging from ±1.35V to ±18V. Most parameters vary only slightly throughout this supply voltage range—see typical performance curves. Operation at very low supply voltage requires careful attention to assure that the input voltages remain within their linear range. Voltage swing requirements of internal nodes limit the input common-mode range with low power supply voltage. Typical performance curves, “Input Common-Mode Range vs Output Voltage” show the range of linear operation for a various supply voltages and gains.

SINGLE SUPPLY OPERATION

The INA118 can be used on single power supplies of +2.7V to +36V. Figure 5 shows a basic single supply circuit. The output Ref terminal is connected to ground. Zero differential input voltage will demand an output voltage of 0V (ground). Actual output voltage swing is limited to approximately 35mV above ground, when the load is referred to ground as shown. The typical performance curve "Output Voltage vs Output Current" shows how the output voltage swing varies with output current.

With single supply operation, V_{IN}^{+} and V_{IN}^{-} must both be 0.98V above ground for linear operation. You cannot, for instance, connect the inverting input to ground and measure a voltage connected to the non-inverting input.

To illustrate the issues affecting low voltage operation, consider the circuit in Figure 5. It shows the INA118, operating from a single 3V supply. A resistor in series with the low side of the bridge assures that the bridge output voltage is within the common-mode range of the amplifier's inputs. Refer to the typical performance curve "Input Common-Mode Range vs Output Voltage" for 3V single supply operation.

INPUT PROTECTION

The inputs of the INA118 are individually protected for voltages up to ±40V. For example, a condition of –40V on one input and +40V on the other input will not cause damage. Internal circuitry on each input provides low series impedance under normal signal conditions. To provide equivalent protection, series input resistors would contribute excessive noise. If the input is overloaded, the protection circuitry limits the input current to a safe value of approximately 1.5 to 5mA. The typical performance curve "Input Bias Current vs Input Overload Voltage" shows this input current limit behavior. The inputs are protected even if the power supplies are disconnected or turned off.

INSIDE THE INA118

Figure 1 shows a simplified representation of the INA118. The more detailed diagram shown here provides additional insight into its operation.

Each input is protected by two FET transistors that provide a low series resistance under normal signal conditions, preserving excellent noise performance. When excessive voltage is applied, these transistors limit input current to approximately 1.5 to 5mA.

The differential input voltage is buffered by Q_1 and Q_2 and impressed across R_G, causing a signal current to flow through R_G, R_1 and R_2. The output difference amp, A_3, removes the common-mode component of the input signal and refers the output signal to the Ref terminal.

Equations in the figure describe the output voltages of A_1 and A_2. The V_{BE} and IR drop across R_1 and R_2 produce output voltages on A_1 and A_2 that are approximately 1V lower than the input voltages.

A_1 Out = $V_{CM} - V_{BE} - (10\mu A \cdot 25k\Omega) - V_O/2$
A_2 Out = $V_{CM} - V_{BE} - (10\mu A \cdot 25k\Omega) + V_O/2$
Output Swing Range A_1, A_2; (V+) – 0.65V to (V–) + 0.06V
Amplifier Linear Input Range: (V+) – 0.65V to (V–) + 0.98V

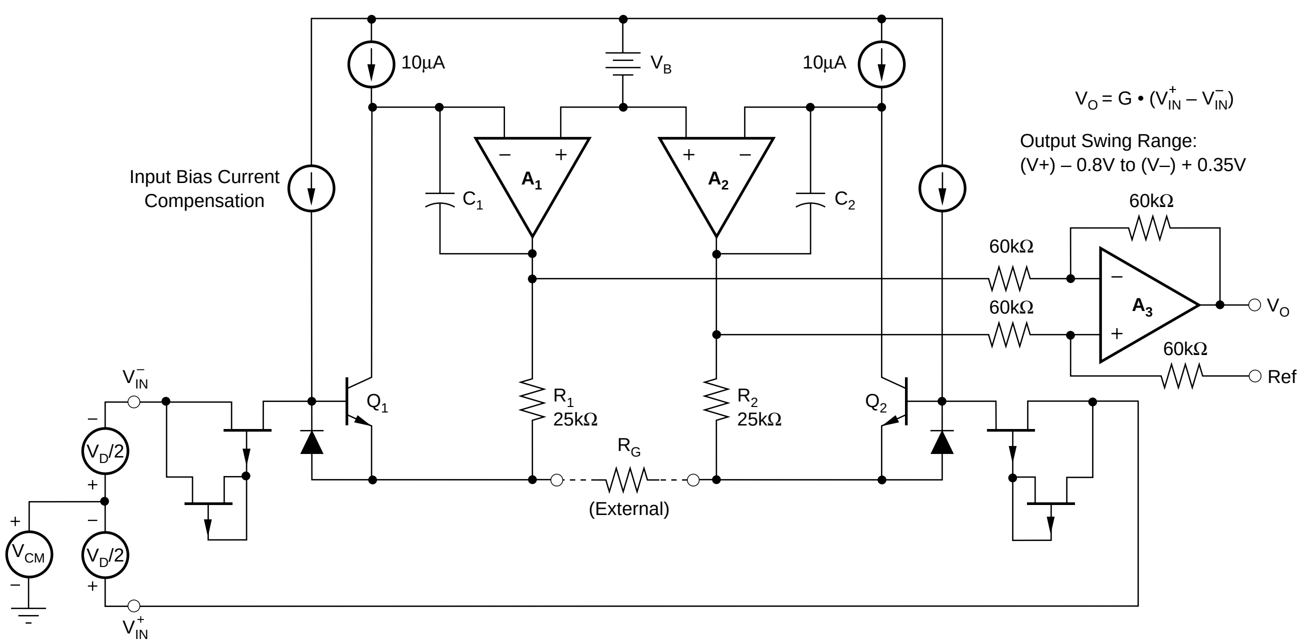


FIGURE 4. INA118 Simplified Circuit Diagram.

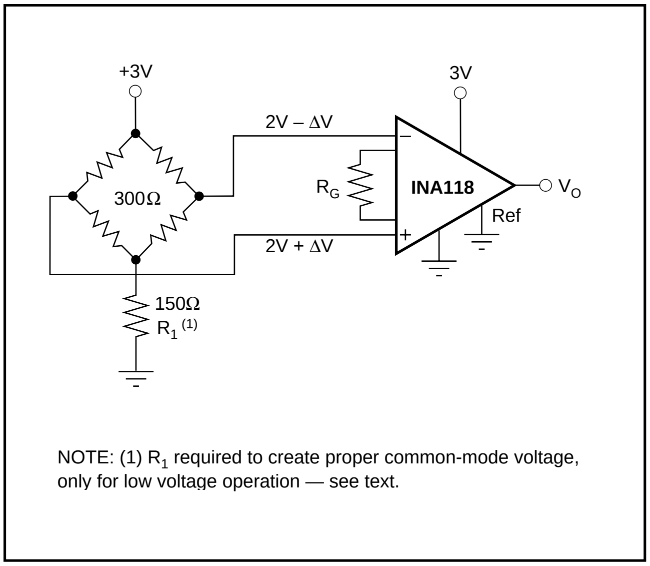
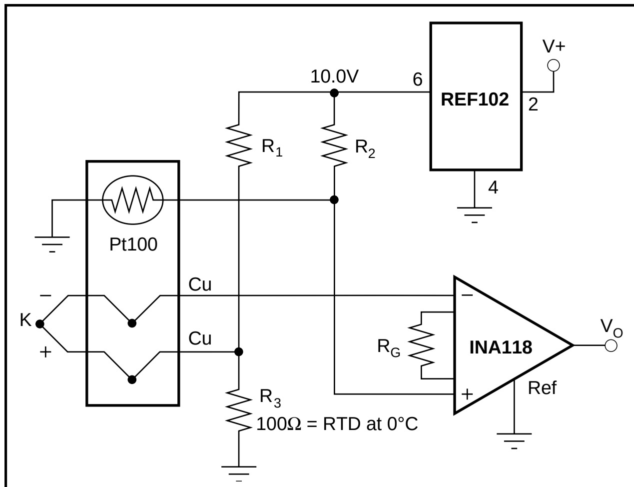


FIGURE 5. Single-Supply Bridge Amplifier.



ISA TYPE	MATERIAL	SEEBECK COEFFICIENT (µV/°C)	R_1, R_2
E	+ Chromel – Constantan	58.5	66.5kΩ
J	+ Iron – Constantan	50.2	76.8kΩ
K	+ Chromel – Alumel	39.4	97.6kΩ
T	+ Copper – Constantan	38.0	102kΩ

FIGURE 7. Thermocouple Amplifier With Cold Junction Compensation.

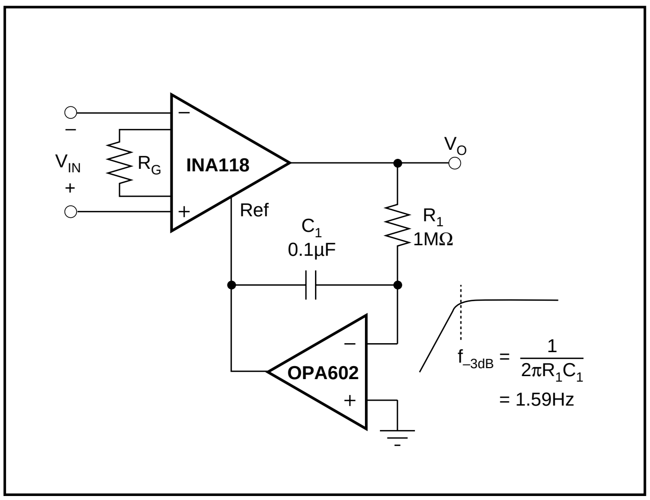
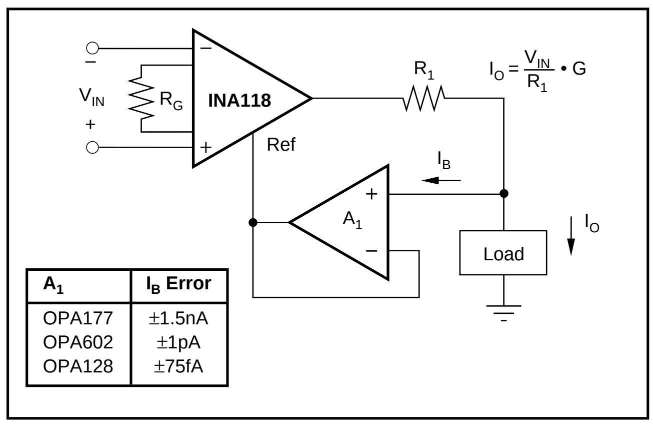


FIGURE 6. AC-Coupled Instrumentation Amplifier.



A_1	I_B Error
OPA177	±1.5nA
OPA602	±1pA
OPA128	±75fA

FIGURE 8. Differential Voltage to Current Converter.

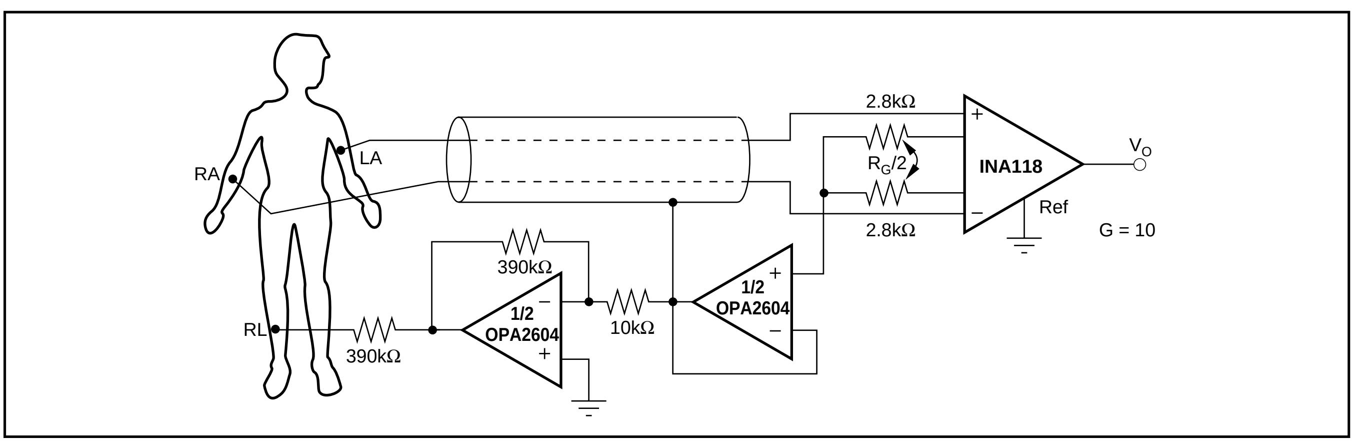


FIGURE 9. ECG Amplifier With Right-Leg Drive.

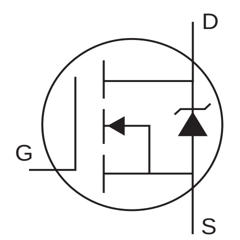
International
IOR Rectifier

PD - 91541B

IRLR/U120N

HEXFET® Power MOSFET

- Surface Mount (IRLR120N)
- Straight Lead (IRLU120N)
- Advanced Process Technology
- Fast Switching
- Fully Avalanche Rated



V_{DSS} = 100V

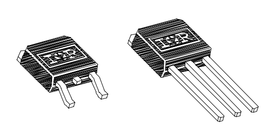
$R_{DS(on)}$ = 0.185Ω

I_D = 10A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve the lowest possible on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient device for use in a wide variety of applications.

The D-PAK is designed for surface mounting using vapor phase, infrared, or wave soldering techniques. The straight lead version (IRFU series) is for through-hole mounting applications. Power dissipation levels up to 1.5 watts are possible in typical surface mount applications.



D-PAK TO-252AA   I-PAK TO-251AA

Absolute Maximum Ratings

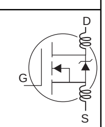
	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	10	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	7.0	
I_{DM}	Pulsed Drain Current ①⑥	35	
P_D @T_C = 25°C	Power Dissipation	48	W
	Linear Derating Factor	0.32	W/°C
V_{GS}	Gate-to-Source Voltage	± 16	V
E_{AS}	Single Pulse Avalanche Energy②⑥	85	mJ
I_{AR}	Avalanche Current①⑥	6.0	A
E_{AR}	Repetitive Avalanche Energy①⑥	4.8	mJ
dv/dt	Peak Diode Recovery dv/dt ③	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	

Thermal Resistance

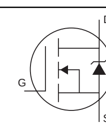
	Parameter	Typ.	Max.	Units
$R_{θJC}$	Junction-to-Case	——	3.1	°C/W
$R_{θJA}$	Junction-to-Ambient (PCB mount) **	——	50	
$R_{θJA}$	Junction-to-Ambient	——	110	

5/11/98

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	100	——	——	V	V_{GS} = 0V, I_D = 250µA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	——	0.12	——	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	——	——	0.185	W	V_{GS} = 10V, I_D = 6.0A ④
		——	——	0.225		V_{GS} = 5.0V, I_D = 6.0A ④
		——	——	0.265		V_{GS} = 4.0V, I_D = 5.0A ④
$V_{GS(th)}$	Gate Threshold Voltage	1.0	——	2.0	V	V_{DS} = V_{GS}, I_D = 250µA
g_{fs}	Forward Transconductance	3.1	——	——	S	V_{DS} = 25V, I_D = 6.0A⑥
I_{DSS}	Drain-to-Source Leakage Current	——	——	25	µA	V_{DS} = 100V, V_{GS} = 0V
		——	——	250		V_{DS} = 80V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	——	——	100	nA	V_{GS} = 16V
	Gate-to-Source Reverse Leakage	——	——	-100		V_{GS} = -16V
Q_g	Total Gate Charge	——	——	20	nC	I_D = 6.0A
Q_{gs}	Gate-to-Source Charge	——	——	4.6		V_{DS} = 80V
Q_{gd}	Gate-to-Drain ("Miller") Charge	——	——	10		V_{GS} = 5.0V, See Fig. 6 and 13 ④⑥
$t_{d(on)}$	Turn-On Delay Time	——	4.0	——	ns	V_{DD} = 50V
t_r	Rise Time	——	35	——		I_D = 6.0A
$t_{d(off)}$	Turn-Off Delay Time	——	23	——		R_G = 11Ω, V_{GS} = 5.0V
t_f	Fall Time		22			R_D = 8.2Ω, See Fig. 10 ④⑥
L_D	Internal Drain Inductance	——	4.5	——	nH	Between lead, 6mm (0.25in.) from package and center of die contact⑤ 
L_S	Internal Source Inductance	——	7.5	——		
C_{iss}	Input Capacitance	——	440	——	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	——	97	——		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	——	50	——		ƒ = 1.0MHz, See Fig. 5⑥

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	——	——	10	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①⑥	——	——	35		
V_{SD}	Diode Forward Voltage	——	——	1.3	V	T_J = 25°C, I_S = 6.0A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	——	110	160	ns	T_J = 25°C, I_F =6.0A
Q_{rr}	Reverse RecoveryCharge	——	410	620	nC	di/dt = 100A/µs ④⑥
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11)

② V_{DD} = 25V, starting T_J = 25°C, L = 4.7mH R_G = 25Ω, I_{AS} = 6.0A. (See Figure 12)

③ I_{SD} ≤ 6.0A, di/dt ≤ 340A/µs, V_{DD} ≤ $V_{(BR)DSS}$, T_J ≤ 175°C

④ Pulse width ≤ 300µs; duty cycle ≤ 2%.

⑤ This is applied for I-PAK, L_S of D-PAK is measured between lead and center of die contact

⑥ Uses IRL520N data and test conditions.

** When mounted on 1" square PCB (FR-4 or G-10 Material) .
For recommended footprint and soldering techniques refer to application note #AN-994

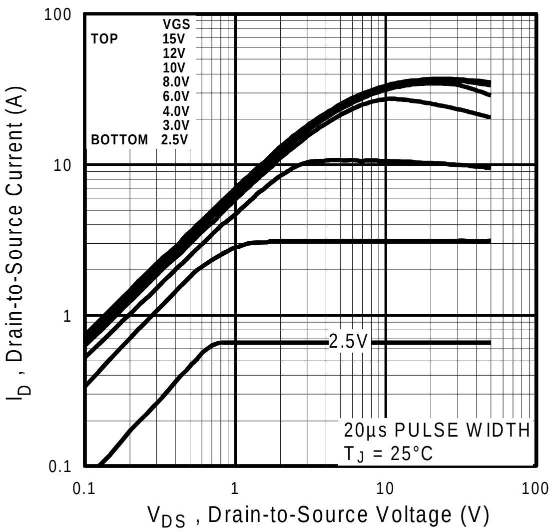


Fig 1. Typical Output Characteristics

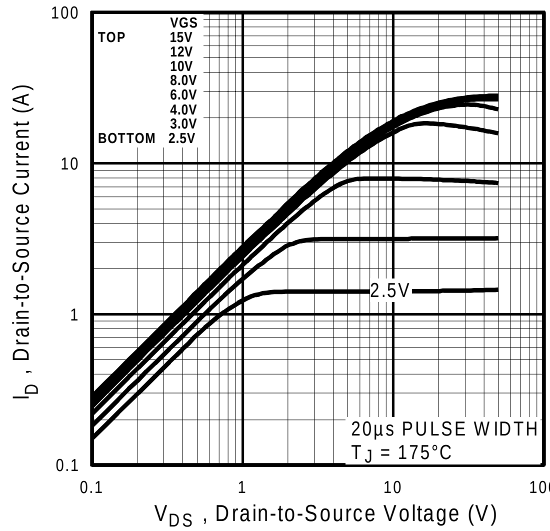


Fig 2. Typical Output Characteristics

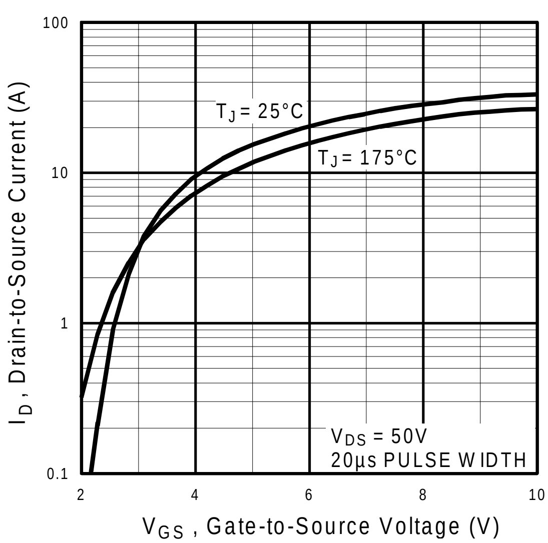


Fig 3. Typical Transfer Characteristics

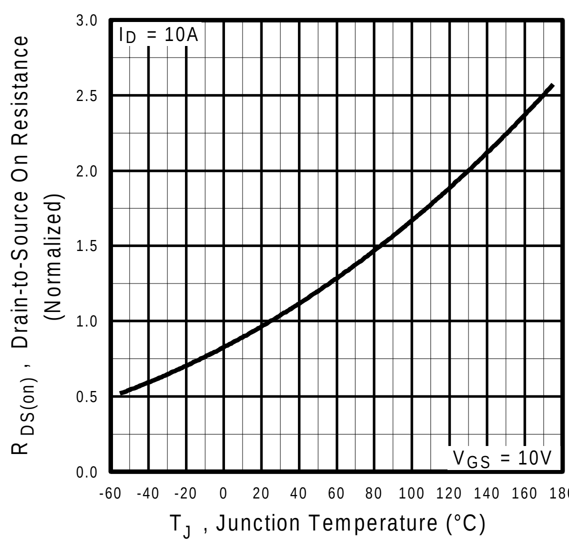
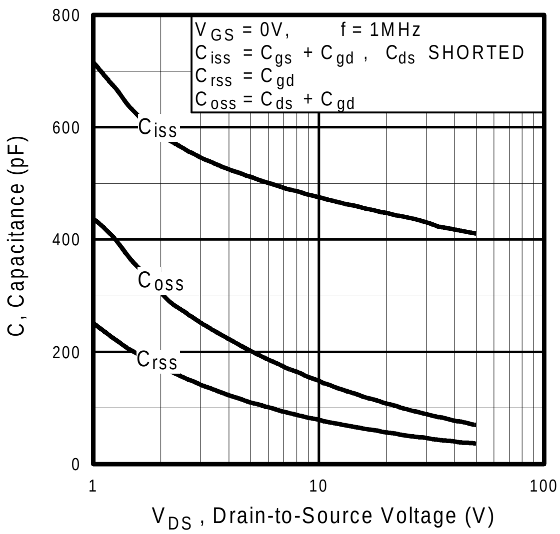


Fig 4. Normalized On-Resistance Vs. Temperature

and



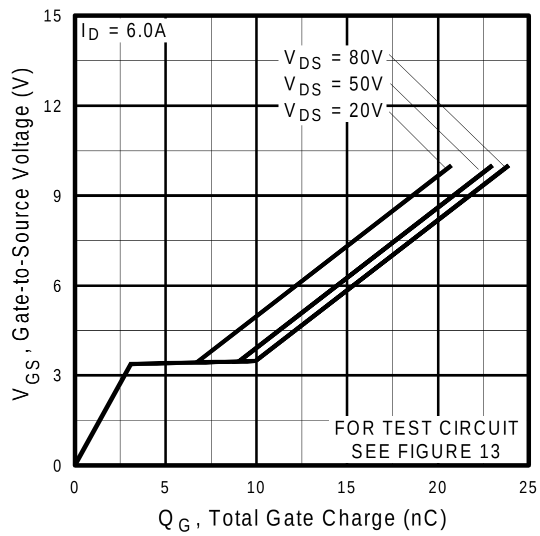
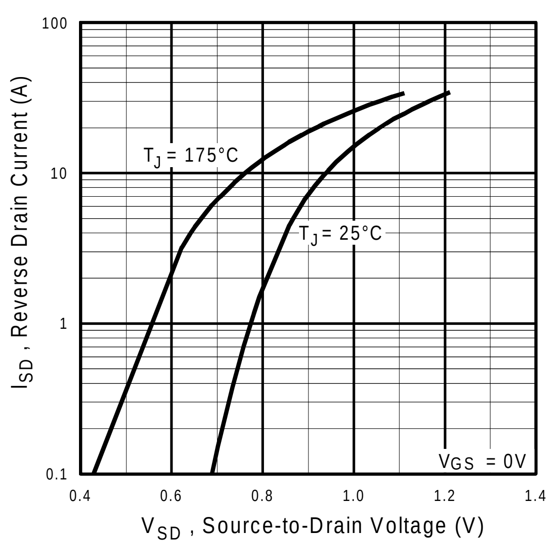


Fig 5. Typical Capacitance Vs. Drain-to-Source Voltage

Fig 6. Typical Gate Charge Vs. Gate-to-Source Voltage



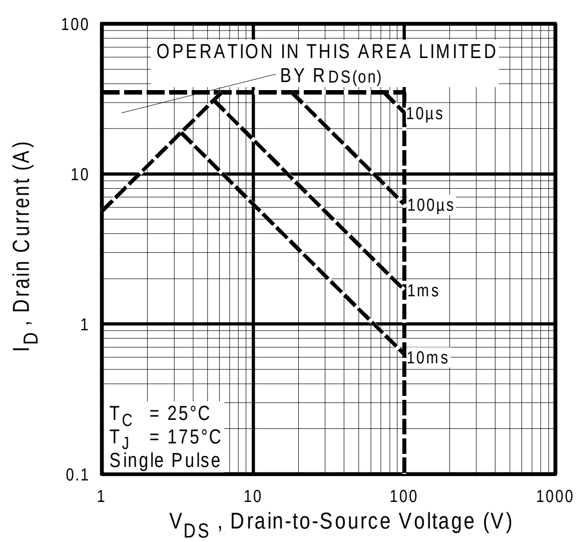


Fig 7. Typical Source-Drain Diode Forward Voltage

Fig 8. Maximum Safe Operating Area

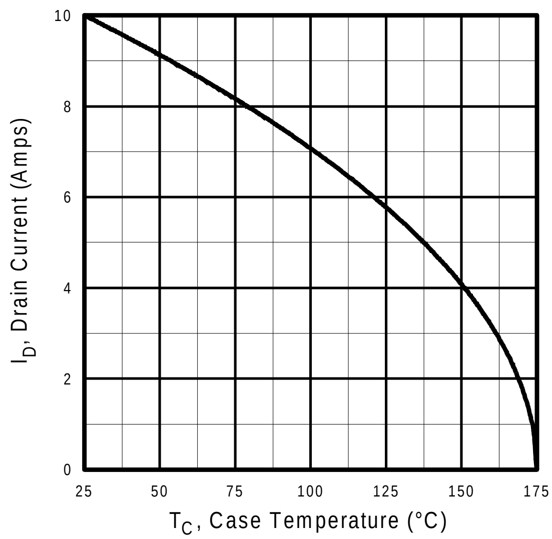


Fig 9. Maximum Drain Current Vs. Case Temperature

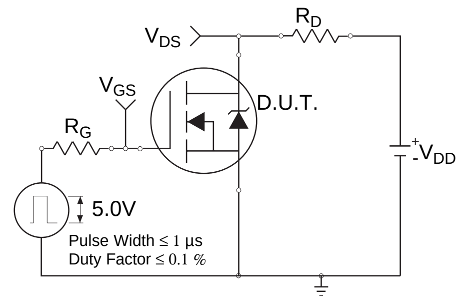


Fig 10a. Switching Time Test Circuit

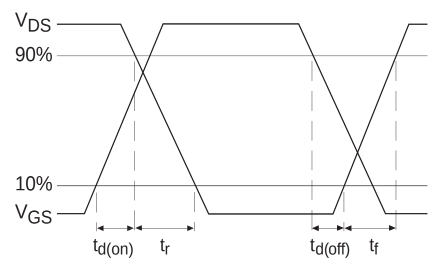


Fig 10b. Switching Time Waveforms

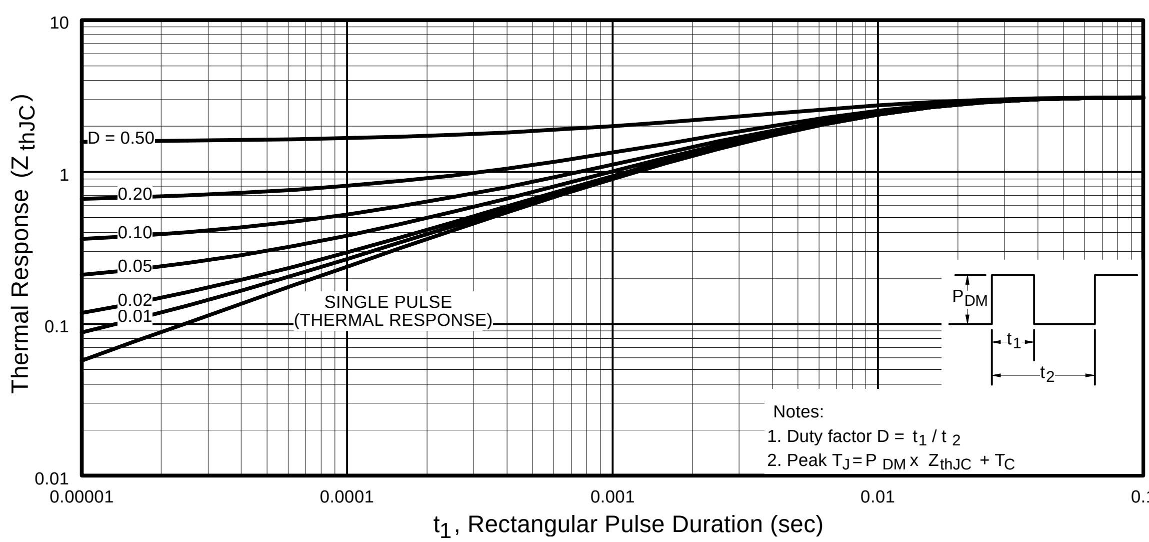


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

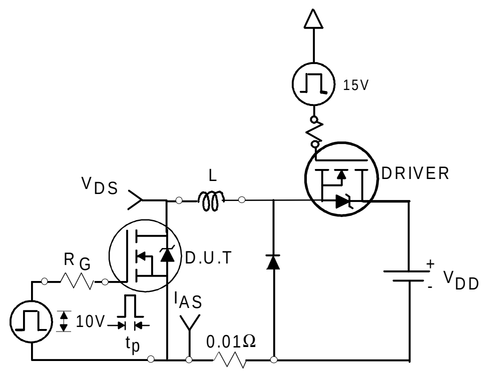


Fig 12a. Unclamped Inductive Test Circuit

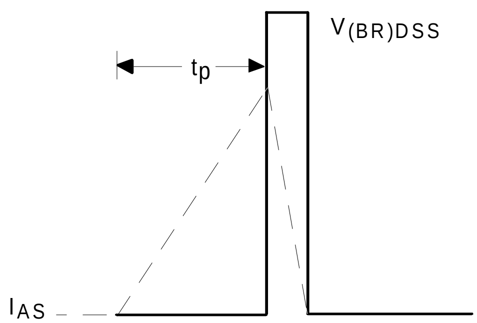


Fig 12b. Unclamped Inductive Waveforms

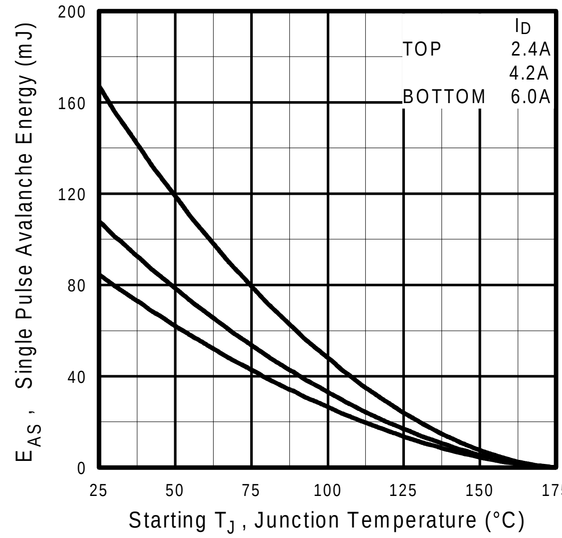


Fig 12c. Maximum Avalanche Energy Vs. Drain Current

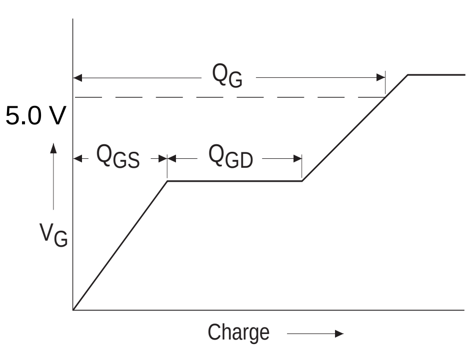


Fig 13a. Basic Gate Charge Waveform

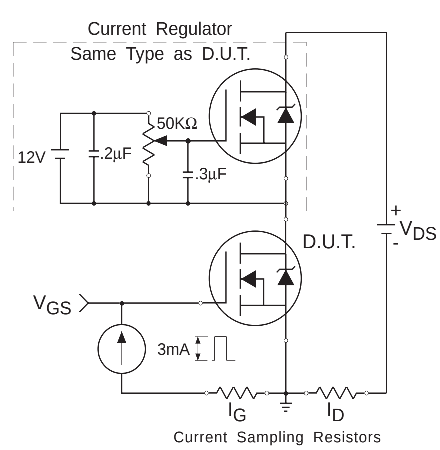
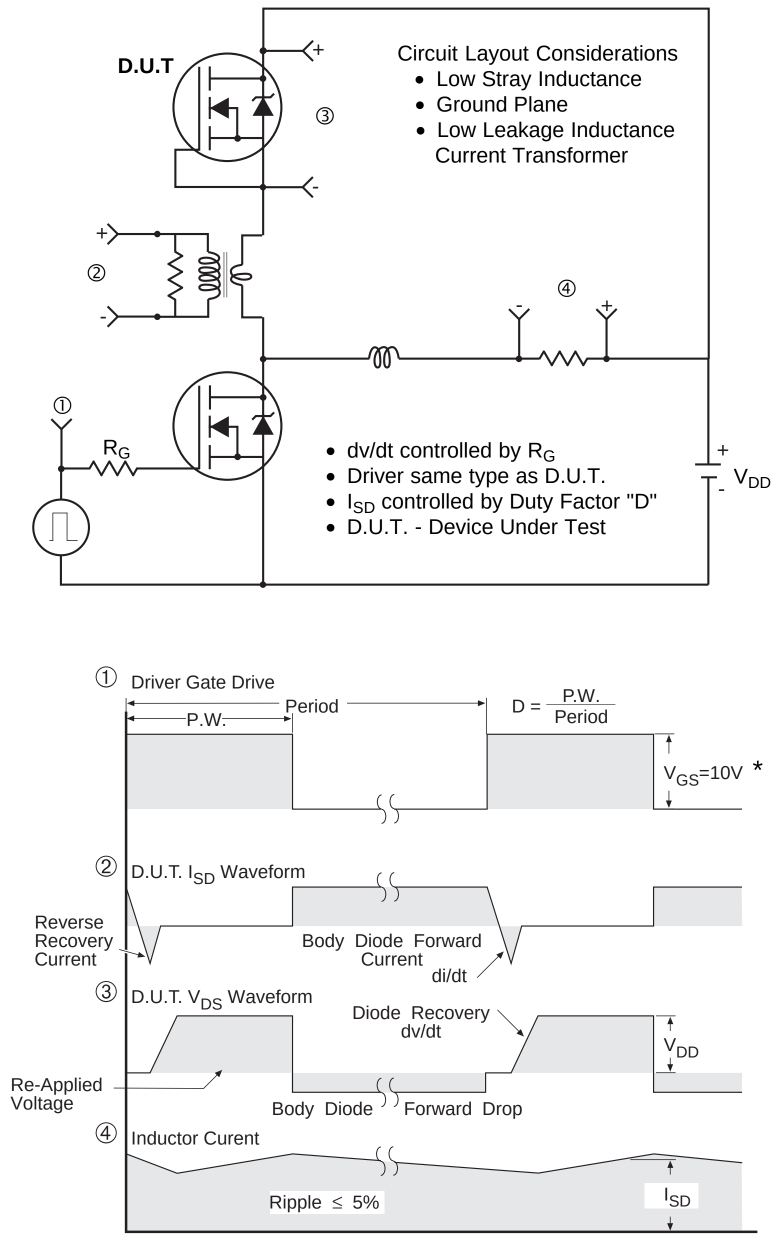


Fig 13b. Gate Charge Test Circuit

Peak Diode Recovery dv/dt Test Circuit

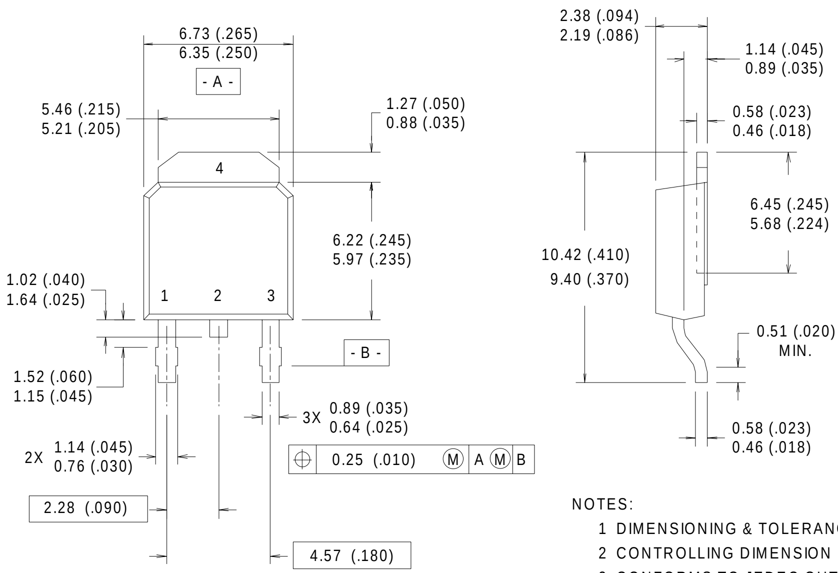


* V_{GS} = 5V for Logic Level Devices

Fig 14. For N-Channel HEXFETS

Package Outline

TO-252AA Outline
Dimensions are shown in millimeters (inches)



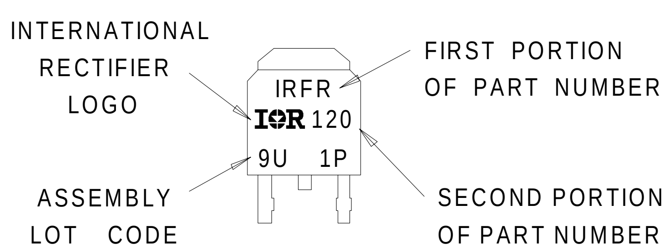
LEAD ASSIGNMENTS
1 - GATE
2 - DRAIN
3 - SOURCE
4 - DRAIN

NOTES:
1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION : INCH.
3 CONFORMS TO JEDEC OUTLINE TO-252AA.
4 DIMENSIONS SHOWN ARE BEFORE SOLDER DIP, SOLDER DIP MAX. +0.16 (.006).

Part Marking Information

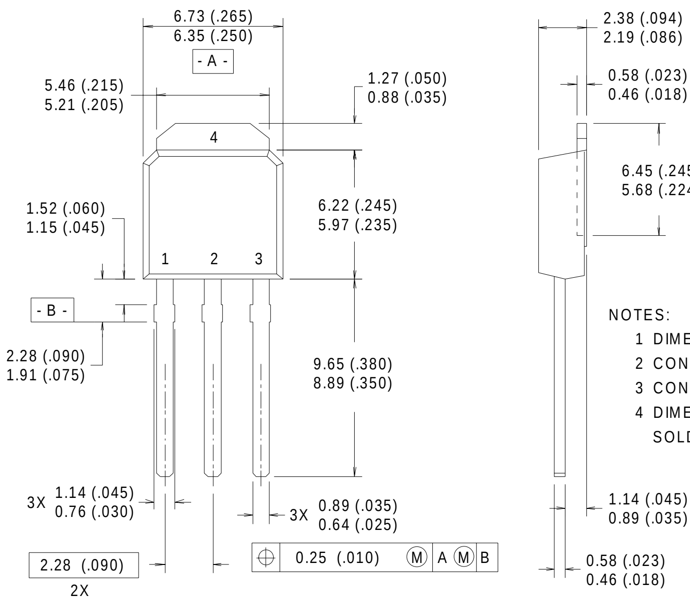
TO-252AA (D-PARK)

EXAMPLE : THIS IS AN IRFR120
WITH ASSEMBLY
LOT CODE 9U1P



Package Outline

TO-251AA Outline
Dimensions are shown in millimeters (inches)



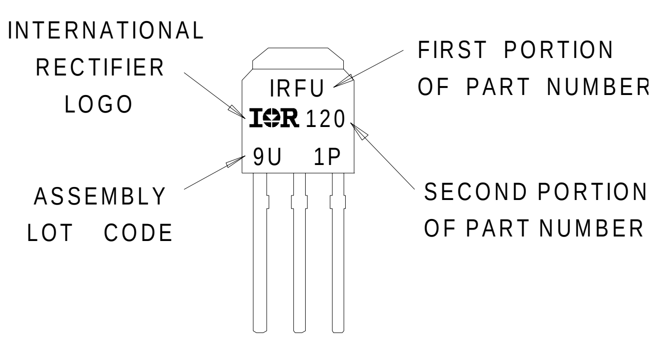
LEAD ASSIGNMENTS
1 - GATE
2 - DRAIN
3 - SOURCE
4 - DRAIN

NOTES:
1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION : INCH.
3 CONFORMS TO JEDEC OUTLINE TO-252AA.
4 DIMENSIONS SHOWN ARE BEFORE SOLDER DIP, SOLDER DIP MAX. +0.16 (.006).

Part Marking Information

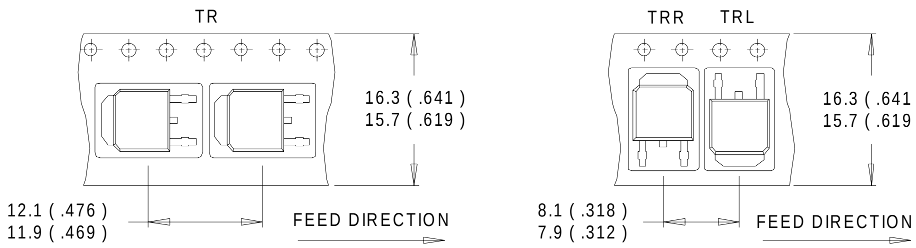
TO-251AA (I-PARK)

EXAMPLE : THIS IS AN IRFU120
WITH ASSEMBLY
LOT CODE 9U1P

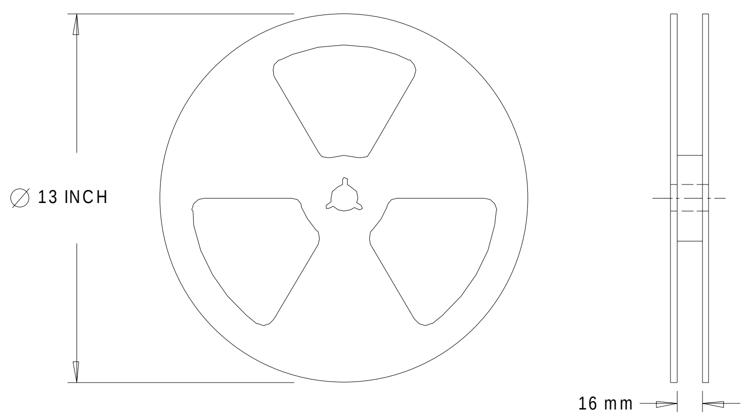


Tape & Reel Information

TO-252AA



NOTES :
1. CONTROLLING DIMENSION : MILLIMETER.
2. ALL DIMENSIONS ARE SHOWN IN MILLIMETERS (INCHES).
3. OUTLINE CONFORMS TO EIA-481 & EIA-541.



NOTES :
1. OUTLINE CONFORMS TO EIA-481.

International
IOR Rectifier

WORLD HEADQUARTERS: 233 Kansas St., El Segundo, California 90245, Tel: (310) 322 3331
EUROPEAN HEADQUARTERS: Hurst Green, Oxted, Surrey RH8 9BB, UK Tel: ++ 44 1883 732020
IR CANADA: 15 Lincoln Court, Brampton, Ontario L6T 3Z2, Tel: (905) 453 2200
IR GERMANY: Saalburgstrasse 157, 61350 Bad Homburg Tel: ++ 49 6172 96590
IR ITALY: Via Liguria 49, 10071 Borgaro, Torino Tel: ++ 39 11 451 0111
IR FAR EAST: 171 (K&H Bldg.) 30-4 Nishi-ikebukuro 3-chome, Toshima-ku, Tokyo Japan Tel: 81 33 983 0086
IR SOUTHEAST ASIA: 315 Outram Road, #10-02 Tan Boon Liat Building, Singapore 16907 Tel: 65 221 8371

Data and specifications subject to change without notice. *5/98*

National Semiconductor

November 1994

LM741 Operational Amplifier

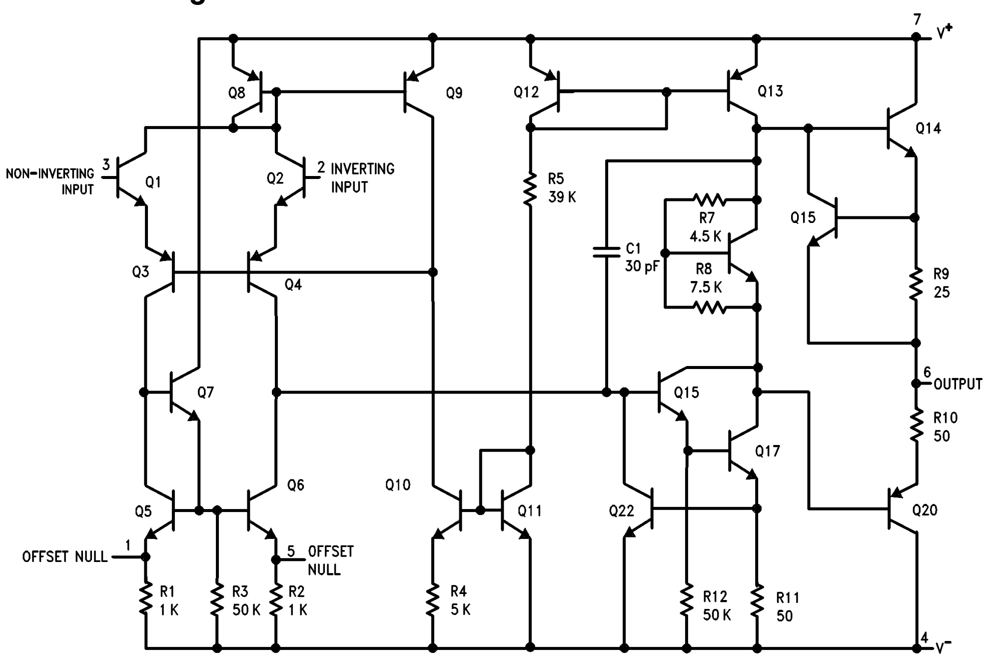
General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

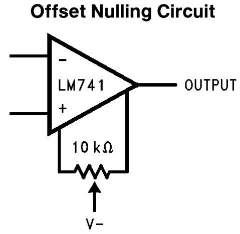
The LM741C/LM741E are identical to the LM741/LM741A except that the LM741C/LM741E have their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Schematic Diagram



TL/H/9341–1

Offset Nulling Circuit



TL/H/9341–7

RRD-B30M115/Printed in U. S. A.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.
(Note 5)

	LM741A	LM741E	LM741	LM741C
Supply Voltage	±22V	±22V	±22V	±18V
Power Dissipation (Note 1)	500 mW	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V	±30V
Input Voltage (Note 2)	±15V	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	0°C to +70°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	100°C	150°C	100°C
Soldering Information				
N-Package (10 seconds)	260°C	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C	300°C
M-Package				
Vapor Phase (60 seconds)	215°C	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C	215°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

	LM741A	LM741E	LM741	LM741C
ESD Tolerance (Note 6)	400V	400V	400V	400V

Electrical Characteristics (Note 3)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							$\mu V/°C$
Input Offset Voltage Adjustment Range	$T_A = 25°C, V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25°C, V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		$M\Omega$
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$	0.5									$M\Omega$
Input Voltage Range	$T_A = 25°C$							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V
Large Signal Voltage Gain	$T_A = 25°C, R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V, V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V, V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $R_L \geq 2\ k\Omega$,										
	$V_S = \pm 20V, V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V, V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V, V_O = \pm 2V$	10									V/mV

Electrical Characteristics (Note 3) (Continued)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit Current	$T_A = 25°C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB
Supply Voltage Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$ to $V_S = \pm 5V$										
	$R_S \leq 50\Omega$	86	96								dB
	$R_S \leq 10\ k\Omega$				77	96		77	96		dB
Transient Response	$T_A = 25°C$, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		μs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 4)	$T_A = 25°C$	0.437	1.5								MHz
Slew Rate	$T_A = 25°C$, Unity Gain	0.3	0.7			0.5			0.5		V/μs
Supply Current	$T_A = 25°C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25°C$										
	$V_S = \pm 20V$		80	150							mW
	$V_S = \pm 15V$					50	85		50	85	mW
LM741A	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741E	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			150							mW
	$T_A = T_{AMAX}$			150							mW
LM741	$V_S = \pm 15V$										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 1: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 2: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 3: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \leq T_A \leq +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \leq T_A \leq +70°C$.

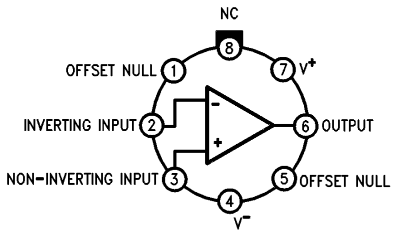
Note 4: Calculated value from: BW (MHz) = 0.35/Rise Time(μs).

Note 5: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 6: Human body model, 1.5 kΩ in series with 100 pF.

Connection Diagrams

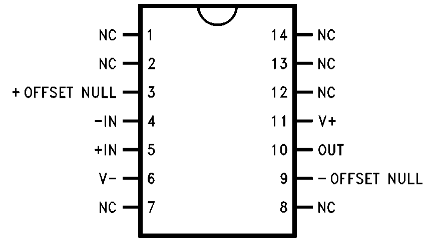
Metal Can Package



TL/H/9341–2

Order Number LM741H, LM741H/883*, LM741AH/883 or LM741CH
See NS Package Number H08C

Ceramic Dual-In-Line Package



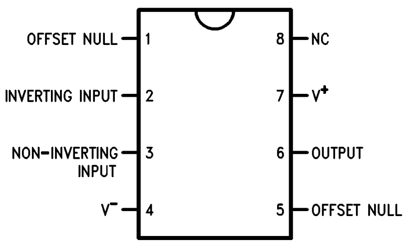
TL/H/9341–5

Order Number LM741J-14/883*, LM741AJ-14/883**
See NS Package Number J14A

*also available per JM38510/10101

**also available per JM38510/10102

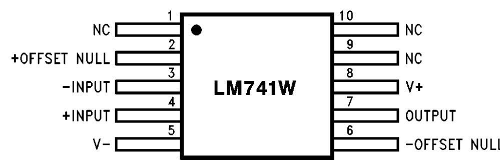
Dual-In-Line or S.O. Package



TL/H/9341–3

Order Number LM741J, LM741J/883, LM741CM, LM741CN or LM741EN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak

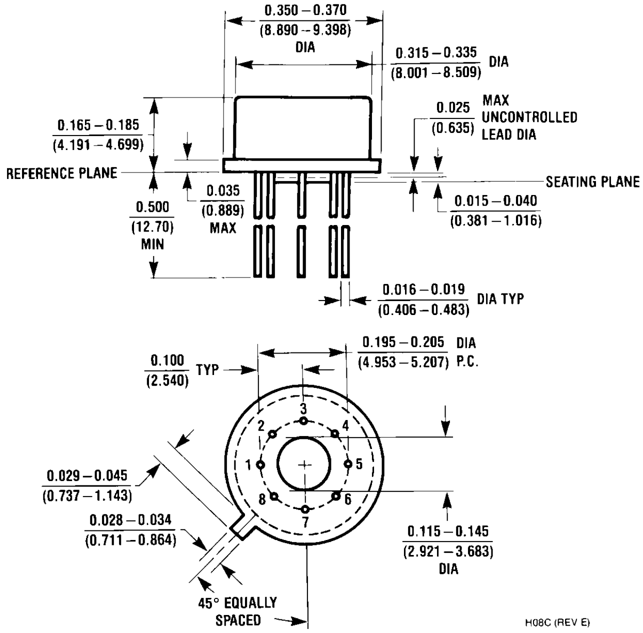


TL/H/9341–6

Order Number LM741W/883
See NS Package Number W10A

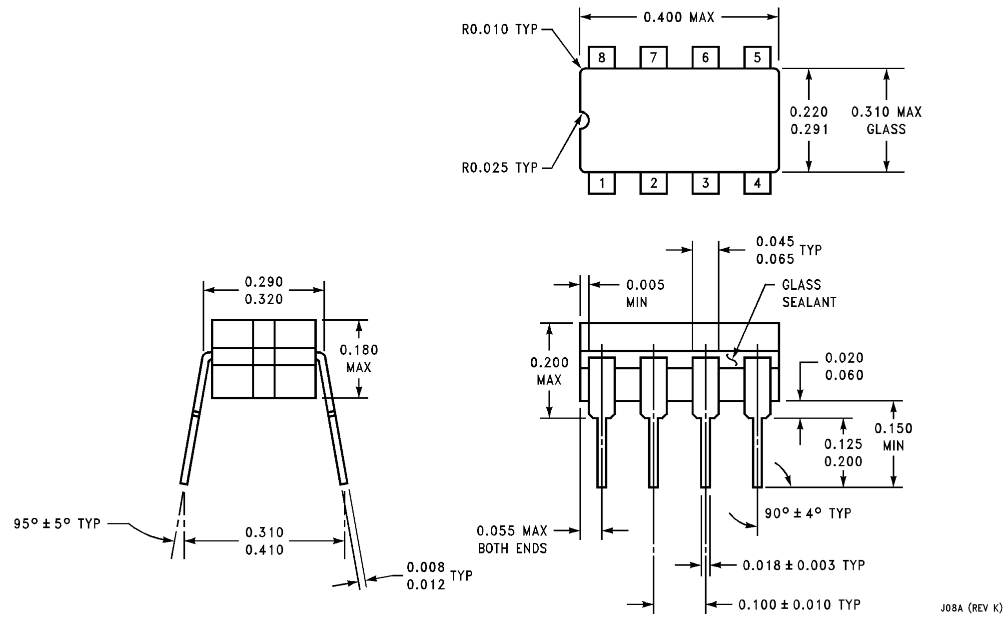
*LM741H is available per JM38510/10101

Physical Dimensions inches (millimeters)

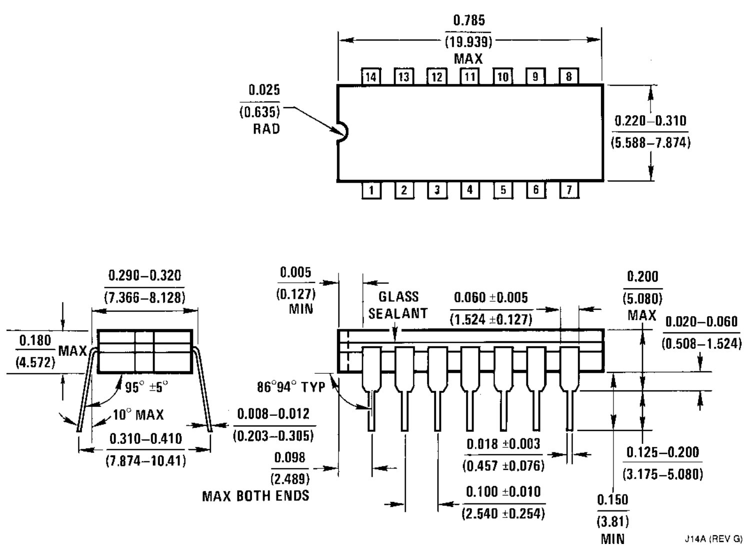


Metal Can Package (H)
Order Number LM741H, LM741H/883, LM741AH/883, LM741CH or LM741EH
NS Package Number H08C

Physical Dimensions inches (millimeters) (Continued)

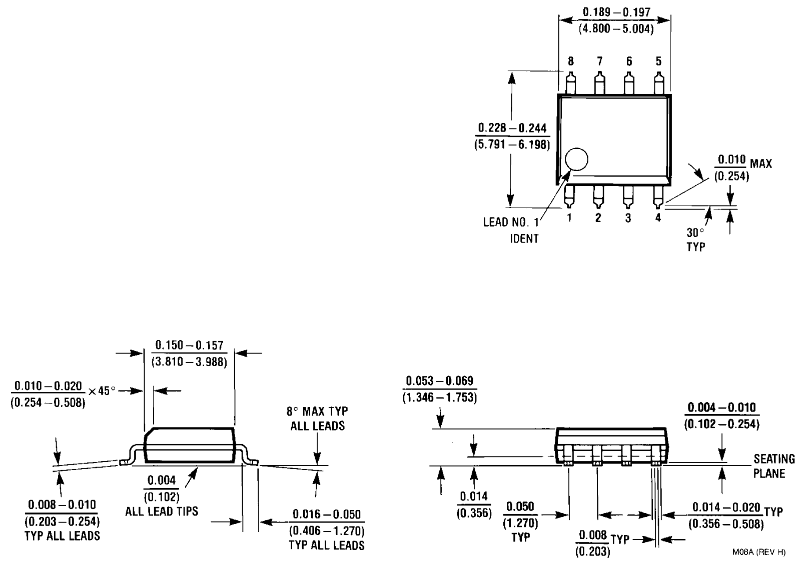


Ceramic Dual-In-Line Package (J)
Order Number LM741CJ or LM741J/883
NS Package Number J08A

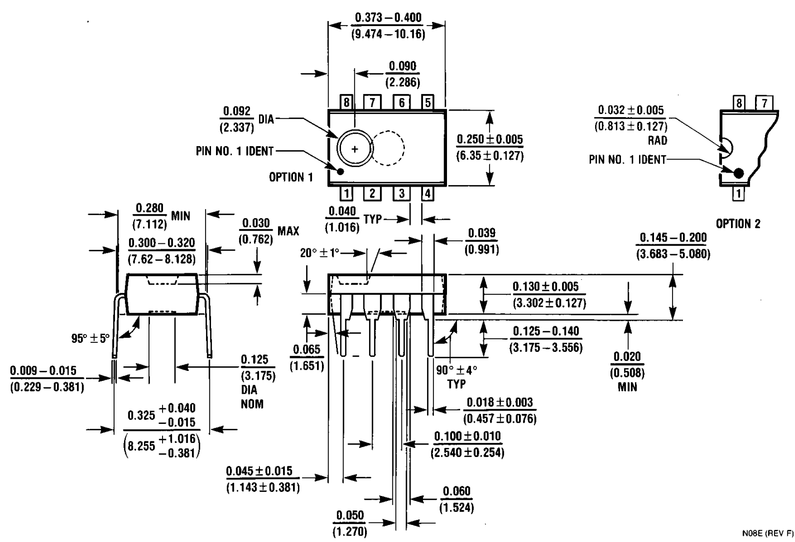


Ceramic Dual-In-Line Package (J)
Order Number LM741J-14/883 or LM741AJ-14/883
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

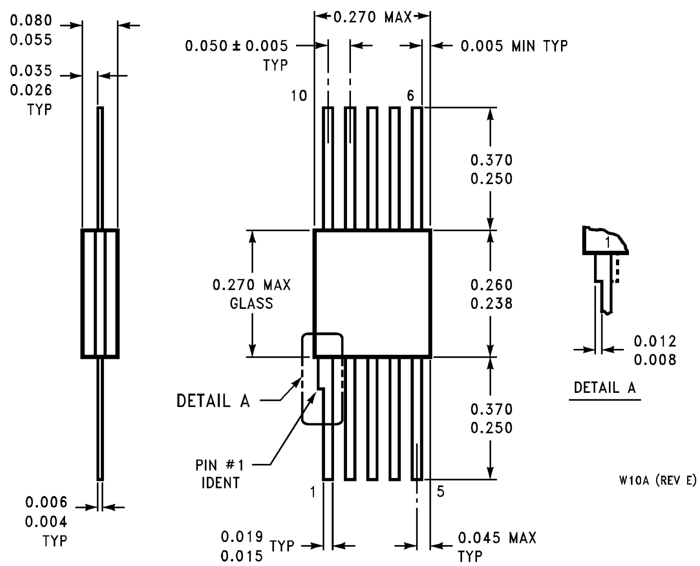


Small Outline Package (M)
Order Number LM741CM
NS Package Number M08A



Dual-In-Line Package (N)
Order Number LM741CN or LM741EN
NS Package Number N08E

Physical Dimensions inches (millimeters) (Continued)



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883
NS Package Number W10A

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National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

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Tel: 81-043-299-2309
Fax: 81-043-299-2408

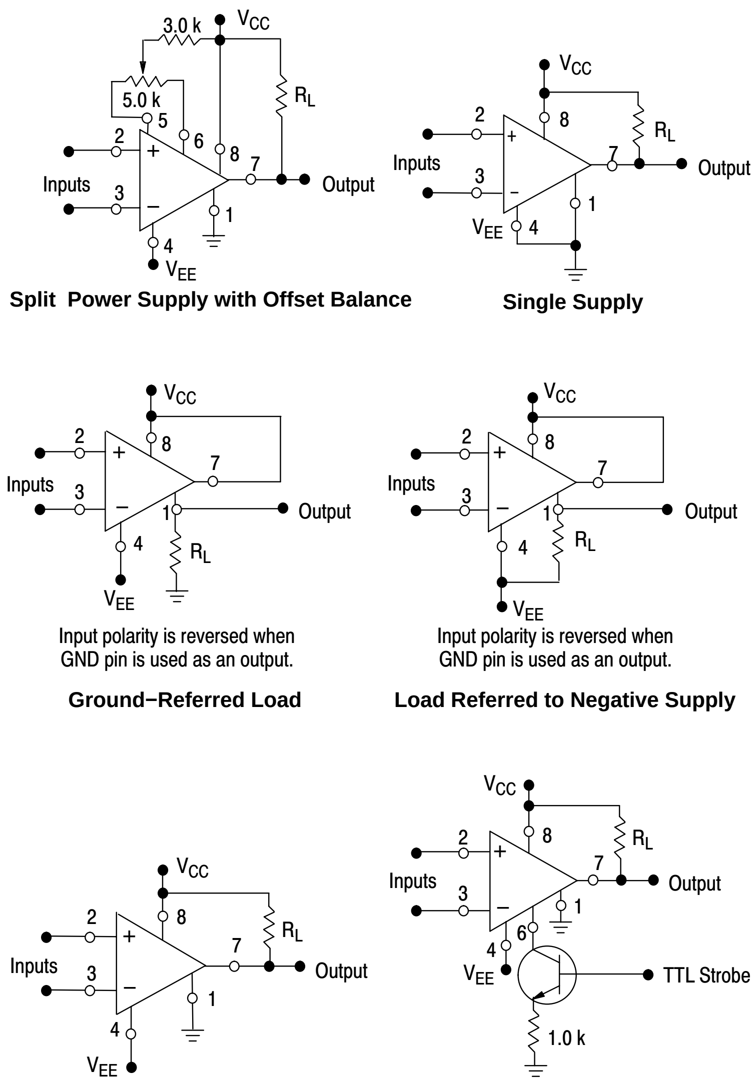
LM211, LM311

Single Comparators

The ability to operate from a single power supply of 5.0 V to 30 V or ± 15 V split supplies, as commonly used with operational amplifiers, makes the LM211/LM311 a truly versatile comparator. Moreover, the inputs of the device can be isolated from system ground while the output can drive loads referenced either to ground, the V_{CC} or the V_{EE} supply. This flexibility makes it possible to drive DTL, RTL, TTL, or MOS logic. The output can also switch voltages to 50 V at currents to 50 mA, therefore, the LM211/LM311 can be used to drive relays, lamps or solenoids.

Features

- Pb−Free Packages are Available



Split Power Supply with Offset Balance

Single Supply

Ground−Referred Load

Load Referred to Negative Supply

Load Referred to Positive Supply

Strobe Capability

Figure 1. Typical Comparator Design Configurations

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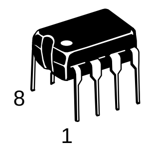
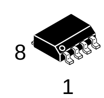
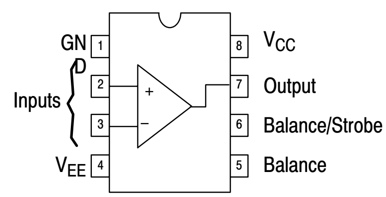


PDIP−8
N SUFFIX
CASE 626



SOIC−8
D SUFFIX
CASE 751

PIN CONNECTIONS



(Top View)

ORDERING & DEVICE MARKING INFORMATION

See detailed ordering and shipping information and marking information in the package dimensions section on page 7 of this data sheet.

MAXIMUM RATINGS (T_A = +25°C, unless otherwise noted.)

Rating	Symbol	LM211	LM311	Unit
Total Supply Voltage	$V_{CC} + \|V_{EE}\|$	36	36	Vdc
Output to Negative Supply Voltage	$V_O - V_{EE}$	50	40	Vdc
Ground to Negative Supply Voltage	V_{EE}	30	30	Vdc
Input Differential Voltage	V_{ID}	±30	±30	Vdc
Input Voltage (Note 2)	V_{in}	±15	±15	Vdc
Voltage at Strobe Pin	−	V_{CC} to V_{CC}−5	V_{CC} to V_{CC}−5	Vdc
Power Dissipation and Thermal Characteristics Plastic DIP Derate Above T_A = +25°C	 P_D $R_{\theta JA}$	 625 5.0		 mW mW/°C
Operating Ambient Temperature Range	T_A	−25 to +85	0 to +70	°C
Operating Junction Temperature	$T_{J(max)}$	+150	+150	°C
Storage Temperature Range	T_{stg}	−65 to +150	−65 to +150	°C

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

ELECTRICAL CHARACTERISTICS (V_{CC} = +15 V, V_{EE} = −15 V, T_A = 25°C, unless otherwise noted) Note 1

Characteristic	Symbol	LM211			LM311			Unit
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage (Note 3) $R_S \leq$ 50 kΩ, T_A = +25°C $R_S \leq$ 50 kΩ, $T_{low} \leq T_A \leq T_{high}$*	V_{IO}	 − −	 0.7 −	 3.0 4.0	 − −	 2.0 −	 7.5 10	mV
Input Offset Current (Note 3) T_A = +25°C $T_{low} \leq T_A \leq T_{high}$*	I_{IO}	− −	1.7 −	10 20	− −	1.7 −	50 70	nA
Input Bias Current T_A = +25°C $T_{low} \leq T_A \leq T_{high}$*	I_{IB}	− −	45 −	100 150	− −	45 −	250 300	nA
Voltage Gain	A_V	40	200	−	40	200	−	V/mV
Response Time (Note 4)		−	200	−	−	200	−	ns
Saturation Voltage $V_{ID} \leq -5.0$ mV, I_O = 50 mA, T_A = 25°C $V_{ID} \leq -10$ mV, I_O = 50 mA, T_A = 25°C $V_{CC} \geq 4.5$ V, V_{EE} = 0, $T_{low} \leq T_A \leq T_{high}$* $V_{ID} \angle\leq 6.0$ mV, $I_{sink} \leq 8.0$ mA $V_{ID} \angle\leq 10$ mV, $I_{sink} \leq 8.0$ mA	V_{OL}	 − − − −	 0.75 − 0.23 −	 1.5 − 0.4 −	 − − − −	 − 0.75 − 0.23	 − 1.5 − 0.4	V
Strobe "On" Current (Note 5)	I_S	−	3.0	−	−	3.0	−	mA
Output Leakage Current $V_{ID} \geq 5.0$ mV, V_O= 35 V, T_A = 25°C, I_{strobe}= 3.0 mA $V_{ID \geq 10\ mV}$, V_O= 35 V, T_A = 25°C, I_{strobe}= 3.0 mA $V_{ID \geq 5.0\ mV}$, V_O= 35 V, $T_{low} \leq T_A \leq T_{high}$*		 − − −	 0.2 − 0.1	 10 − 0.5	 − − −	 − 0.2 −	 − 50 −	 nA nA μA
Input Voltage Range ($T_{low} \leq T_A \leq T_{high}$*)	V_{ICR}	−14.5	−14.7 to 13.8	+13.0	−14.5	−14.7 to 13.8	+13.0	V
Positive Supply Current	I_{CC}	−	+2.4	+6.0	−	+2.4	+7.5	mA
Negative Supply Current	I_{EE}	−	−1.3	−5.0	−	−1.3	−5.0	mA

* LM211: T_{low} = −25°C, T_{high} = +85°C
  LM311: T_{low} = 0°C, T_{high} = +70°C

1. Offset voltage, offset current and bias current specifications apply for a supply voltage range from a single 5.0 V supply up to ±15 V supplies.
2. This rating applies for ±15 V supplies. The positive input voltage limit is 30 V above the negative supply. The negative input voltage limit is equal to the negative supply voltage or 30 V below the positive supply, whichever is less.
3. The offset voltages and offset currents given are the maximum values required to drive the output within a volt of either supply with a 1.0 mA load. Thus, these parameters define an error band and take into account the "worst case" effects of voltage gain and input impedance.
4. The response time specified is for a 100 mV input step with 5.0 mV overdrive.
5. Do not short the strobe pin to ground; it should be current driven at 3.0 mA to 5.0 mA.

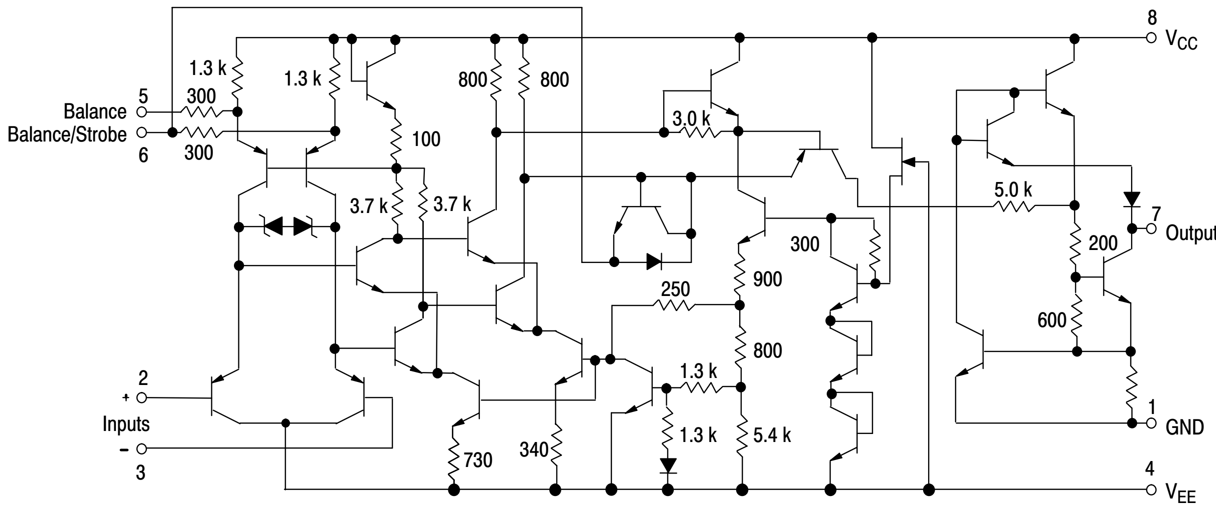


Figure 2. Circuit Schematic

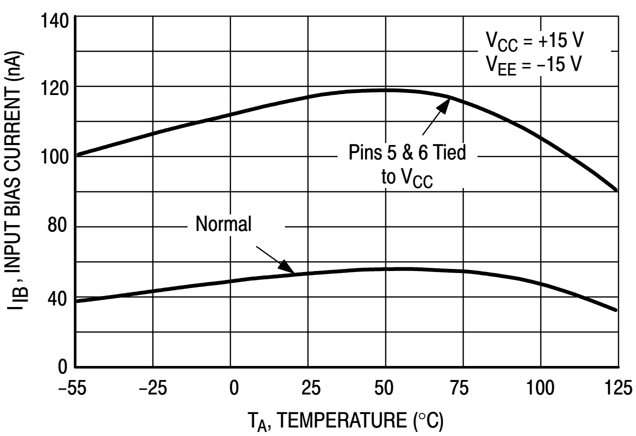


Figure 3. Input Bias Current versus Temperature

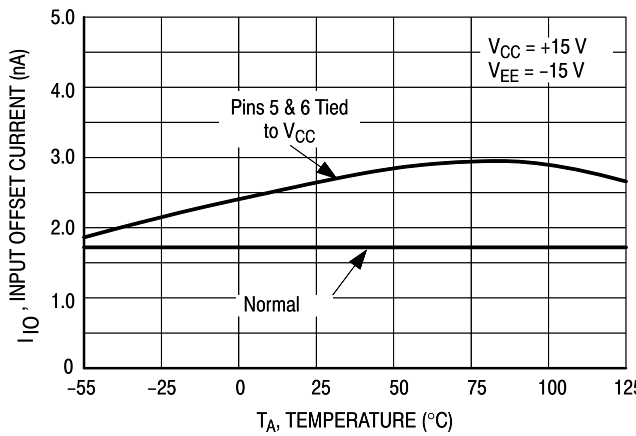


Figure 4. Input Offset Current versus Temperature

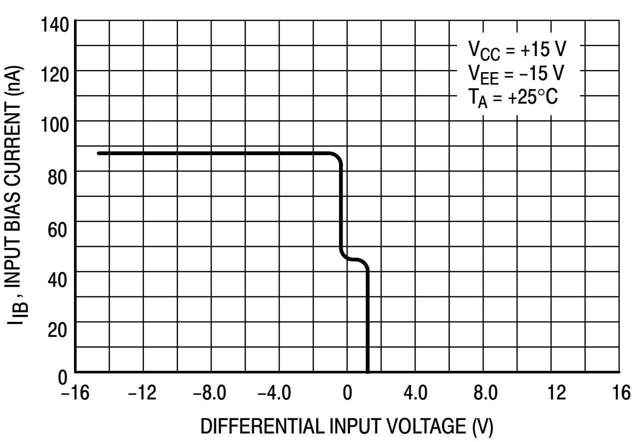


Figure 5. Input Bias Current versus Differential Input Voltage

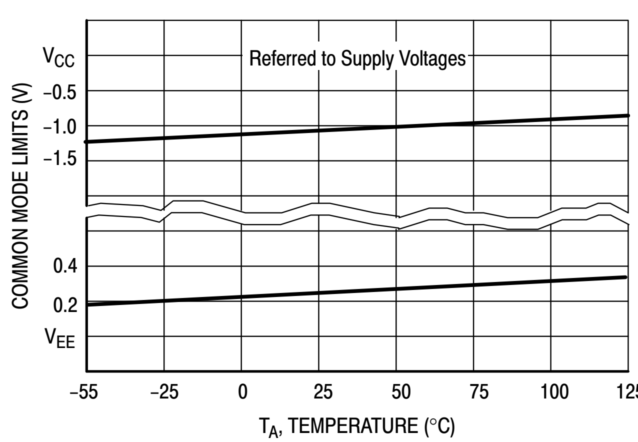


Figure 6. Common Mode Limits versus Temperature

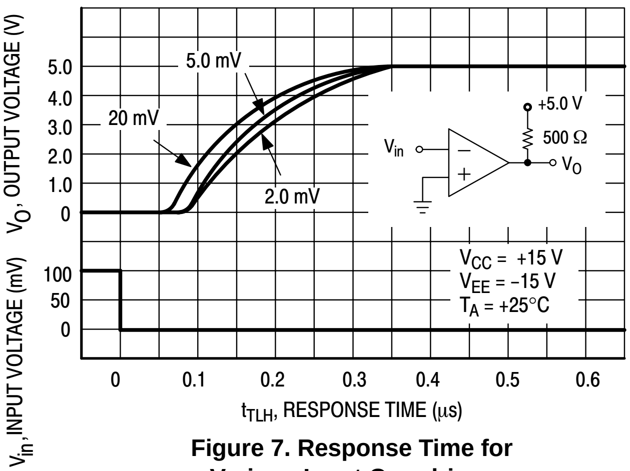


Figure 7. Response Time for Various Input Overdrives

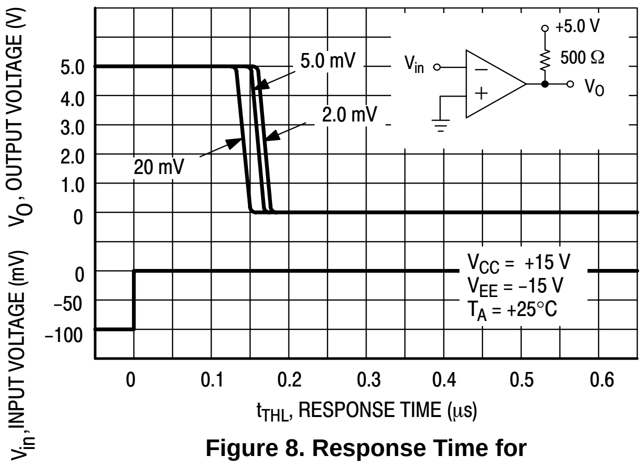


Figure 8. Response Time for Various Input Overdrives

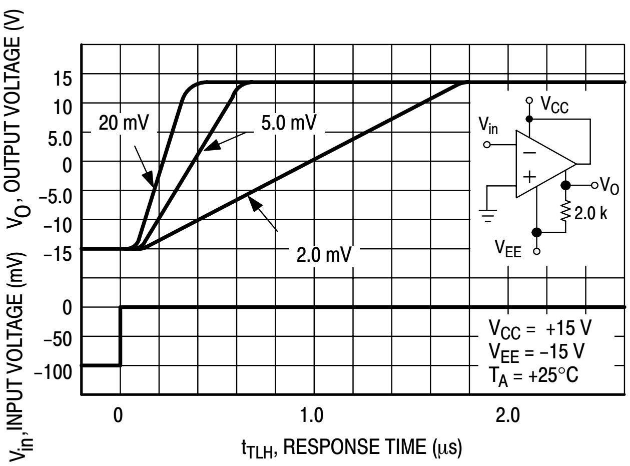


Figure 9. Response Time for Various Input Overdrives

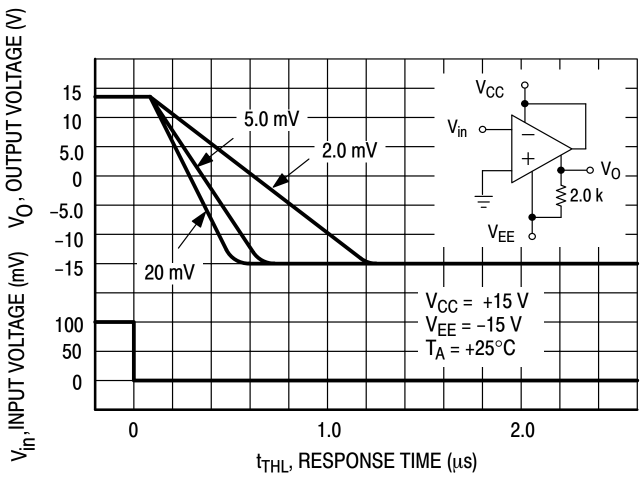


Figure 10. Response Time for Various Input Overdrives

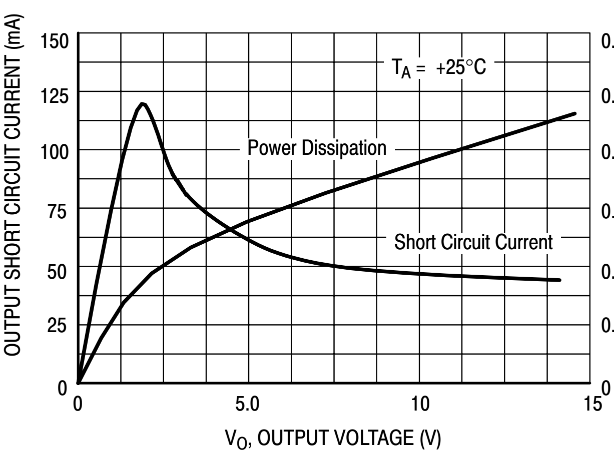


Figure 11. Output Short Circuit Current Characteristics and Power Dissipation

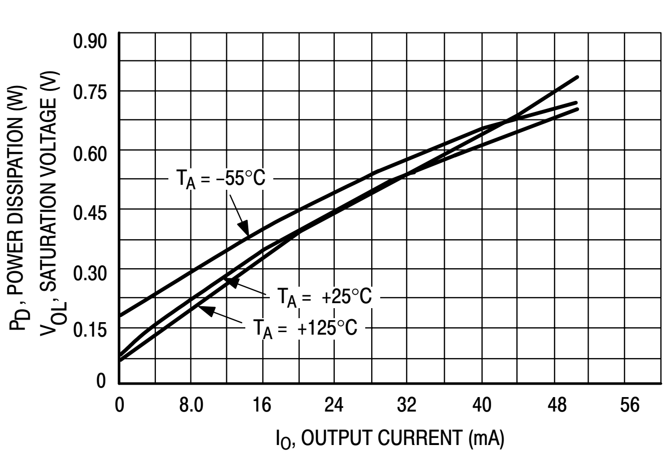


Figure 12. Output Saturation Voltage versus Output Current

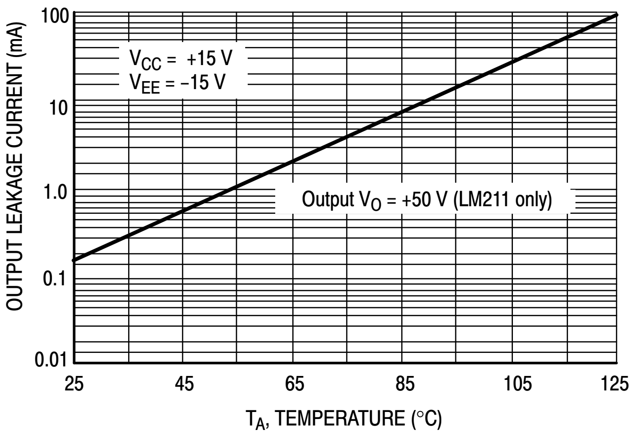


Figure 13. Output Leakage Current versus Temperature

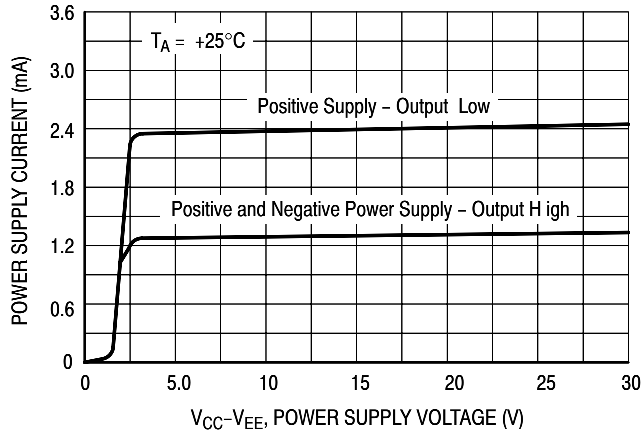


Figure 14. Power Supply Current versus Supply Voltage

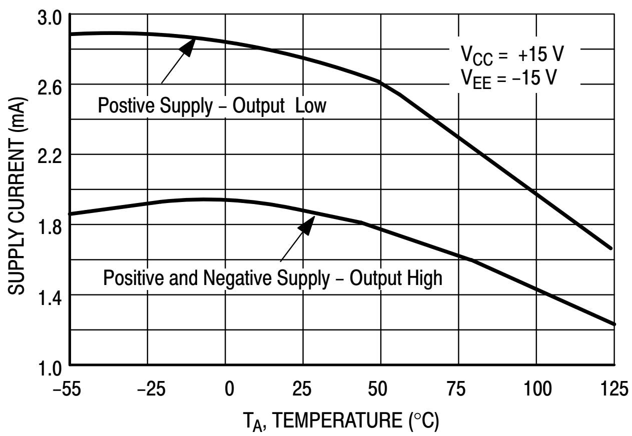


Figure 15. Power Supply Current versus Temperature

APPLICATIONS INFORMATION

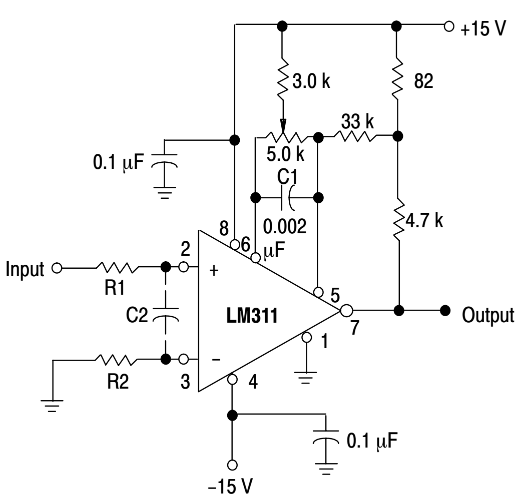


Figure 16. Improved Method of Adding Hysteresis Without Applying Positive Feedback to the Inputs

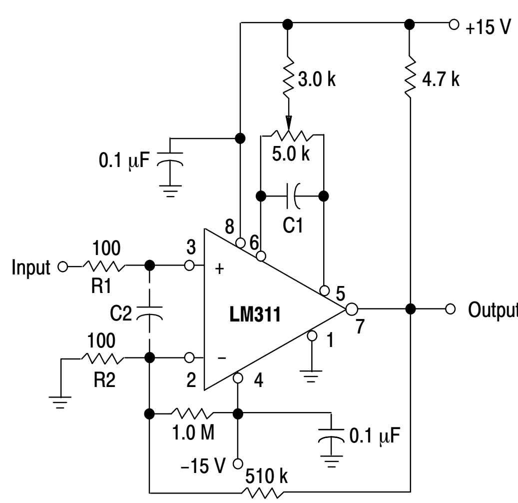


Figure 17. Conventional Technique for Adding Hysteresis

TECHNIQUES FOR AVOIDING OSCILLATIONS IN COMPARATOR APPLICATIONS

When a high speed comparator such as the LM211 is used with high speed input signals and low source impedances, the output response will normally be fast and stable, providing the power supplies have been bypassed (with 0.1 μF disc capacitors), and that the output signal is routed well away from the inputs (Pins 2 and 3) and also away from Pins 5 and 6.

However, when the input signal is a voltage ramp or a slow sine wave, or if the signal source impedance is high (1.0 kΩ to 100 kΩ), the comparator may burst into oscillation near the crossing−point. This is due to the high gain and wide bandwidth of comparators like the LM211 series. To avoid oscillation or instability in such a usage, several precautions are recommended, as shown in Figure 16.

The trim pins (Pins 5 and 6) act as unwanted auxiliary inputs. If these pins are not connected to a trim−pot, they should be shorted together. If they are connected to a trim−pot, a 0.01 μF capacitor (C1) between Pins 5 and 6 will minimize the susceptibility to AC coupling. A smaller capacitor is used if Pin 5 is used for positive feedback as in Figure 16. For the fastest response time, tie both balance pins to V_{CC}.

Certain sources will produce a cleaner comparator output waveform if a 100 pF to 1000 pF capacitor (C2) is connected directly across the input pins. When the signal source is applied through a resistive network, R1, it is usually advantageous to choose R2 of the same value, both for DC and for dynamic (AC) considerations. Carbon, tin−oxide, and metal−film resistors have all been used with good results in comparator input circuitry, but inductive wirewound resistors should be avoided.

When comparator circuits use input resistors (e.g., summing resistors), their value and placement are particularly important. In all cases the body of the resistor should be close to the device or socket. In other words, there should be a very short lead length or printed−circuit foil run between comparator and resistor to radiate or pick up signals. The same applies to capacitors, pots, etc. For example, if R1 = 10 kΩ, as little as 5 inches of lead between the resistors and the input pins can result in oscillations that are very hard to dampen. Twisting these input leads tightly is the best alternative to placing resistors close to the comparator.

Since feedback to almost any pin of a comparator can result in oscillation, the printed−circuit layout should be engineered thoughtfully. Preferably there should be a groundplane under the LM211 circuitry (e.g., one side of a double layer printed circuit board). Ground, positive supply or negative supply foil should extend between the output and the inputs to act as a guard. The foil connections for the inputs should be as small and compact as possible, and should be essentially surrounded by ground foil on all sides to guard against capacitive coupling from any fast high−level signals (such as the output). If Pins 5 and 6 are not used, they should be shorted together. If they are connected to a trim−pot, the trim−pot should be located no more than a few inches away from the LM211, and a 0.01 μF capacitor should be installed across Pins 5 and 6. If this capacitor cannot be used, a shielding printed−circuit foil may be advisable between Pins 6 and 7. The power supply bypass capacitors should be located within a couple inches of the LM211.

A standard procedure is to add hysteresis to a comparator to prevent oscillation, and to avoid excessive noise on the output. In the circuit of Figure 17, the feedback resistor of 510 kΩ from the output to the positive input will cause about 3.0 mV of hysteresis. However, if R2 is larger than 100 Ω, such as 50 kΩ, it would not be practical to simply increase the value of the positive feedback resistor proportionally above 510 kΩ to maintain the same amount of hysteresis.

When both inputs of the LM211 are connected to active signals, or if a high−impedance signal is driving the positive input of the LM211 so that positive feedback would be disruptive, the circuit of Figure 16 is ideal. The positive feedback is applied to Pin 5 (one of the offset adjustment pins). This will be sufficient to cause 1.0 mV to 2.0 mV hysteresis and sharp transitions with input triangle waves from a few Hz to hundreds of kHz. The positive−feedback signal across the 82 Ω resistor swings 240 mV below the positive supply. This signal is centered around the nominal voltage at Pin 5, so this feedback does not add to the offset voltage of the comparator. As much as 8.0 mV of offset voltage can be trimmed out, using the 5.0 kΩ pot and 3.0 kΩ resistor as shown.

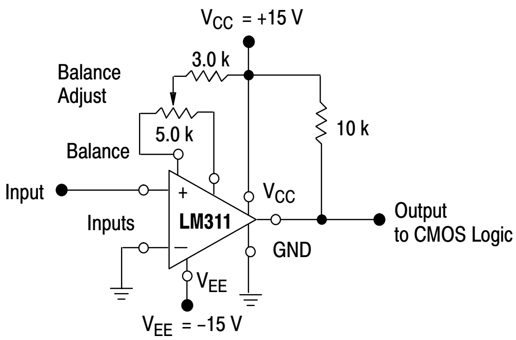


Figure 18. Zero−Crossing Detector Driving CMOS Logic

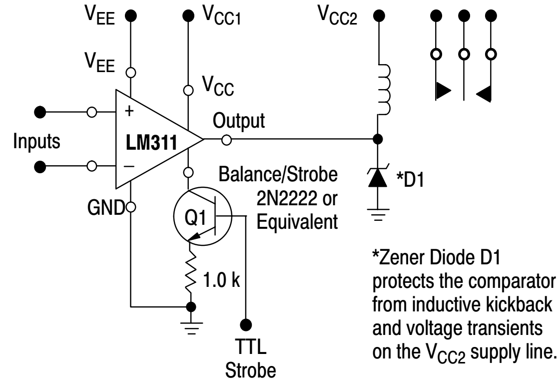


Figure 19. Relay Driver with Strobe Capability

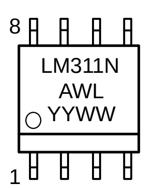
ORDERING INFORMATION

Device	Package	Shipping†
LM211D	SOIC−8	98 Units / Rail
LM211DR2	SOIC−8	
LM211DR2G	SOIC−8 (Pb−Free)	
LM311D	SOIC−8	2500 Units / Reel
LM311DG	SOIC−8 (Pb−Free)	98 Units / Rail
LM311DR2	SOIC−8	2500 Units / Reel
LM311DR2G	SOIC−8 (Pb−Free)	
LM311N	PDIP−8	50 Units / Rail
LM311NG	PDIP−8 (Pb−Free)	

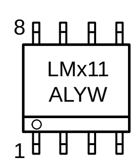
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

MARKING DIAGRAMS

PDIP−8
N SUFFIX
CASE 626



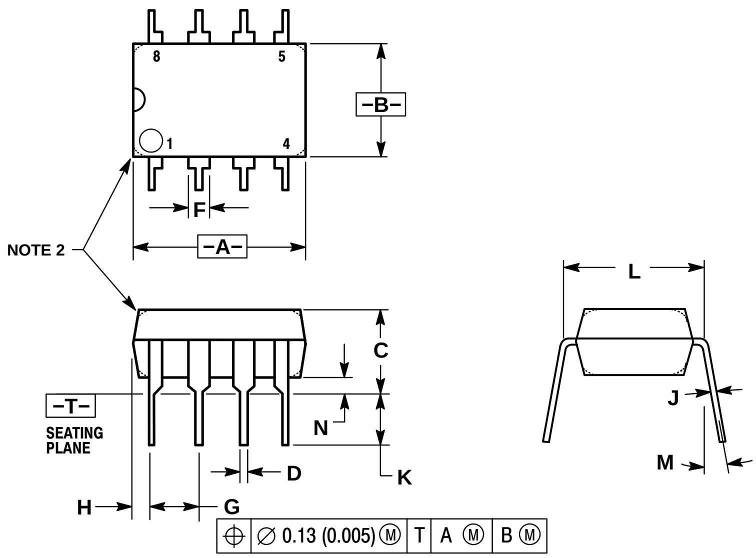
SOIC−8
D SUFFIX
CASE 751



x = 2 or 3
A = Assembly Location
WL, L = Wafer Lot
YY, Y = Year
WW, W = Work Week

PACKAGE DIMENSIONS

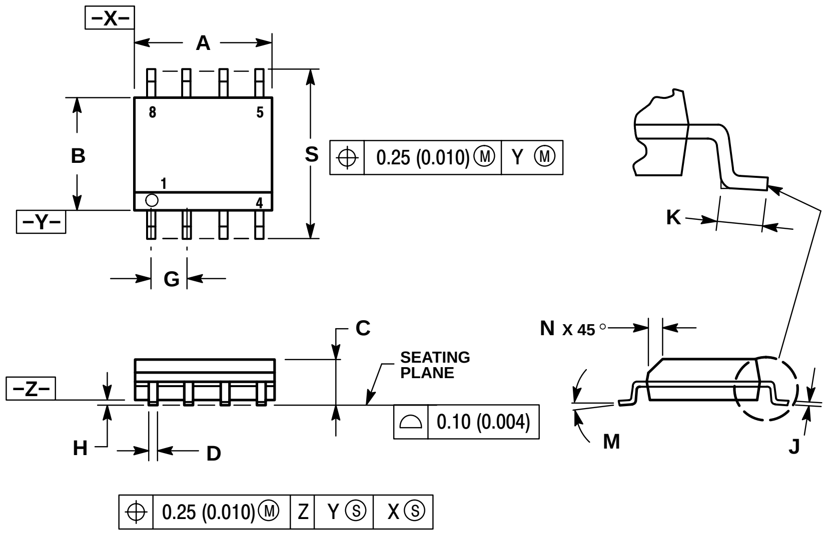
PDIP−8
N SUFFIX
CASE 626−05
ISSUE L



NOTES:
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	---	10°	---	10°
N	0.76	1.01	0.030	0.040

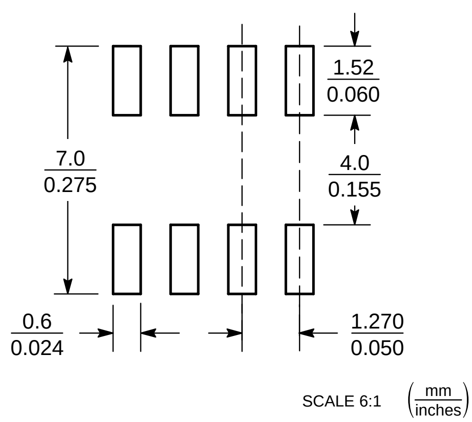
SOIC−8
D SUFFIX
CASE 751−07
ISSUE AC



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. 751−01 THRU 751−06 ARE OBSOLETE. NEW STANDARD IS 751−07.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	4.80	5.00	0.189	0.197
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.053	0.069
D	0.33	0.51	0.013	0.020
G	1.27 BSC		0.050 BSC	
H	0.10	0.25	0.004	0.010
J	0.19	0.25	0.007	0.010
K	0.40	1.27	0.016	0.050
M	0 °	8 °	0 °	8 °
N	0.25	0.50	0.010	0.020
S	5.80	6.20	0.228	0.244

SOLDERING FOOTPRINT*



*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

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Japan: ON Semiconductor, Japan Customer Focus Center
2−9−1 Kamimeguro, Meguro−ku, Tokyo, Japan 153−0051
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Order Literature: http://www.onsemi.com/litorder

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MC78XX/LM78XX/MC78XXA

3-Terminal 1A Positive Voltage Regulator

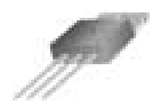
Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The MC78XX/LM78XX/MC78XXA series of three terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

TO-220



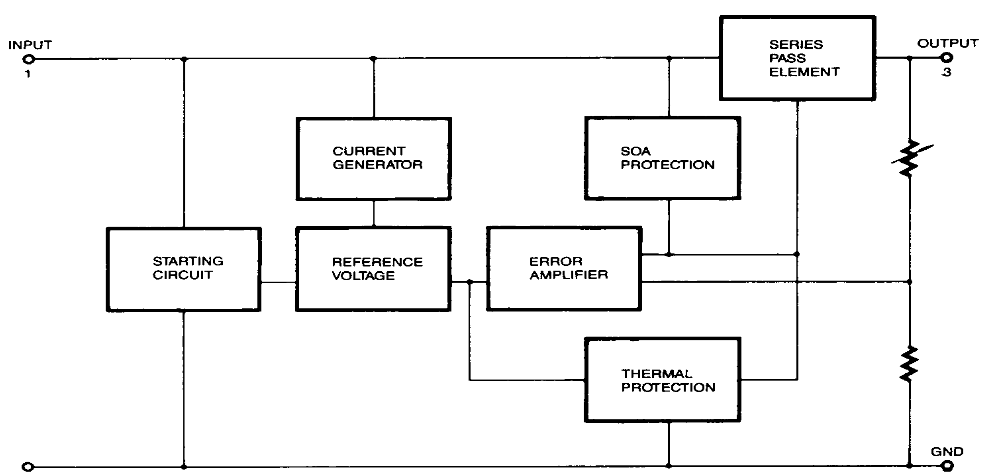
1

D-PAK

1

1. Input 2. GND 3. Output

Internal Block Digram



Rev. 1.0.1

Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	$^oC/W$
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	$^oC/W$
Operating Temperature Range	T_{OPR}	0 ~ +125	^oC
Storage Temperature Range	T_{STG}	-65 ~ +150	^oC

Electrical Characteristics (MC7805/LM7805)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I = 10V, C_I= 0.33μF, C_O= 0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7805/LM7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 ^oC		4.8	5.0	5.2	V
		5.0mA ≤ Io ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 ^oC	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 ^oC	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 ^oC		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/ ^oC
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 ^oC		-	42	-	μV/Vo
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 ^oC		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 ^oC		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 ^oC		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7806)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =11V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7806 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		5.75	6.0	6.25	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 8.0V to 21V		5.7	6.0	6.3	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 8V to 25V	-	5	120	mV
			V_I = 9V to 13V	-	1.5	60	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O =5mA to 1.5A	-	9	120	mV
			I_O =250mA to750A	-	3	60	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8V to 25V		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	45	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 9V to 19V		59	75	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7808)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =14V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7808 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		7.7	8.0	8.3	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 10.5V to 23V		7.6	8.0	8.4	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 10.5V to 25V	-	5.0	160	mV
			V_I = 11.5V to 17V	-	2.0	80	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5.0mA to 1.5A	-	10	160	mV
			I_O= 250mA to 750mA	-	5.0	80	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.05	0.5	mA
		V_I = 10.5A to 25V		-	0.5	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	52	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, V_I= 11.5V to 21.5V		56	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7809)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =15V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7809			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25°C		8.65	9	9.35	V
		5.0mA≤ I_O ≤1.0A, P_O ≤15W V_I= 11.5V to 24V		8.6	9	9.4	
Line Regulation (Note1)	Regline	T_J=+25°C	V_I = 11.5V to 25V	-	6	180	mV
			V_I = 12V to 17V	-	2	90	
Load Regulation (Note1)	Regload	T_J=+25°C	I_O = 5mA to 1.5A	-	12	180	mV
			I_O = 250mA to 750mA	-	4	90	
Quiescent Current	I_Q	T_J=+25°C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	**mA**
		V_I = 11.5V to 26V		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	58	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 13V to 23V		56	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25°C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25°C		-	250	-	mA
Peak Current	I_{PK}	T_J= +25°C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7810)

(Refer to test circuit ,0°C< T_J < 125°C, I_O = 500mA, V_I =16V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7810 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		9.6	10	10.4	V
		5.0mA ≤ I_O≤1.0A, P_O ≤15W V_I = 12.5V to 25V		9.5	10	10.5	
Line Regulation (Note1)	Regline	T_J =+25°C	V_I = 12.5V to 25V	-	10	200	mV
			V_I = 13V to 25V	-	3	100	
Load Regulation (Note1)	Regload	T_J =+25°C	I_O = 5mA to 1.5A	-	12	200	mV
			I_O = 250mA to 750mA	-	4	400	
Quiescent Current	I_Q	T_J =+25°C		-	5.1	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 12.5V to 29V		-	-	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	58	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 13V to 23V		56	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7812)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =19V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7812 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		11.5	12	12.5	V
		5.0mA ≤ I_O≤1.0A, P_O≤15W V_I = 14.5V to 27V		11.4	12	12.6	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 14.5V to 30V	-	10	240	mV
			V_I = 16V to 22V	-	3.0	120	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	11	240	mV
			I_O = 250mA to 750mA	-	5.0	120	
Quiescent Current	I_Q	T_J =+25 °C		-	5.1	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.1	0.5	mA
		V_I = 14.5V to 30V		-	0.5	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	76	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 15V to 25V		55	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	18	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J = +25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7815)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =23V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7815			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		14.4	15	15.6	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 17.5V to 30V		14.25	15	15.75	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 17.5V to 30V	-	11	300	mV
			V_I = 20V to 26V	-	3	150	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	12	300	mV
			I_O = 250mA to 750mA	-	4	150	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 17.5V to 30V		-	-	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	90	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 18.5V to 28.5V		54	70	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7818)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =27V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7818 Min.	MC7818 Typ.	MC7818 Max.	Unit
Output Voltage	V_O	T_J =+25 °C		17.3	18	18.7	V
		5.0mA ≤ I_O ≤1.0A, P_O ≤15W V_I = 21V to 33V		17.1	18	18.9	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 21V to 33V	-	15	360	mV
			V_I = 24V to 30V	-	5	180	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	15	360	mV
			I_O = 250mA to 750mA	-	5.0	180	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 21V to 33V		-	-	1	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	110	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 22V to 32V		53	69	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	22	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7824)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =33V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7824 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		23	24	25	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 27V to 38V		22.8	24	25.25	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 27V to 38V	-	17	480	mV
			V_I = 30V to 36V	-	6	240	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	15	480	mV
			I_O = 250mA to 750mA	-	5.0	240	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.1	0.5	mA
		V_I = 27V to 38V		-	0.5	1	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1.5	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	60	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 28V to 38V		50	67	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	28	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7805A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 10V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		4.9	5	5.1	V
		I_O = 5mA to 1A, $P_O \leq$ 15W V_I = 7.5V to 20V		4.8	5	5.2	
Line Regulation (Note1)	Regline	V_I = 7.5V to 25V I_O = 500mA		-	5	50	mV
		V_I = 8V to 12V		-	3	50	
		T_J =+25 °C	V_I= 7.3V to 20V	-	5	50	
			V_I= 8V to 12V	-	1.5	25	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	9	100	mV
		I_O = 5mA to 1A		-	9	100	
		I_O = 250mA to 750mA		-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8 V to 25V, I_O = 500mA		-	-	0.8	
		V_I = 7.5V to 20V, T_J =+25 °C		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	Io = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 8V to 18V		-	68	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J= +25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7806A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I =11V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		5.58	6	6.12	V
		I_O = 5mA to 1A, $P_O \le$ 15W V_I = 8.6V to 21V		5.76	6	6.24	
Line Regulation (Note1)	Regline	V_I= 8.6V to 25V I_O = 500mA		-	5	60	mV
		V_I= 9V to 13V		-	3	60	
		T_J =+25 °C	V_I= 8.3V to 21V	-	5	60	
			V_I= 9V to 13V	-	1.5	30	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	9	100	mV
		I_O = 5mA to 1A		-	4	100	
		I_O = 250mA to 750mA		-	5.0	50	
Quiescent Current	I_Q	T_J =+25 °C		-	4.3	6	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 9V to 25V, I_O = 500mA		-	-	0.8	
		V_I= 8.5V to 21V, T_J =+25 °C		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 9V to 19V		-	65	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7808A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 14V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		7.84	8	8.16	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 10.6V to 23V		7.7	8	8.3	
Line Regulation (Note1)	Regline	V_I= 10.6V to 25V I_O = 500mA		-	6	80	mV
		V_I= 11V to 17V		-	3	80	
		T_J =+25 °C	V_I= 10.4V to 23V	-	6	80	
			V_I= 11V to 17V	-	2	40	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 11V to 25V, I_O = 500mA		-	-	0.8	
		V_I= 10.6V to 23V, T_J =+25 °C		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 11.5V to 21.5V		-	62	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	18	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7809A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 15V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25°C		8.82	9.0	9.18	V
		I_O = 5mA to 1A, P_O≤15W V_I = 11.2V to 24V		8.65	9.0	9.35	
Line Regulation (Note1)	Regline	V_I= 11.7V to 25V I_O = 500mA		-	6	90	mV
		V_I= 12.5V to 19V		-	4	45	
		T_J =+25°C	V_I= 11.5V to 24V	-	6	90	
			V_I= 12.5V to 19V	-	2	45	
Load Regulation (Note1)	Regload	T_J =+25°C I_O = 5mA to 1.0A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 11.7V to 25V, T_J=+25 °C		-	-	0.8	mA
		V_I = 12V to 25V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 12V to 22V		-	62	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25°C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant, junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7810A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 16V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25°C		9.8	10	10.2	V
		I_O = 5mA to 1A, $P_O \le$ 15W V_I =12.8V to 25V		9.6	10	10.4	
Line Regulation (Note1)	Regline	V_I= 12.8V to 26V I_O = 500mA		-	8	100	mV
		V_I= 13V to 20V		-	4	50	
		T_J =+25 °C	V_I= 12.5V to 25V	-	8	100	
			V_I= 13V to 20V	-	3	50	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 13V to 26V, T_J=+25 °C		-	-	0.5	mA
		V_I = 12.8V to 25V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 14V to 24V		-	62	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25°C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7812A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 19V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		11.75	12	12.25	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 14.8V to 27V		11.5	12	12.5	
Line Regulation (Note1)	Regline	V_I= 14.8V to 30V I_O = 500mA		-	10	120	mV
		V_I= 16V to 22V		-	4	120	
		T_J =+25 °C	V_I= 14.5V to 27V	-	10	120	
			V_I= 16V to 22V	-	3	60	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25°C		-	5.1	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 15V to 30V, T_J=+25 °C		-		0.8	mA
		V_I = 14V to 27V, I_O = 500mA		-		0.8	
		I_O = 5mA to 1.0A		-		0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25°C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 14V to 24V		-	60	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25°C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	18	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7815A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I =23V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		14.7	15	15.3	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 17.7V to 30V		14.4	15	15.6	
Line Regulation (Note1)	Regline	V_I= 17.9V to 30V I_O = 500mA		-	10	150	mV
		V_I= 20V to 26V		-	5	150	
		T_J =+25°C	V_I= 17.5V to 30V	-	11	150	
			V_I= 20V to 26V	-	3	75	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 17.5V to 30V, T_J =+25 °C		-	-	0.8	mA
		V_I = 17.5V to 30V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	ΔV/ΔT	I_O = 5mA		-	-1.0	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 18.5V to 28.5V		-	58	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25°C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7818A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 27V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		17.64	18	18.36	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 21V to 33V		17.3	18	18.7	
Line Regulation (Note1)	Regline	V_I= 21V to 33V I_O = 500mA		-	15	180	mV
		V_I= 21V to 33V		-	5	180	
		T_J =+25 °C	V_I= 20.6V to 33V	-	15	180	
			V_I= 24V to 30V	-	5	90	
Load Regulation (Note1)	Regload	T_J =+25°C I_O = 5mA to 1.5A		-	15	100	mV
		I_O = 5mA to 1.0A		-	15	100	
		I_O = 250mA to 750mA		-	7	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 21V to 33V, T_J=+25 °C		-	-	0.8	mA
		V_I = 21V to 33V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25°C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 22V to 32V		-	57	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25°C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25°C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7824A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 33V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		23.5	24	24.5	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 27.3V to 38V		23	24	25	
Line Regulation (Note1)	Regline	V_I= 27V to 38V I_O = 500mA		-	18	240	mV
		V_I= 21V to 33V		-	6	240	
		T_J =+25 °C	V_I= 26.7V to 38V	-	18	240	
			V_I= 30V to 36V	-	6	120	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	15	100	mV
		I_O = 5mA to 1.0A		-	15	100	
		I_O = 250mA to 750mA		-	7	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 27.3V to 38V, T_J =+25 °C		-	-	0.8	mA
		V_I = 27.3V to 38V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.5	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A = 25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 28V to 38V		-	54	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	20	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in VO due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Typical Perfomance Characteristics

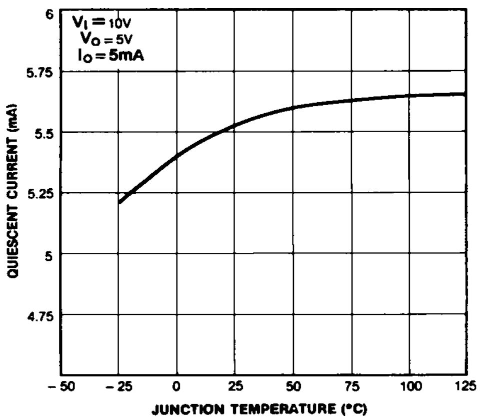


Figure 1. Quiescent Current

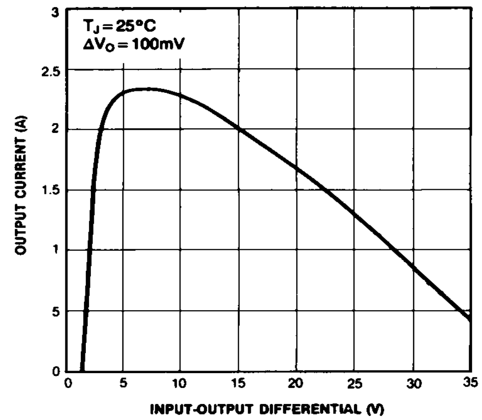


Figure 2. Peak Output Current

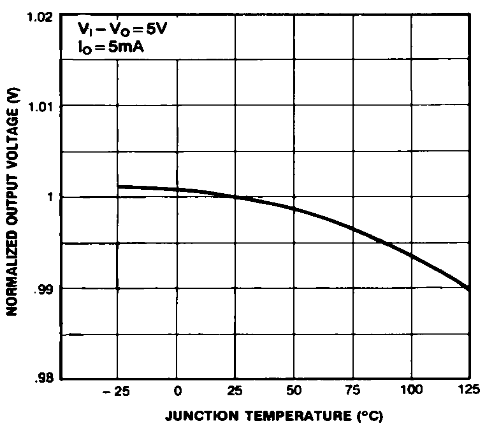


Figure 3. Output Voltage

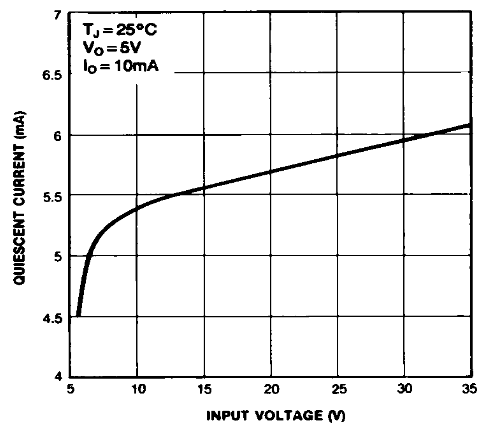


Figure 4. Quiescent Current

Typical Applications

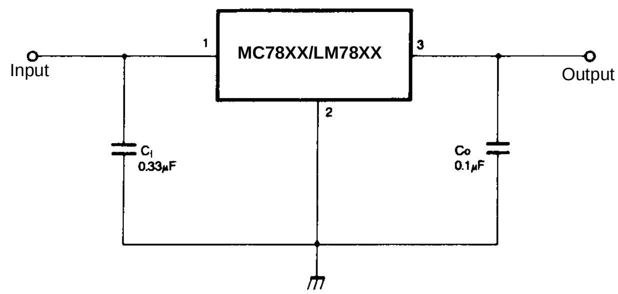


Figure 5. DC Parameters

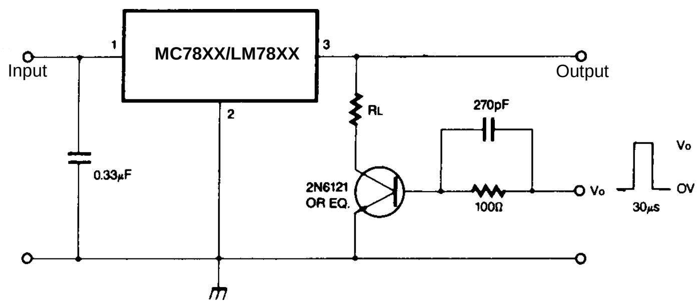


Figure 6. Load Regulation

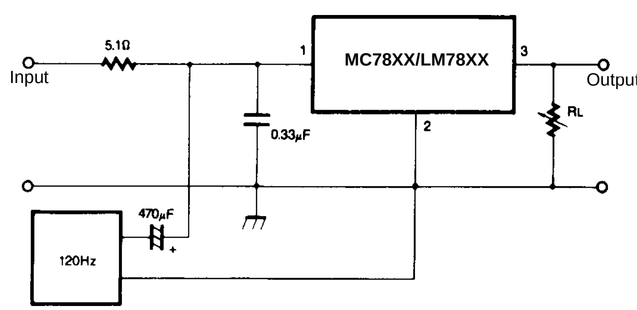


Figure 7. Ripple Rejection

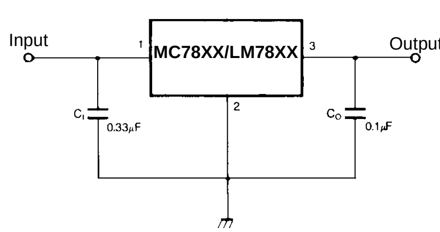
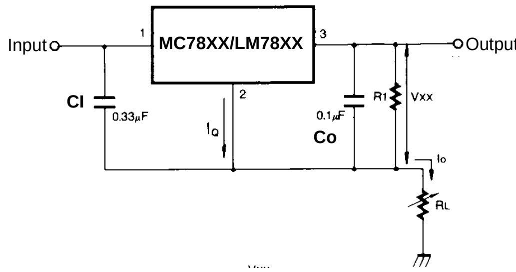


Figure 8. Fixed Output Regulator



$$I_O = \frac{V_{XX}}{R_1} + I_Q$$

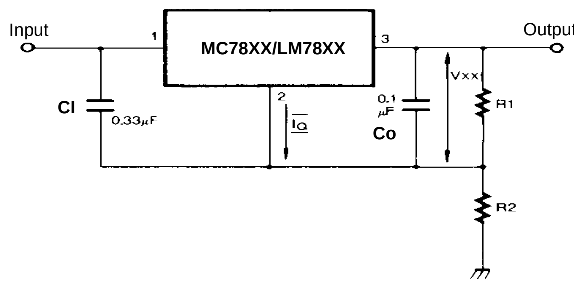
Figure 9. Constant Current Regulator

Notes:

(1) To specify an output voltage. substitute voltage value for "XX." A common ground is required between the input and the Output voltage. The input voltage must remain typically 2.0V above the output voltage even during the low point on the input ripple voltage.

(2) C_I is required if regulator is located an appreciable distance from power Supply filter.

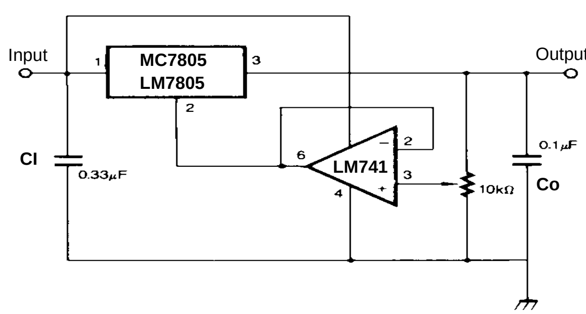
(3) C_O improves stability and transient response.



$$I_{RI} \geq 5I_Q$$

$$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$$

Figure 10. Circuit for Increasing Output Voltage



$$I_{RI} \geq 5\ I_Q$$

$$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$$

Figure 11. Adjustable Output Regulator (7 to 30V)

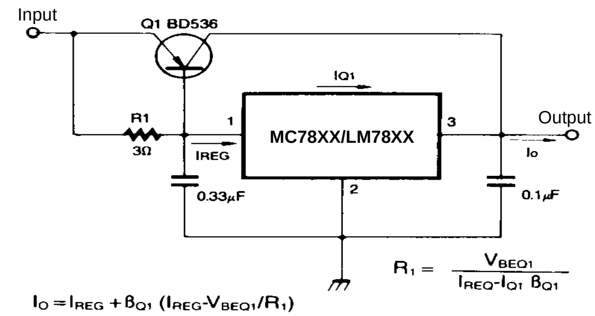


Figure 12. High Current Voltage Regulator

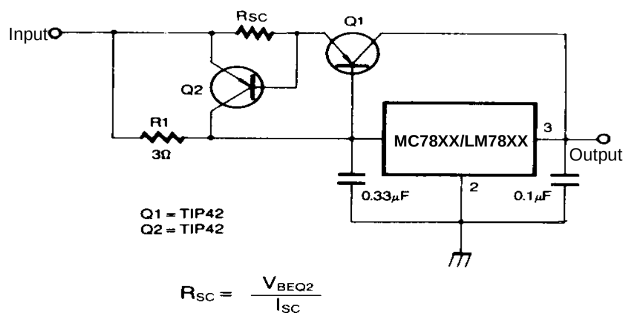


Figure 13. High Output Current with Short Circuit Protection

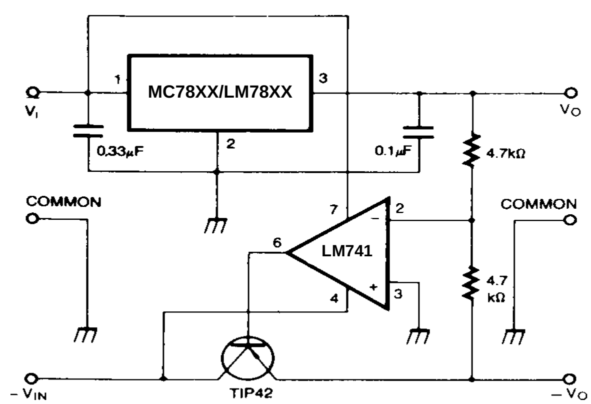


Figure 14. Tracking Voltage Regulator

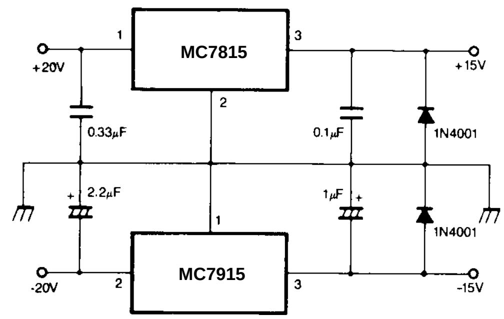


Figure 15. Split Power Supply (±15V-1A)

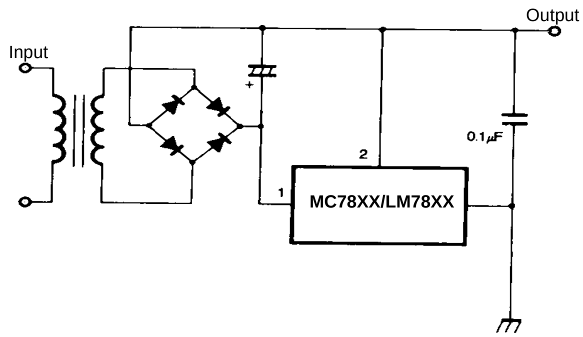


Figure 16. Negative Output Voltage Circuit

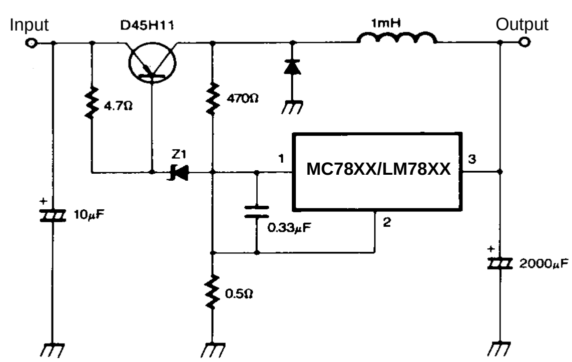
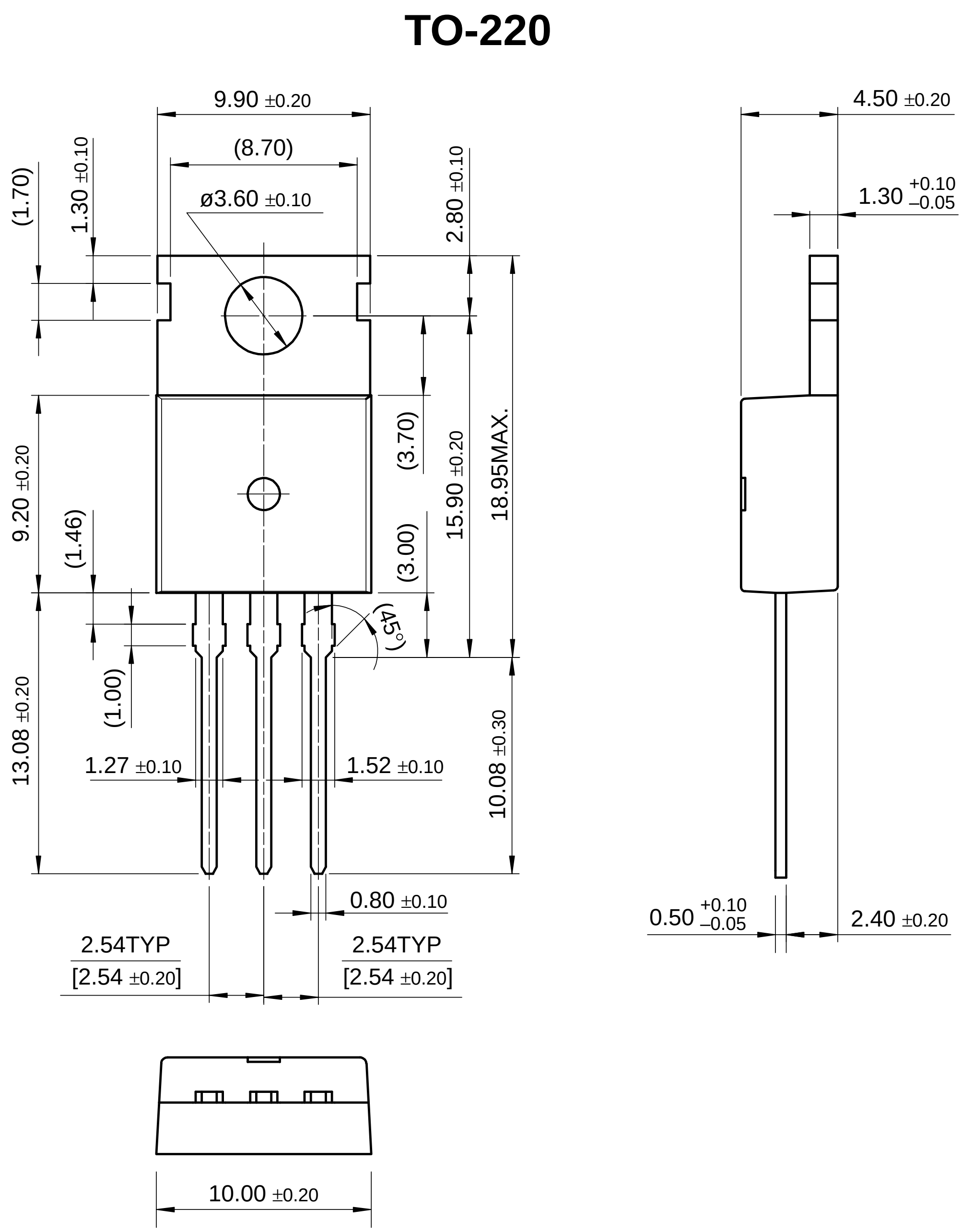


Figure 17. Switching Regulator

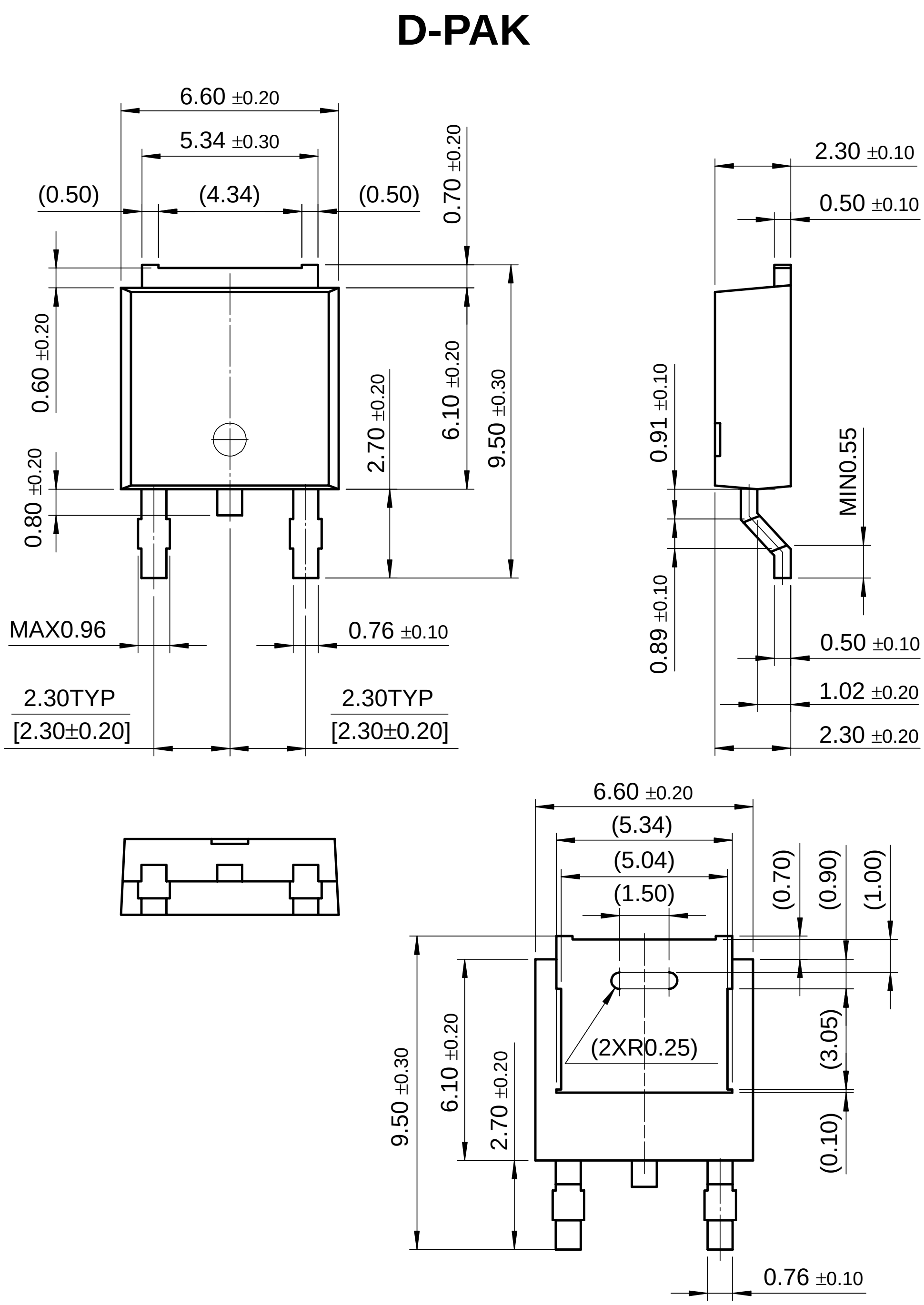
Mechanical Dimensions

Package



Mechancal Dimensions (Continued)

Package



Ordering Information

Product Number	Output Voltage Tolerance	Package	Operating Temperature
LM7805CT	±4%	TO-220	0 ~ + 125°C

Product Number	Output Voltage Tolerance	Package	Operating Temperature
MC7805CT	±4%	TO-220	0 ~ + 125°C
MC7806CT			
MC7808CT			
MC7809CT			
MC7810CT			
MC7812CT			
MC7815CT			
MC7818CT			
MC7824CT			
MC7805CDT		D-PAK	
MC7806CDT			
MC7808CDT			
MC7809CDT			
MC7810CDT			
MC7812CDT			
MC7805ACT	±2%	TO-220	
MC7806ACT			
MC7808ACT			
MC7809ACT			
MC7810ACT			
MC7812ACT			
MC7815ACT			
MC7818ACT			
MC7824ACT			

7/2/01 0.0m 001
Stock#DSxxxxxxxx

September 2001

National Semiconductor

LM79XX Series
3-Terminal Negative Regulators

General Description

The LM79XX series of 3-terminal regulators is available with fixed output voltages of −5V, −12V, and −15V. These devices need only one external component — a compensation capacitor at the output. The LM79XX series is packaged in the TO-220 power package and is capable of supplying 1.5A of output current.

These regulators employ internal current limiting safe area protection and thermal shutdown for protection against virtually all overload conditions.

Low ground pin current of the LM79XX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current drain of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

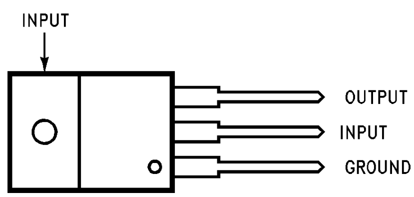
For applications requiring other voltages, see LM137 datasheet.

Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 1.5A output current
- 4% tolerance on preset output voltage

Connection Diagrams

TO-220 Package

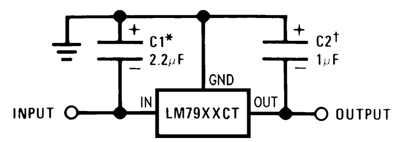


DS007340-14

Front View
Order Number LM7905CT, LM7912CT or LM7915CT
See NS Package Number TO3B

Typical Applications

Fixed Regulator



DS007340-3

*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25µF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25µF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100µF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

 DS007340

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_o = −5V)	−25V
(V_o = −12V and −15V)	−35V
Input-Output Differential	
(V_o = −5V)	25V
(V_o = −12V and −15V)	30V
Power Dissipation (Note 2)	Internally Limited
Operating Junction Temperature Range	0˚C to +125˚C
Storage Temperature Range	−65˚C to +150˚C
Lead Temperature (Soldering, 10 sec.)	230˚C

Electrical Characteristics

Conditions unless otherwise noted: I_{OUT} = 500mA, C_{IN} = 2.2µF, C_{OUT} = 1µF, 0˚C ≤ T_J ≤ +125˚C, Power Dissipation ≤ 1.5W.

Part Number			LM7905C			Units
Output Voltage			−5V			
Input Voltage (unless otherwise specified)			−10V			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	T_J = 25˚C	−4.8	−5.0	−5.2	V
		5mA ≤ I_{OUT} ≤ 1A,	−4.75		−5.25	V
		P ≤ 15W		(−20 ≤ V_{IN} ≤ −7)		V
ΔV_O	Line Regulation	T_J = 25˚C, (Note 3)		8	50	mV
				(−25 ≤ V_{IN} ≤ −7)		V
				2	15	mV
				(−12 ≤ V_{IN} ≤ −8)		V
ΔV_O	Load Regulation	T_J = 25˚C, (Note 3)				
		5mA ≤ I_{OUT} ≤ 1.5A		15	100	mV
		250mA ≤ I_{OUT} ≤ 750mA		5	50	mV
I_Q	Quiescent Current	T_J = 25˚C		1	2	mA
ΔI_Q	Quiescent Current Change	With Line			0.5	mA
				(−25 ≤ V_{IN} ≤ −7)		V
		With Load, 5mA ≤ I_{OUT} ≤ 1A			0.5	mA
V_n	Output Noise Voltage	T_A = 25˚C, 10Hz ≤ f ≤ 100Hz		125		µV
	Ripple Rejection	f = 120Hz	54	66		dB
				(−18 ≤ V_{IN} ≤ −8)		V
	Dropout Voltage	T_J = 25˚C, I_{OUT} = 1A		1.1		V
I_{OMAX}	Peak Output Current	T_J = 25˚C		2.2		A
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5mA, 0 C ≤ T_J ≤ 100˚C		0.4		mV/˚C

Electrical Characteristics

Conditions unless otherwise noted: I_{OUT} = 500mA, C_{IN} = 2.2µF, C_{OUT} = 1µF, 0˚C ≤ T_J ≤ +125˚C, Power Dissipation ≤ 1.5W.

Part Number			LM7912C			LM7915C			Units
Output Voltage			−12V			−15V			
Input Voltage (unless otherwise specified)			−19V			−23V			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	T_J = 25˚C	−11.5	−12.0	−12.5	−14.4	−15.0	−15.6	V
		5mA ≤ I_{OUT} ≤ 1A,	−11.4		−12.6	−14.25		−15.75	V
		P ≤ 15W		(−27 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)		V
ΔV_O	Line Regulation	T_J = 25˚C, (Note 3)		5	80		5	100	mV
				(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN}≤ −17.5)		V
				3	30		3	50	mV
				(−22 ≤ V_{IN} ≤ −16)			(−26 ≤ V_{IN} ≤−20)		V
ΔV_O	Load Regulation	T_J = 25˚C, (Note 3)							

Electrical Characteristics (Continued)

Conditions unless otherwise noted: I_{OUT} = 500mA, C_{IN} = 2.2µF, C_{OUT} = 1µF, 0˚C ≤ T_J ≤ +125˚C, Power Dissipation ≤ 1.5W.

Part Number			LM7912C			LM7915C			Units
Output Voltage			−12V			−15V			
Input Voltage (unless otherwise specified)			−19V			−23V			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
		5mA ≤ I_{OUT} ≤ 1.5A		15	200		15	200	mV
		250mA ≤ I_{OUT} ≤ 750mA		5	75		5	75	mV
I_Q	Quiescent Current	T_J = 25˚C		1.5	3		1.5	3	mA
ΔI_Q	Quiescent Current Change	With Line			0.5			0.5	mA
				(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)		V
		With Load, 5mA ≤ I_{OUT} ≤ 1A			0.5			0.5	mA
V_n	Output Noise Voltage	T_A = 25˚C, 10Hz ≤ f ≤ 100Hz		300			375		µV
	Ripple Rejection	f = 120 Hz	54	70		54	70		dB
				(−25 ≤ V_{IN} ≤ −15)			(−30 ≤ V_{IN} ≤ −17.5)		V
	Dropout Voltage	T_J = 25˚C, I_{OUT} = 1A		1.1			1.1		V
I_{OMAX}	Peak Output Current	T_J = 25˚C		2.2			2.2		A
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5mA, 0 C ≤ T_J ≤ 100˚C		−0.8			−1.0		mV/˚C

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee Specific Performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Refer to Typical Performance Characteristics and Design Considerations for details.

Note 3: Regulation is measured at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

Design Considerations

The LM79XX fixed voltage regulator series has thermal overload protection from excessive power dissipation, internal short circuit protection which limits the circuit's maximum current, and output transistor safe-area compensation for reducing the output current as the voltage across the pass transistor is increased.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature (125˚C) in order to meet data sheet specifications. To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

Package	Typ θ_{JC} ˚C/W	Max θ_{JC} ˚C/W	Typ θ_{JA} ˚C/W	Max θ_{JA} ˚C/W
TO-220	3.0	5.0	60	40

$$P_{D\,MAX} = \frac{T_{J\,Max} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or } \frac{T_{J\,Max}\ \ T_A}{\theta_{JA}}$$

$$\theta_{CA} = \theta_{CS} + \theta_{SA} \text{ (without heat sink)}$$

Solving for T_J:

$T_J = T_A + P_D (\theta_{JC} + \theta_{CA})$ or

$= T_A + P_D\theta_{JA}$ (without heat sink)

Where:

T_J = Junction Temperature

T_A = Ambient Temperature

P_D = Power Dissipation

θ_{JA} = Junction-to-Ambient Thermal Resistance

θ_{JC} = Junction-to-Case Thermal Resistance

θ_{CA} = Case-to-Ambient Thermal Resistance

θ_{CS} = Case-to-Heat Sink Thermal Resistance

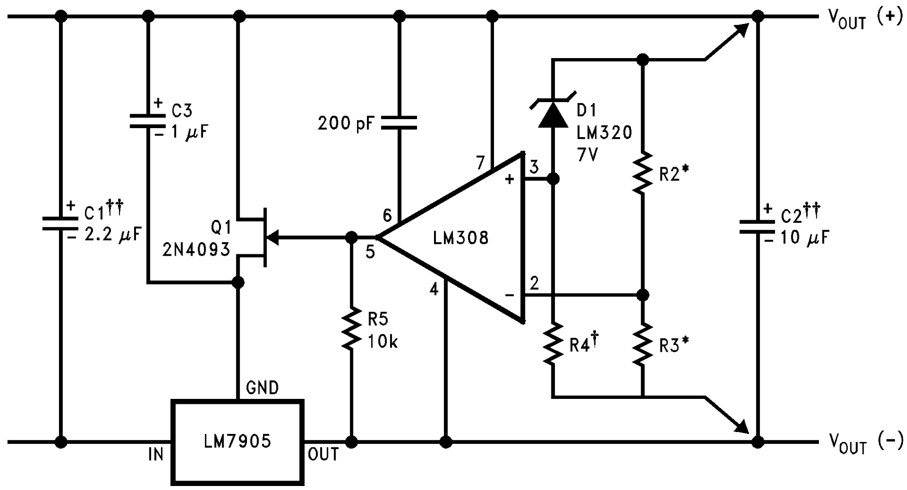
θ_{SA} = Heat Sink-to-Ambient Thermal Resistance

Typical Applications

Bypass capacitors are necessary for stable operation of the LM79XX series of regulators over the input voltage and output current ranges. Output bypass capacitors will improve the transient response by the regulator.

The bypass capacitors, (2.2µF on the input, 1.0µF on the output) should be ceramic or solid tantalum which have good high frequency characteristics. If aluminum electrolytics are used, their values should be 10µF or larger. The bypass capacitors should be mounted with the shortest leads, and if possible, directly across the regulator terminals.

High Stability 1 Amp Regulator



DS007340-5

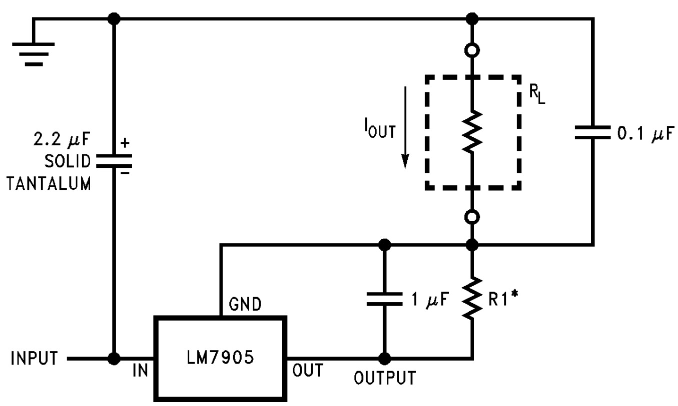
Load and line regulation < 0.01% temperature stability ≤ 0.2%

†Determine Zener current

††Solid tantalum

*Select resistors to set output voltage. 2 ppm/°C tracking suggested

Current Source

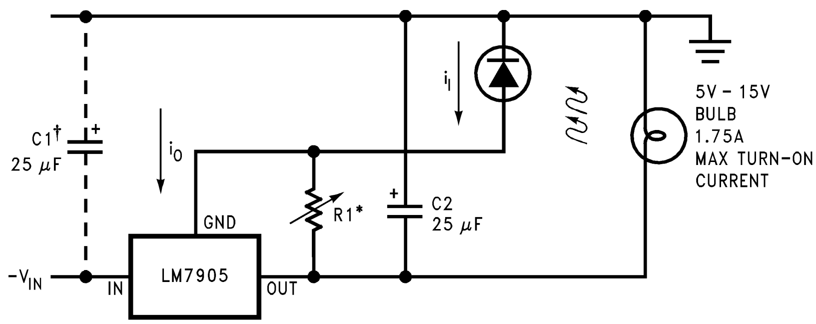


DS007340-7

$$*I_{OUT} = 1\text{ mA} + \frac{5V}{R1}$$

Typical Applications (Continued)

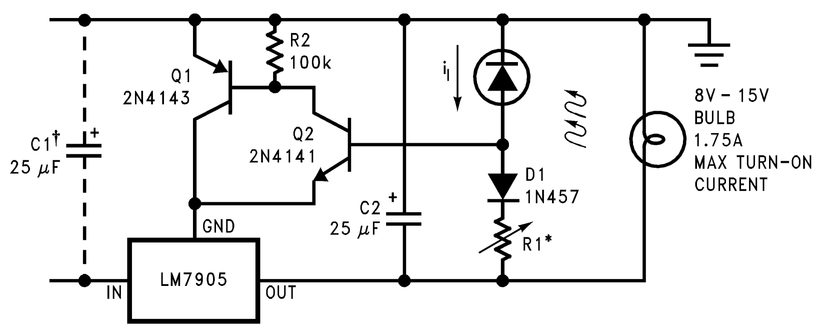
Light Controller Using Silicon Photo Cell



DS007340-8

*Lamp brightness increase until $i_l = i_Q$ (≈ 1 mA) + 5V/R1.
†Necessary only if raw supply filter capacitor is more that 2" from LM7905CT

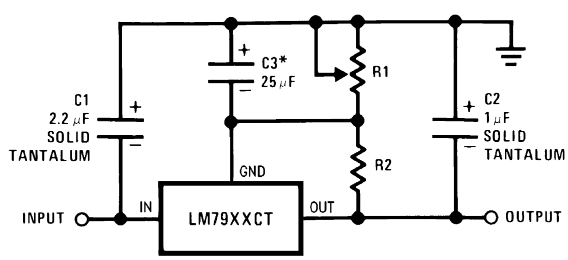
High-Sensitivity Light Controller



DS007340-9

*Lamp brightness increases until i_i = 5V/R1 (I_i can be set as low as 1 µA)
†Necessary only if raw supply filter capacitor is more that 2" from LM7905

Variable Output



DS007340-2

*Improves transient response and ripple rejection. Do not increase beyond 50 µF.

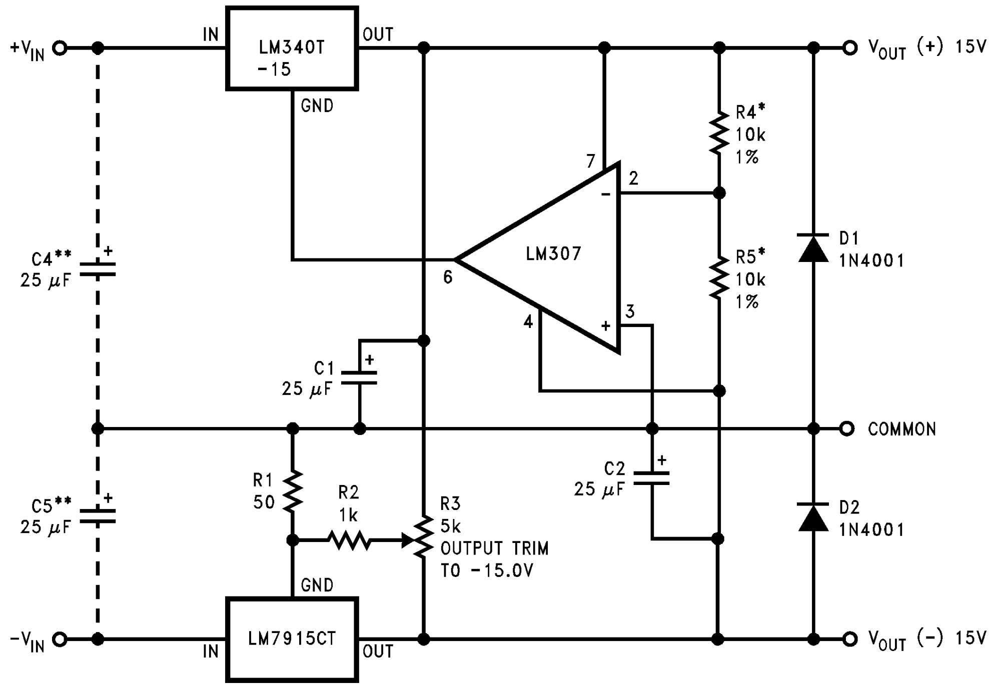
$$V_{OUT} = V_{SET}\left(\frac{R1 + R2}{R2}\right)$$

Select R2 as follows:

LM7905CT	300Ω
LM7912CT	750Ω
LM7915CT	1k

Typical Applications (Continued)

±15V, 1 Amp Tracking Regulators



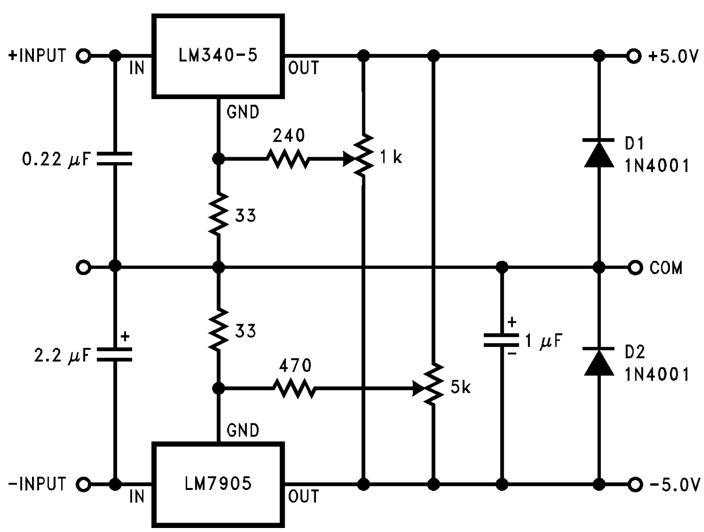
DS007340-1

	(-15)	(+15)
Load Regulation at $\Delta I_L = 1A$	40mV	2mV
Output Ripple, $C_{IN} = 3000\mu F$, $I_L = 1A$	100 µVms	100 µVms
Temperature Stability	50mV	50mV
Output Noise $10Hz \leq f \leq 10kHz$	150 µVms	150 µVms

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs.

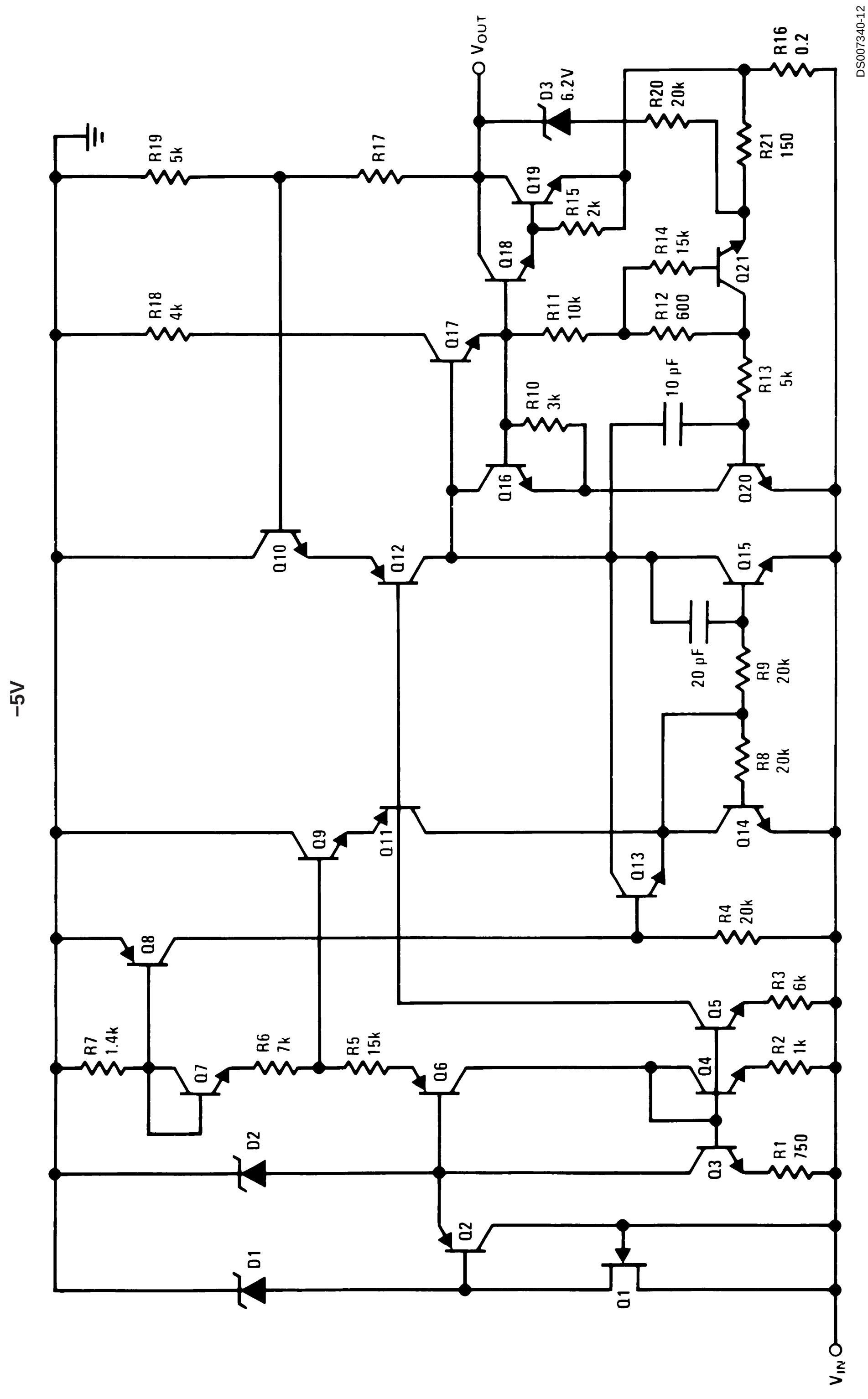
**Necessary only if raw supply filter capacitors are more than 3" from regulators.

Dual Trimmed Supply

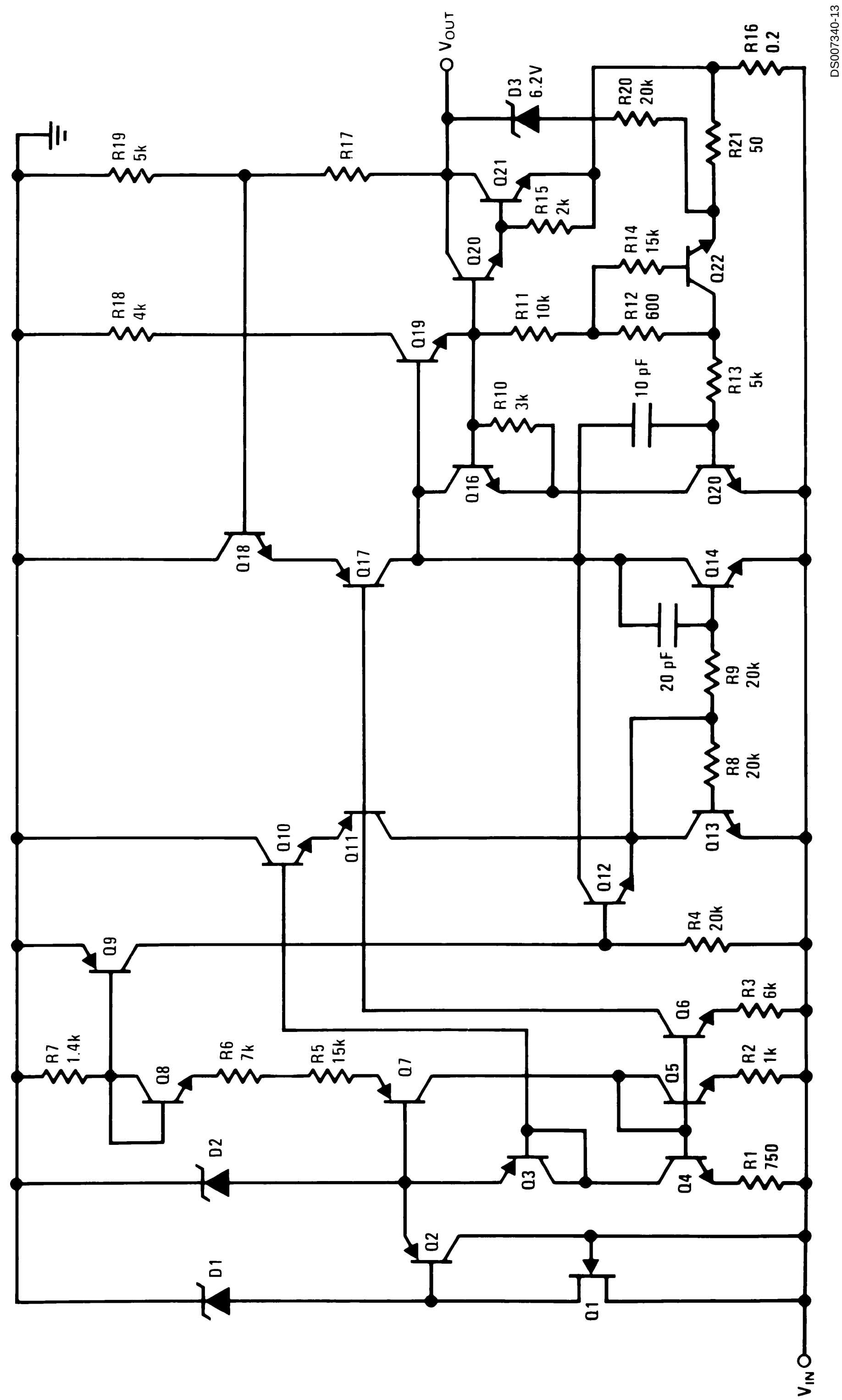


DS007340-4

Schematic Diagrams

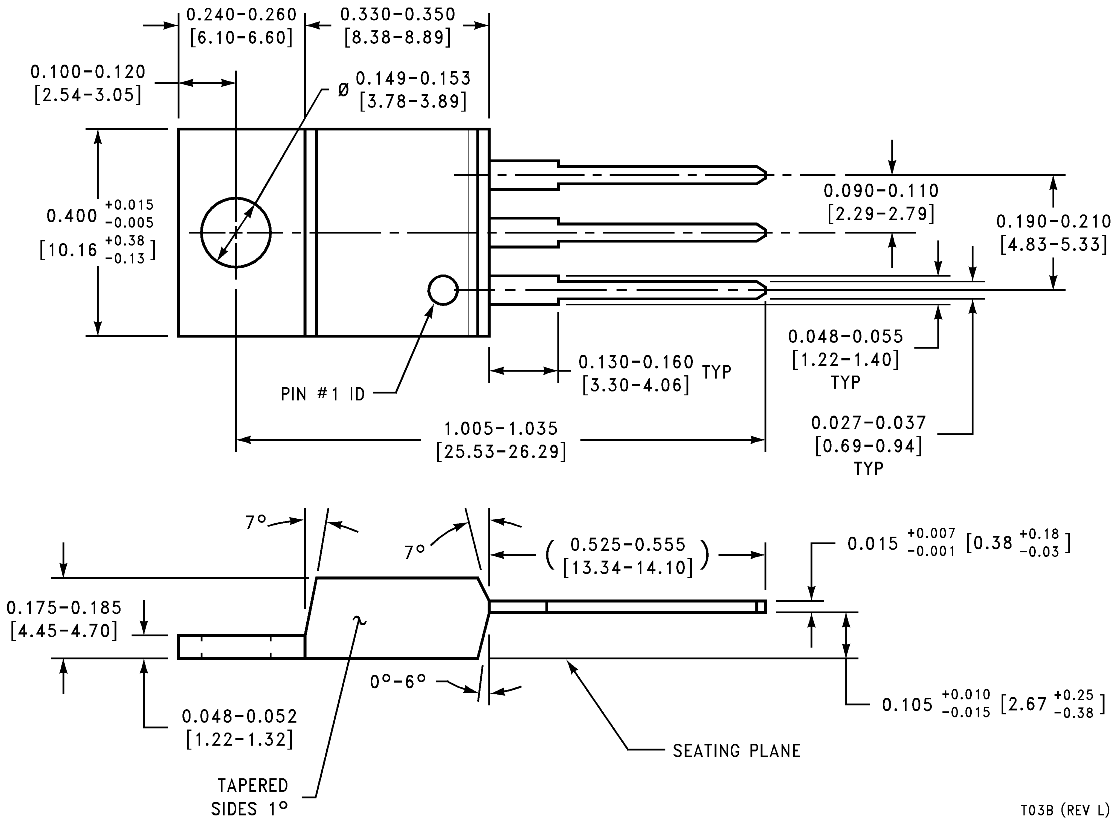


Schematic Diagrams (Continued)



−12V and −15V

Physical Dimensions inches (millimeters) unless otherwise noted



TO-220 Outline Package (T)
Order Number LM7905CT, LM7912CT or LM7915CT
NS Package Number T03B

LIFE SUPPORT POLICY

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National Semiconductor Corporation
Americas
Email: support@nsc.com

www.national.com

National Semiconductor Europe
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507

- **Meet or Exceed TIA/EIA-232-F and ITU Recommendation V.28**
- **Operate With Single 5-V Power Supply**
- **Operate Up to 120 kbit/s**
- **Two Drivers and Two Receivers**
- **±30-V Input Levels**
- **Low Supply Current . . . 8 mA Typical**
- **Designed to be Interchangeable With Maxim MAX232**
- **ESD Protection Exceeds JESD 22**
  – 2000-V Human-Body Model (A114-A)
- **Applications**
  TIA/EIA-232-F
  Battery-Powered Systems
  Terminals
  Modems
  Computers

MAX232 . . . D, DW, N, OR NS PACKAGE
MAX232I . . . D, DW, OR N PACKAGE
(TOP VIEW)

C1+	1	16	V_{CC}
V_{S+}	2	15	GND
C1–	3	14	T1OUT
C2+	4	13	R1IN
C2–	5	12	R1OUT
V_{S-}	6	11	T1IN
T2OUT	7	10	T2IN
R2IN	8	9	R2OUT

description/ordering information

The MAX232 is a dual driver/receiver that includes a capacitive voltage generator to supply EIA-232 voltage levels from a single 5-V supply. Each receiver converts EIA-232 inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V and a typical hysteresis of 0.5 V, and can accept ±30-V inputs. Each driver converts TTL/CMOS input levels into EIA-232 levels. The driver, receiver, and voltage-generator functions are available as cells in the Texas Instruments LinASIC™ library.

ORDERING INFORMATION

T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP (N)	Tube	MAX232N	MAX232N
	SOIC (D)	Tube	MAX232D	MAX232
		Tape and reel	MAX232DR	
	SOIC (DW)	Tube	MAX232DW	MAX232
		Tape and reel	MAX232DWR	
	SOP (NS)	Tape and reel	MAX232NSR	MAX232
–40°C to 85°C	PDIP (N)	Tube	MAX232IN	MAX232IN
	SOIC (D)	Tube	MAX232ID	MAX232I
		Tape and reel	MAX232IDR	
	SOIC (DW)	Tube	MAX232IDW	MAX232I
		Tape and reel	MAX232IDWR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

Function Tables

EACH DRIVER

INPUT TIN	OUTPUT TOUT
L	H
H	L

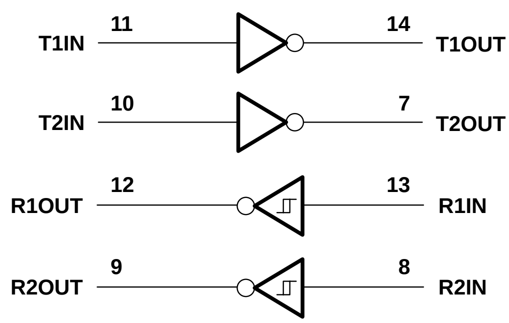
H = high level, L = low level

EACH RECEIVER

INPUT RIN	OUTPUT ROUT
L	H
H	L

H = high level, L = low level

logic diagram (positive logic)



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Input supply voltage range, V_{CC} (see Note 1) .... –0.3 V to 6 V
Positive output supply voltage range, V_{S+} .... V_{CC} – 0.3 V to 15 V
Negative output supply voltage range, V_{S-} .... –0.3 V to –15 V
Input voltage range, V_I: Driver .... –0.3 V to V_{CC} + 0.3 V
Receiver .... ±30 V
Output voltage range, V_O: T1OUT, T2OUT .... V_{S-} – 0.3 V to V_{S+} + 0.3 V
R1OUT, R2OUT .... –0.3 V to V_{CC} + 0.3 V
Short-circuit duration: T1OUT, T2OUT .... Unlimited
Package thermal impedance, θ_{JA} (see Note 2): D package .... 73°C/W
DW package .... 57°C/W
N package .... 67°C/W
NS package .... 64°C/W
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds .... 260°C
Storage temperature range, T_{stg} .... –65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to network ground terminal.
2. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

			MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage		4.5	5	5.5	V
V_{IH}	High-level input voltage (T1IN,T2IN)		2			V
V_{IL}	Low-level input voltage (T1IN, T2IN)				0.8	V
R1IN, R2IN	Receiver input voltage				±30	V
T_A	Operating free-air temperature	MAX232	0		70	°C
		MAX232I	–40		85	

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Note 3 and Figure 4)

PARAMETER		TEST CONDITIONS	MIN	TYP‡	MAX	UNIT
I_{CC}	Supply current	V_{CC} = 5.5 V, All outputs open, T_A = 25°C		8	10	mA

‡ All typical values are at V_{CC} = 5 V and T_A = 25°C.

NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

DRIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

PARAMETER			TEST CONDITIONS	MIN	TYP†	MAX	UNIT
V_{OH}	High-level output voltage	T1OUT, T2OUT	R_L = 3 kΩ to GND	5	7		V
V_{OL}	Low-level output voltage‡	T1OUT, T2OUT	R_L = 3 kΩ to GND		–7	–5	V
r_o	Output resistance	T1OUT, T2OUT	$V_{S+} = V_{S-} = 0$, $V_O = \pm 2$ V	300			Ω
I_{OS}§	Short-circuit output current	T1OUT, T2OUT	V_{CC} = 5.5 V, V_O = 0		±10		mA
I_{IS}	Short-circuit input current	T1IN, T2IN	V_I = 0			200	µA

† All typical values are at V_{CC} = 5 V, T_A = 25°C.
‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.
§ Not more than one output should be shorted at a time.
NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 3)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SR	Driver slew rate	R_L = 3 kΩ to 7 kΩ, See Figure 2			30	V/µs
SR(t)	Driver transition region slew rate	See Figure 3		3		V/µs
	Data rate	One TOUT switching		120		kbit/s

NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

RECEIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

PARAMETER			TEST CONDITIONS	MIN	TYP†	MAX	UNIT
V_{OH}	High-level output voltage	R1OUT, R2OUT	I_{OH} = –1 mA	3.5			V
V_{OL}	Low-level output voltage‡	R1OUT, R2OUT	I_{OL} = 3.2 mA			0.4	V
V_{IT+}	Receiver positive-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C		1.7	2.4	V
V_{IT-}	Receiver negative-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C	0.8	1.2		V
V_{hys}	Input hysteresis voltage	R1IN, R2IN	V_{CC} = 5 V	0.2	0.5	1	V
r_i	Receiver input resistance	R1IN, R2IN	V_{CC} = 5, T_A = 25°C	3	5	7	kΩ

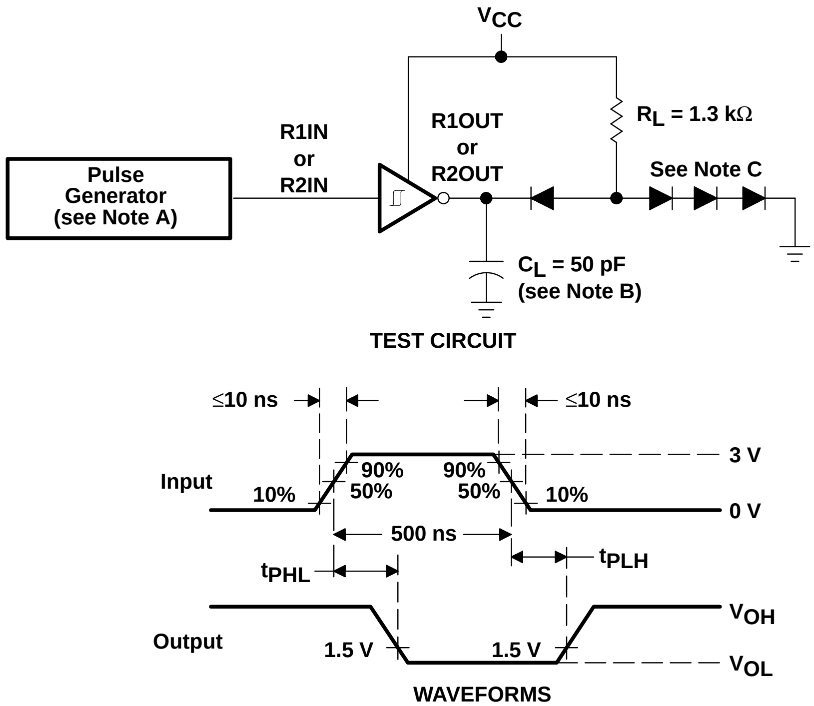
† All typical values are at V_{CC} = 5 V, T_A = 25°C.
‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.
NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 3 and Figure 1)

PARAMETER		TYP	UNIT
$t_{PLH(R)}$	Receiver propagation delay time, low- to high-level output	500	ns
$t_{PHL(R)}$	Receiver propagation delay time, high- to low-level output	500	ns

NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

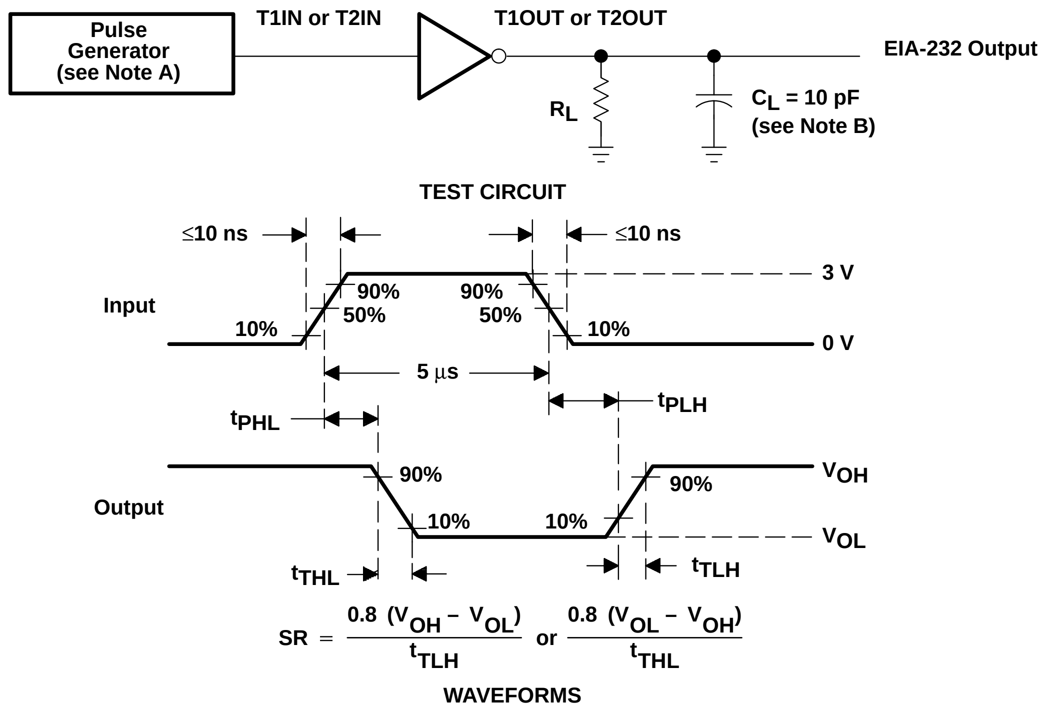
PARAMETER MEASUREMENT INFORMATION



NOTES: A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.
B. C_L includes probe and jig capacitance.
C. All diodes are 1N3064 or equivalent.

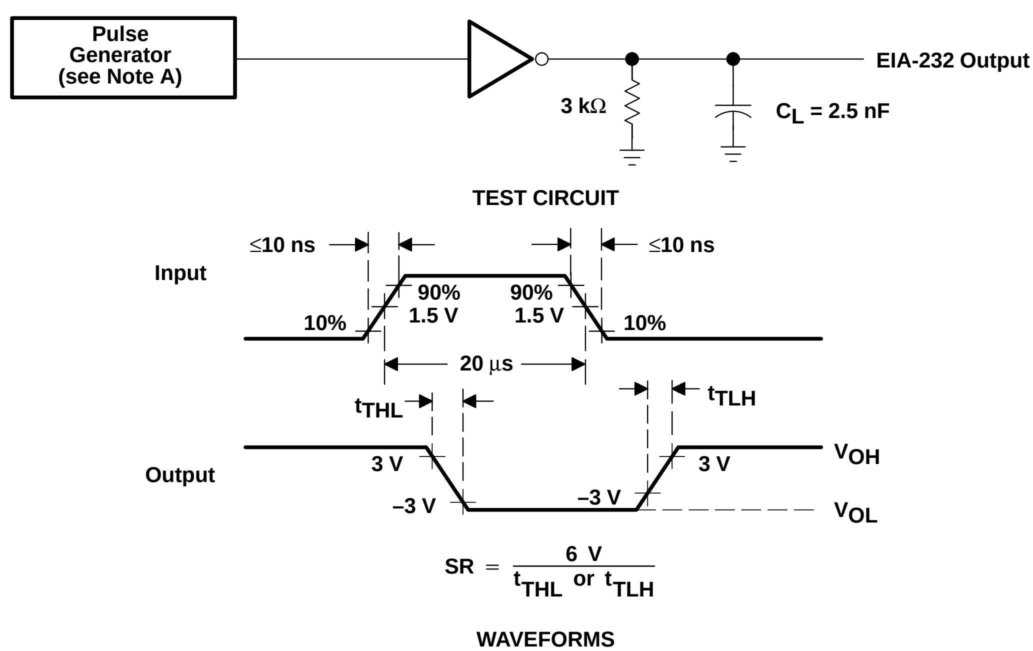
Figure 1. Receiver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements

PARAMETER MEASUREMENT INFORMATION



NOTES: A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.
B. C_L includes probe and jig capacitance.

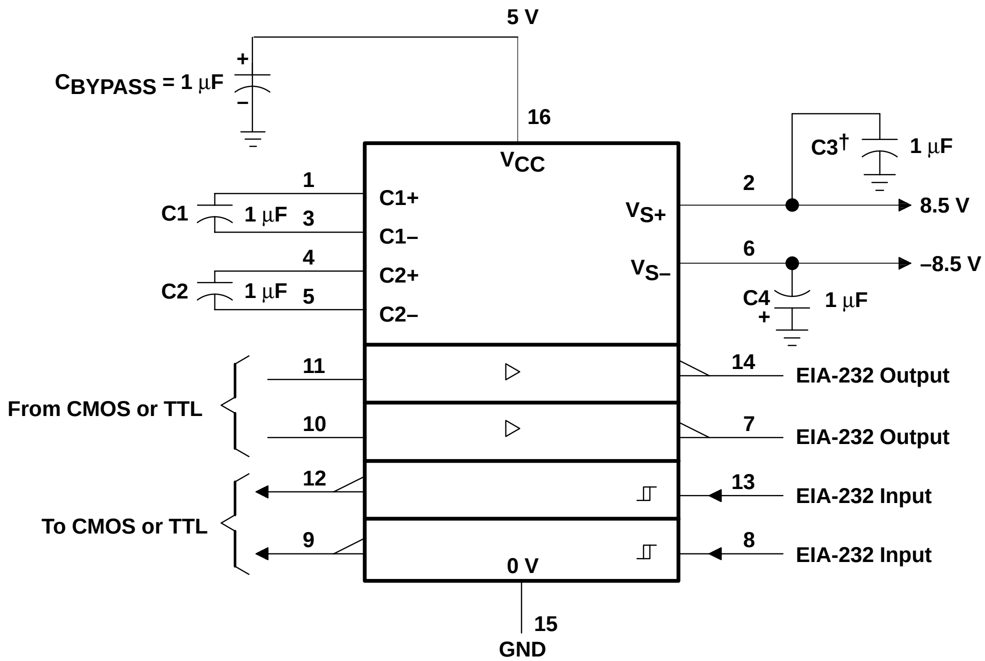
Figure 2. Driver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements (5-µs Input)



NOTE A: The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.

Figure 3. Test Circuit and Waveforms for t_{THL} and t_{TLH} Measurements (20-µs Input)

APPLICATION INFORMATION



† C3 can be connected to V_{CC} or GND.

Figure 4. Typical Operating Circuit

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Mailing Address:

Texas Instruments
Post Office Box 655303
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Power-Supply Monitor with Reset

General Description

The MAX700/701/702 are supervisory circuits used to monitor the power supplies in µP and digital systems. The $\overline{\text{RESET}}$/RESET outputs of the MAX700/701/702 are guaranteed to be in the correct state for V_{CC} voltages down to +1V (Figure 4). They provide excellent circuit reliability and low cost by eliminating external components and adjustments when used with +5V powered circuits.

The MAX702 is the simplest part in the family. When V_{CC} falls to 4.65V, $\overline{\text{RESET}}$ goes low. The MAX702 also provides a debounced manual reset input. The MAX701 performs the same functions but has both $\overline{\text{RESET}}$ and RESET outputs. Their primary function is to provide a system reset. Accordingly, an active reset signal is supplied for low supply voltages and for at least 200ms after the supply voltage reaches its operating value.

In addition to the features of the MAX701 and MAX702, the MAX700 provides preset or adjustable voltage detection so thresholds other than 4.65V can be selected, and adjustable hysteresis. All parts are supplied in 8-pin Plastic DIP and Narrow SO packages in commercial and extended temperature ranges.

Applications

Computers

Controllers

Intelligent Instruments

Automotive Systems

Critical µP Power Monitoring

Features

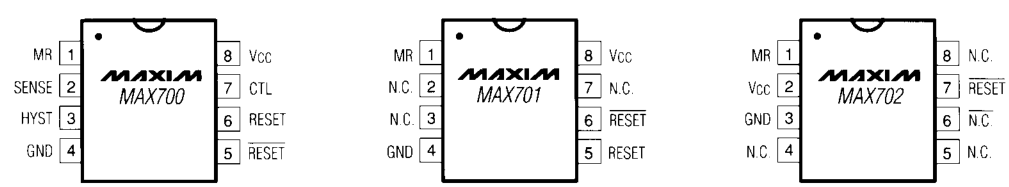
- **Min 200ms $\overline{\text{RESET}}$ Pulse on Power-Up, Power-Down, and During Low-Voltage Conditions**
- **Reset Threshold Factory Trimmed for +5V Systems**
- **No External Components or Adjustments With +5V Powered Circuits**
- **Debounced Manual Reset Input**
- **Preset or Adjustable Voltage Detection (MAX700)**
- **Adjustable Hysteresis (MAX700)**
- **8-Pin Plastic DIP and Narrow SO Packages**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX700CPA	0°C to +70°C	8 Plastic DIP
MAX700CSA	0°C to +70°C	8 Narrow SO
MAX700C/D	0°C to +70°C	Dice
MAX700EPA	-40°C to +85°C	8 Plastic DIP
MAX700ESA	-40°C to +85°C	8 Narrow SO
MAX701CPA	0°C to +70°C	8 Plastic DIP
MAX701CSA	0°C to +70°C	8 Narrow SO
MAX701C/D	0°C to +70°C	Dice
MAX701EPA	-40°C to +85°C	8 Plastic DIP
MAX701ESA	-40°C to +85°C	8 Narrow SO
MAX702CPA	0°C to +70°C	8 Plastic DIP
MAX702CSA	0°C to +70°C	8 Narrow SO
MAX702C/D	0°C to +70°C	Dice
MAX702EPA	-40°C to +85°C	8 Plastic DIP
MAX702ESA	-40°C to +85°C	8 Narrow SO

Pin Configurations

TOP VIEW



DIP/SO DIP/SO DIP/SO

Power-Supply Monitor with Reset

ABSOLUTE MAXIMUM RATINGS

V_{CC} .... -0.3V to +15.5V
Voltage (with respect to GND) at RESET, $\overline{RESET}$, HYST,
CTL, SENSE .... -0.3V to Vcc
Operating Temperature Range
MAX70_C .... 0°C to +70°C
MAX70_E .... -40°C to +85°C

Rate of Rise, V_{CC} 100V/µs
Power Dissipation, any package 380mW
Storage Temperature Range .... -65°C to +150°C
Lead Temperature (Soldering, 10 sec.) .... 300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect the device reliability.

ELECTRICAL CHARACTERISTICS

(T_A = 25°C, V_{CC} = +5V, CTL = GND on MAX700, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{CC} Monitor Voltage Range MAX700 Only	$T_A = T_{MIN}$ to T_{MAX} CTL = V_{CC}	3		15	V
Min V_{CC} For Valid Reset Output, Declining Supply	$T_A = T_{MIN}$ to T_{MAX} $\overline{RESET}$ ≤ 0.4V when sinking 1mA	1.5	1		V
Supply Current			100	200	µA
Reset Threshold Power-up Power-down	$T_A = T_{MIN}$ to T_{MAX}	 4.5 4.5	 4.65 4.62	 4.75 4.75	V
Internal Hysteresis	HYST not connected		30		mV
Reset Output Pulse Width		200	350	500	ms
RESET Fall Time	MAX700/701 Only, C_{LOAD} = 100pF		200		ns
V_{CC} Pulse Duration Guaranteeing No Reset Reset	5V to 4V V_{CC} Pulse	 100	 10 10	 1	µs
MR Input Threshold			0.7		V
MR Pullup Current			-5	-30	µA
MAX700					
RESET Output Low RESET Output High	I_{SINK} = 3.2mA, V_{CC} = 5V I_{SINK} = 1.6mA, V_{CC} = 3V I_{SOURCE} = 3.2mA, V_{CC} = 4.25V I_{SOURCE} = 1.6mA, V_{CC} = 3V I_{SOURCE} = 0.5mA, V_{CC} = 1.5V	 V_{CC}-0.4 V_{CC}-0.4 V_{CC}-0.4		0.4 0.4	V
$\overline{RESET}$ Output Low $\overline{RESET}$ Output High	I_{SINK} = 16mA, V_{CC} = 4.25V I_{SINK} = 1.6mA, V_{CC} = 3V I_{SINK} = 0.4mA, V_{CC} = 1.5V I_{SOURCE} = 3.2mA, V_{CC} = 5V I_{SOURCE} = 1.6mA, V_{CC} = 3V	 V_{CC}-0.4 V_{CC}-0.4		0.4 0.4 0.4	V
MAX701					
RESET Output Low RESET Output High	I_{SINK} = 16mA, V_{CC} = 5V I_{SOURCE} = 3.2mA, V_{CC} = 4.25V I_{SOURCE} = 1.6mA, V_{CC} = 3V I_{SOURCE} = 0.5mA, V_{CC} = 1.5V	 V_{CC}-0.4 V_{CC}-0.4 V_{CC}-0.4		0.4	V
$\overline{RESET}$ Output Low $\overline{RESET}$ Output High	I_{SINK} = 3.2mA, V_{CC} = 4.25V I_{SINK} = 1.6mA, V_{CC} = 3V I_{SINK} = 0.4mA, V_{CC} = 1.5V I_{SOURCE} = 3.2mA, V_{CC} = 5V	 V_{CC}-0.4		0.4 0.4 0.4	V

ELECTRICAL CHARACTERISTICS (continued)

(T_A = 25°C, V_{CC} = +5V, CTL = GND on MAX700, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
MAX702					
$\overline{\text{RESET}}$ Output Low	I_{SINK} = 3.2mA, V_{CC} = 4.25V I_{SINK} = 1.6mA, V_{CC} = 3V I_{SINK} = 0.4mA, V_{CC} = 1.5V			0.4 0.4 0.4	V
$\overline{\text{RESET}}$ Output High	I_{SOURCE} = 3.2mA, V_{CC} = 5V	V_{CC}-0.4			V
MAX700 ONLY (CTL = V_{CC}, unless otherwise noted.)					
SENSE Input Threshold	T_A = T_{MIN} to T_{MAX}	1.25	1.29	1.35	V
SENSE Input Current			0.1		nA
HYST Input On Resistance			0.5		kΩ
CTL Input Threshold			2		V
CTL Pulldown Current			30	100	µA

Pin Description

NAME	FUNCTION
V_{CC}	Chip power and +5V sensing input (when CTL = GND on MAX700).
GND	Ground
$\overline{\text{RESET}}$	Goes low when V_{CC} falls below 4.65V, or when CTL = V_{CC} on the MAX700 goes low when SENSE falls below 1.9V.
RESET	MAX700, 701 only – Inverted Version of $\overline{\text{RESET}}$.
$\overline{\text{MR}}$	Input for manual push button reset. Has internal 5µA pull up. Low input activates the RESET/$\overline{\text{RESET}}$ outputs.
CTL	MAX700 only – When CTL = GND, V_{CC} is monitored by the reset circuit. When CTL = V_{CC}, V_{CC} is ignored and SENSE is monitored, allowing the threshold to be set with external resistors.
HYST	MAX700 only – Normally NOT used when voltage is monitored through V_{CC} (CTL = GND). When monitoring through SENSE (CTL = V_{CC}), HYST allows hysteresis to be added, reducing noise and spurious reset activity (Figure 3). HYST turns on 5µs before the RESET/$\overline{\text{RESET}}$ outputs are activated, and its on resistance to GND is typically 1kΩ.
SENSE	MAX700 only – The voltage sense input when CTL = V_{CC}. Its threshold is 1.29V. Sense always remains connected to the internal comparator. So, when V_{CC} is being monitored internally (CTL = GND), SENSE should be left open circuit.

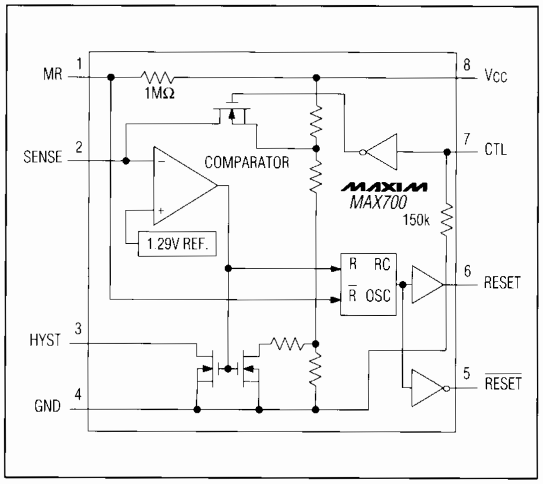


Figure 1. MAX700 Block Diagram

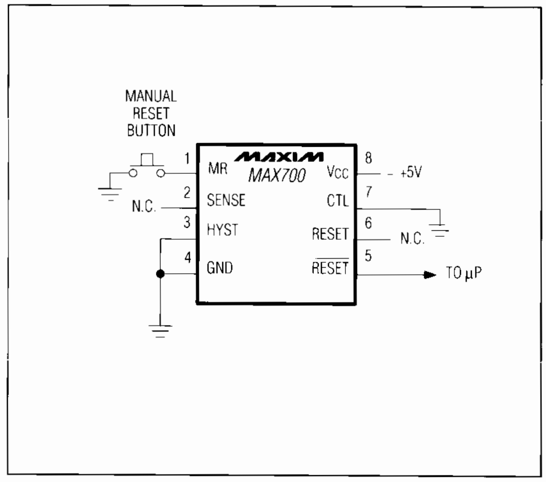
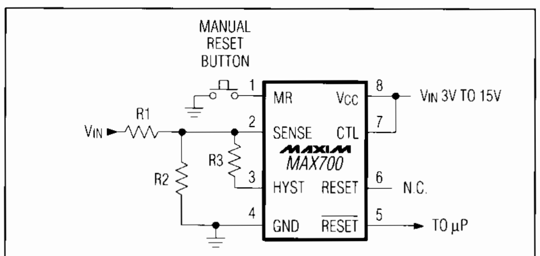


Figure 2. MAX700 Typical Connection Diagram



$$R1 = R2\left(\frac{V_L}{1.29} - 1\right);\ V_L = \text{LOWER VOLTAGE THRESHOLD}$$

$$R3 = \frac{V_T\,R1}{V_U - V_L};\ V_U = \text{UPPER VOLTAGE THRESHOLD}$$

$$\text{HYSTERESIS} = V_U - V_L$$

Figure 3. MAX700 Connected for External Sense and Hysteresis

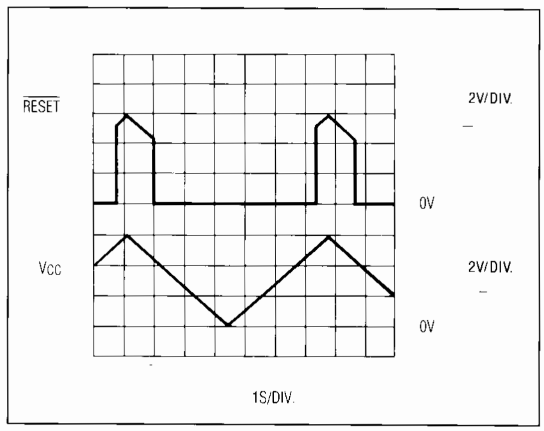


Figure 4. Typical MAX700/701/702 $\overline{\text{RESET}}$ Output vs. V_{CC}

Figure 4 shows the $\overline{\text{RESET}}$ output of the MAX700/701/702 in the correct state for V_{CC} voltages down to 0V. Note the effect of the built-in hysteresis on the trigger level of $\overline{\text{RESET}}$.

19-2551; Rev 0; 6/02

Low-Power, 16-Bit Analog-to-Digital Converters with Parallel Interface

General Description

The MAX1165/MAX1166 16-bit, low-power, successive-approximation analog-to-digital converters (ADCs) feature automatic power-down, factory-trimmed internal clock, and a 16-bit wide (MAX1165) or byte wide (MAX1166) parallel interface. The devices operate from a single +4.75V to +5.25V analog supply and a +2.7V to +5.25V digital supply.

The MAX1165/MAX1166 use an internal 4.096V reference or an external reference. The MAX1165/MAX1166 consume only 1.8mA at a sampling rate of 165ksps with external reference and 2.7mA with internal reference. AutoShutdown™ reduces supply current to 0.1mA at 10ksps.

The MAX1165/MAX1166 are ideal for high-performance, battery-powered, data-acquisition applications. Excellent dynamic performance and low power consumption in a small package make the MAX1165/MAX1166 ideal for circuits with demanding power consumption and space requirements.

The 16-bit wide MAX1165 is available in a 28-pin TSSOP package and the byte wide MAX1166 is available in a 20-pin TSSOP package. Both devices are available in either the 0°C to +70°C commercial, or the -40°C to +85°C extended temperature range.

AutoShutdown is a trademark of Maxim Integrated Products, Inc.

Applications

- Temperature Sensor/Monitor
- Industrial Process Control
- I/O Boards
- Data-Acquisition Systems
- Cable/Harness Tester
- Accelerometer Measurements
- Digital Signal Processing

Pin Configurations appear at end of data sheet.
Functional Diagram appears at end of data sheet.

Features

- **16-Bit Wide (MAX1165) and Byte Wide (MAX1166) Parallel Interface**
- **High Speed: 165ksps Sample Rate**
- **Accurate: ±2LSB INL, 16 Bit No Missing Codes**
- **4.096V, 35ppm/°C Internal Reference**
- **External Reference Range: +3.8V to +5.25V**
- **Single +4.75V to +5.25V Analog Supply Voltage**
- **+2.7V to +5.25V Digital Supply Voltage**
- **Low Supply Current**
  - **1.8mA (External Reference)**
  - **2.7mA (Internal Reference)**
  - **0.1µA (10ksps, External Reference)**
- **Small Footprint**
  - **28-Pin TSSOP Package (16-Bit Wide)**
  - **20-Pin TSSOP Package (Byte Wide)**

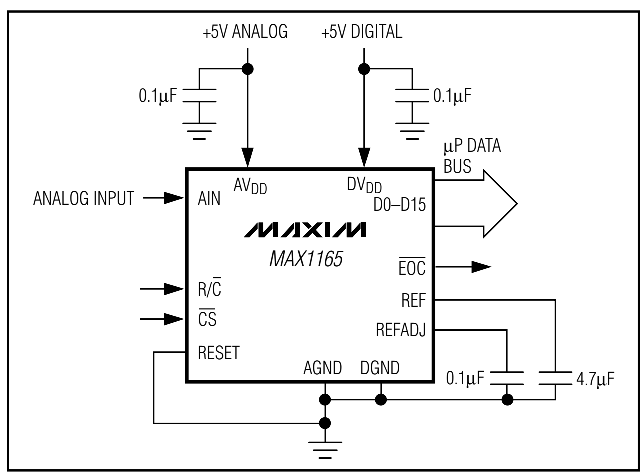
Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	INL
MAX1165ACUI*	0°C to +70°C	28 TSSOP	±2
MAX1165BCUI	0°C to +70°C	28 TSSOP	±2
MAX1165CCUI	0°C to +70°C	28 TSSOP	±4
MAX1165AEUI*	-40°C to +85°C	28 TSSOP	±2
MAX1165BEUI*	-40°C to +85°C	28 TSSOP	±2
MAX1165CEUI*	-40°C to +85°C	28 TSSOP	±4

**Future product—contact factory for availability.*

Ordering Information continued at end of data sheet.

Typical Operating Circuit



ABSOLUTE MAXIMUM RATINGS

AV_{DD} to AGND ....-0.3V to +6V
DV_{DD} to DGND ....-0.3V to (AV_{DD} + 0.3V)
AGND to DGND..-0.3V to +0.3V
AIN, REF, REFADJ to AGND...................-0.3V to (AV_{DD} + 0.3V)
$\overline{CS}$, HBEN, R/$\overline{C}$, RESET to DGND ....-0.3V to +6V
Digital Output (D15–D0, $\overline{EOC}$)
  to DGND ....-0.3V to (DV_{DD} + 0.3V)
Maximum Continuous Current Into Any Pin 50mA

Continuous Power Dissipation (T_A = +70°C)
  20-Pin TSSOP (derate 10.9mW/°C above+70°C) 879mW
  28-Pin TSSOP (derate 12.8mW/°C above +70°C) 1026mW
Operating Temperature Ranges
  MAX116_ _CU_ ....0°C to +70°C
  MAX116_ _EU_ ....-40°C to +85°C
Storage Temperature Range ....-65°C to +150°C
Junction Temperature ....+150°C
Lead Temperature (soldering, 10s) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(AV_{DD} = DV_{DD} = +5V, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
DC ACCURACY							
Resolution	N			16			Bits
Relative Accuracy (Note 1)	INL	MAX116_A				±2	LSB
		MAX116_B				±2	
		MAX116_C				±4	
Differential Nonlinearity	DNL	No missing codes over temperature	MAX116_A			±1	LSB
			MAX116_B	-1		±1.5	
		MAX116_C				±2	
Transition Noise		RMS noise, external reference, includes quantization noise			0.65		LSB_{RMS}
		Internal reference			0.7		LSB_{RMS}
Offset Error					0.05	1	mV
Gain Error		(Note 2)			±0.002	±0.02	%FSR
Offset Drift					0.6		ppm/°C
Gain Drift					0.2		ppm/°C
DYNAMIC PERFORMANCE ($f_{IN(SINE-WAVE)}$ = 1kHz, V_{IN} = 4.096V_{P-P}, 165ksps)							
Signal-to-Noise Plus Distortion	SINAD			86	90		dB
Signal-to-Noise Ratio	SNR			87	90		dB
Total Harmonic Distortion	THD				-102	-90	dB
Spurious-Free Dynamic Range	SFDR			92	105		dB
Full-Power Bandwidth		-3dB point			4		MHz
Full-Linear Bandwidth		SINAD > 81dB			33		kHz
CONVERSION RATE							
Sample Rate	f_{SAMPLE}					165	ksps
Aperture Delay					27		ns
Aperture Jitter					<100		ps
ANALOG INPUT							
Input Range	V_{AIN}			0		V_{REF}	V
Input Capacitance	C_{AIN}				40		pF

ELECTRICAL CHARACTERISTICS (continued)

($AV_{DD} = DV_{DD}$ = +5V, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
INTERNAL REFERENCE							
REF Output Voltage	V_{REF}			4.056	4.096	4.136	V
REF Output Tempco	TC_{REF}				±25		ppm/°C
REF Short-Circuit Current	I_{REFSC}				±10		mA
Capacitive Bypass at REFADJ	C_{REFADJ}			0.1			µF
Capacitive Bypass at REF	C_{REF}			1			µF
REFADJ Input Leakage Current	I_{REFADJ}				20		µA
EXTERNAL REFERENCE							
REFADJ Buffer Disable Threshold		To power down the internal reference		AV_{DD} - 0.4		AV_{DD} - 0.1	V
REF Input Voltage Range		Internal reference disabled		3.8		AV_{DD}	V
REF Input Current	I_{REF}	V_{REF} = +4.096V, f_{SAMPLE} = 165ksps			50	120	µA
		Shutdown mode			±0.1		
DIGITAL INPUTS/OUTPUTS							
Input High Voltage	V_{IH}			0.7 × DV_{DD}			V
Input Low Voltage	V_{IL}					0.3 × DV_{DD}	V
Input Leakage Current	I_{IN}	V_{IH} = 0 or DV_{DD}			±0.1	±1	µA
Input Hysteresis	V_{HYST}				0.1		V
Input Capacitance	C_{IN}				15		pF
Output High Voltage	V_{OH}	I_{SOURCE} = 0.5mA, DV_{DD} = +2.7V to +5.25V, AV_{DD} = +5.25V		DV_{DD} - 0.4			V
Output Low Voltage	V_{OL}	I_{SINK} = 1.6mA, DV_{DD} = +2.7V to +5.25V, AV_{DD} = +5.25V				0.4	V
Three-State Leakage Current	I_{OZ}	D0–D15			±0.1	±10	µA
Three-State Output Capacitance	C_{OZ}				15		pF
POWER REQUIREMENTS							
Analog Supply Voltage	AV_{DD}			4.75		5.25	V
Digital Supply	DV_{DD}			2.7		AV_{DD}	V
Analog Supply Current	I_{AVDD}	Internal reference	165ksps		2.7	3.2	mA
			100ksps		2.0		
			10ksps		1.0		
			1ksps		1.0		
		External reference	165ksps		1.8	2.3	
			100ksps		1.1		
			10ksps		0.1		
			1ksps		0.01		

ELECTRICAL CHARACTERISTICS (continued)

(AV_{DD} = DV_{DD} = +5V, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Digital Supply Current	I_{DVDD}	D0–D15 = all zeros	165ksps		0.5	0.7	mA
			100ksps		0.3		
			10ksps		0.03		
			1ksps		0.003		
Shutdown Supply Current	I_{SHDN}	Full power-down	I_{AVDD}		0.5	5	µA
			I_{DVDD}		0.5	5	
		REF and REF buffer enabled (standby mode)	I_{AVDD}		1.0	1.2	mA
			I_{DVDD} (Note 3)		0.5	5	µA
Power-Supply Rejection Ratio	PSRR	AV_{DD} = +5V ±5%, full-scale input (Note 4)			68		dB

TIMING CHARACTERISTICS (Figures 1 and 2)

(AV_{DD} = +4.75V to +5.25V, DV_{DD} = +2.7V to AV_{DD}, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, C_{LOAD} = 20pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A= +25°C.)

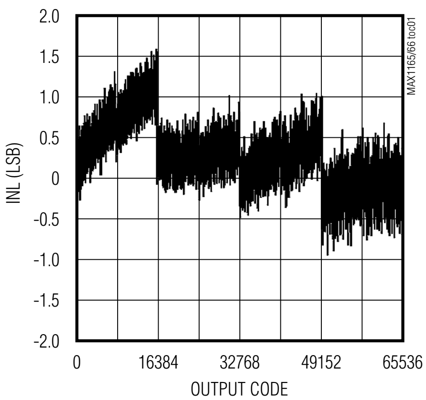
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Acquisition Time	t_{ACQ}		1.1			µs
Conversion Time	t_{CONV}				4.7	
$\overline{CS}$ Pulse Width High	t_{CSH}	(Note 5)	40			ns
$\overline{CS}$ Pulse Width Low (Note 5)	t_{CSL}	V_{DVDD} = 4.75V to 5.25V	40			ns
		V_{DVDD} = 2.7V to 5.25V	60			
R/$\overline{C}$ to $\overline{CS}$ Fall Setup Time	t_{DS}		0			ns
R/$\overline{C}$ to $\overline{CS}$ Fall Hold Time	t_{DH}	V_{DVDD} = 4.75V to 5.25V	40			ns
		V_{DVDD} = 2.7V to 5.25V	60			
$\overline{CS}$ to Output Data Valid	t_{DO}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	
HBEN Transition to Output Data Valid (MAX1166 Only)	t_{DO1}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	
$\overline{EOC}$ Fall to $\overline{CS}$ Fall	t_{DV}		0			ns
$\overline{CS}$ Rise to $\overline{EOC}$ Rise	t_{EOC}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	
Bus Relinquish Time (Note 5)	t_{BR}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	

Note 1: Relative accuracy is the deviation of the analog value at any code from its theoretical value after offset and gain errors have been removed.
Note 2: Offset nulled.
Note 3: Shutdown supply currents are typically 0.5µA, maximum specification is limited by automated test equipment.
Note 4: Defined as the change in positive full scale caused by a ±5% variation in the nominal supply.
Note 5: To ensure best performance, finish reading the data and wait t_{BR} before starting a new acquisition.

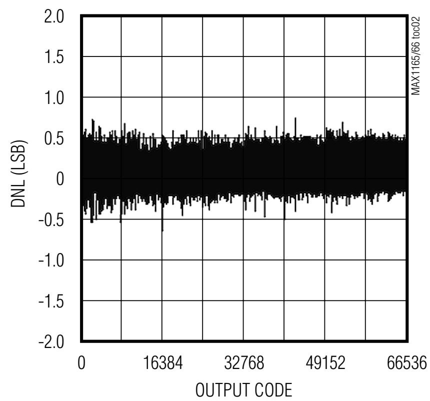
Typical Operating Characteristics

($AV_{DD} = DV_{DD} = +5V$, external reference = +4.096V, $C_{REF} = 4.7\mu F$, $C_{REFADJ} = 0.1\mu F$, $T_A = +25°C$, unless otherwise noted.)

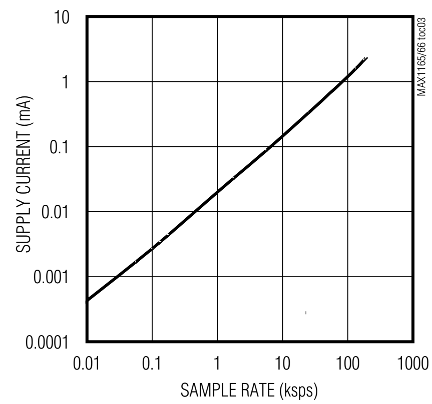
INL vs. OUTPUT CODE



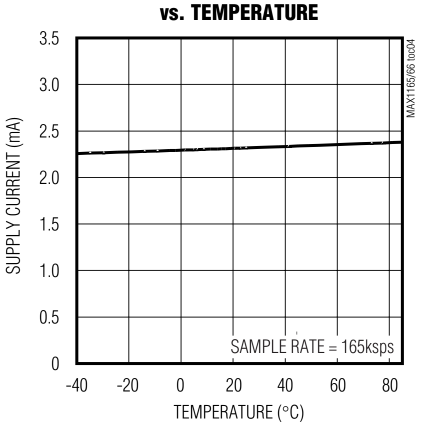
DNL vs. OUTPUT CODE



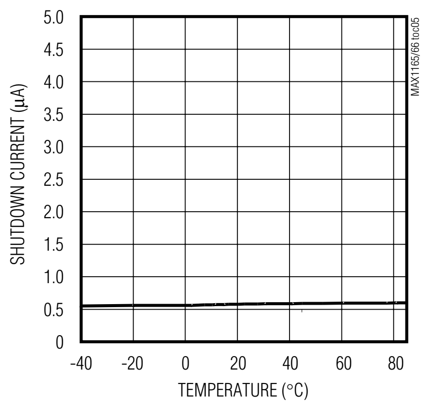
IAV_{DD} + IDV_{DD} SUPPLY CURRENT vs. SAMPLE RATE



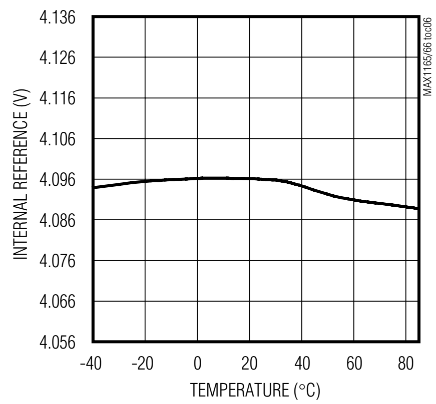
IAV_{DD} + IDV_{DD} SUPPLY CURRENT vs. TEMPERATURE



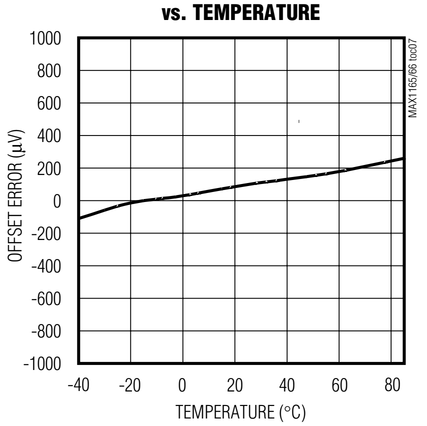
IAV_{DD} + IDV_{DD} SHUTDOWN CURRENT vs. TEMPERATURE



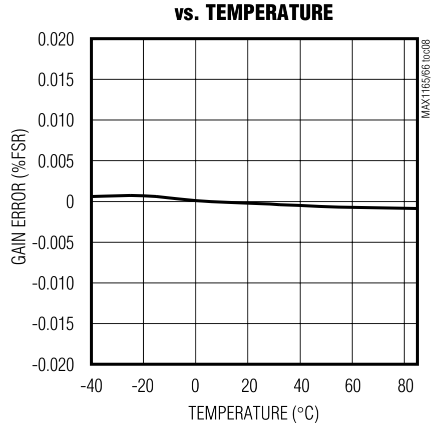
INTERNAL REFERENCE vs. TEMPERATURE



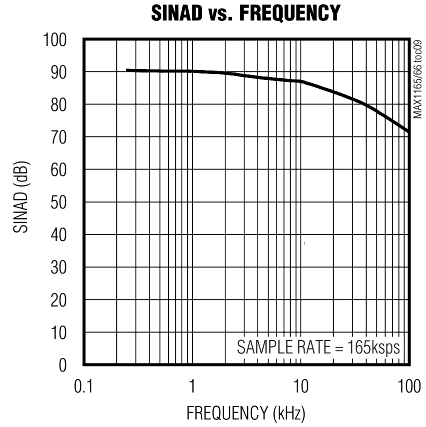
OFFSET ERROR vs. TEMPERATURE



GAIN ERROR vs. TEMPERATURE

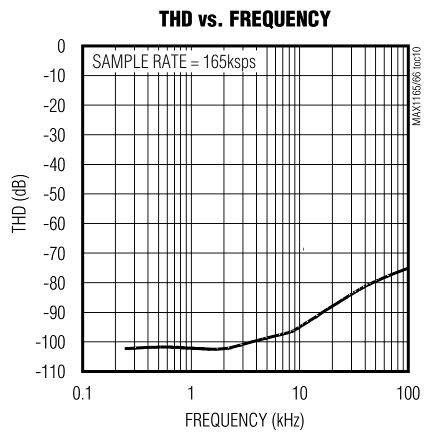


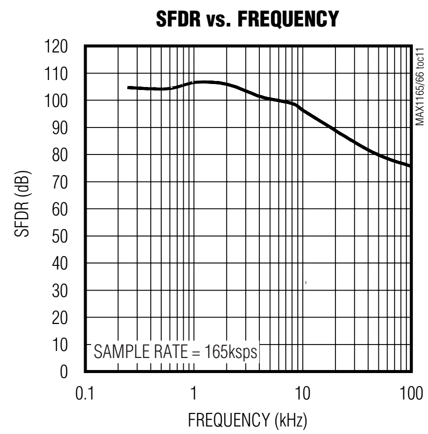
SINAD vs. FREQUENCY

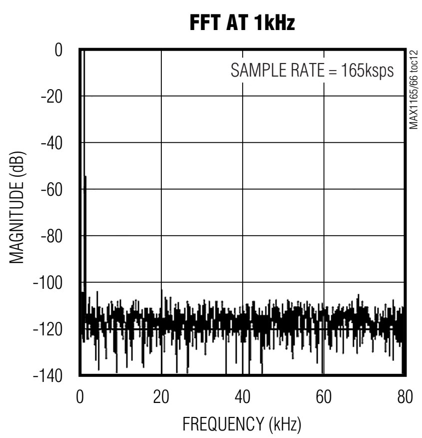


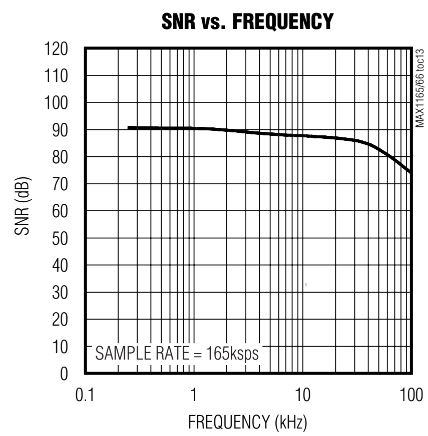
Typical Operating Characteristics (continued)

($AV_{DD} = DV_{DD}$ = +5V, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, T_A = +25°C, unless otherwise noted.)









Pin Description

PIN		NAME		FUNCTION
MAX1165	MAX1166	MAX1165	MAX1166	
1	1	D8	D4/D12	Three-State Digital Data Output
2	2	D9	D5/D13	Three-State Digital Data Output
3	3	D10	D6/D14	Three-State Digital Data Output
4	4	D11	D7/D15	Three-State Digital Data Output. D15 is the MSB.
5	—	D12	—	Three-State Digital Data Output
6	—	D13	—	Three-State Digital Data Output
7	—	D14	—	Three-State Digital Data Output
8	—	D15	—	Three-State Digital Data Output (MSB)
9	5	$R/\overline{C}$		Read/$\overline{\text{Convert}}$ Input. Power up and put the MAX1165/MAX1166 in acquisition mode by holding $R/\overline{C}$ low during the first falling edge of $\overline{CS}$. During the second falling edge of $\overline{CS}$, the level on $R/\overline{C}$ determines whether the reference and reference buffer power down or remain on after conversion. Set $R/\overline{C}$ high during the second falling edge of $\overline{CS}$ to power down the reference and buffer, or set $R/\overline{C}$ low to leave the reference and buffer powered up. Set $R/\overline{C}$ high during the third falling edge of $\overline{CS}$ to put valid data on the bus.
10	6	$\overline{EOC}$		End of Conversion. $\overline{EOC}$ drives low when conversion is complete.
11	7	AV_{DD}		Analog Supply Input. Bypass with a 0.1µF capacitor to AGND.
12	8	AGND		Analog Ground. Primary analog ground (star ground).
13	9	AIN		Analog Input
14	10	AGND		Analog Ground. Connect pin 14 to pin 12 (MAX1165). Connect pin 10 to pin 8 (MAX1166).
15	11	REFADJ		Reference Buffer Output. Bypass REFADJ with a 0.1µF capacitor to AGND for internal reference mode. Connect REFADJ to AV_{DD} to select external reference mode.
16	12	REF		Reference Input/Output. Bypass REF with a 4.7µF capacitor to AGND for internal reference mode. External reference input when in external reference mode.
17	—	RESET		Reset Input. Logic high resets the device.
—	13	HBEN		High-Byte Enable Input. Used to multiplex the 14-bit conversion result: 1: Most significant byte available on the data bus. 0: Least significant byte available on the data bus.
18	14	$\overline{CS}$		Convert Start. The first falling edge of $\overline{CS}$ powers up the device and enables acquire mode when $R/\overline{C}$ is low. The second falling edge of $\overline{CS}$ starts conversion. The third falling edge of $\overline{CS}$ loads the result onto the bus when $R/\overline{C}$ is high.
19	15	DGND		Digital Ground
20	16	DV_{DD}		Digital Supply Voltage. Bypass with a 0.1µF capacitor to DGND.
21	17	D0	D0/D8	Three-State Digital Data Output
22	18	D1	D1/D9	Three-State Digital Data Output
23	19	D2	D2/D10	Three-State Digital Data Output
24	20	D3	D3/D11	Three-State Digital Data Output
25	—	D4	—	Three-State Digital Data Output
26	—	D5	—	Three-State Digital Data Output
27	—	D6	—	Three-State Digital Data Output
28	—	D7	—	Three-State Digital Data Output

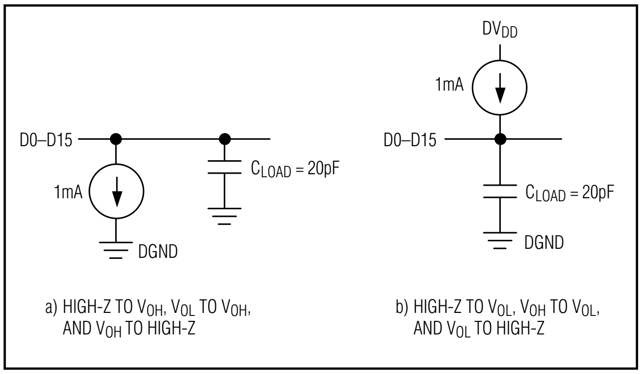


Figure 1. Load Circuits

Detailed Description

Converter Operation

The MAX1165/MAX1166 use a successive-approximation (SAR) conversion technique with an inherent track-and-hold (T/H) stage to convert an analog input into a 16-bit digital output. Parallel outputs provide a high-speed interface to most microprocessors (µPs). The *Functional Diagram* shows a simplified internal architecture of the MAX1165/MAX1166. Figure 3 shows a typical application circuit for the MAX1166.

Analog Input

The equivalent input circuit is shown in Figure 4. A switched capacitor digital-to-analog converter (DAC) provides an inherent T/H function. The single-ended input is connected between AIN and AGND.

Input Bandwidth

The ADC's input-tracking circuitry has a 4MHz small-signal bandwidth, so it is possible to digitize high-speed transient events and measure periodic signals with bandwidths exceeding the ADC's sampling rate by using undersampling techniques. To avoid aliasing of unwanted high-frequency signals into the frequency band of interest, use anti-alias filtering.

Analog Input Protection

Internal protection diodes, which clamp the analog input to AV_{DD} and/or AGND, allow the input to swing from AGND - 0.3V to AV_{DD} + 0.3V, without damaging the device.

If the analog input exceeds 300mV beyond the supplies, limit the input current to 10mA.

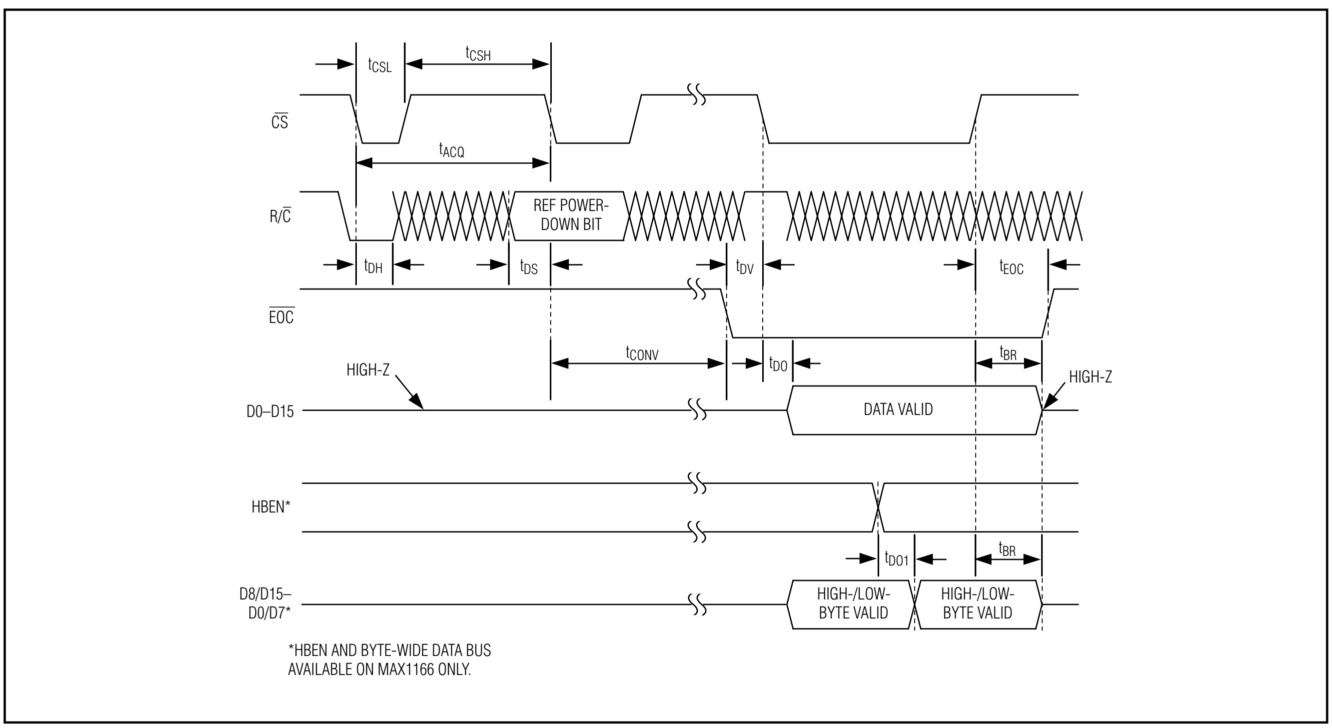


Figure 2. MAX1165/MAX1166 Timing Diagram

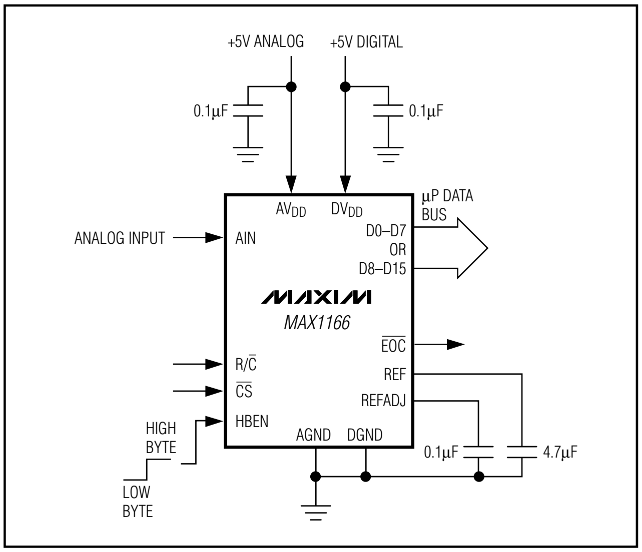


Figure 3. Typical Application Circuit for the MAX1166

Track and Hold (T/H)

In track mode, the analog signal is acquired on the internal hold capacitor. In hold mode, the T/H switches open and the capacitive DAC samples the analog input.

During the acquisition, the analog input (AIN) charges capacitor C_{DAC}. The acquisition ends on the second falling edge of $\overline{CS}$. At this instant, the T/H switches open. The retained charge on C_{DAC} represents a sample of the input.

In hold mode, the capacitive DAC adjusts during the remainder of the conversion time to restore node ZERO to zero within the limits of 16-bit resolution. Force $\overline{CS}$ low to put valid data on the bus at the end of the conversion.

The time required for the T/H to acquire an input signal is a function of how quickly its input capacitance is charged. If the input signal's source impedance is high, the acquisition time lengthens and more time must be allowed between conversions. The acquisition time (t_{ACQ}) is the maximum time the device takes to acquire the signal. Use the following formula to calculate acquisition time:

$$t_{ACQ} = 11 (R_S + R_{IN}) \times 35pF$$

where R_{IN} = 800Ω, R_S = the input signal's source impedance, and t_{ACQ} is never less than 1.1µs. A source impedance less than 1kΩ does not significantly affect the ADC's performance.

To improve the input signal bandwidth under AC conditions, drive AIN with a wideband buffer (>4MHz) that can drive the ADC's input capacitance and settle quickly.

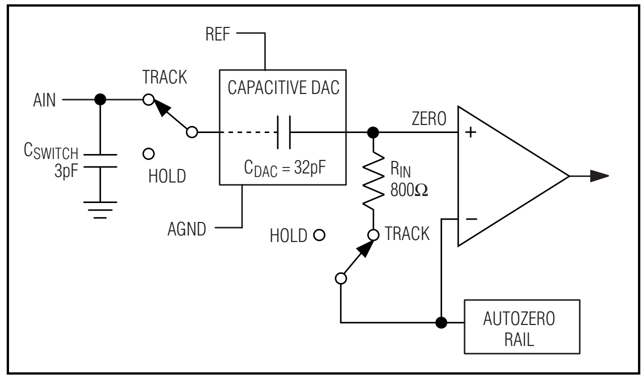


Figure 4. Equivalent Input Circuit

Power-Down Modes

Select standby mode or shutdown mode with the R/$\overline{C}$ bit during the second falling edge of $\overline{CS}$ (see the *Selecting Standby or Shutdown Mode* section). The MAX1165/MAX1166 automatically enter either standby mode (reference and buffer on) or shutdown (reference and buffer off) after each conversion depending on the status of R/$\overline{C}$ during the second falling edge of $\overline{CS}$.

Internal Clock

The MAX1165/MAX1166 generate an internal conversion clock. This frees the microprocessor from the burden of running the SAR conversion clock. Total conversion time after entering hold mode (second falling edge of $\overline{CS}$) to end of conversion ($\overline{EOC}$) falling is 4.7µs (max).

Applications Information

Starting a Conversion

$\overline{CS}$ and R/$\overline{C}$ control acquisition and conversion in the MAX1165/MAX1166 (Figure 2). The first falling edge of $\overline{CS}$ powers up the device and puts it in acquire mode if R/$\overline{C}$ is low. The convert start is ignored if R/$\overline{C}$ is high. The MAX1165/MAX1166 need at least 10ms (C_{REFADJ} = 0.1µF, C_{REF} = 4.7µF) for the internal reference to wake up and settle before starting the conversion if powering up from shutdown. The ADC can wake up, from shutdown, to an unknown state. Put the ADC in a known state by completing one "dummy" conversion. The MAX1165/MAX1166 are in a known state, ready for actual data acquisition, after the completion of the dummy conversion. A dummy conversion consists of one full conversion cycle.

The MAX1165 provides an alternative reset function to reset the device (see the *RESET* section).

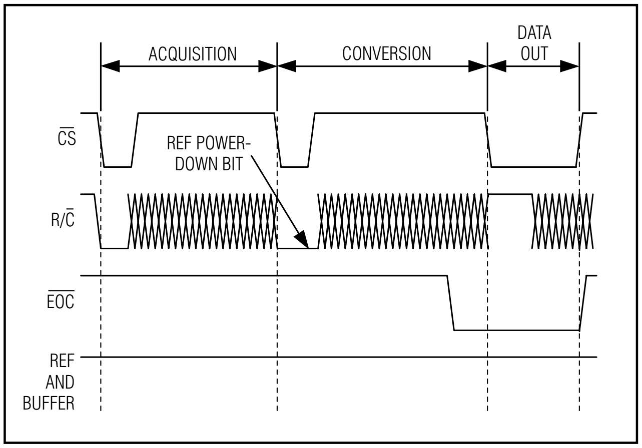


Figure 5. Selecting Standby Mode

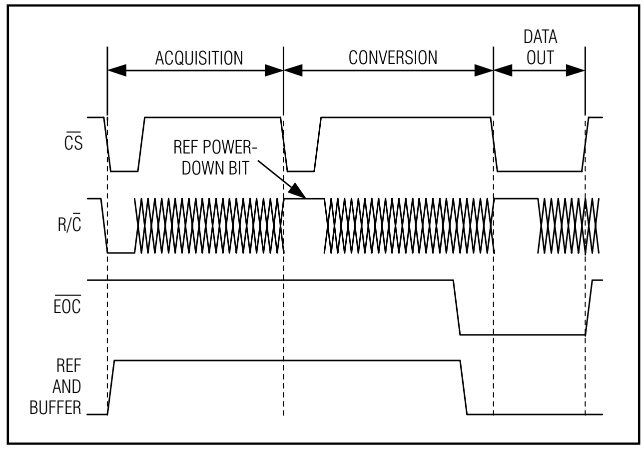


Figure 6. Selecting Shutdown Mode

Selecting Standby or Shutdown Mode

The MAX1165/MAX1166 have a selectable standby or low-power shutdown mode. In standby mode, the ADC's internal reference and reference buffer do not power down between conversions, eliminating the need to wait for the reference to power up before performing the next conversion. Shutdown mode powers down the reference and reference buffer after completing a conversion. The reference and reference buffer require a minimum of 10ms (C_{REFADJ} = 0.1µF, C_{REF} = 4.7µF) to power up and settle from shutdown.

The state of R/$\overline{C}$ at the second falling edge of $\overline{CS}$ selects which power-down mode the MAX1165/MAX1166 enter upon conversion completion. Holding R/$\overline{C}$ low causes the MAX1165/MAX1166 to enter standby mode. The reference and buffer are left on after the conversion completes. R/$\overline{C}$ high causes the MAX1165/MAX1166 to enter shutdown mode and shut down the reference and buffer after conversion (Figures 5 and 6). When using an external reference, set the REF power-down bit high for lowest current operation.

Standby Mode

While in standby mode, the supply current is reduced to less than 1mA (typ). The next falling edge of $\overline{CS}$ with R/$\overline{C}$ low causes the MAX1165/MAX1166 to exit standby mode and begin acquisition. The reference and reference buffer remain active to allow quick turn-on time. Standby mode allows significant power savings while running at the maximum sample rate.

Shutdown Mode

In shutdown mode, the reference and reference buffer are shut down between conversions. Shutdown mode reduces supply current to 0.5µA (typ) immediately after the conversion. The falling edge of $\overline{CS}$ with R/$\overline{C}$ low causes the reference and buffer to wake up and enter acquisition mode. To achieve 16-bit accuracy, allow 10ms (C_{REFADJ} = 0.1µF, C_{REF} = 4.7µF) for the internal reference to wake up.

Internal and External Reference

Internal Reference

The internal reference of the MAX1165/MAX1166 is internally buffered to provide +4.096V output at REF. Bypass REF to AGND and REFADJ to AGND with 4.7µF and 0.1µF, respectively.

Fine adjustments can be made to the internal reference voltage by sinking or sourcing current at REFADJ. The input impedance of REFADJ is nominally 5kΩ. The internal reference voltage is adjustable to ±1.5% with the circuit of Figure 7.

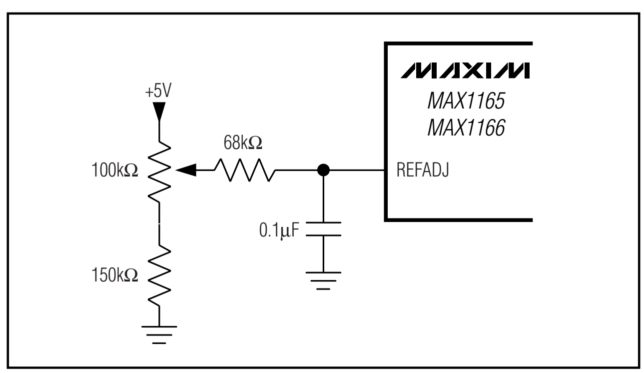


Figure 7. MAX1165/MAX1166 Reference Adjust Circuit

External Reference

An external reference can be placed at either the input (REFADJ) or the output (REF) of the MAX1165/MAX1166s' internal buffer amplifier. When connecting an external reference to REFADJ, the input impedance is typically 5kΩ. Using the buffered REFADJ input makes buffering the external reference unnecessary; however, the internal buffer output must be bypassed at REF with a 1µF capacitor.

Connect REFADJ to AV_{DD} to disable the internal buffer. Directly drive REF using an external reference. During conversion the external reference must be able to drive 100µA of DC load current and have an output impedance of 10Ω or less. REFADJ's impedance is typically 5kΩ. The DC input impedance of REF is a minimum 40kΩ.

For optimal performance, buffer the reference through an op amp and bypass REF with a 1µF capacitor. Consider the MAX1165/MAX1166s' equivalent input noise ($38µV_{RMS}$) when choosing a reference.

Reading a Conversion Result

$\overline{EOC}$ is provided to flag the microprocessor when a conversion is complete. The falling edge of $\overline{EOC}$ signals that the data is valid and ready to be output to the bus.

D0–D15 are the parallel outputs of the MAX1165/MAX1166. These three-state outputs allow for direct connection to a microcontroller I/O bus. The outputs remain high-impedance during acquisition and conversion. Data is loaded onto the bus with the third falling edge of $\overline{CS}$ with R/$\overline{C}$ high after t_{DO}. Bringing $\overline{CS}$ high forces the output bus back to high impedance. The MAX1165/MAX1166 then wait for the next falling edge of $\overline{CS}$ to start the next conversion cycle (Figure 2).

The MAX1165 loads the conversion result onto a 16-bit wide data bus while the MAX1166 has a byte-wide output format. HBEN toggles the output between the most/least significant byte. The least significant byte is loaded onto the output bus when HBEN is low and the most significant byte is on the bus when HBEN is high (Figure 2).

RESET

Toggle RESET with $\overline{CS}$ high. The next falling edge of $\overline{CS}$ begins acquisition. This reset is an alternative to the dummy conversion explained in the *Starting a Conversion* section.

Transfer Function

Figure 8 shows the MAX1165/MAX1166 output transfer function. The output is coded in standard binary.

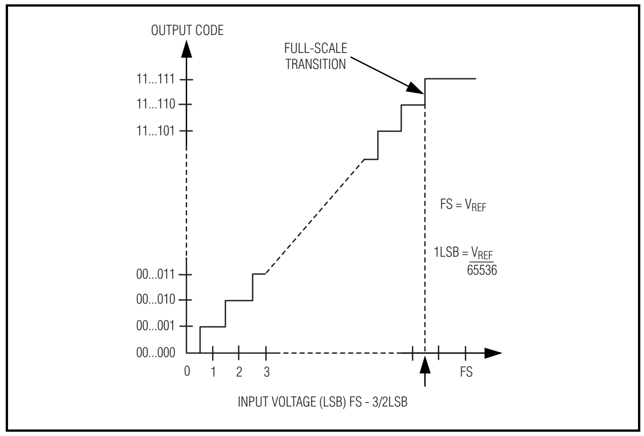


Figure 8. MAX1165/MAX1166 Transfer Function

Input Buffer

Most applications require an input buffer amplifier to achieve 16-bit accuracy. If the input signal is multiplexed, the input channel should be switched immediately after acquisition, rather than near the end of or after a conversion. This allows more time for the input buffer amplifier to respond to a large step change in input signal. The input amplifier must have a high enough slew rate to complete the required output voltage change before the beginning of the acquisition time. At the beginning of acquisition, the internal sampling capacitor array connects to AIN (the amplifier output), causing some output disturbance. Ensure that the sampled voltage has settled to within the required limits before the end of the acquisition time. If the frequency of interest is low, AIN can be bypassed with a large enough capacitor to charge the internal sampling capacitor with very little ripple. However, for AC use, AIN must be driven by a wideband buffer (at least 10MHz), which must be stable with the ADC's capacitive load (in parallel with any AIN bypass capacitor used) and also settle quickly. An example of this circuit using the MAX4434 is given in Figure 9.

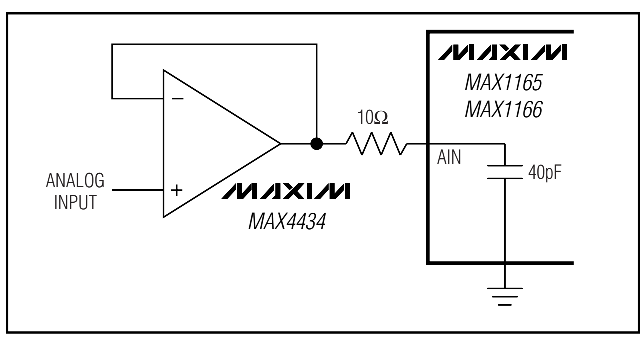


Figure 9. MAX1165/MAX1166 Fast Settling Input Buffer

Layout, Grounding, and Bypassing

For best performance, use printed circuit boards. Do not run analog and digital lines parallel to each other, and do not lay out digital signal paths underneath the ADC package. Use separate analog and digital ground planes with only one point connecting the two ground systems (analog and digital) as close to the device as possible.

Route digital signals far away from sensitive analog and reference inputs. If digital lines must cross analog lines, do so at right angles to minimize coupling digital noise onto the analog lines. If the analog and digital sections share the same supply, then isolate the digital and analog supply by connecting them with a low-value (10Ω) resistor or ferrite bead.

The ADC is sensitive to high-frequency noise on the AV_{DD} supply. Bypass AV_{DD} to AGND with a 0.1µF capacitor in parallel with a 1µF to 10µF low-ESR capacitor with the smallest capacitor closest to the device. Keep capacitor leads short to minimize stray inductance.

Definitions

Integral Nonlinearity

Integral nonlinearity (INL) is the deviation of the values on an actual transfer function from a straight line. This straight line can be either a best-straight-line fit or a line drawn between the end points of the transfer function, once offset and gain errors have been nullified. The static linearity parameters for the MAX1165/MAX1166 are measured using the end-point method.

Differential Nonlinearity

Differential nonlinearity (DNL) is the difference between an actual step width and the ideal value of 1 LSB. A DNL error specification of ±1 LSB guarantees no missing codes and a monotonic transfer function.

Aperture Jitter and Delay

Aperture jitter is the sample-to-sample variation in the time between samples. Aperture delay is the time between the rising edge of the sampling clock and the instant when the actual sample is taken.

Signal-to-Noise Ratio

For a waveform perfectly reconstructed from digital samples, signal-to-noise ratio (SNR) is the ratio of the full-scale analog input (RMS value) to the RMS quantization error (residual error). The ideal, theoretical minimum analog-to-digital noise is caused by quantization noise error only and results directly from the ADC's resolution (N bits):

$$SNR = (6.02 \times N + 1.76)dB$$

where N = 16 bits.

In reality, there are other noise sources besides quantization noise: thermal noise, reference noise, clock jitter, etc. SNR is computed by taking the ratio of the RMS signal to the RMS noise, which includes all spectral components minus the fundamental, the first five harmonics, and the DC offset.

Signal-to-Noise Plus Distortion

Signal-to-noise plus distortion (SINAD) is the ratio of the fundamental input frequency's RMS amplitude to the RMS equivalent of all the other ADC output signals:

$$SINAD\,(dB) = 20 \times \log\left[\frac{Signal_{RMS}}{(Noise + Distortion)_{RMS}}\right]$$

Effective Number of Bits

Effective number of bits (ENOB) indicates the global accuracy of an ADC at a specific input frequency and sampling rate. An ideal ADC's error consists of quantization noise only. With an input range equal to the full-scale range of the ADC, calculate the effective number of bits as follows:

$$ENOB = \frac{SINAD - 1.76}{6.02}$$

Total Harmonic Distortion

Total harmonic distortion (THD) is the ratio of the RMS sum of the first five harmonics of the input signal to the fundamental itself. This is expressed as:

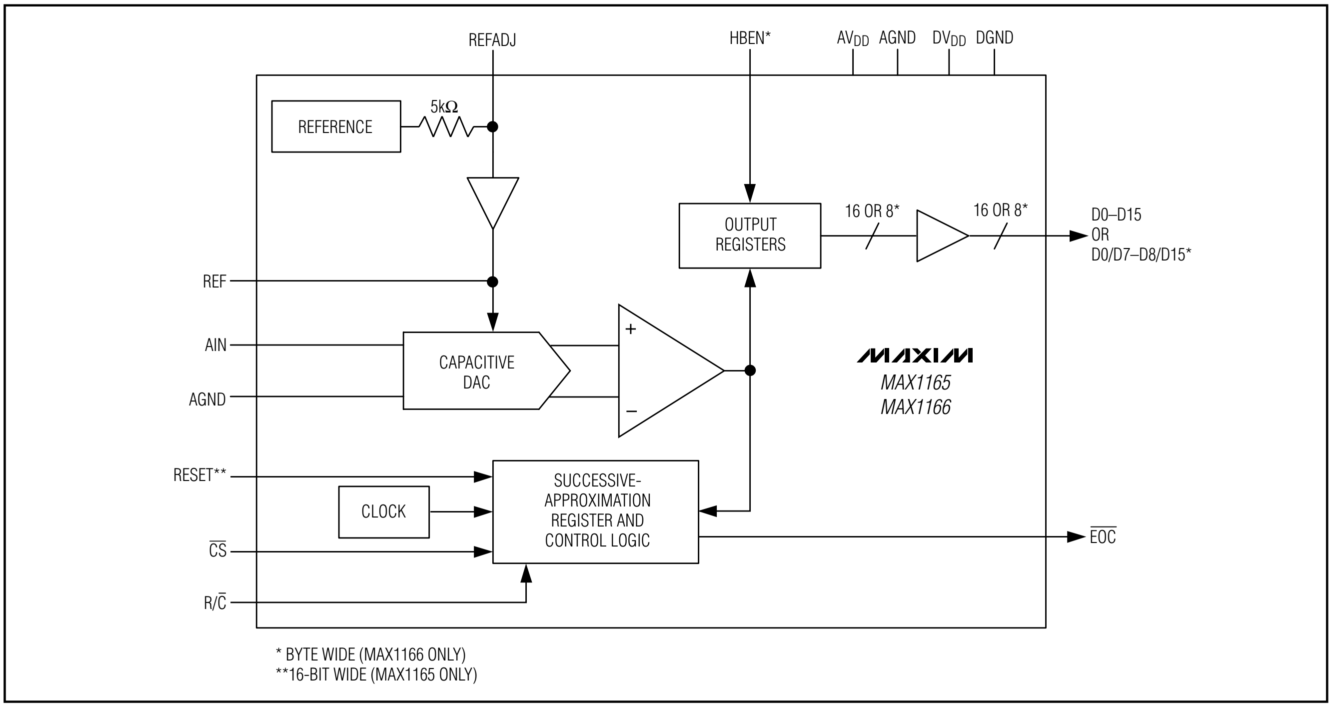
$$THD = 20 \times \log\left[\frac{\left(\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2}\right)}{V_1}\right]$$

where V_1 is the fundamental amplitude and V_2 through V_5 are the 2nd- through 5th-order harmonics.

Spurious-Free Dynamic Range

Spurious-free dynamic range (SFDR) is the ratio of the RMS amplitude of the fundamental (maximum signal component) to the RMS value of the next largest frequency component.

Functional Diagram



Ordering Information (continued)

PART	TEMP RANGE	PIN-PACKAGE	INL
MAX1166ACUP*	0°C to +70°C	20 TSSOP	±2
MAX1166BCUP	0°C to +70°C	20 TSSOP	±2
MAX1166CCUP	0°C to +70°C	20 TSSOP	±4
MAX1166AEUP*	-40°C to +85°C	20 TSSOP	±2
MAX1166BEUP*	-40°C to +85°C	20 TSSOP	±2
MAX1166CEUP*	-40°C to +85°C	20 TSSOP	±4

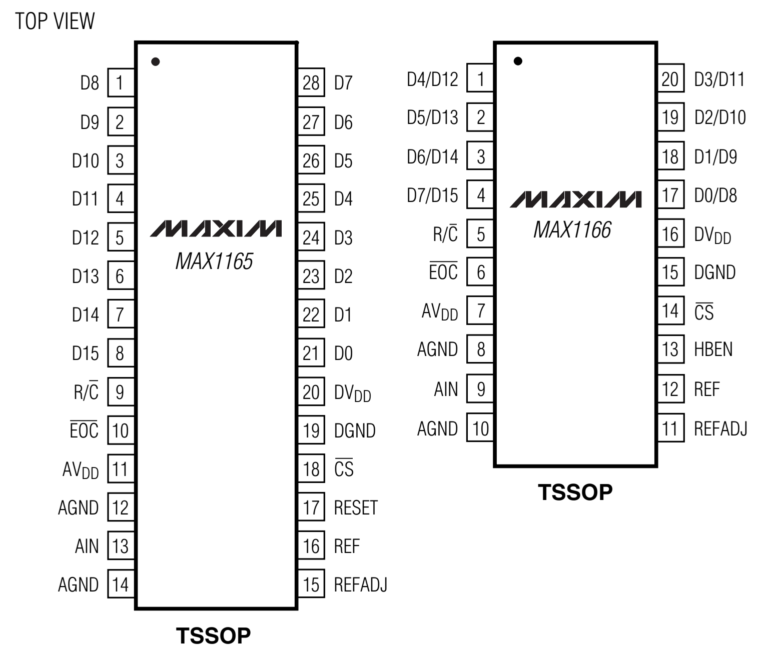
**Future product—contact factory for availability.*

Chip Information

TRANSISTOR COUNT: 15,140

PROCESS: BiCMOS

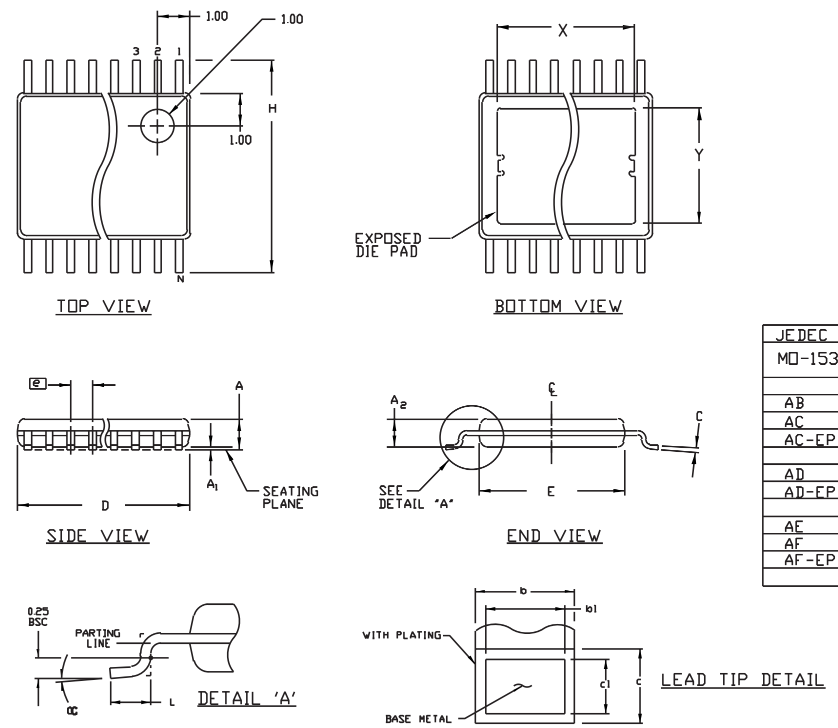
Pin Configurations



Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

TSSOP.EPS



S Y M B O L	COMMON DIMENSIONS			
	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	—	1.10		.043
A1	0.05	0.15	.002	.006
A2	0.85	0.95	.033	.037
b	0.19	0.30	.007	.012
b1	0.19	0.25	.007	.010
c	0.090	0.20	.0035	.008
c1	0.090	0.135	.0035	.0053
D	SEE VARIATIONS		SEE VARIATIONS	
E	4.30	4.50	.169	.177
e	0.65 BSC		.026 BSC	
H	6.25	6.50	.246	.256
L	0.50	0.70	.020	.028
N	SEE VARIATIONS		SEE VARIATIONS	
Y	2.85	3.15	.112	.124
α	0°	8°	0°	8°

JEDEC MO-153	N		VARIATIONS			
			MILLIMETERS		INCHES	
			MIN.	MAX.	MIN.	MAX.
AB	14	D	4.90	5.10	.193	.201
AC	16	D	4.90	5.10	.193	.201
AC-EP	16	D	4.90	5.10	.193	.201
		X	2.85	3.15	.112	.124
AD	20	D	6.40	6.60	.252	.260
AD-EP	20	D	6.40	6.60	.252	.260
		X	4.00	4.34	.157	.171
AE	24	D	7.70	7.90	.303	.311
AF	28	D	9.60	9.80	.378	.386
AF-EP		D	9.60	9.80	.378	.386
		X	5.35	5.65	.211	.222

NOTES:
1. DIMENSIONS D AND E DO NOT INCLUDE FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15 mm PER SIDE.
3. CONTROLLING DIMENSION: MILLIMETER.
4. MEETS JEDEC OUTLINE MO-153 VARIATIONS AB, AC, AD, AE, AF.
5. DIMENSIONS X AND Y APPLY TO EXPOSED PAD (EP) VERSIONS ONLY.
6. EXPOSED PAD FLUSH WITH BOTTOM OF PACKAGE WITHIN .002".

MAXIM
PROPRIETARY INFORMATION
TITLE:
PACKAGE OUTLINE, TSSOP, 4.40mm BODY, 0.65mm PITCH

APPROVAL	DOCUMENT CONTROL NO.	REV	
	21-0066	C	1/1

19-1497; Rev 0; 8/99

MAXIM

Dual, 5Ω Analog Switches

General Description

The MAX4621/MAX4622/MAX4623 are precision, dual, high-speed analog switches. The single-pole/single-throw (SPST) MAX4621 and double-pole/single-throw (DPST) MAX4623 dual switches are normally open (NO). The single-pole/double-throw (SPDT) MAX4622 has two normally closed (NC) and two NO poles. All three parts offer low 5Ω on-resistance guaranteed to match to within 0.5Ω between channels and to remain flat over the full analog signal range (Δ0.5Ω max). They also offer low leakage (<500pA at +25°C, <5nA at +85°C) and fast switching times (turn-on time <250ns, turn-off time <200ns).

These analog switches are ideal in low-distortion applications and are the preferred solution over mechanical relays in automatic test equipment or applications where current switching is required. They have low power requirements, use less board space, and are more reliable than mechanical relays.

The MAX4621/MAX4622/MAX4623 are pin-compatible replacements for the DG401/DG403/DG405, respectively, offering improved overall performance. These monolithic switches operate from a single positive supply (+4.5V to +36V) or with bipolar supplies (±4.5V to ±18V) while retaining CMOS-logic input compatibility.

Features

- ♦ **Low On-Resistance: 3Ω (typ), 5Ω (max)**
- ♦ **Guaranteed R_{ON} Match Between Channels (0.5Ω max)**
- ♦ **Guaranteed Break-Before-Make Operation (MAX4622)**
- ♦ **Guaranteed Off-Channel Leakage <5nA at +85°C**
- ♦ **Single-Supply Operation (+4.5V to +36V) Bipolar-Supply Operation (±4.5V to ±18V)**
- ♦ **TTL/CMOS-Logic Compatible**
- ♦ **Rail-to-Rail® Analog Signal Handling Capability**
- ♦ **Pin Compatible with DG401/DG403/DG405**

Applications

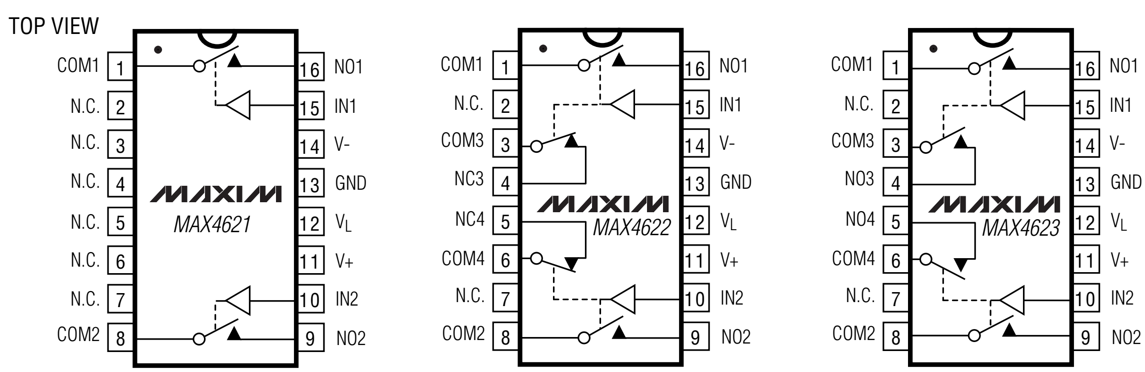
Reed Relay Replacement	Military Radios
Test Equipment	PBX, PABX Systems
Communication Systems	Audio-Signal Routing
Data-Acquisition Systems	Avionics

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX4621CSE	0°C to +70°C	16 Narrow SO
MAX4621CPE	0°C to +70°C	16 Plastic DIP

Ordering Information continued at end of data sheet.

Pin Configurations/Functional Diagrams/Truth Tables



SO/DIP **SO/DIP** **SO/DIP**

MAX4621	
LOGIC	SWITCH
0	OFF
1	ON

MAX4622		
LOGIC	SWITCHES 1, 2	SWITCHES 3, 4
0	OFF	ON
1	ON	OFF

MAX4623	
LOGIC	SWITCH
0	OFF
1	ON

SWITCHES SHOWN FOR LOGIC "0" INPUT

Dual, 5Ω Analog Switches

ABSOLUTE MAXIMUM RATINGS

(Voltages Referenced to GND)
V+ to GND ....-0.3V to +44V
V- to GND ....+0.3V to -44V
V+ to V- ....-0.3V to +44V
V_L to GND ....-0.3V to (V+ + 0.3V)
All Other Pins to GND (Note 1) .... (V- - 0.3V) to (V+ + 0.3V)
Continuous Current (COM_, NO_, NC_) ....±100mA
Peak Current (COM_, NO_, NC_)
(pulsed at 1ms, 10% duty cycle) .... ±300mA

Continuous Power Dissipation (T_A = +70°C)
Narrow SO (derate 8.70mW/°C above +70°C) 696mW
Narrow DIP (derate 10.53mW/°C above +70°C) 842mW
Operating Temperature Ranges
MAX462_C_ _ ....0°C to +70°C
MAX462_E_ _....................-40°C to +85°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10sec) ....+300°C

Note 1: Signals on NO_, NC_, or COM_ exceeding V+ or V- are clamped by internal diodes. Limit forward-diode current to maximum current rating.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—Dual Supplies

(V+ = +15V, V- = -15V, V_L = +5V, GND = 0, V_{INH} = +2.4V, V_{INL} = +0.8V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
ANALOG SWITCH							
Input Voltage Range (Note 3)	$V_{COM\_}$, $V_{NO\_}$, $V_{NC\_}$			V-		V+	V
On-Resistance	R_{ON}	$I_{COM\_}$ = 10mA, $V_{NO\_}$ or $V_{NC\_}$ = ±10V	T_A = +25°C		3	5	Ω
			T_A = T_{MIN} to T_{MAX}			7	
On-Resistance Match Between Channels (Notes 3, 4)	ΔR_{ON}	$I_{COM\_}$ = 10mA, $V_{NO\_}$ or $V_{NC\_}$ = ±10V	T_A = +25°C		0.25	0.5	Ω
			T_A = T_{MIN} to T_{MAX}			0.7	
On-Resistance Flatness (Notes 3, 5)	$R_{FLAT(ON)}$	$I_{COM\_}$ = 10mA; $V_{NO\_}$ or $V_{NC\_}$ = -5V, 0, 5V	T_A = +25°C		0.2	0.5	Ω
			T_A = T_{MIN} to T_{MAX}			0.7	
Off-Leakage Current (NO_ or NC_) (Note 6)	$I_{NO\_}$, $I_{NC\_}$	$V_{NO\_}$ or $V_{NC\_}$ = ±10V, $V_{COM\_}$ = ∓10V	T_A = +25°C	-0.5	0.01	0.5	nA
			T_A = T_{MIN} to T_{MAX}	-5		5	
COM_ Off-Leakage Current (Note 6)	$I_{COM\_(OFF)}$	$V_{COM\_}$ = ±10V, $V_{NO\_}$ or $V_{NC\_}$ = ∓10V	T_A = +25°C	-0.5	0.01	0.5	nA
			T_A = T_{MIN} to T_{MAX}	-5		5	
COM_ On-Leakage Current (Note 6)	$I_{COM\_(ON)}$	$V_{COM\_}$ = ±10V, $V_{NO\_}$ or $V_{NC\_}$ = ∓10V or floating	T_A = +25°C	-1	0.02	1	nA
			T_A = T_{MIN} to T_{MAX}	-10		10	
LOGIC INPUT							
Input Current with Input Voltage High	I_{INH}	$V_{IN\_}$ = 2.4V		-0.5	0.001	0.5	µA
Input Current with Input Voltage Low	I_{INL}	$V_{IN\_}$ = 0.8V		-0.5	0.001	0.5	µA
Logic Input Voltage High	V_{INH}			2.4			V
Logic Input Voltage Low	V_{INL}					0.8	V

ELECTRICAL CHARACTERISTICS—Dual Supplies (continued)

($V+ = +15V$, $V- = -15V$, $V_L = +5V$, GND = 0, $V_{INH} = +2.4V$, $V_{INL} = +0.8V$, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are at $T_A = +25°C$.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
POWER SUPPLY							
Power-Supply Range				±4.5		±20.0	V
Positive Supply Current	I+	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Negative Supply Current	I-	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Logic Supply Current	I_L	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Ground Current	I_{GND}	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
SWITCH DYNAMIC CHARACTERISTICS							
Turn-On Time	t_{ON}	$V_{COM\_}$ = ±10V, Figure 2	$T_A = +25°C$		120	250	ns
			$T_A = T_{MIN}$ to T_{MAX}			325	
Turn-Off Time	t_{OFF}	$V_{COM\_}$ = ±10V, Figure 2	$T_A = +25°C$		90	200	ns
			$T_A = T_{MIN}$ to T_{MAX}			275	
Break-Before-Make Time Delay (MAX4622 only)	t_D	$V_{COM\_}$ = ±10V, Figure 3, $T_A = +25°C$		5	25		ns
Charge Injection	Q	C_L = 1.0nF, V_{GEN} = 0, R_{GEN} = 0, Figure 4, $T_A = +25°C$			480		pC
Off-Isolation (Note 7)	V_{ISO}	$R_L = 50Ω$, f = 1MHz, Figure 5, $T_A = +25°C$			-62		dB
Crosstalk (Note 8)	V_{CT}	$R_L = 50Ω$, f = 1MHz, Figure 6, $T_A = +25°C$			-60		dB
NC_ or NO_ Capacitance	C_{OFF}	f = 1MHz, Figure 7, $T_A = +25°C$			34		pF
COM_ Off-Capacitance	C_{COM}	f = 1MHz, Figure 7, $T_A = +25°C$			34		pF
On-Capacitance	C_{COM}	f = 1MHz, Figure 8, $T_A = +25°C$			150		pF

ELECTRICAL CHARACTERISTICS—Single Supply

($V+ = +12V$, $V- = 0$, $V_L = +5V$, GND = 0, $V_{INH} = +2.4V$, $V_{INL} = +0.8V$, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are $T_A = +25°C$.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
ANALOG SWITCH							
Input Voltage Range (Note 3)	$V_{COM\_}$, $V_{NO\_}$, $V_{NC\_}$			GND		V+	V
On-Resistance	R_{ON}	$I_{COM\_}$ = 10mA, $V_{NO\_}$ or $V_{NC\_}$ = 10V	$T_A = +25°C$		5.5	8	Ω
			$T_A = T_{MIN}$ to T_{MAX}			10	
On-Resistance Match Between Channels (Notes 3, 4)	ΔR_{ON}	$I_{COM\_}$ = 10mA, $V_{NO\_}$ or $V_{NC\_}$ = 10V, $T_A = +25°C$			0.2	0.5	Ω
On-Resistance Flatness (Notes 3, 5)	$R_{FLAT(ON)}$	$I_{COM\_}$ = 10mA; $V_{NO\_}$ or $V_{NC\_}$ = 3V, 6V, 9V; $T_A = +25°C$			0.9	1.3	Ω
NO_ or NC_ Off-Leakage Current (Notes 6, 9)	$I_{NO\_(OFF)}$, $I_{NC\_(OFF)}$	$V_{COM\_}$ = 1V, 10V; $V_{NO\_}$ or $V_{NC\_}$ = 10V, 1V	$T_A = +25°C$	-0.5	0.01	0.5	nA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
COM_ Off-Leakage Current (Notes 6, 9)	$I_{COM\_(OFF)}$	$V_{COM\_}$ = 10V, 1V; $V_{NO\_}$ or $V_{NC\_}$ = 1V, 10V	$T_A = +25°C$	-0.5	0.01	0.5	nA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
COM_ On-Leakage Current (Notes 6, 9)	$I_{COM\_(ON)}$	$V_{COM\_}$ = 10V, 1V; $V_{NO\_}$ or $V_{NC\_}$ = 10V, 1V, or floating	$T_A = +25°C$	-1	0.02	1	nA
			$T_A = T_{MIN}$ to T_{MAX}	-10		10	
LOGIC INPUT							
Input Current with Input Voltage High	I_{INH}	$V_{IN\_}$ = 2.4V		-0.5	0.001	0.5	µA
Input Current with Input Voltage Low	I_{INL}	$V_{IN\_}$ = 0.8V		-0.5	0.001	0.5	µA
Logic Input Voltage High	V_{INH}			2.4			V
Logic Input Voltage Low	V_{INL}					0.8	V
POWER SUPPLY							
Power-Supply Range				4.5		36.0	V
Positive Supply Current	I+	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Logic Supply Current	I_L	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Ground Current	I_{GND}	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	

ELECTRICAL CHARACTERISTICS—Single Supply (continued)

($V+ = +12V$, $V- = 0$, $V_L = +5V$, $GND = 0$, $V_{INH} = +2.4V$, $V_{INL} = +0.8V$, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are $T_A = +25°C$.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
SWITCH DYNAMIC CHARACTERISTICS							
Turn-On Time (Note 3)	t_{ON}	$V_{COM\_} = 10V$, Figure 2	$T_A = +25°C$		200	350	ns
			$T_A = T_{MIN}$ to T_{MAX}			475	
Turn-Off Time (Note 3)	t_{OFF}	$V_{COM\_} = 10V$, Figure 2	$T_A = +25°C$		100	200	ns
			$T_A = T_{MIN}$ to T_{MAX}			300	
Break-Before-Make Time Delay (MAX4622 only) (Note 3)	t_D	$R_L = 100\Omega$, $C_L = 35pF$, Figure 3, $T_A = +25°C$		10	75		ns
Charge Injection	Q	$C_L = 1.0nF$, $V_{GEN} = 0$, $R_{GEN} = 0$, Figure 4			45		pC
Off-Isolation (Note 7)	V_{ISO}	$R_L = 50\Omega$, f = 1MHz, Figure 5			-62		dB
Crosstalk (Note 8)	V_{CT}	$R_L = 50\Omega$, f = 1MHz, Figure 6			-60		dB

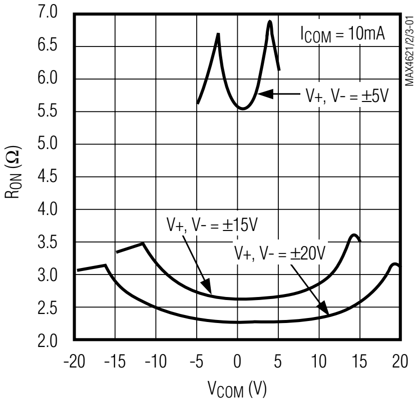
Note 2: The algebraic convention, where the most negative value is a minimum and the most positive value is a maximum, is used in this data sheet.
Note 3: Guaranteed by design.
Note 4: $\Delta R_{ON} = R_{ON\_MAX} - R_{ON\_MIN}$.
Note 5: Flatness is defined as the difference between the maximum and minimum values of on-resistance as measured over the specified analog signal range.
Note 6: Leakage currents are 100% tested at the maximum-rated hot temperature and guaranteed by correlation at +25°C.
Note 7: Off-isolation = $20\log_{10} [V_{COM\_} / (V_{NC\_}$ or $V_{NO\_})]$. $V_{COM\_}$ = output, $V_{NC\_}$ or $V_{NO\_}$ = input to off switch.
Note 8: Between any two switches.
Note 9: Leakage testing for single-supply operation is guaranteed by testing with dual supplies.

Dual, 5Ω Analog Switches

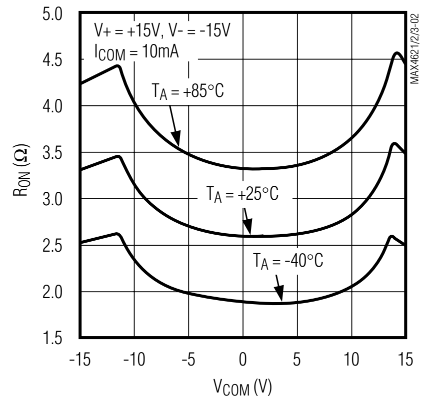
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

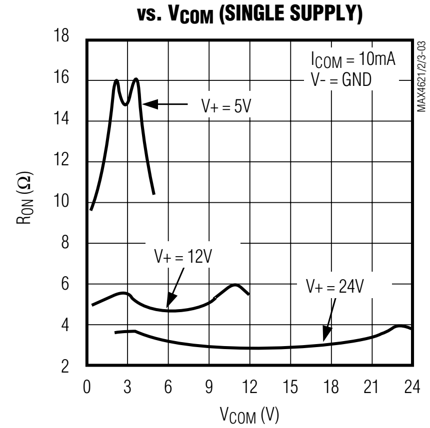
ON-RESISTANCE vs. V_{COM} (DUAL SUPPLIES)



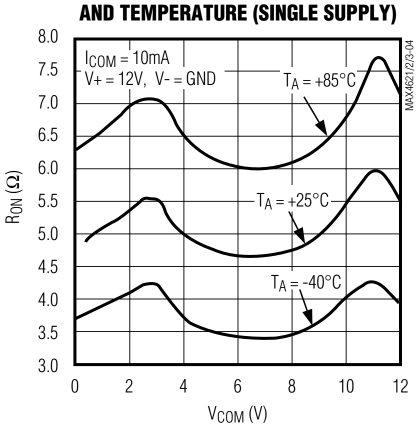
ON-RESISTANCE vs. V_{COM} AND TEMPERATURE (DUAL SUPPLIES)



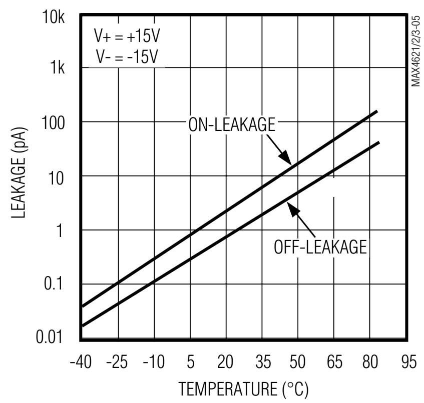
ON-RESISTANCE vs. V_{COM} (SINGLE SUPPLY)



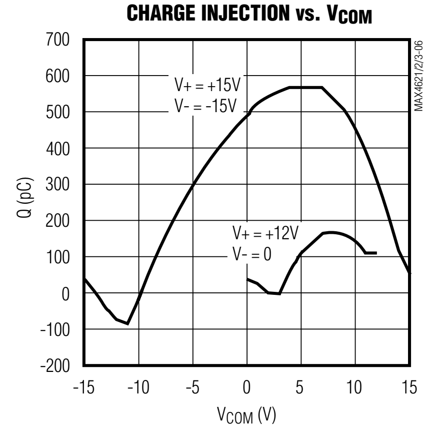
ON-RESISTANCE vs. V_{COM} AND TEMPERATURE (SINGLE SUPPLY)



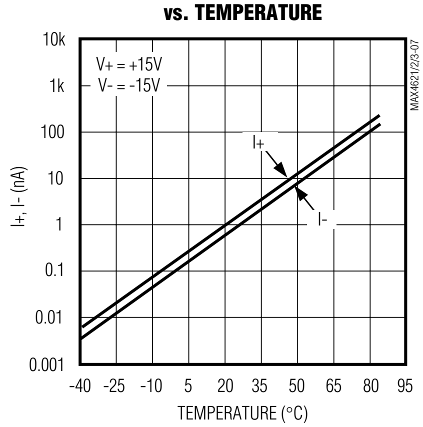
ON/OFF-LEAKAGE CURRENT vs. TEMPERATURE



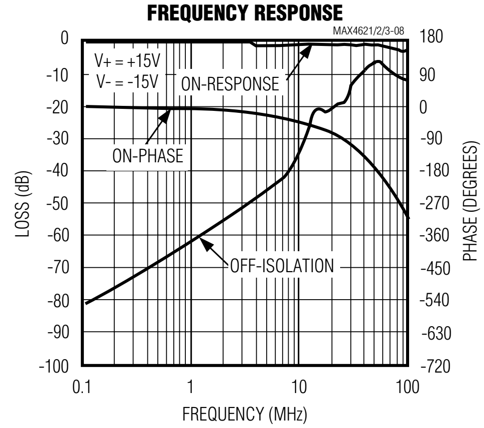
CHARGE INJECTION vs. V_{COM}



SUPPLY CURRENT vs. TEMPERATURE



FREQUENCY RESPONSE



Pin Description

PIN	NAME	FUNCTION
MAX4621		
1, 8	COM1, COM2	Switch Common Terminal
2–7	N.C.	Not internally connected
9, 16	NO2, NO1	Switch Normally Open Terminal
10, 15	IN2, IN1	Digital Logic Inputs
11	V+	Positive Supply-Voltage Input
12	V_L	Logic Supply-Voltage Input
13	GND	Ground
14	V-	Negative Supply Voltage Input
MAX4622		
1, 3, 6, 8	COM_	Switch Common Terminal
2, 7	N.C.	Not internally connected
4, 5, 9, 16	NC_, NO_	Switch Normally Closed/Open Terminal
10, 15	IN2, IN1	Digital Logic Inputs
11	V+	Positive Supply-Voltage Input
12	V_L	Logic Supply-Voltage Input
13	GND	Ground
14	V-	Negative Supply Voltage Input
MAX4623		
1, 3, 6, 8	COM_	Switch Common Terminal
2, 7	N.C.	Not internally connected
4, 5, 9, 16	NO_	Switch Normally Open Terminal
10, 15	IN2, IN1	Digital Logic Inputs
11	V+	Positive Supply-Voltage Input
12	V_L	Logic Supply-Voltage Input
13	GND	Ground
14	V-	Negative Supply Voltage

Applications Information

Operation with Supply Voltages Other than ±15V

The MAX4621/MAX4622/MAX4623 switches operate with ±4.5V to ±18V bipolar supplies and a +4.5V to +36V single supply. In either case, analog signals ranging from V+ to V- can be switched. The *Typical Operating Characteristics* graphs show the typical on-resistance variation with analog signal and supply voltage.

Overvoltage Protection

Proper power-supply sequencing is recommended for all CMOS devices. It is important not to exceed the absolute maximum ratings because stresses beyond the listed ratings may cause permanent damage to the devices. Always sequence V+ on first, followed by V_L, V-, and logic inputs. If power-supply sequencing is not possible, add two small signal diodes in series with the supply pins and a Schottky diode between V+ and V_L (Figure 1). Adding diodes reduces the analog signal range to 1V below V+ and 1V above V-, but low switch resistance and low leakage characteristics are unaffected. The difference between V+ and V- should not exceed +44V.

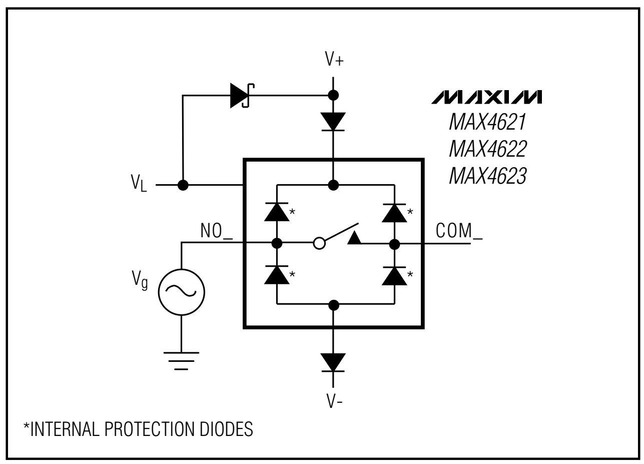


Figure 1. Overvoltage Protection Using Blocking Diodes

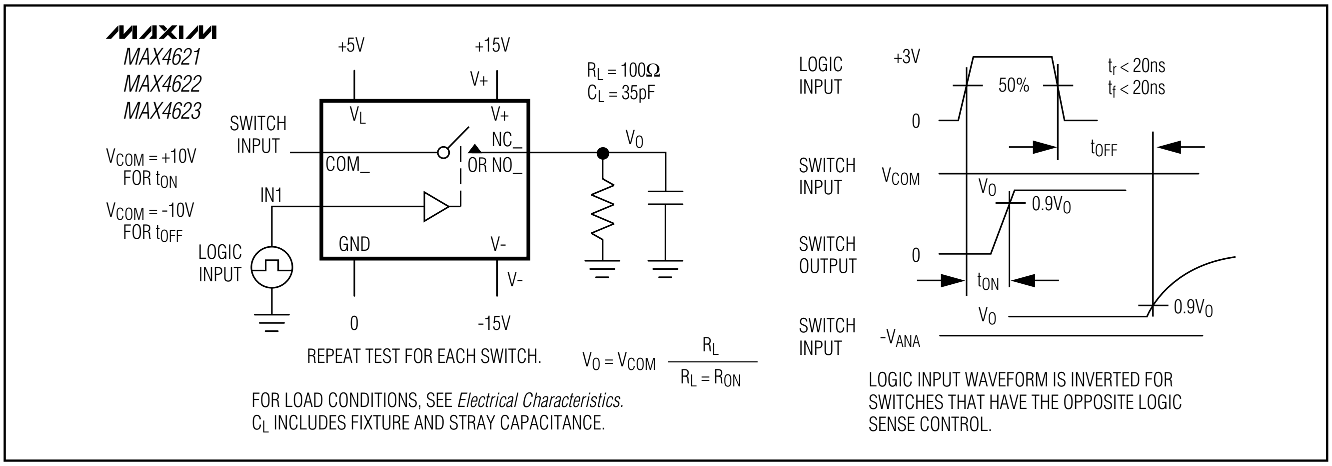


Figure 2. Switching-Time Test Circuit

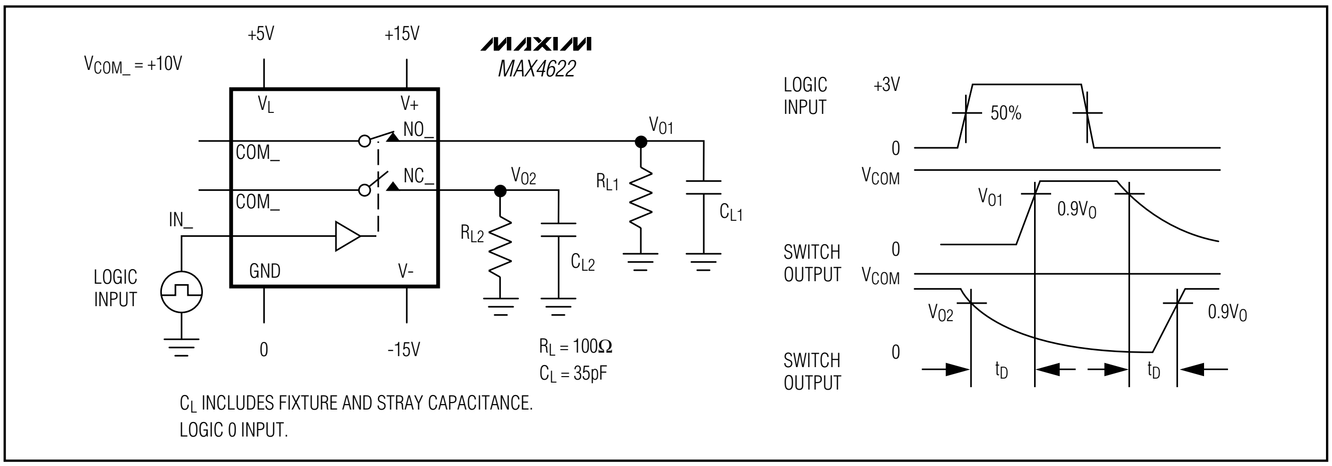


Figure 3. MAX4622 Break-Before-Make Test Circuit

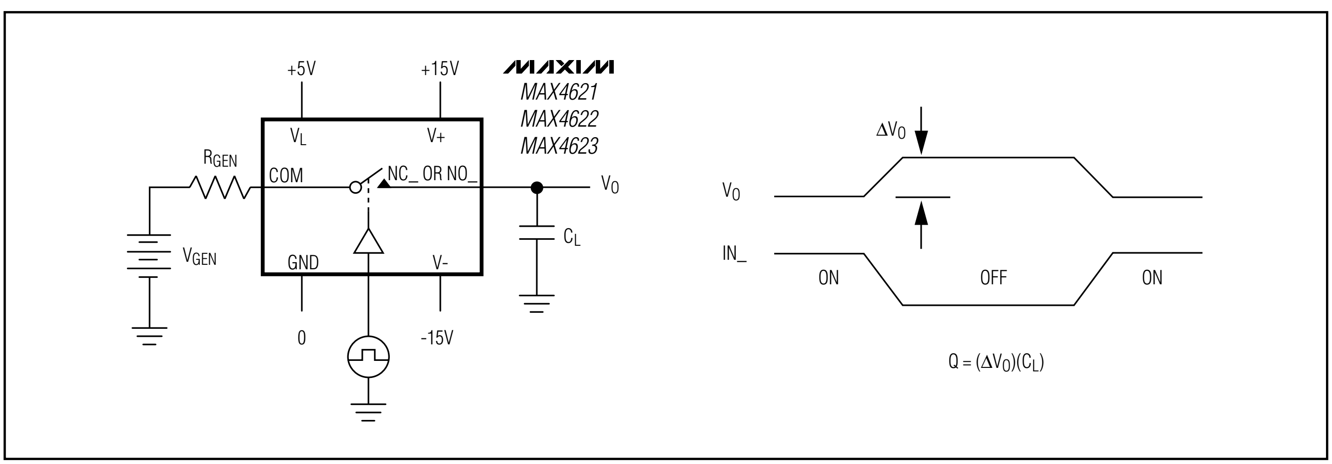
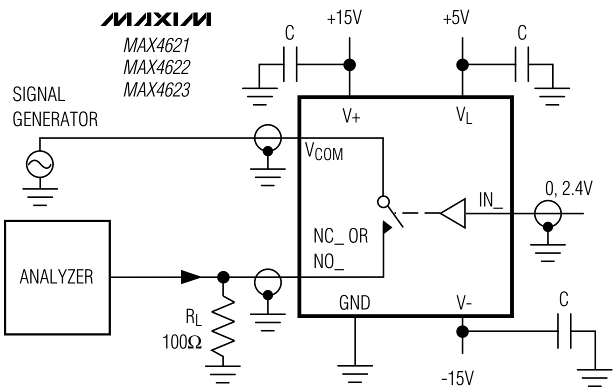


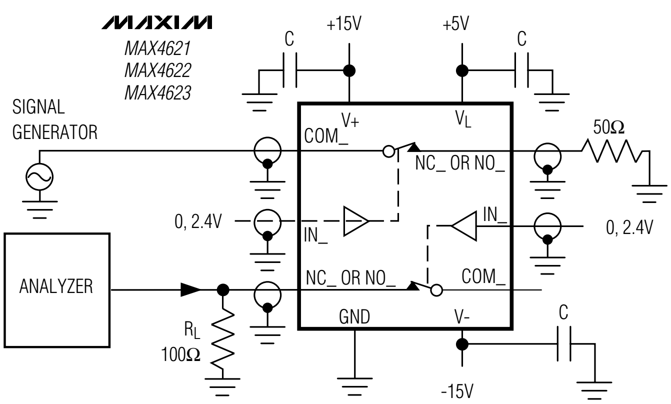
Figure 4. Charge-Injection Test Circuit



FREQUENCY TESTED	SIGNAL GENERATOR	ANALYZER
1MHz	AUTOMATIC SYNTHESIZER	TRACKING SPECTRUM ANALYZER

$$\text{OFF-ISOLATION} = 20\text{LOG} \frac{V_{COM}}{V_{NC} \text{ OR } V_{NO}}$$

Figure 5. Off-Isolation



FREQUENCY TESTED	SIGNAL GENERATOR	ANALYZER
1MHz	AUTOMATIC SYNTHESIZER	TRACKING SPECTRUM ANALYZER

Figure 6. Crosstalk Test Circuit

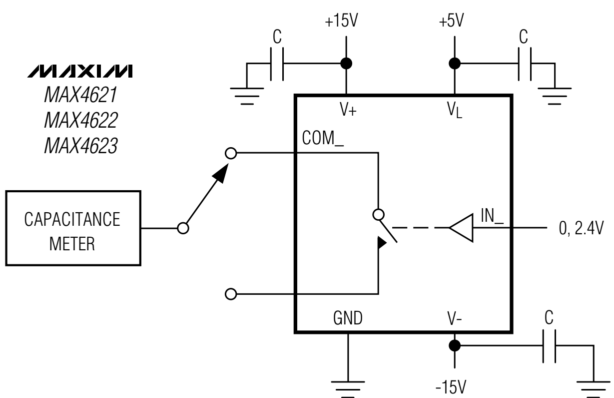


Figure 7. Channel-On Capacitance

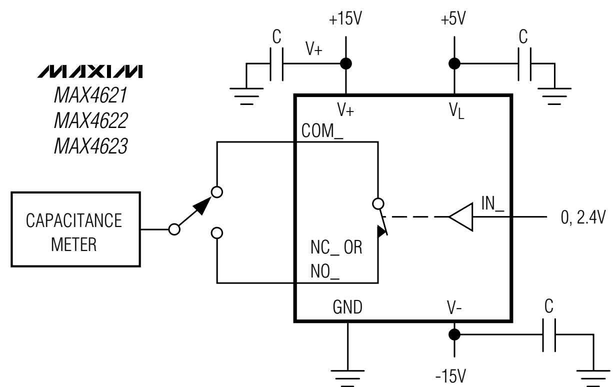


Figure 8. Channel-Off Capacitance

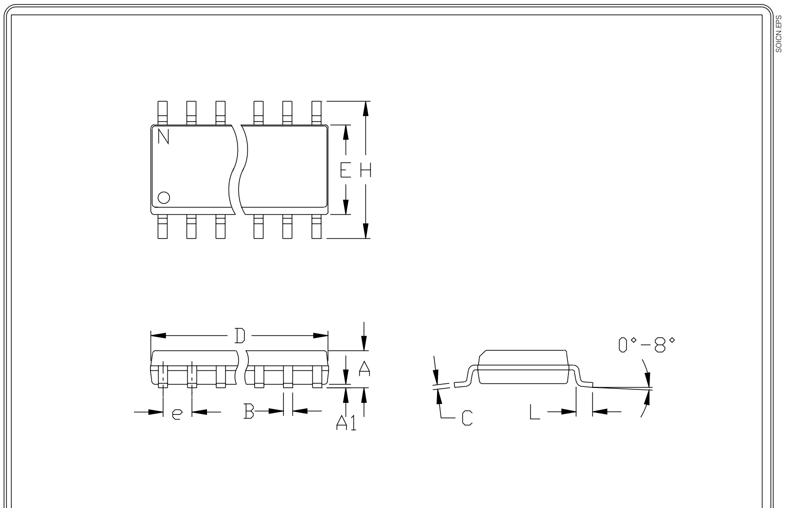
Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE
MAX4621ESE	-40°C to +85°C	16 Narrow SO
MAX4621EPE	-40°C to +85°C	16 Plastic DIP
MAX4622CSE	0°C to +70°C	16 Narrow SO
MAX4622CPE	0°C to +70°C	16 Plastic DIP
MAX4622ESE	-40°C to +85°C	16 Narrow SO
MAX4622EPE	-40°C to +85°C	16 Plastic DIP
MAX4623CSE	0°C to +70°C	16 Narrow SO
MAX4623CPE	0°C to +70°C	16 Plastic DIP
MAX4623ESE	-40°C to +85°C	16 Narrow SO
MAX4623EPE	-40°C to +85°C	16 Plastic DIP

Chip Information

TRANSISTOR COUNT: 82

Package Information



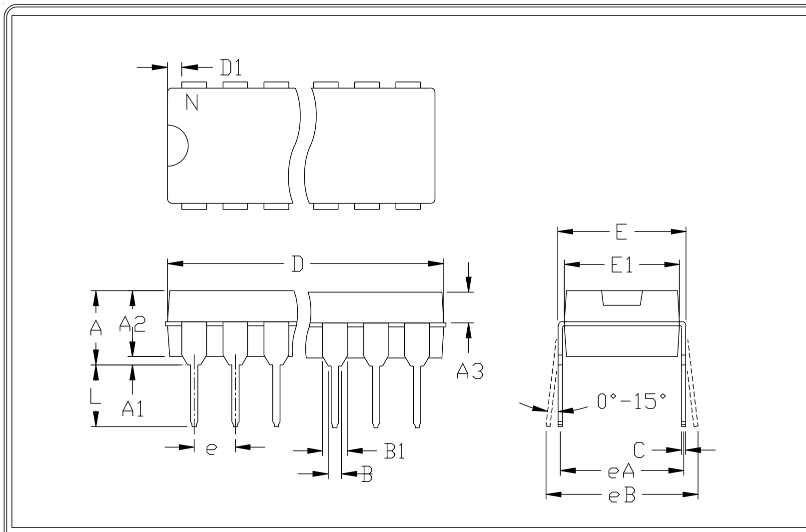
	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.004	0.010	0.10	0.25
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
e	0.050		1.27	
E	0.150	0.157	3.80	4.00
H	0.228	0.244	5.80	6.20
h	0.010	0.020	0.25	0.50
L	0.016	0.050	0.40	1.27

	INCHES		MILLIMETERS			
	MIN	MAX	MIN	MAX	N	MS012
D	0.189	0.197	4.80	5.00	8	A
D	0.337	0.344	8.55	8.75	14	B
D	0.386	0.394	9.80	10.00	16	C

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. LEADS TO BE COPLANAR WITHIN .102mm (.004")
4. CONTROLLING DIMENSION: MILLIMETER
5. MEETS JEDEC MS012-XX AS SHOWN IN ABOVE TABLE
6. N = NUMBER OF PINS

MAXIM 120 SAN GABRIEL DR. SUNNYVALE CA 94086 FAX (408) 737 7194 PROPRIETARY INFORMATION | TITLE: PACKAGE FAMILY OUTLINE: SOIC .150" | 1/1 | DOCUMENT CONTROL NUMBER 21-0041 REV A

Package Information (continued)



	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	---	0.200	---	5.08
A1	0.015	---	0.38	---
A2	0.125	0.175	3.18	4.45
A3	0.055	0.080	1.40	2.03
B	0.016	0.022	0.41	0.56
B1	0.045	0.065	1.14	1.65
C	0.008	0.012	0.20	0.30
D1	0.005	0.080	0.13	2.03
E	0.300	0.325	7.62	8.26
E1	0.240	0.310	6.10	7.87
e	0.100	---	2.54	---
eA	0.300	---	7.62	---
eB	---	0.400	---	10.16
L	0.115	0.150	2.92	3.81

	INCHES		MILLIMETERS			
	MIN	MAX	MIN	MAX	N	MS001
D	0.348	0.390	8.84	9.91	8	AB
D	0.735	0.765	18.67	19.43	14	AC
D	0.745	0.765	18.92	19.43	16	AA
D	0.885	0.915	22.48	23.24	18	AD
D	1.015	1.045	25.78	26.54	20	AE
D	1.14	1.265	28.96	32.13	24	AF
D	1.360	1.380	34.54	35.05	28	*5

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. CONTROLLING DIMENSION: MILLIMETER
4. MEETS JEDEC MS001-XX AS SHOWN IN ABOVE TABLE
5. SIMILIAR TO JEDEC MO-058AB
6. N = NUMBER OF PINS

MAXIM
120 SAN GABRIEL DR. SUNNYVALE CA 94086 FAX (408) 737 7194
PROPRIETARY INFORMATION

TITLE: PACKAGE FAMILY OUTLINE: PDIP .300"

1/1

DOCUMENT CONTROL NUMBER: 21-0043 REV: A

NOTES

Flags Used from Bit Addressable Ram
Communications Microcontroller

Flag	Description
00H	Set after first reading is stored as a reference value
01H	Set when the last cycle, for the high register for the number of bars, are to be run
02H	Indicates that the system was paused
03H	Indicates to the “Wait for reading signal” loop that an error occurred
04H	Indicates to Reading Sub that the system is in manual mode & the Communications Microcontroller must not try to communicate with the Automation Microcontroller
05H	Indicates to the Reading subroutine that multiple readings are being taken and therefore the Communications Microcontroller must not try to communicate with the Automation Microcontroller

Flags Used from Bit Addressable Ram
Automation Microcontroller

Flag	Description
00H	FOR 3rd BAR PROCESS
01H	FOR 3rd BAR PROCESS
02H	FOR 3rd BAR PROCESS
03H	FOR TIMER CYCLE COMPLETE – INDICATES ERROR1
04H	FLAG - EXTERNAL INTERRUPT 1
05H	TAKE TIMER READING ON 3RD BAR IN EX1ISR
~~06H~~	~~ON 1ST LOWERING OF DETECTION UNIT.~~
07H	FOR TIMER CYCLE COMPLETE – INDICATES ERROR2
08H	EXTERNAL INTERRUPT 0
09H	To Indicate Pause has been entered
0AH	To indicate to the Error 4 subroutine that Error 2 has occurred
0BH	To indicate to Error 2 subroutine that Error 4 has occurred
0CH	To Indicate to External Interrupt 0 that Run_Up subroutine was running when interrupted, and the timer value must not be logged.
0DH	To indicate that error3 occurred and if there is a Run up error (error4) It must be ignored, so that power down is entered
0EH	Set in ERROR READING PROCEDURE Subroutine to indicate to EX0 that interrupt was triggered in this subroutine, and must be ignored.

Flag 06H was used because a stored value was reloaded for both the up and down count. On the first down count there is no stored value, so this flag is not set, and the 10s default value is loaded. But now a value is stored on the down count and reloaded for the up count. The flag is therefore no longer needed.

Input / Output Port Utilization
Communications Microcontroller – Communication & Signaling

Communications Microcontroller (CM) – Communication & Signaling	
Port Number	**Utilization**
Port 0	
P0.0 (39)	**O** – Start / Analogue Switch on ADC line
P0.1 (38)	**O** – End
P0.2 (37)	I – Over-voltage Detection on the ADC In line
P0.3 (36)	**O** – Take Reading (Manual)
P0.4 (35)	**O** – Continue After Reading (Manual) & Communication with AM
P0.5 (34)	**O** – Emergency Stop from GUI
P0.6 (33)	**O** – Automatic / Manual Toggle To u2➔ 0 = MAN, 1 =AUTO
P0.7 (32)	**O** – Continue After Reading (Automatic)
Port 1	
P1.0 (1)	**I** – A to D line
P1.1 (2)	**I** – A to D line
P1.2 (3)	**I** – A to D line
P1.3 (4)	**I** – A to D line
P1.4 (5)	**I** – A to D line
P1.5 (6)	**I** – A to D line
P1.6 (7)	**I** – A to D line
P1.7 (8)	**I** – A to D line
Port 2	
P2.0 (21)	**O – ADC R/C pin**
P2.1 (22)	**I – ADC Waits for Low pulse from EOC – conversion complete**
P2.2 (23)	**I** – Take Reading (Automatic) & Communication with AM
P2.3 (24)	**I** – Increment No. Of Bars
P2.4 (25)	**I** – Error 1 – Pair Not Detected.
P2.5 (26)	**I** – Error 2 – Test Probes Not Lowered.
P2.6 (27)	**I** – Error 3 – Current On-Time Exceeded.
P2.7 (28)	**O** – Not Last Pair
Port 3	
P3.0 (10)	**Serial Communication**
P3.1 (11)	**Serial Communication**
P3.2 (12)	**I – External Interrupt 0** – All Error Inputs Connected here as well/ manual emergency stop & Safety Interlocks connected to AM P1.5 as well.
P3.3 (13)	**O – ADC HBEN pin**
P3.4 (14)	**I** – Error 4 – Test Probes Not Raised
P3.5 (15)	**O – ADC CS pin**
P3.6 (16)	I – Take Manual Reading Switch
P3.7 (17)	O – Led to indicate that the system is ready after power on and ADC initialization

Input / Output Port Utilization

Automation Microcontroller – Automation Control

Automation Microcontroller (AM) – Automation Control	
Port Number	**Utilization**
	Port 0
P0.0 (39)	**O** – Take Reading (Automatic)
P0.1 (38)	**O** – Increment No. Of Bars
P0.2 (37)	**O** – Detection Unit Motor (Up)
P0.3 (36)	**O** – Detection Unit Motor (Down)
P0.4 (35)	**O** – Armature Drive Motor
P0.5 (34)	**O** – Set to clear D-FF on test detection signal (connected to CLR)
P0.6 (33)	
P0.7 (32)	
	Port 1
P1.0 (1)	**I** – Start
P1.1 (2)	**I** – End
P1.2 (3)	
P1.3 (4)	**I** – Take Reading (Manual)
P1.4 (5)	**I** – Continue Test (Manual)
P1.5 (6)	**I** – Emergency Stop & Safety Interlocks (Connect to ex0 of this uC as well)
P1.6 (7)	**I** – Automatic / Manual Toggle From u1
P1.7 (8)	**I** – Continue After Reading (Automatic)
	Port 2
P2.0 (21)	O – Led to indicate probes r on the com b4 the current is to be switched on
P2.1 (22)	O - Led to indicate probes r on the com b4 the current is to be switched off
P2.2 (23)	
P2.3 (24)	
P2.4 (25)	
P2.5 (26)	
P2.6 (27)	**O** – Error 4 – Test Probes Not Raised.
P2.7 (28)	**O** – Switch Test Current
	Port 3
P3.0 (10)	**I** – Not Last Pair
P3.1 (11)	**I** – Current On-Time Exceeded
P3.2 (12)	**I** – **External Interrupt 0** – Test Probe Switch (Lowered) & Emergency Stop from CM and AM P1.5
P3.3 (13)	**I** – **External Interrupt 1** – Bar Detection
P3.4 (14)	
P3.5 (15)	**O** – Error 1 – Pair Not Detected.
P3.6 (16)	**O** – Error 2 – Test Probes Not Lowered.
P3.7 (17)	**O** – Error 3 – Current On-Time Exceeded.

Register Utilization
Communications Microcontroller

Register Bank 0	
Register – R0	High byte for number of bars
Register – R1	Low byte for number of bars
Register – R2	Value for percentage variance from first reading
Register – R3	Holds the low byte 8-bit word from the A-D converter
Register – R4	Holds the reference value (i.e. the first reading)
Register – R5	Holds the high byte from adc
Register – R6	Holds reference value minus the specified percentage variance
Register – R7	
Register Bank 1	
Register – R0	Holds P0 values when the system is paused
Register – R1	Holds P1 values when the system is paused
Register – R2	Holds P2 values when the system is paused
Register – R3	Holds P3 values when the system is paused
Register – R4	Used for > 10ms delay for ADC’s internal ref to “Wake”
Register – R5	Used for > 10ms delay for ADC’s internal ref to “Wake”
Register – R6	Used along with R4 and R5 to create a 1s delay after uC1 starts. This is for the tri-state buffers
Register – R7	

Registers Used – Microcontroller 2 – Automation

Register Bank 0	
Register – R0	DELAYLOOP, LOOP COUNT
Register – R1	LOAD TIMER HIGH REGISTER, SAFETY & RECORDING ON 3RD BAR
Register – R2	LOAD TIMER LOW REGISTER, SAFETY & RECORDING ON 3RD BAR
Register – R3	LOOP COUNT SAFETY AND RECORDING ON 3RD BAR
Register – R4	HIGH BYTE OF TIMER VALUE TAKEN ON 3RD BAR
Register – R5	LOW BYTE OF TIMER VALUE TAKEN ON 3RD BAR
Register – R6	LOOP COUNT FOR RECORDING ON 3RD BAR
Register – R7	LOOP COUNT FOR THE DETECTION UNIT
Register Bank 1	
Register – R0	LOAD TIMER HIGH REGISTER, FOR THE DETECTION UNIT
Register – R1	LOAD TIMER LOW REGISTER, FOR THE DETECTION UNIT
Register – R2	Holds P0 values when the system is paused
Register – R3	Holds P1 values when the system is paused
Register – R4	Holds P2 values when the system is paused
Register – R5	Holds P3 values when the system is paused
Register – R6	LOAD TIMER HIGH REGISTER, FOR THE DETECTION UNIT
Register – R7	LOAD TIMER LOW REGISTER, FOR THE DETECTION UNIT
Register Bank 2	
Register – R0	
Register – R1	
Register – R2	
Register – R3	
Register – R4	
Register – R5	
Register – R6	
Register – R7	
Register Bank 3	
Register – R0	
Register – R1	
Register – R2	
Register – R3	
Register – R4	
Register – R5	
Register – R6	
Register – R7	

```
;Date Last modified : 09-01-06
;Date Last modified : 07-03-06
;Date Last modified : 08-03-06
;Date Last modified : 23-03-06
;Date Last modified : 21-04-06


        ORG     0H
        LJMP    MAIN
        ORG     0003H
        LJMP    EX0ISR
        ORG     0023H
        LJMP    SPISR


        ORG     0030H
;****************************iNTILIZE I/O PORTS ****************************

MAIN:   MOV     P0,#00000100B
        MOV     P1,#11111111B
        MOV     P2,#01111110B
        MOV     P3,#01010111B ; (rEC & tRANS PORTS SET TO 1), only for sim
;****************************iNTILIZE I/O PORTS ****************************

        SETB    P3.5

        CLR     RS0                 ;1S
        SETB    RS1
        MOV     R6,#50
DLY3:   mov     r5,#100
dly:    mov     r4,#100
dly2:   djnz    r4,dly2
        djnz    r5,dly
        DJNZ    R6,DLY3
        CLR     RS0
        CLR     RS1                 ; 1S


        CLR     00H ;CLEARING FLAGS
        CLR     01H
        CLR     02H
        CLR     03H
        CLR     04H
        CLR     05H

;****************************iNTILIZE ADC - DUMMY RUN ********************
        CLR     P2.0
        NOP
        CLR     P3.5

        CLR     RS0                 ;20US
        SETB    RS1
        MOV     R6,#20
D1:     DJNZ    R6,D1
        CLR     RS0
        CLR     RS1                 ;20US
```

```
RDG_SUB_DUMMY:NOP
        CLR     RS0                 ;TIME 4 INTERNAL REF TO "WAKE UP" AFTER SI
        SETB    RS1
        mov     r5,#100
adc_2nd:mov     r4,#100
adc_dly:djnz    r4,adc_dly
        djnz    r5,adc_2nd
        CLR     RS0
        CLR     RS1                 ;TIME 4 INTERNAL REF TO "WAKE UP" AFTER SI



        SETB    P3.5; CS


        CLR     P2.0
        NOP             ; EXTRA TIME BEFORE CS IS FORCED LOW, NOT REALLY N
        CLR     P3.5; AQUISITAION MODE, p3,5 cleared 1us after p2.0 (1mach

ADC_W_DUMMY:  JB        P2.1,ADC_W_DUMMY      ;EOC'

        SETB    P3.5
        SETB    P3.7

        CLR     RS0                 ;20US
        SETB    RS1
        MOV     R6,#20
D2:     DJNZ    R6,D2
        CLR     RS0
        CLR     RS1                 ;20US


        SETB    P2.0; TO PUT DATA OUT
        NOP             ; EXTRA TIME BEFORE CS IS FORCED LOW, NOT REALLY NI
        CLR     P3.5;***(CS fALLING eDGE 3)

        CLR     RS0                 ;20US
        SETB    RS1
        MOV     R6,#20
D3:     DJNZ    R6,D3
        CLR     RS0
        CLR     RS1                 ;20US

        NOP             ;WAIT FOR VALID DATA,Tdo+Tdv (tdv = 0)
        CLR     P3.3;   ;HBEN - LOW BYTE
        NOP             ;tdo1, MAY NEED MORE TIME
        NOP
        SETB    P3.3    ;HBEN - HIGH BYTE
        NOP             ;tdo1, MAT NEED MORE TIME
        NOP
        SETB    P3.5;   ***(CS 1ST RISING EDGE AFTER fALLING eDGE 3)
;**************************iNTILIZE ADC - DUMMY RUN ********************
```

```
;*************************************************************
;    MAIN - SERIAL INITIALIZITION - no PARITY - IN/OUT CHAR
;*************************************************************
MAIN2:  MOV     SCON,#01010000B
        MOV     TMOD,#20H
        MOV     TH1,#-13
        SETB    TR1

        MOV     IE,#10000000B
        MOV     IP,#00010000B; SET SP AT HIGHER PRIORIYY THAN EX0
        SETB    IT0 ;NEGATIVE EDE TRIGGERED
        ;SETB    TR1
        ;SETB    P2.0
        SETB    ES
        JMP     START


CH_OUT: CLR     ES


        MOV     SBUF,A
        ;CLR     ACC.7 ;may not need 21/11, but check
TX2:    JNB     TI,TX2
        CLR     TI
        SETB    ES ; COME BACK TO THIS
        RET



;*************************************************************
;  RECIEVING TEST DATA
;*************************************************************

START:  cjne    A,#'A',CAL ; SRL1, wait for all the data to be in the nb b
        JMP     NB_AM
CAL:    CJNE    A,#'H',START ; 4 CALIB
        CLR     P0.6 ;IN MAN MODE FOR CALIBRATION
        SETB    04H
        CALL    RDG_SUB
        CLR     04H
        SETB    P0.6
        JMP     START           ; 4 CALIB

NB_AM:  MOV     A,#'b'; SEND PROMPT, FOR MAN/AUTO
        CALL    CH_OUT

SRL2:   CJNE    A,#'G',X ; G->MAN

; reading is taken each time the man sw is pressed and exits when end is p
        CLR     P0.6
manRsub:NOP
W_ENDx: CJNE    A,#'B',TK_RDx
        LJMP    FINISH
```

```
TK_RDx: JNB      P3.6,manRsub ; MAN SWITCH
TK_RDx2:JB       P3.6,TK_RDx2'
        SETB     04H
        MOV      A,#'I'             ;INC BARS
        CALL     CH_OUT
        CALL     RDG_SUB
        jmp      manRsub



X:      CJNE     A,#'g',SRL2
        CLR      C; A should hold 'g'
        SETB     P0.6

        MOV      A,#'d'; SEND PROMPT & WAIT FOR START PULSE
        CALL     CH_OUT
WT_STRT:CJNE     A,#'A',WT_STRT ; START PULSE TO U2
        jmp      fstbar
WT_U2ST:JNB      P2.3,WT_U2ST ; LOOP STARTS
fstbar: JMP      BARS

;*************************************************************************
;              INC BARS; using the nb
;*************************************************************************
BARS:   MOV      A,#'I'             ;INC BARS
        CALL     CH_OUT
W_END:  CJNE     A,#'p',sa ;not last bar
        JMP      GO
sa:     cjne     A,#'P',W_END    ;LAST BAR REACHED
        CLR      P2.7 ; to u2 to signal last bar
        jmp      Finish

;DEC NO OF BARS FROM THE TOTAL IN U1 HERE
;ALSO CHECK FOR LAST BAR - IF YES, ALLERT NB
;THEN WAIT FOR THE "END"PULSE FROM NB AND JUMP TO END
;*************************************************************************

GO:     SETB     P0.0; START TO U2 / ANA SW ON


        SETB     P2.7 ;NOT LAST BAR
BGN_TW: JNB      P2.2,BGN_TW ; WAIT TO CHECK IF PULSE WAS RECIEVED
        CLR      P2.7 ; to u2 to signal last bar
        CLR      P0.0, ANA SW OFF

        SETB     EX0
        NOP
        NOP
        NOP
        NOP
WT_RDNG:JNB      P2.2,WT_RDNGE ; WAIT FOR TAKE READING PULSE
        SETB     P0.7; TO U2 TO CONT AFTER READING TAKEN
        NOP
        NOP
        NOP
        CLR      P0.7
```

```
        CALL    RDG_SUB
        JMP     WT_U2ST; LOOP ENDS NORMALLY
WT_RDNGE:JNB    03H,WT_RDNG
        CLR     03H


        JMP     WT_U2ST; LOOP ENDS AFTER ERROR 1 ND 2



;************************************************************************
; EXTERNAL INTERRUPT 0 ISR - FOR ERRORS 1 TO 4 & Emergency Stop
;************************************************************************

EX0ISR: JNB     P2.4,ERR2
        CALL    ER1_SUB
        SETB    03H; FLAG TO INDICATE TO WT_RDNG LOOP THAT EN ERROR OCCURE
        JMP     EX0OUT
ERR2:   JNB     P2.5,ERR3
        CALL    ER2_SUB
        SETB    03H
        JMP     EX0OUT
ERR3:   JNB     P2.6,ERR4
        CALL    ER3_SUB
        JMP     EX0OUT
ERR4:   JNB     P3.4,EX0OUT
        CALL    ER4_SUB
EX0OUT: MOV     A,#'O'              ;MANUAL EMERGENCY STOP
        CALL    CH_OUT
        JMP     EXT
        RETI

;************************************************************************


;************************************************************
;                  READING SUBPROGRAM
;************************************************************

RDG_SUB:NOP

;NEG_TST:JB     P3.6,NO_NEG
;       MOV     A,#'N'
;       CALL    CH_OUT
;NEG_R: CJNE    A,#'C',NEG_R
;       JMP     NEG_TST


NO_NEG: JB      04H,NO_COM
```

```
         JB      05H,NO_COM
WT_RD:   JNB     P2.2,WT_RD ; WAIT FOR CURRENT TO BE SWITCHED BY U2
         SETB    P0.7; TO U2 TO SIGNAL READY TO TAKE READING
         NOP
         NOP
         CLR     P0.7

NO_COM:  NOP


;EXTRA 1S DELAY IN Uc2 (X) 4 INPUT CCTRY

OV_CHK:  JNB     P0.2,DWN ; for pcb, for tst cct, jb p0.2
         JMP     FET_ON
DWN:     LJMP    OVRVOL
FET_ON:  SETB    P0.0 ; ANA SW ON


         CLR     P2.0

         CLR     RS0                 ;20US
         SETB    RS1
         MOV     R6,#24
D4:      DJNZ    R6,D4
         CLR     RS0
         CLR     RS1                 ;20US

         CLR     P3.5; AQUISITAION MODE, p3,5 cleared 1us after p2.0 (1mach

         CLR     RS0                 ;20US
         SETB    RS1
         MOV     R6,#20
D5:      DJNZ    R6,D5
         CLR     RS0
         CLR     RS1                 ;20US
         NOP         ;Tcsl and tdh
         SETB    P3.5

         CLR     RS0                 ;20US
         SETB    RS1
         MOV     R6,#24
D6:      DJNZ    R6,D6
         CLR     RS0
         CLR     RS1                 ;20US

         CLR     P3.5; FOR STANDBY MODE ***(CS fALLING eDGE 2)


ADC_W:   JB      P2.1,ADC_W          ;EOC'

         SETB    P3.5
         SETB    P2.0; TO PUT DATA OUT
         CLR     P3.3;   ;HBEN - LOW BYTE nu 28/11
         NOP             ; EXTRA TIME BEFORE CS IS FORCED LOW, NOT REALLY NI
         CLR     P3.5; ***(CS fALLING eDGE 3)
```

```
          NOP                   ;WAIT FOR VALID DATA,Tdo+Tdv (tdv = 0)
          CLR       P3.3;       ;HBEN - LOW BYTE redundancy

          CLR       RS0                 ;20US
          SETB      RS1
          MOV       R6,#10
D7:       DJNZ      R6,D7
          CLR       RS0
          CLR       RS1                 ;20US        nop

          MOV       R3,P1       ;HOLD L BYT
          SETB      P3.3        ;HBEN - HIGH BYTE
          CLR       RS0                 ;20US
          SETB      RS1
          MOV       R6,#10
D8:       DJNZ      R6,D8
          CLR       RS0
          CLR       RS1                 ;20US

          MOV       R5,P1       ;HOLD H BYT
          SETB      P3.5;       ***(CS 1ST RISING EDGE AFTER fALLING eDGE 3)

NA_CK:    CJNE      R5,#11111111B,OUT_RNG ;CHECK IF NOT ALLOWED CODE
          CJNE      R3,#11111110B,OUT_RNG
          MOV       R5,#11111111B
          MOV       R3,#11111111B

OUT_RNG:MOV         A,#'z'
          CALL      CH_OUT
OUT_H:    MOV       A,R5
          CALL      CH_OUT
          MOV       A,#'y'
          CALL      CH_OUT
OUT_L:    MOV       A,R3
          CALL      CH_OUT
WT_NBCT:CJNE        A,#'E',WT_100C; WAIT FOR CONTINUE FROM NB
          SETB      05H
          JMP       RDG_SUB
WT_100C:CJNE        A,#'S',WT_NBCT; WAIT FOR end of 100 reading cycle FROM NB
          CLR       05H

RDG_END:JB          04H,NO_COM2
          JB        05H,NO_COM2
          SETB      P0.7; TO U2 TO CONT AFTER READING TAKEN
RG_END:   JNB       P2.2,RG_END
          CLR       P0.7
          CLR       P0.0 ;ANA SW OFF
          JMP       NO_COM2

OVRVOL:   MOV       A,#'z'
          CALL      CH_OUT
          MOV       A,#11111111B
          CALL      CH_OUT
          MOV       A,#'y'
          CALL      CH_OUT
          MOV       A,#11111110B
```

```
        CALL    CH_OUT

WT_NBC: CJNE    A,#'E',WT_100E ; WAIT FOR CONTINUE FROM NB
        SETB    05H
        JMP     RDG_SUB
WT_100E:CJNE    A,#'S',WT_NBC; WAIT FOR end of 100 reading cycle FROM NB
        CLR     05H
RDG_EDS:JB      04H,NO_COM2
        JB      05H,NO_COM2
        SETB    P0.7; TO U2 TO CONT AFTER READING TAKEN
RG_EDS: JNB     P2.2,RG_EDS
        CLR     P0.7
        CLR     P0.0 ;ANA SW OFF
NO_COM2:RET
;************************************************************


;**************************************************
;       ERROR 1 SUB
;**************************************************

ER1_SUB:MOV     A,#'J'
        CALL    CH_OUT
E1E2:   NOP
MAN_RDG:CJNE    A,#'D',E1E2
        ;SETB    P3.7
        SETB    P0.3
TK_RDG: JNB     P3.6,TK_RDG  ; MAN RDNG SWITCH, wait for switch to be pres
TK_RDG2:JB      P3.6,TK_RDG2

        SETB    P0.4            ;TEL U2 SWITCH I ON
E1_CK1: JNB     P2.2,E1_CK1
        JB      P2.2,$
        CLR     P0.4

E3_RDNG:JNB     P2.2,E3_RDNG ; WAIT FOR TAKE READING PULSE
        SETB    P0.7; TO U2 TO CONT AFTER READING TAKEN
        NOP
        NOP
        NOP
        CLR     P0.7
        CALL    RDG_SUB
        ;CLR     P3.7
        CLR     P0.3
E_CON:  CJNE    A,#'C',E_CON ;29/01/06
        SETB    P0.4
E1_WT:  JNB     P2.2,E1_WT ; CHECK IF U2 RECIEVED EXIT PULSE
        CLR     P0.4
        NOP
        NOP
        RET
;**************************************************

;**************************************************
;       ERROR 2 SUB
;**************************************************
```

```
ER2_SUB:MOV     A,#'m'
        CALL    CH_OUT
        CALL    E1E2
        RET
;**************************************************

;**************************************************
;       ERROR 3 SUB
;**************************************************

ER3_SUB:MOV     A,#'L'
        CALL    CH_OUT
        JMP     CRNT_E ;IN SPISR TO ENTER POWERDOWN IF CURRENT ON TIME IS
        RET
;SEE PREV VERSION FOR NOTES
;****************************************************

;**************************************************
;       ERROR 4 SUB
;**************************************************

ER4_SUB:MOV     A,#'Q'
        CALL    CH_OUT
E3E4:   NOP
WT_NBC3:CJNE    A,#'C',E3E4  ;  WAIT FOR CONTINUE FROM NB
        SETB    P0.4
E3_WT:  JNB     P2.2,E3_WT  ; CHECK IF U2 RECIEVED EXIT PULSE
        CLR     P0.4
        RET

;**************************************************

;**************************************************
;       SERIAL PORT ISR
;**************************************************

SPISR:  CLR     EX0 ;? needed? 06/12
        JNB     TI,REC
        ;CLR     TI; cleared in ch_out
        JMP     SP_OUT
REC:    NOP
SLCH_IN:JNB     RI,$
        CLR     RI
        MOV     A,SBUF
        CJNE    A,#'B',SPNXT ;END
ENDD:   SETB    P0.1; END TO U2
SP_END: JNB     P3.4,SP_END; ERROR 4 PULSE USED TO
                           ; ENSURE THAT U2 IS ABOUT TO END
        CLR     P0.1
        MOV     P0,#0H
        MOV     P1,#0H
        MOV     P2,#0H
        MOV     P3,#00000011B
        MOV     PCON,#00000010B;POWER DOWN, ONLY EXIT IS RESET
        NOP
```

```
         JMP      ED
SPNXT:   CJNE     A,#'F',SP_END3  ;SP_END2 EMERGENCY STOP
CRNT_E:  SETB     P0.5
SP_ENDx:JNB       P3.4,SP_ENDx; ERROR 4 PULSE USED TO
                              ; ENSURE THAT U2 IS ABOUT TO END
         CLR      P0.5
         MOV      P0,#0H
         MOV      P1,#0H
         MOV      P2,#0H
         MOV      P3,#00000011B
         MOV      PCON,#00000010B;POWER DOWN, ONLY EXIT IS RESET
         NOP
         JMP      ED

SP_END3:JMP       SP_OUT
SP_OUT:  SETB     EX0;? needed?06/12
         RETI

;*******************************************************



FINISH: CLR       EX0
        SETB      P0.1; END TO U2
        CLR       EA ; DISABLE INTERUPT AS THE P3.4 IS USED FOR SIGNALLING

WX_END: JNB       P3.4,WX_END; ERROR 4 PULSE USED TO
                             ; ENSURE THAT U2 IS ABOUT TO END

EXT:     MOV      P0,#0H
         MOV      P1,#0H
         MOV      P2,#0H
         MOV      P3,#00000011B
         MOV      PCON,#00000010B;POWER DOWN, ONLY EXIT IS RESET
;         MOV      PCON,#00000001B ;IDLE MODE, system remains in idle mode u
         NOP
ED:      END
```

```
;Date Last modified : 09-01-06
;Date Last modified : 07-03-06
;Date Last modified : 08-03-06
;Date Last modified : 23-03-06
;Date Last modified : 21-04-06


        ORG     0H
        LJMP    MAIN
        ORG     0003H
        LJMP    EX0ISR
        ORG     0023H
        LJMP    SPISR


        ORG     0030H
;***************************iNTILIZE I/O PORTS ***************************

MAIN:   MOV     P0,#00000100B
        MOV     P1,#11111111B
        MOV     P2,#01111110B
        MOV     P3,#01010111B ; (rEC & tRANS PORTS SET TO 1), only for sim
;***************************iNTILIZE I/O PORTS ***************************

        SETB    P3.5

        CLR     RS0             ;1S
        SETB    RS1
        MOV     R6,#50
DLY3:   mov     r5,#100
dly:    mov     r4,#100
dly2:   djnz    r4,dly2
        djnz    r5,dly
        DJNZ    R6,DLY3
        CLR     RS0
        CLR     RS1             ; 1S


        CLR     00H ;CLEARING FLAGS
        CLR     01H
        CLR     02H
        CLR     03H
        CLR     04H
        CLR     05H

;***************************iNTILIZE ADC - DUMMY RUN ********************
        CLR     P2.0
        NOP
        CLR     P3.5

        CLR     RS0             ;20US
        SETB    RS1
        MOV     R6,#20
D1:     DJNZ    R6,D1
        CLR     RS0
        CLR     RS1             ;20US
```

```
RDG_SUB_DUMMY:NOP
        CLR     RS0                 ;TIME 4 INTERNAL REF TO "WAKE UP" AFTER SH
        SETB    RS1
        mov     r5,#100
adc_2nd:mov     r4,#100
adc_dly:djnz    r4,adc_dly
        djnz    r5,adc_2nd
        CLR     RS0
        CLR     RS1                 ;TIME 4 INTERNAL REF TO "WAKE UP" AFTER SH



        SETB    P3.5; CS


        CLR     P2.0
        NOP             ; EXTRA TIME BEFORE CS IS FORCED LOW, NOT REALLY N
        CLR     P3.5; AQUISITAION MODE, p3,5 cleared 1us after p2.0 (1mach

ADC_W_DUMMY:  JB       P2.1,ADC_W_DUMMY      ;EOC'

        SETB    P3.5
        SETB    P3.7

        CLR     RS0                 ;20US
        SETB    RS1
        MOV     R6,#20
D2:     DJNZ    R6,D2
        CLR     RS0
        CLR     RS1                 ;20US


        SETB    P2.0; TO PUT DATA OUT
        NOP             ; EXTRA TIME BEFORE CS IS FORCED LOW, NOT REALLY NE
        CLR     P3.5;***(CS fALLING eDGE 3)

        CLR     RS0                 ;20US
        SETB    RS1
        MOV     R6,#20
D3:     DJNZ    R6,D3
        CLR     RS0
        CLR     RS1                 ;20US

        NOP             ;WAIT FOR VALID DATA,Tdo+Tdv (tdv = 0)
        CLR     P3.3;   ;HBEN - LOW BYTE
        NOP             ;tdo1, MAY NEED MORE TIME
        NOP
        SETB    P3.3    ;HBEN - HIGH BYTE
        NOP             ;tdo1, MAT NEED MORE TIME
        NOP
        SETB    P3.5;   ***(CS 1ST RISING EDGE AFTER fALLING eDGE 3)
;***************************iNTILIZE ADC - DUMMY RUN *********************
```

```
;***************************************************************
;    MAIN - SERIAL INITIALIZITION - no PARITY - IN/OUT CHAR
;***************************************************************
MAIN2:  MOV     SCON,#01010000B
        MOV     TMOD,#20H
        MOV     TH1,#-13
        SETB    TR1

        MOV     IE,#10000000B
        MOV     IP,#00010000B; SET SP AT HIGHER PRIORIYY THAN EX0
        SETB    IT0 ;NEGATIVE EDE TRIGGERED
        ;SETB    TR1
        ;SETB    P2.0
        SETB    ES
        JMP     START


CH_OUT: CLR     ES


        MOV     SBUF,A
        ;CLR     ACC.7 ;may not need 21/11, but check
TX2:    JNB     TI,TX2
        CLR     TI
        SETB    ES ; COME BACK TO THIS
        RET



;***************************************************************
;  RECIEVING TEST DATA
;***************************************************************

START:  cjne    A,#'A',CAL ; SRL1, wait for all the data to be in the nb b
        JMP     NB_AM
CAL:    CJNE    A,#'H',START ; 4 CALIB
        CLR     P0.6 ;IN MAN MODE FOR CALIBRATION
        SETB    04H
        CALL    RDG_SUB
        CLR     04H
        SETB    P0.6
        JMP     START           ; 4 CALIB

NB_AM:  MOV     A,#'b'; SEND PROMPT, FOR MAN/AUTO
        CALL    CH_OUT

SRL2:   CJNE    A,#'G',X ; G->MAN

; reading is taken each time the man sw is pressed and exits when end is p
        CLR     P0.6
manRsub:NOP
W_ENDx: CJNE    A,#'B',TK_RDx
        LJMP    FINISH
```

```
TK_RDx: JNB      P3.6,manRsub ; MAN SWITCH
TK_RDx2:JB       P3.6,TK_RDx2'
        SETB     04H
        MOV      A,#'I'              ;INC BARS
        CALL     CH_OUT
        CALL     RDG_SUB
        jmp      manRsub



X:      CJNE     A,#'g',SRL2
        CLR      C; A should hold 'g'
        SETB     P0.6

        MOV      A,#'d'; SEND PROMPT & WAIT FOR START PULSE
        CALL     CH_OUT
WT_STRT:CJNE     A,#'A',WT_STRT ; START PULSE TO U2
        jmp      fstbar
WT_U2ST:JNB      P2.3,WT_U2ST ; LOOP STARTS
fstbar: JMP      BARS

;**********************************************************************
;              INC BARS; using the nb
;**********************************************************************
BARS:   MOV      A,#'I'              ;INC BARS
        CALL     CH_OUT
W_END:  CJNE     A,#'p',sa ;not last bar
        JMP      GO
sa:     cjne     A,#'P',W_END   ;LAST BAR REACHED
        CLR      P2.7 ; to u2 to signal last bar
        jmp      Finish

;DEC NO OF BARS FROM THE TOTAL IN U1 HERE
;ALSO CHECK FOR LAST BAR - IF YES, ALLERT NB
;THEN WAIT FOR THE "END"PULSE FROM NB AND JUMP TO END
;**********************************************************************

GO:     SETB     P0.0; START TO U2 / ANA SW ON


        SETB     P2.7 ;NOT LAST BAR
BGN_TW: JNB      P2.2,BGN_TW ; WAIT TO CHECK IF PULSE WAS RECIEVED
        CLR      P2.7 ; to u2 to signal last bar
        CLR      P0.0, ANA SW OFF

        SETB     EX0
        NOP
        NOP
        NOP
        NOP
WT_RDNG:JNB      P2.2,WT_RDNGE ; WAIT FOR TAKE READING PULSE
        SETB     P0.7; TO U2 TO CONT AFTER READING TAKEN
        NOP
        NOP
        NOP
        CLR      P0.7
```

```
         CALL     RDG_SUB
         JMP      WT_U2ST; LOOP ENDS NORMALLY
WT_RDNGE:JNB      03H,WT_RDNG
         CLR      03H


         JMP      WT_U2ST; LOOP ENDS AFTER ERROR 1 ND 2



;*************************************************************************
; EXTERNAL INTERRUPT 0 ISR - FOR ERRORS 1 TO 4 & Emergency Stop
;*************************************************************************

EX0ISR:  JNB      P2.4,ERR2
         CALL     ER1_SUB
         SETB     03H; FLAG TO INDICATE TO WT_RDNG LOOP THAT EN ERROR OCCURE
         JMP      EX0OUT
ERR2:    JNB      P2.5,ERR3
         CALL     ER2_SUB
         SETB     03H
         JMP      EX0OUT
ERR3:    JNB      P2.6,ERR4
         CALL     ER3_SUB
         JMP      EX0OUT
ERR4:    JNB      P3.4,EX0OUT
         CALL     ER4_SUB
EX0OUT:  MOV      A,#'O'              ;MANUAL EMERGENCY STOP
         CALL     CH_OUT
         JMP      EXT
         RETI

;*************************************************************************


;***********************************************************
;                    READING SUBPROGRAM
;***********************************************************

RDG_SUB:NOP

;NEG_TST:JB       P3.6,NO_NEG
;        MOV      A,#'N'
;        CALL     CH_OUT
;NEG_R:  CJNE     A,#'C',NEG_R
;        JMP      NEG_TST


NO_NEG: JB        04H,NO_COM
```

```
         JB       05H,NO_COM
WT_RD:   JNB      P2.2,WT_RD ; WAIT FOR CURRENT TO BE SWITCHED BY U2
         SETB     P0.7; TO U2 TO SIGNAL READY TO TAKE READING
         NOP
         NOP
         CLR      P0.7

NO_COM:  NOP


;EXTRA 1S DELAY IN Uc2 (X) 4 INPUT CCTRY

OV_CHK:  JNB      P0.2,DWN ; for pcb, for tst cct, jb p0.2
         JMP      FET_ON
DWN:     LJMP     OVRVOL
FET_ON:  SETB     P0.0 ; ANA SW ON


         CLR      P2.0

         CLR      RS0                ;20US
         SETB     RS1
         MOV      R6,#24
D4:      DJNZ     R6,D4
         CLR      RS0
         CLR      RS1                ;20US

         CLR      P3.5; AQUISITAION MODE, p3,5 cleared 1us after p2.0 (1mach

         CLR      RS0                ;20US
         SETB     RS1
         MOV      R6,#20
D5:      DJNZ     R6,D5
         CLR      RS0
         CLR      RS1                ;20US
         NOP          ;Tcsl and tdh
         SETB     P3.5

         CLR      RS0                ;20US
         SETB     RS1
         MOV      R6,#24
D6:      DJNZ     R6,D6
         CLR      RS0
         CLR      RS1                ;20US

         CLR      P3.5; FOR STANDBY MODE ***(CS fALLING eDGE 2)


ADC_W:   JB       P2.1,ADC_W         ;EOC'

         SETB     P3.5
         SETB     P2.0; TO PUT DATA OUT
         CLR      P3.3;     ;HBEN - LOW BYTE nu 28/11
         NOP                ; EXTRA TIME BEFORE CS IS FORCED LOW, NOT REALLY NI
         CLR      P3.5; ***(CS fALLING eDGE 3)
```

```
        NOP                 ;WAIT FOR VALID DATA,Tdo+Tdv (tdv = 0)
        CLR     P3.3;       ;HBEN - LOW BYTE redundancy

        CLR     RS0                 ;20US
        SETB    RS1
        MOV     R6,#10
D7:     DJNZ    R6,D7
        CLR     RS0
        CLR     RS1                 ;20US        nop

        MOV     R3,P1       ;HOLD L BYT
        SETB    P3.3        ;HBEN - HIGH BYTE
        CLR     RS0                 ;20US
        SETB    RS1
        MOV     R6,#10
D8:     DJNZ    R6,D8
        CLR     RS0
        CLR     RS1                 ;20US

        MOV     R5,P1       ;HOLD H BYT
        SETB    P3.5;       ***(CS 1ST RISING EDGE AFTER fALLING eDGE 3)

NA_CK:  CJNE    R5,#11111111B,OUT_RNG ;CHECK IF NOT ALLOWED CODE
        CJNE    R3,#11111110B,OUT_RNG
        MOV     R5,#11111111B
        MOV     R3,#11111111B

OUT_RNG:MOV     A,#'z'
        CALL    CH_OUT
OUT_H:  MOV     A,R5
        CALL    CH_OUT
        MOV     A,#'y'
        CALL    CH_OUT
OUT_L:  MOV     A,R3
        CALL    CH_OUT
WT_NBCT:CJNE    A,#'E',WT_100C; WAIT FOR CONTINUE FROM NB
        SETB    05H
        JMP     RDG_SUB
WT_100C:CJNE    A,#'S',WT_NBCT; WAIT FOR end of 100 reading cycle FROM NB
        CLR     05H

RDG_END:JB      04H,NO_COM2
        JB      05H,NO_COM2
        SETB    P0.7; TO U2 TO CONT AFTER READING TAKEN
RG_END: JNB     P2.2,RG_END
        CLR     P0.7
        CLR     P0.0 ;ANA SW OFF
        JMP     NO_COM2

OVRVOL: MOV     A,#'z'
        CALL    CH_OUT
        MOV     A,#11111111B
        CALL    CH_OUT
        MOV     A,#'y'
        CALL    CH_OUT
        MOV     A,#11111110B
```

```
          CALL     CH_OUT

WT_NBC:   CJNE     A,#'E',WT_100E ; WAIT FOR CONTINUE FROM NB
          SETB     05H
          JMP      RDG_SUB
WT_100E:CJNE       A,#'S',WT_NBC; WAIT FOR end of 100 reading cycle FROM NB
          CLR      05H
RDG_EDS:JB         04H,NO_COM2
          JB       05H,NO_COM2
          SETB     P0.7; TO U2 TO CONT AFTER READING TAKEN
RG_EDS:   JNB      P2.2,RG_EDS
          CLR      P0.7
          CLR      P0.0 ;ANA SW OFF
NO_COM2:RET
;***********************************************************


;*************************************************
;       ERROR 1 SUB
;*************************************************

ER1_SUB:MOV        A,#'J'
          CALL     CH_OUT
E1E2:     NOP
MAN_RDG:CJNE       A,#'D',E1E2
          ;SETB     P3.7
          SETB     P0.3
TK_RDG:   JNB      P3.6,TK_RDG  ; MAN RDNG SWITCH, wait for switch to be pres
TK_RDG2:JB         P3.6,TK_RDG2

          SETB     P0.4              ;TEL U2 SWITCH I ON
E1_CK1:   JNB      P2.2,E1_CK1
          JB       P2.2,$
          CLR      P0.4

E3_RDNG:JNB        P2.2,E3_RDNG ; WAIT FOR TAKE READING PULSE
          SETB     P0.7; TO U2 TO CONT AFTER READING TAKEN
          NOP
          NOP
          NOP
          CLR      P0.7
          CALL     RDG_SUB
          ;CLR      P3.7
          CLR      P0.3
E_CON:    CJNE     A,#'C',E_CON ;29/01/06
          SETB     P0.4
E1_WT:    JNB      P2.2,E1_WT ; CHECK IF U2 RECIEVED EXIT PULSE
          CLR      P0.4
          NOP
          NOP
          RET
;*************************************************

;*************************************************
;       ERROR 2 SUB
;*************************************************
```

```
ER2_SUB:MOV     A,#'m'
        CALL    CH_OUT
        CALL    E1E2
        RET
;*************************************************

;*************************************************
;       ERROR 3 SUB
;*************************************************

ER3_SUB:MOV     A,#'L'
        CALL    CH_OUT
        JMP     CRNT_E ;IN SPISR TO ENTER POWERDOWN IF CURRENT ON TIME IS
        RET
;SEE PREV VERSION FOR NOTES
;*****************************************************

;*************************************************
;       ERROR 4 SUB
;*************************************************

ER4_SUB:MOV     A,#'Q'
        CALL    CH_OUT
E3E4:   NOP
WT_NBC3:CJNE    A,#'C',E3E4  ;  WAIT FOR CONTINUE FROM NB
        SETB    P0.4
E3_WT:  JNB     P2.2,E3_WT  ; CHECK IF U2 RECIEVED EXIT PULSE
        CLR     P0.4
        RET

;*************************************************

;*************************************************
;       SERIAL PORT ISR
;*************************************************

SPISR:  CLR     EX0 ;? needed? 06/12
        JNB     TI,REC
        ;CLR     TI; cleared in ch_out
        JMP     SP_OUT
REC:    NOP
SLCH_IN:JNB     RI,$
        CLR     RI
        MOV     A,SBUF
        CJNE    A,#'B',SPNXT ;END
ENDD:   SETB    P0.1; END TO U2
SP_END: JNB     P3.4,SP_END; ERROR 4 PULSE USED TO
                           ; ENSURE THAT U2 IS ABOUT TO END
        CLR     P0.1
        MOV     P0,#0H
        MOV     P1,#0H
        MOV     P2,#0H
        MOV     P3,#00000011B
        MOV     PCON,#00000010B;POWER DOWN, ONLY EXIT IS RESET
        NOP
```

```
        JMP     ED
SPNXT:  CJNE    A,#'F',SP_END3  ;SP_END2 EMERGENCY STOP
CRNT_E: SETB    P0.5
SP_ENDx:JNB     P3.4,SP_ENDx; ERROR 4 PULSE USED TO
                           ; ENSURE THAT U2 IS ABOUT TO END
        CLR     P0.5
        MOV     P0,#0H
        MOV     P1,#0H
        MOV     P2,#0H
        MOV     P3,#00000011B
        MOV     PCON,#00000010B;POWER DOWN, ONLY EXIT IS RESET
        NOP
        JMP     ED

SP_END3:JMP     SP_OUT
SP_OUT: SETB    EX0;? needed?06/12
        RETI

;*****************************************************


FINISH: CLR     EX0
        SETB    P0.1; END TO U2
        CLR     EA ; DISABLE INTERUPT AS THE P3.4 IS USED FOR SIGNALLING

WX_END: JNB     P3.4,WX_END; ERROR 4 PULSE USED TO
                           ; ENSURE THAT U2 IS ABOUT TO END

EXT:    MOV     P0,#0H
        MOV     P1,#0H
        MOV     P2,#0H
        MOV     P3,#00000011B
        MOV     PCON,#00000010B;POWER DOWN, ONLY EXIT IS RESET
;       MOV     PCON,#00000001B ;IDLE MODE, system remains in idle mode u
        NOP
ED:     END
```

```
;Date Last modified : 09-01-06
;Date Last modified : 07-03-06
;
;Date Last modified : 23-03-06
;Date Last modified : 21-04-06

;**************************************************************************
;            **************   MICROCONTROLLER 2 - AUTOMATION .v2   *******
;**************************************************************************

        ORG     0H
        LJMP    MAIN
        ORG     0003H
        LJMP    EX0ISR
        ORG     0013H
        LJMP    EX1ISR

COUNT   EQU     -10000 ;DELAY LOOP
COUNT2  EQU     -50000 ;SAFTY TIME

        ORG     0030H
MAIN:   MOV     TMOD,#00010001B
        MOV     IP,#00000001B
        MOV     IE,#00000101B

;**************************iNTILIZE I/O PORTS ****************************
        MOV     P0,#0H ; only for sim, input ports must be set to 1
        MOV     P1,#11111111B ; only for sim, input ports must be set to 1
        MOV     P2,#00001000H ; only for sim, input ports must be set to 1
        MOV     P3,#00011111B ; only for sim, input ports must be set to 1
;**************************iNTILIZE I/O PORTS ****************************

; clearing all flags
        CLR     00H
        CLR     01H
        CLR     02H
        CLR     03H
        CLR     04H
        CLR     05H
        CLR     06H
        CLR     07H
        CLR     08H
        CLR     09H
        CLR     0AH
        CLR     0BH
        CLR     0CH
        CLR     0DH
        CLR     0EH

        SETB    EA
        SETB    IT1
        SETB    IT0
AGIAN:  SETB    EX1; ENABLE EX INT1
START:  JNB     P1.0, START
        JB      P1.6, AUTO      ;(1 = AUTO, 0 = MAN)
        MOV     PCON,#00000010B ;
```

```
AUTO:   SETB    P0.5;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        CLR     P0.5;
        SETB    EX1
        SETB    EX0

;********Input Safety Range Check*********(SIRC)
;         CALL    RUN_DWN
;         CALL    DELAYLOOP
;         JB      P2.2,SAFE_R
;         SETB    P2.3; OUT OF RANGE ALLERT
;         SJMP    $
;SAFE_R:  CALL    RUN_UP
;         SETB    P2.4; SWITCH ON INPUT RELAY
;*************END CHECK*******************


        SETB    P0.1
        CLR     0CH
        CALL    DELAYLOOP
NLBAR:  JNB     P3.0,LBAR
        JMP     CONT
LBAR:   JNB     P1.1,NLBAR
        CLR     P0.1
        LJMP    END

CONT:   SETB    P0.0
PW:     JNB     P3.0,PW
        NOP
        NOP
        NOP
        NOP
        CLR     P0.0
        CLR     P0.1

        JB      02H,LOAD; *nu
        JB      00H,ONE
        SETB    00H
        JMP     LOAD
ONE:    JB      01H,TWO
        SETB    01H
        JMP     LOAD
TWO:    JB      02H,LOAD
        SETB    02H
        CLR     00H
        CLR     01H
        JMP     NTRD

LOAD:   JB      02H,THIRD
NTRD:   MOV     R1,#HIGH COUNT2
        MOV     R2,#LOW COUNT2
        MOV     R3,#200 ;*
```

```
        JMP     BEGIN

THIRD:  MOV     A,R4
        MOV     R1,A
        MOV     A,R5
        MOV     R2,A
        MOV     A,R6
        MOV     R3,A
        MOV     A,#200  ;*
        CALL    CALC_TIME

        SETB    P0.4
        CALL    DELAYLOOP
CNT_RT: MOV     TH1,#HIGH COUNT2
        MOV     TL1,#LOW COUNT2
        SETB    TR1
WAIT_R: JNB     TF1,WAIT_R
        clr     tr1
        clr     tf1
        DJNZ    R3,CNT_RT
        JB      04H,TMR_OUT
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
WAIT_RX:JNB     TF1,WAIT_RX
        clr     tr1
        clr     tf1
        SETB    03H
        JMP     TMR_OUT

BEGIN:  SETB    P0.4
        CALL    DELAYLOOP

TMR:    MOV     TH0,#0H
        MOV     TL0,#0H
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
        SETB    TR0
WAIT_T1:JNB     TF1,WAIT_T1
        clr     tr1
        CLR     TR0
        clr     tf1
        CLR     TF0
        DJNZ    R3,TMR
        SETB    03H
        JMP     TMR_OUT

;*****************************************************
;               CALC_TIME
;*****************************************************
CALC_TIME:      CLR     C
                SUBB    A,R3
                MOV     R3,A
                CLR     C
                CLR     AC
```

```
                CLR     OV

                MOV     A,R2

                CPL     A
                ADD     A,#1
                MOV     R2,A

                MOV     A,R1
                CPL     A
                JNC     SUM
                CLR     C;      ;08/12
                ADD     A,#1
                JNC     SUM;    ;08/12
                MOV     A,#255; ;08/12
SUM:            MOV     R1,A

                CLR     C
                CLR     AC
                CLR     OV


GO1:      MOV     A,R3
          MOV     B,#5
          DIV     AB
          ADD     A,R3
          JNC     TOLL
          MOV     R3,#255
          CLR     C
TOLL:     MOV     R3,A
          CLR     OV
          CLR     AC
          RET

TMR_OUT:CLR     EX1
          JB     04H, NO_ERR1
          CALL    ERROR1

NO_ERR1:CLR     04H
          SETB    EX1
          JMP     AUTO


;**********************************************************************
;                   EXTERNAL INTERUPT 1 - ISR - v2
;**********************************************************************

EX1ISR: CLR     P0.4
        SETB    P0.5;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        CLR     P0.5;
        CALL    DELAYLOOP
```

```
        CLR     TR1 ;04/06
        CLR     TR0 ;04/06
        SETB    04H
        JNB     02H,RUN_DWN
        JB      05H,RUN_DWN
        MOV     R4,TH0
        MOV     R5,TL0
        MOV     B,R3
        MOV     R6,B
        SETB    05H

;***************************
;            DOWN
;***************************

RUN_DWN:CALL    RUN_DWNX

;***************************
;          READING
;***************************

        CALL    READING

;***************************
;         RUN_UP
;***************************

        CALL    RUN_UP


EXR1OUT:MOV     TH1,#-10
        MOV     TL1,#-10
        MOV     R3,#1
        SETB    TR1
        RETI

;***********************************************************************
;                    EXTERNAL INTERUPT 0 - ISR - v2
;***********************************************************************

EX0ISR: jnb     P1.5,no_stop
        ljmp    end
no_stop:JB      0EH,IG
        CLR     P0.2
        CLR     P0.3
        JNB     0CH,S
        CLR     P2.7 ;CURRENT OFF
S:      CLR     TR1 ;04/06
        CLR     TR0 ;04/06
        CALL    DELAYLOOP
        SETB    08H
        JB      0CH,EXR0OUT
        ;SETB    06H
        ;SETB    06H ;06/12
        MOV     B,R3
        MOV     R7,B
```

```
        CLR     RS0     ;
        SETB    RS1     ;REG BANK 1
        MOV     R1,TH0
        MOV     R2,TL0
        CLR     RS0     ;
        CLR     RS1     ;REG BANK 0

        ;MOV     R3,#1H


EXR0OUT:CLR     0CH
        MOV     TH1,#-10
        MOV     TL1,#-10
        MOV     R3,#1
        SETB    TR1
IG:     RETI

;**********************************************************************
;                               DELAY LOOP
;**********************************************************************
DELAYLOOP:          MOV     R0,#100 ;1SEC = 100X10000
RPT:                MOV     TH0,#HIGH COUNT
                    MOV     TL0,#LOW COUNT
                    SETB    TR0
DLY:                JNB     TF0,DLY
                    CLR     TR0
                    CLR     TF0
                    DJNZ    R0,RPT

                    RET
;**********************************************************************
;                       DOWN - LOWER DETECTION UNIT
;**********************************************************************
RUN_DWNX:SETB    EX0
         CLR     0CH
        SETB    P2.7; CUTTENT ON
        CALL    DELAYLOOP
        ;JB      06H,DECT_2 ; 25-08
        MOV     R1,#HIGH COUNT2
        MOV     R2,#LOW COUNT2
        MOV     R3,#200 ;*

        SETB    P0.3
        CALL    DELAYLOOP
TMR2:   MOV     TH0,#0H
        MOV     TL0,#0H
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
        SETB    TR0
WAIT_T2:JNB     TF1,WAIT_T2
        clr     tr1
        CLR     TR0
        clr     tf1
        CLR     TF0
        DJNZ    R3,TMR2
```

```
        SETB    07H
        JMP     TMR_OUT2



TMR_OUT2:;CLR    EX0
        JB      08H,NO_ERR2
        CALL    ERROR2
        SETB    EX0
        JMP     EXR1OUT

NO_ERR2:SETB    EX0
        CLR     08H
        RET
;*********************************************************************
;                               RUN_UP SUB - rAISE DETECTION UNIT
;*********************************************************************
RUN_UP: SETB    EX0
        SETB    0CH
DECT_3: CLR     RS0;
        SETB    RS1;    REG BANK1

        MOV     A,R1
        MOV     B,R2

        CLR     RS0;
        CLR     RS1;    REG BANK0


        MOV     R1,A
        MOV     R2,B
        MOV     A,R7
        MOV     R3,A
        MOV     A,#200          ;*
        CALL    CALC_TIME

        SETB    P0.2
        CALL    DELAYLOOP

CNT_DN: MOV     TH1,#HIGH COUNT2
        MOV     TL1,#LOW COUNT2
        SETB    TR1
WAIT_D: JNB     TF1,WAIT_D
        clr     tr1
        clr     tf1
        DJNZ    R3,CNT_DN
        JB      08H,TMR_OUT3; EX0 OCCURED SO SKIP
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
WAIT_DX:JNB     TF1,WAIT_DX
        clr     tr1
        clr     tf1
        SETB    07H

TMR_OUT3:
```

```
                JB      08H,NO_ERR3
                JB      0DH,NO_ERR3
                CALL    ERROR4
                SETB    EX0
                JMP     OUT2

NO_ERR3:CLR     08H
        CLR     0DH


OUT2:   SETB    EX0
        CLR     0CH
        CLR     0DH
        CLR     08H

        RET
;*******************************************************************
;                               READING
;*******************************************************************
READING:SETB    P0.0

RD_WT:  JNB     P1.7,RD_WT
        CLR     P0.0
        ;SETB    P2.7
        ;CALL    DELAYLOOP
        ;SETB    P0.6
        NOP
        NOP
        CALL    DELAYLOOP
        SETB    P0.0
RDNG0:  JNB     P1.7,RDNG0
        CLR     P0.0
        CALL    DELAYLOOP
RDNG:   JNB     P1.7,RDNGX
        JMP     RDNGOK
RDNGX:  JB      P3.1,RDNG ; 555 output is high for thr preset time ofter t:
        CALL    ERROR3
        CLR     P0.0
        JMP     OUT2
RDNGOK: SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        ;CLR    P0.6
        NOP
        NOP
        ;CLR     P2.7
        ;CALL    DELAYLOOP
        JB      P3.1,cnt_chk
        CALL    ERROR3
cnt_chk:RET


;*******************************************************************
;                    ERROR 1 - BARS NOT DETECTED
;*******************************************************************
```

```
ERROR1: CLR     P0.4
        JB      05H,S1          ;
        JNB     02H,S1          ;
        MOV     R4,#HIGH COUNT2 ;
        MOV     R5,#LOW COUNT2  ;
        MOV     B,#200          ;
        MOV     R6,B
        CLR     05H     ; *nu IF ERR OCCURS ON 3RD PAIR, THEN TIME READING
        CLR     02H     ;   "
        SETB    00H     ;   "
        SETB    01H     ; ABOVE 4 ERROR ON 3RD BAR, BUT NOT REALLY REQUIREC
S1:     SETB    P0.5 ;
        nop          ;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        CLR     P0.5 ;
        SETB    P3.5 ;TO MIC1
        CALL    ER_I_SW
        CLR     P3.5
        RET

;*******************************************************************
;                    ERROR 2 - TEST PROBES NOT LOWERED
;*******************************************************************

ERROR2: CLR     P0.3
        CLR     P2.7
        CALL    DELAYLOOP
        SETB    0AH

        JB      08H,NO_RELD  ;23-03-06 reload values for run_up
        CLR     TR1          ;cos EX0 is not triggered on Error 2
        CLR     TR0
        MOV     B,R3
        MOV     R7,B
        CLR     RS0     ;
        SETB    RS1     ;REG BANK 1
        MOV     R1,TH0
        MOV     R2,TL0
        CLR     RS0     ;
        CLR     RS1     ;REG BANK 0 ;23-03-06 reload values for run_up

NO_RELD:CALL    RUN_UP
;SEE NOTE HERE IN PREVIOUS VERSIONS OF CODE
        JB      0BH,E2_OUT
        SETB    P3.6 ;TO MIC1
        CALL    ER_I_SW
        CLR     P3.6
E2_OUT: CLR     0AH
        CLR     0BH
        RET
```

```
;*******************************************************************
;              ERROR 3 - TEST CUTTENT TIME EXCEEDED
;*******************************************************************

ERROR3: SETB    0DH
        CALL    RUN_UP
        CLR     P2.7
        ;CALL    DELAYLOOP; NOT NEEDED
        SETB    P3.7
        nop
        CALL    DELAYLOOP
        CLR     P3.7
E3_HLD: JNB     P1.4, E3_HLD
        SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        CLR     0DH
        RET

;*******************************************************************
;              ERROR 4 - TEST PROBES NOT RAISED
;*******************************************************************
ERROR4: JB      0DH,E4_OUT
        CLR     P0.2
        CLR     P2.7
        CALL    DELAYLOOP
        SETB    P2.6
        nop
        CALL    DELAYLOOP
        CLR     P2.6
E4_HLD: JNB     P1.4,E4_HLD
        SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        JNB     0AH,E4_OUT
        SETB    0BH
        SETB    P3.6 ;TO MIC1
        CALL    ER_I_SW
        CLR     P3.6
        CLR     0AH
E4_OUT: RET

;*****************************************************
;                  ERROR READING PROCEDURE
;*****************************************************

ER_I_SW:SETB    0EH
E1_CK1: JNB     P1.4,E1_CK1
        ;CLR     EX0;? needed?06/12
AGN:    JB      P3.2,ON_I
        SETB    P2.0
        JMP     AGN
ON_I:   CALL    DELAYLOOP
        SETB    P2.7
```

```
          CLR       P2.0
PRBS_WT:JB          P3.2,PRBS_WT
          CALL      DELAYLOOP
          JB        P3.2,PRBS_WT
          ;CALL      DELAYLOOP
          SETB      P0.0
          NOP
          NOP
          CLR       P0.0
          CALL      READING
E1_HLD:   JNB       P1.4,E1_HLD
          SETB      P0.0
          NOP
          NOP
          CLR       P0.0
AGN2:     JB        P3.2,OF_I
          SETB      P2.1
          JMP       AGN2
OF_I:     CALL      DELAYLOOP
          CLR       P2.7
          CLR       P2.1
          CALL      DELAYLOOP
          ;SETB      EX0 ;? needed?06/12
          CLR       0EH
          RET
;**********************************************************************
END:      MOV       P0,#0H
          MOV       P1,#0H
          MOV       P2,#0H
          MOV       P3,#0H
          SETB      P2.6
          MOV       PCON,#00000010B;POWER DOWN
          NOP
          END
```

12-04-06 Micro2 latest

```
;Date Last modified : 09-01-06
;Date Last modified : 07-03-06
;
;Date Last modified : 23-03-06
;Date Last modified : 21-04-06

;*****************************************************************************
;               **************   MICROCONTROLLER 2 - AUTOMATION .v2   *******
;*****************************************************************************

        ORG     0H
        LJMP    MAIN
        ORG     0003H
        LJMP    EX0ISR
        ORG     0013H
        LJMP    EX1ISR

COUNT   EQU     -10000 ;DELAY LOOP
COUNT2  EQU     -50000 ;SAFTY TIME

        ORG     0030H
MAIN:   MOV     TMOD,#00010001B
        MOV     IP,#00000001B
        MOV     IE,#00000101B

;***************************iNTILIZE I/O PORTS ****************************
        MOV     P0,#0H ; only for sim, input ports must be set to 1
        MOV     P1,#11111111B ; only for sim, input ports must be set to 1
        MOV     P2,#00001000H ; only for sim, input ports must be set to 1
        MOV     P3,#00011111B ; only for sim, input ports must be set to 1
;***************************iNTILIZE I/O PORTS ****************************

; clearing all flags
        CLR     00H
        CLR     01H
        CLR     02H
        CLR     03H
        CLR     04H
        CLR     05H
        CLR     06H
        CLR     07H
        CLR     08H
        CLR     09H
        CLR     0AH
        CLR     0BH
        CLR     0CH
        CLR     0DH
        CLR     0EH

        SETB    EA
        SETB    IT1
        SETB    IT0
AGIAN:  SETB    EX1; ENABLE EX INT1
START:  JNB     P1.0, START
        JB      P1.6, AUTO      ;(1 = AUTO, 0 = MAN)
        MOV     PCON,#00000010B ;
```

```
AUTO:   SETB    P0.5;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        CLR     P0.5;
        SETB    EX1
        SETB    EX0

;********Input Safety Range Check*********(SIRC)
;           CALL    RUN_DWN
;           CALL    DELAYLOOP
;           JB      P2.2,SAFE_R
;           SETB    P2.3; OUT OF RANGE ALLERT
;           SJMP    $
;SAFE_R:    CALL    RUN_UP
;           SETB    P2.4; SWITCH ON INPUT RELAY
;*************END CHECK*******************



        SETB    P0.1
        CLR     0CH
        CALL    DELAYLOOP
NLBAR:  JNB     P3.0,LBAR
        JMP     CONT
LBAR:   JNB     P1.1,NLBAR
        CLR     P0.1
        LJMP    END

CONT:   SETB    P0.0
PW:     JNB     P3.0,PW
        NOP
        NOP
        NOP
        NOP
        CLR     P0.0
        CLR     P0.1

        JB      02H,LOAD; *nu
        JB      00H,ONE
        SETB    00H
        JMP     LOAD
ONE:    JB      01H,TWO
        SETB    01H
        JMP     LOAD
TWO:    JB      02H,LOAD
        SETB    02H
        CLR     00H
        CLR     01H
        JMP     NTRD

LOAD:   JB      02H,THIRD
NTRD:   MOV     R1,#HIGH COUNT2
        MOV     R2,#LOW COUNT2
        MOV     R3,#200 ;*
```

```
        JMP     BEGIN

THIRD:  MOV     A,R4
        MOV     R1,A
        MOV     A,R5
        MOV     R2,A
        MOV     A,R6
        MOV     R3,A
        MOV     A,#200  ;*
        CALL    CALC_TIME

        SETB    P0.4
        CALL    DELAYLOOP
CNT_RT: MOV     TH1,#HIGH COUNT2
        MOV     TL1,#LOW COUNT2
        SETB    TR1
WAIT_R: JNB     TF1,WAIT_R
        clr     tr1
        clr     tf1
        DJNZ    R3,CNT_RT
        JB      04H,TMR_OUT
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
WAIT_RX:JNB     TF1,WAIT_RX
        clr     tr1
        clr     tf1
        SETB    03H
        JMP     TMR_OUT

BEGIN:  SETB    P0.4
        CALL    DELAYLOOP

TMR:    MOV     TH0,#0H
        MOV     TL0,#0H
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
        SETB    TR0
WAIT_T1:JNB     TF1,WAIT_T1
        clr     tr1
        CLR     TR0
        clr     tf1
        CLR     TF0
        DJNZ    R3,TMR
        SETB    03H
        JMP     TMR_OUT

;*************************************************************
;                  CALC_TIME
;*************************************************************
CALC_TIME:          CLR     C
                    SUBB    A,R3
                    MOV     R3,A
                    CLR     C
                    CLR     AC
```

```
                CLR     OV

                MOV     A,R2

                CPL     A
                ADD     A,#1
                MOV     R2,A

                MOV     A,R1
                CPL     A
                JNC     SUM
                CLR     C;        ;08/12
                ADD     A,#1
                JNC     SUM;      ;08/12
                MOV     A,#255;   ;08/12
SUM:            MOV     R1,A

                CLR     C
                CLR     AC
                CLR     OV


GO1:     MOV     A,R3
         MOV     B,#5
         DIV     AB
         ADD     A,R3
         JNC     TOLL
         MOV     R3,#255
         CLR     C
TOLL:    MOV     R3,A
         CLR     OV
         CLR     AC
         RET

TMR_OUT:CLR      EX1
        JB      04H, NO_ERR1
        CALL     ERROR1

NO_ERR1:CLR      04H
        SETB     EX1
        JMP      AUTO


;*********************************************************************
;                    EXTERNAL INTERUPT 1 - ISR - v2
;*********************************************************************

EX1ISR: CLR      P0.4
        SETB     P0.5;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        CLR      P0.5;
        CALL     DELAYLOOP
```

```
        CLR     TR1 ;04/06
        CLR     TR0 ;04/06
        SETB    04H
        JNB     02H,RUN_DWN
        JB      05H,RUN_DWN
        MOV     R4,TH0
        MOV     R5,TL0
        MOV     B,R3
        MOV     R6,B
        SETB    05H

;***************************
;            DOWN
;***************************

RUN_DWN:CALL    RUN_DWNX

;***************************
;          READING
;***************************

        CALL    READING

;***************************
;         RUN_UP
;***************************

        CALL    RUN_UP


EXR1OUT:MOV     TH1,#-10
        MOV     TL1,#-10
        MOV     R3,#1
        SETB    TR1
        RETI

;*************************************************************************
;                    EXTERNAL INTERUPT 0 - ISR - v2
;*************************************************************************

EX0ISR: jnb     P1.5,no_stop
        ljmp    end
no_stop:JB      0EH,IG
        CLR     P0.2
        CLR     P0.3
        JNB     0CH,S
        CLR     P2.7 ;CURRENT OFF
S:      CLR     TR1 ;04/06
        CLR     TR0 ;04/06
        CALL    DELAYLOOP
        SETB    08H
        JB      0CH,EXR0OUT
        ;SETB    06H
        ;SETB    06H ;06/12
        MOV     B,R3
        MOV     R7,B
```

```
        CLR     RS0      ;
        SETB    RS1      ;REG BANK 1
        MOV     R1,TH0
        MOV     R2,TL0
        CLR     RS0      ;
        CLR     RS1      ;REG BANK 0

        ;MOV     R3,#1H


EXR0OUT:CLR     0CH
        MOV     TH1,#-10
        MOV     TL1,#-10
        MOV     R3,#1
        SETB    TR1
IG:     RETI

;*******************************************************************
;                           DELAY LOOP
;*******************************************************************
DELAYLOOP:      MOV     R0,#100 ;1SEC = 100X10000
RPT:            MOV     TH0,#HIGH COUNT
                MOV     TL0,#LOW COUNT
                SETB    TR0
DLY:            JNB     TF0,DLY
                CLR     TR0
                CLR     TF0
                DJNZ    R0,RPT

                RET
;*******************************************************************
;                  DOWN - LOWER DETECTION UNIT
;*******************************************************************
RUN_DWNX:SETB    EX0
         CLR     0CH
        SETB    P2.7; CUTTENT ON
        CALL    DELAYLOOP
        ;JB      06H,DECT_2 ; 25-08
        MOV     R1,#HIGH COUNT2
        MOV     R2,#LOW COUNT2
        MOV     R3,#200 ;*

        SETB    P0.3
        CALL    DELAYLOOP
TMR2:   MOV     TH0,#0H
        MOV     TL0,#0H
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
        SETB    TR0
WAIT_T2:JNB     TF1,WAIT_T2
        clr     tr1
        CLR     TR0
        clr     tf1
        CLR     TF0
        DJNZ    R3,TMR2
```

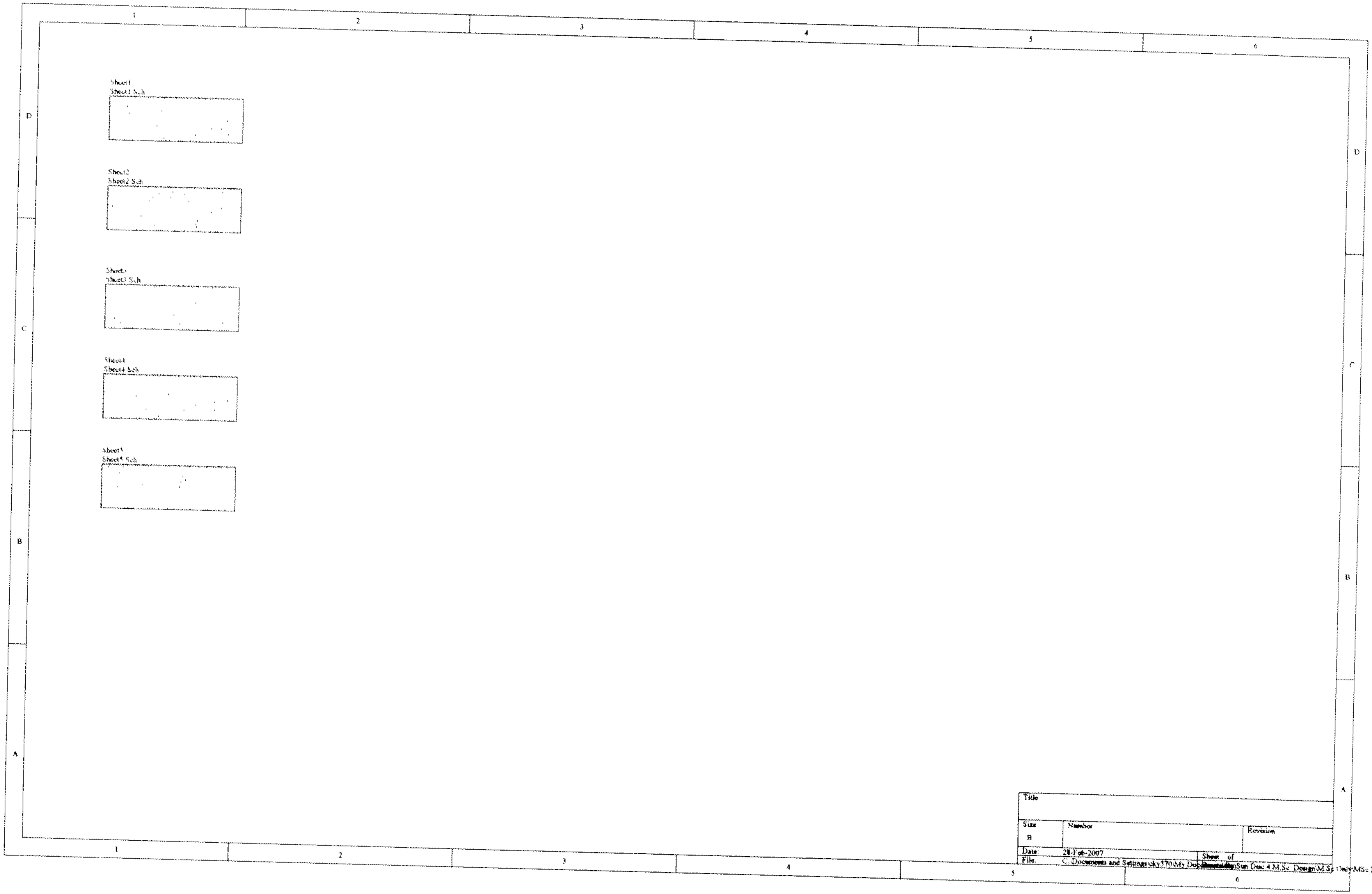
```
        SETB    07H
        JMP     TMR_OUT2



TMR_OUT2:;CLR    EX0
        JB      08H,NO_ERR2
        CALL    ERROR2
        SETB    EX0
        JMP     EXR1OUT

NO_ERR2:SETB    EX0
        CLR     08H
        RET
;*******************************************************************
;                          RUN_UP SUB - rAISE DETECTION UNIT
;*******************************************************************
RUN_UP: SETB    EX0
        SETB    0CH
DECT_3: CLR     RS0;
        SETB    RS1;    REG BANK1

        MOV     A,R1
        MOV     B,R2

        CLR     RS0;
        CLR     RS1;    REG BANK0


        MOV     R1,A
        MOV     R2,B
        MOV     A,R7
        MOV     R3,A
        MOV     A,#200          ;*
        CALL    CALC_TIME

        SETB    P0.2
        CALL    DELAYLOOP

CNT_DN: MOV     TH1,#HIGH COUNT2
        MOV     TL1,#LOW COUNT2
        SETB    TR1
WAIT_D: JNB     TF1,WAIT_D
        clr     tr1
        clr     tf1
        DJNZ    R3,CNT_DN
        JB      08H,TMR_OUT3; EX0 OCCURED SO SKIP
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
WAIT_DX:JNB     TF1,WAIT_DX
        clr     tr1
        clr     tf1
        SETB    07H

TMR_OUT3:
```

```
                JB      08H,NO_ERR3
                JB      0DH,NO_ERR3
                CALL    ERROR4
                SETB    EX0
                JMP     OUT2

NO_ERR3:CLR     08H
        CLR     0DH


OUT2:   SETB    EX0
        CLR     0CH
        CLR     0DH
        CLR     08H

        RET
;****************************************************************
;                            READING
;****************************************************************
READING:SETB    P0.0

RD_WT:  JNB     P1.7,RD_WT
        CLR     P0.0
        ;SETB    P2.7
        ;CALL    DELAYLOOP
        ;SETB    P0.6
        NOP
        NOP
        CALL    DELAYLOOP
        SETB    P0.0
RDNG0:  JNB     P1.7,RDNG0
        CLR     P0.0
        CALL    DELAYLOOP
RDNG:   JNB     P1.7,RDNGX
        JMP     RDNGOK
RDNGX:  JB      P3.1,RDNG ; 555 output is high for thr preset time ofter t
        CALL    ERROR3
        CLR     P0.0
        JMP     OUT2
RDNGOK: SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        ;CLR     P0.6
        NOP
        NOP
        ;CLR     P2.7
        ;CALL    DELAYLOOP
        JB      P3.1,cnt_chk
        CALL    ERROR3
cnt_chk:RET


;****************************************************************
;                ERROR 1 - BARS NOT DETECTED
;****************************************************************
```

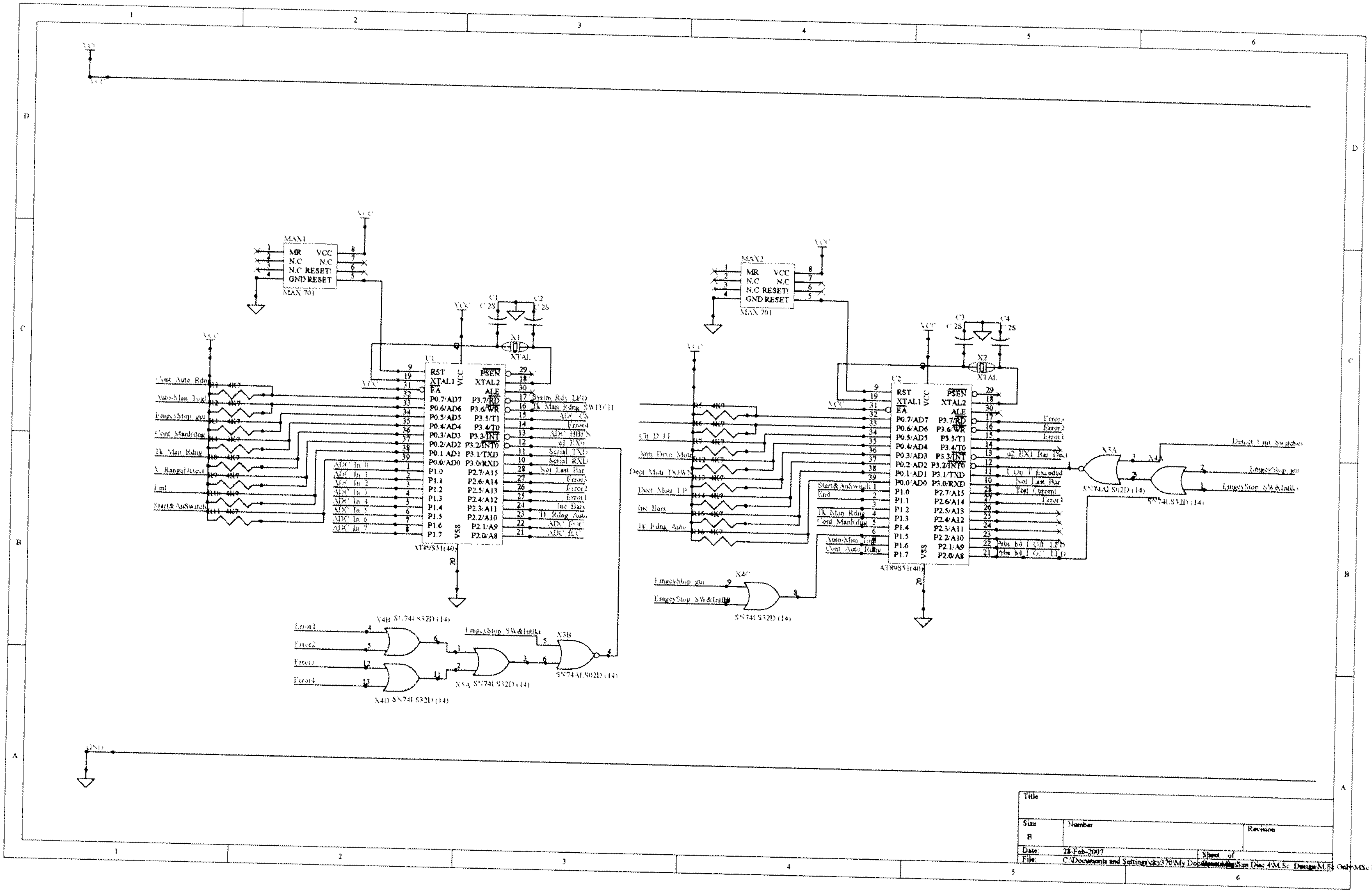
```
ERROR1: CLR     P0.4
        JB      05H,S1          ;
        JNB     02H,S1          ;
        MOV     R4,#HIGH COUNT2 ;
        MOV     R5,#LOW COUNT2  ;
        MOV     B,#200          ;
        MOV     R6,B
        CLR     05H     ; *nu IF ERR OCCURS ON 3RD PAIR, THEN TIME READING
        CLR     02H     ;   "
        SETB    00H     ;   "
        SETB    01H     ; ABOVE 4 ERROR ON 3RD BAR, BUT NOT REALLY REQUIRED
S1:     SETB    P0.5 ;
        nop          ;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        nop         ;
        CLR     P0.5 ;
        SETB    P3.5 ;TO MIC1
        CALL    ER_I_SW
        CLR     P3.5
        RET

;*********************************************************************
;                    ERROR 2 - TEST PROBES NOT LOWERED
;*********************************************************************

ERROR2: CLR     P0.3
        CLR     P2.7
        CALL    DELAYLOOP
        SETB    0AH

        JB      08H,NO_RELD  ;23-03-06 reload values for run_up
        CLR     TR1          ;cos EX0 is not triggered on Error 2
        CLR     TR0
        MOV     B,R3
        MOV     R7,B
        CLR     RS0       ;
        SETB    RS1       ;REG BANK 1
        MOV     R1,TH0
        MOV     R2,TL0
        CLR     RS0       ;
        CLR     RS1       ;REG BANK 0 ;23-03-06 reload values for run_up

NO_RELD:CALL    RUN_UP
;SEE NOTE HERE IN PREVIOUS VERSIONS OF CODE
        JB      0BH,E2_OUT
        SETB    P3.6 ;TO MIC1
        CALL    ER_I_SW
        CLR     P3.6
E2_OUT: CLR     0AH
        CLR     0BH
        RET
```

```
;*********************************************************************
;               ERROR 3 - TEST CUTTENT TIME EXCEEDED
;*********************************************************************

ERROR3: SETB    0DH
        CALL    RUN_UP
        CLR     P2.7
        ;CALL    DELAYLOOP; NOT NEEDED
        SETB    P3.7
        nop
        CALL    DELAYLOOP
        CLR     P3.7
E3_HLD: JNB     P1.4, E3_HLD
        SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        CLR     0DH
        RET

;*********************************************************************
;               ERROR 4 - TEST PROBES NOT RAISED
;*********************************************************************
ERROR4: JB      0DH,E4_OUT
        CLR     P0.2
        CLR     P2.7
        CALL    DELAYLOOP
        SETB    P2.6
        nop
        CALL    DELAYLOOP
        CLR     P2.6
E4_HLD: JNB     P1.4,E4_HLD
        SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        JNB     0AH,E4_OUT
        SETB    0BH
        SETB    P3.6 ;TO MIC1
        CALL    ER_I_SW
        CLR     P3.6
        CLR     0AH
E4_OUT: RET

;*****************************************************
;               ERROR READING PROCEDURE
;*****************************************************

ER_I_SW:SETB    0EH
E1_CK1: JNB     P1.4,E1_CK1
        ;CLR     EX0;? needed?06/12
AGN:    JB      P3.2,ON_I
        SETB    P2.0
        JMP     AGN
ON_I:   CALL    DELAYLOOP
        SETB    P2.7
```

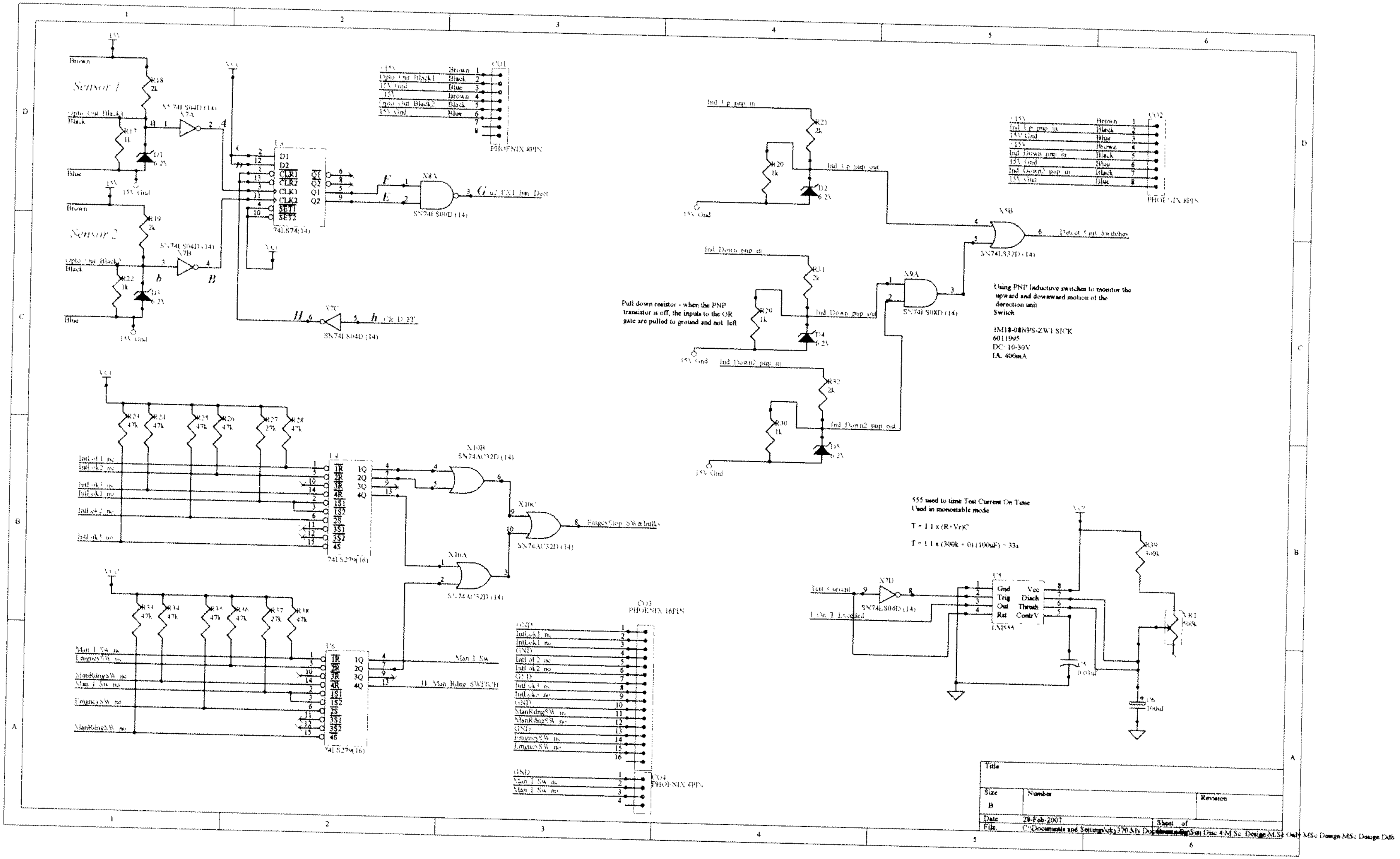
```
            CLR     P2.0
PRBS_WT:JB      P3.2,PRBS_WT
            CALL    DELAYLOOP
            JB      P3.2,PRBS_WT
            ;CALL    DELAYLOOP
            SETB    P0.0
            NOP
            NOP
            CLR     P0.0
            CALL    READING
E1_HLD:     JNB     P1.4,E1_HLD
            SETB    P0.0
            NOP
            NOP
            CLR     P0.0
AGN2:       JB      P3.2,OF_I
            SETB    P2.1
            JMP     AGN2
OF_I:       CALL    DELAYLOOP
            CLR     P2.7
            CLR     P2.1
            CALL    DELAYLOOP
            ;SETB    EX0 ;? needed?06/12
            CLR     0EH
            RET
;*********************************************************************
END:        MOV     P0,#0H
            MOV     P1,#0H
            MOV     P2,#0H
            MOV     P3,#0H
            SETB    P2.6
            MOV     PCON,#00000010B;POWER DOWN
            NOP
            END
```

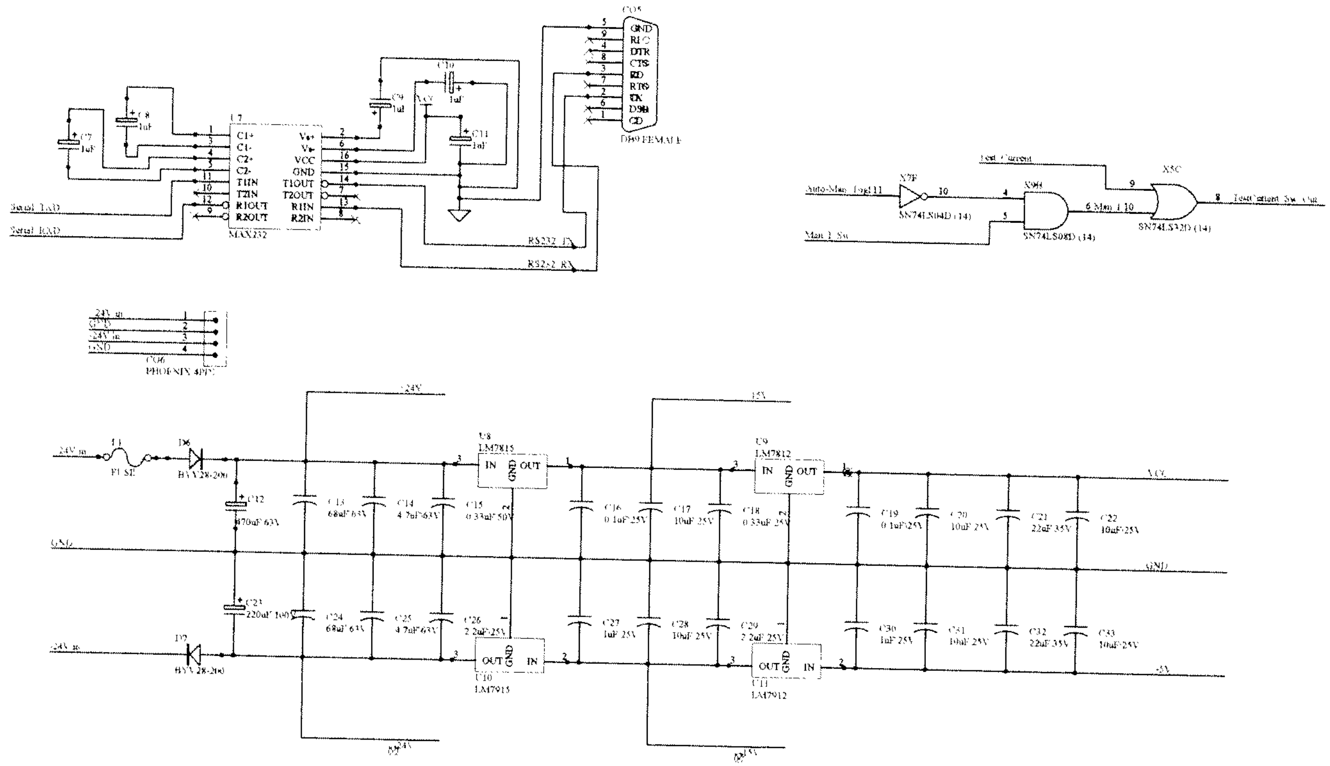


Sheet1
Sheet1.Sch
Sheet2
Sheet2.Sch
Sheet3
Sheet3.Sch
Sheet4
Sheet4.Sch
Sheet5
Sheet5.Sch
Title
Size
B
Number
Revision
Date: 28-Feb-2007
Sheet of
File: C:\Documents and Settings\cky370\My Documents\Sun Disc 4 M.Sc. Design\M.Sc Only\MSc Design MSc Design.Ddb

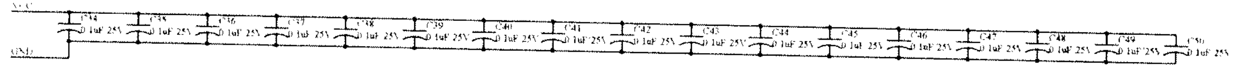


MAX1
MAX 701
MAX2
AT89S51(40)
XTAL
SN74ALS32D (14)
SN74ALS02D (14)
Title
Size
B
Number
Revision
Date: 28-Feb-2007
Sheet of

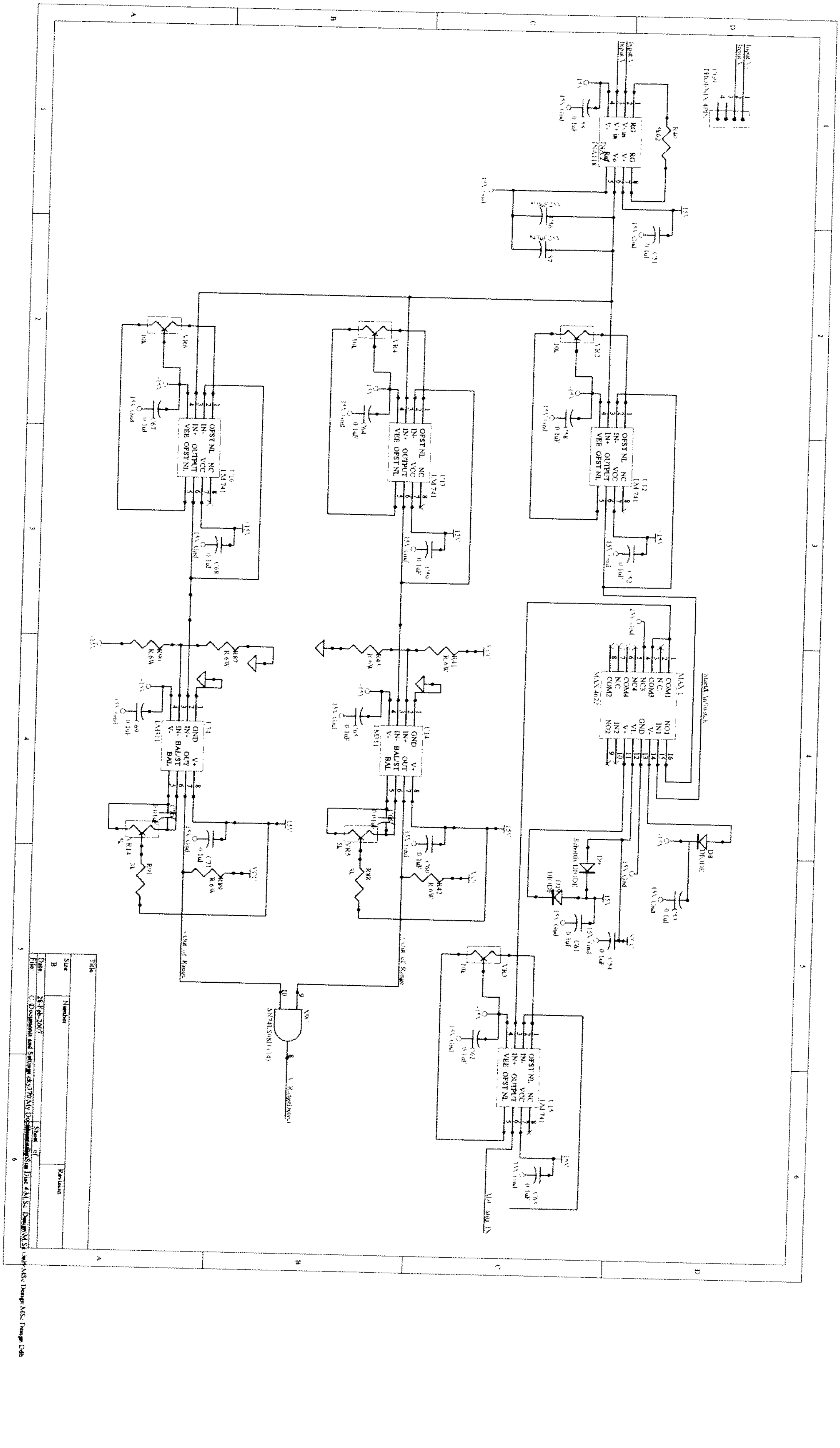

Sensor 1
Sensor 2
PHOENIX 8PIN
PHOENIX 16PIN
PHOENIX 4PIN
Pull down resistor - when the PNP transistor is off, the inputs to the OR gate are pulled to ground and not left
Using PNP Inductive switches to monitor the upward and downward motion of the detection unit
Switch
IM18-08NPS-ZW1 SICK
6011995
DC: 10-30V
IA: 400mA
555 used to time Test Current On Time
Used in monostable mode
T = 1.1 x (R+Vr)C
T = 1.1 x (300k + 0) (100uF) = 33s
Title
Size
B
Number
Revision
Date
28-Feb-2007
Sheet of
File

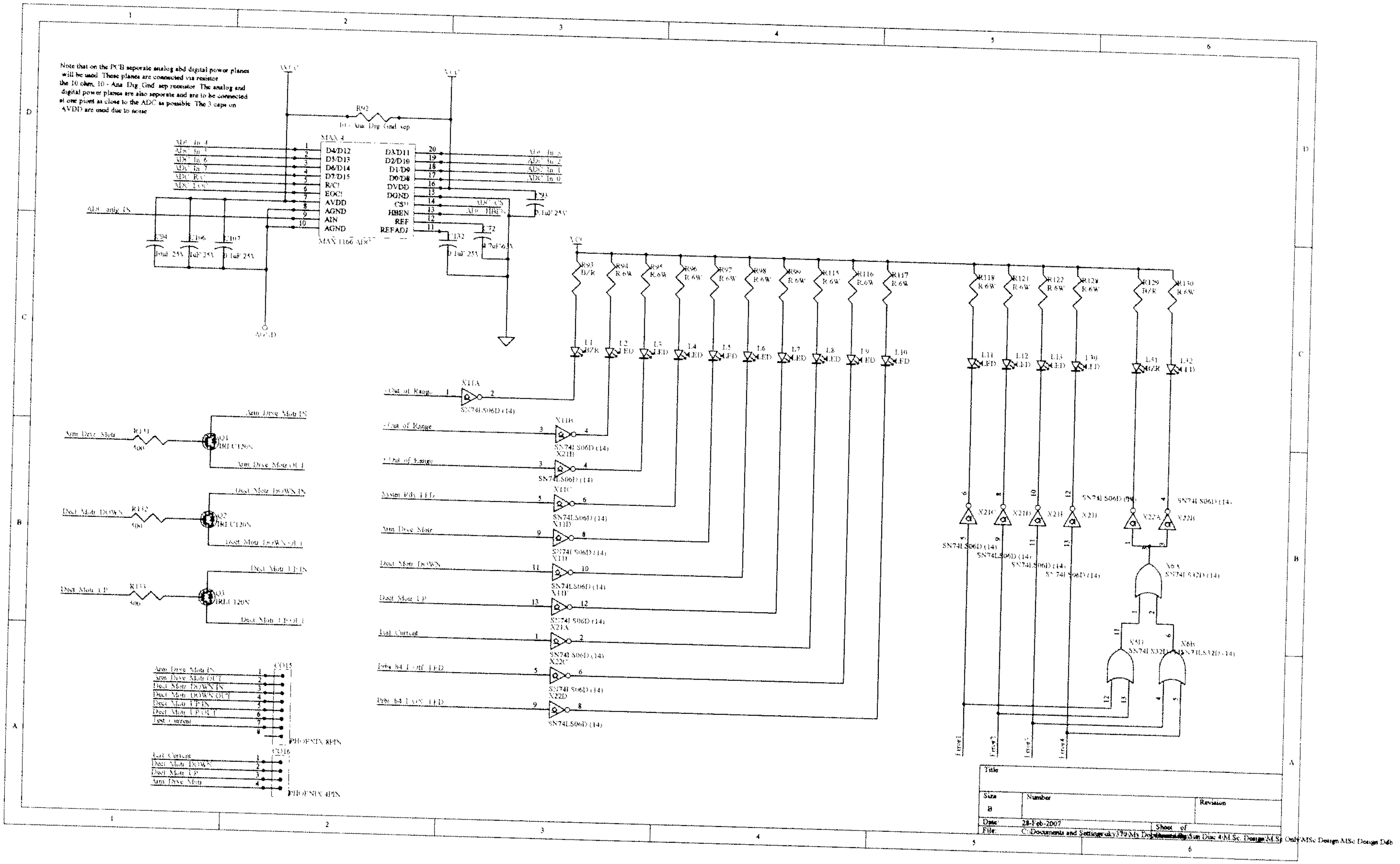


Note the common GND for all voltage supplies. A split ground plane is to be used, for each voltage ground labled in the sch diagram, (eg 12V Gnd). All these plane must be joined at a common point
closest to supply ground

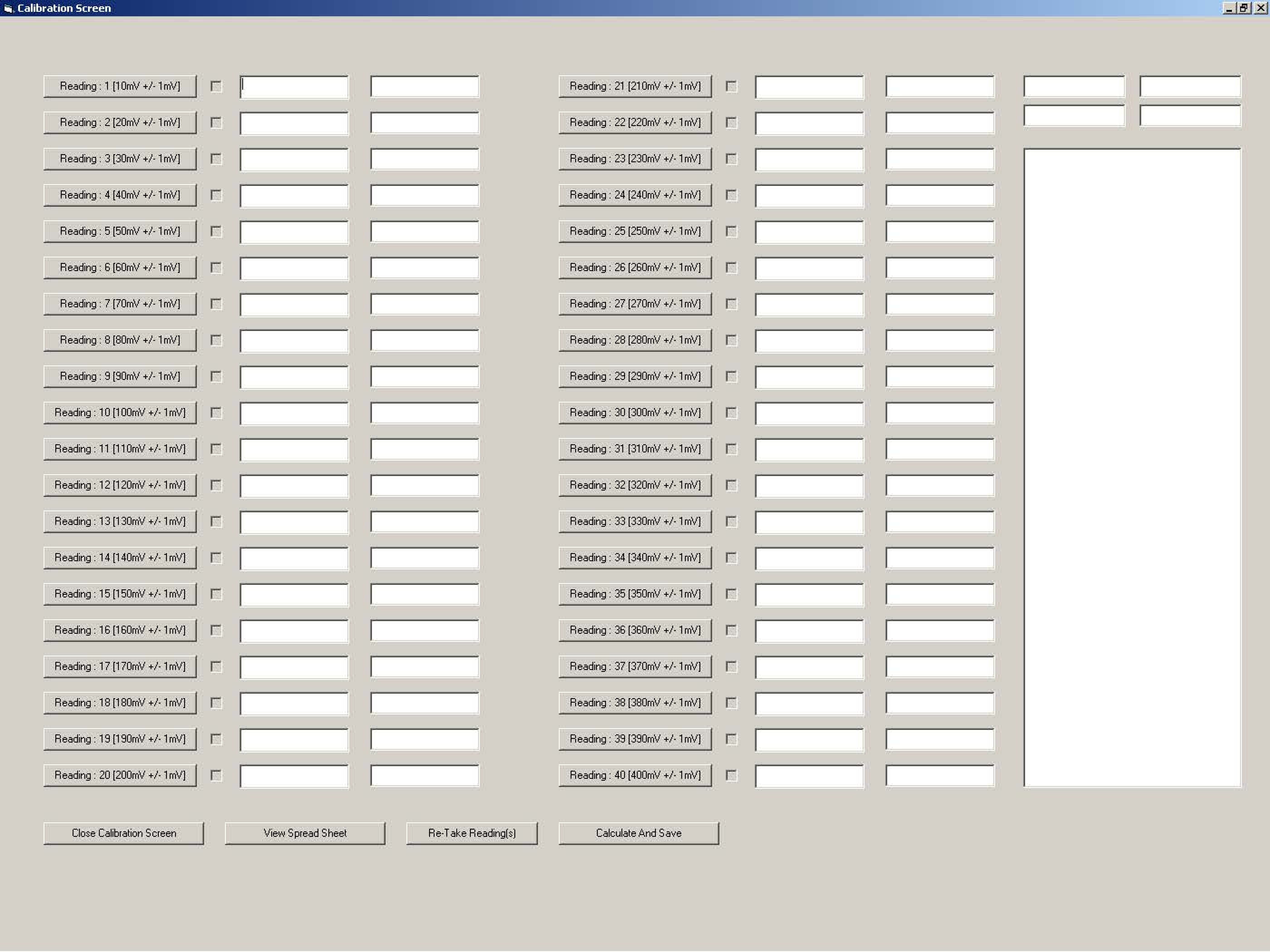


Title		
Size B	Number	Revision
Date	28-Feb-2007	Sheet of
File	C:\Documents and Settings\...\My Documents\...\M.Sc. Design\M.Sc Only\MSc Design\MSc Design Draft	





Note that on the PCB seporate analog abd digital power planes will be used. These planes are connected via resistor the 10 ohm, 10 - Ana_Dig_Gnd_sep resistor. The analog and digital power planes are also seporate and are to be connected at one piont as close to the ADC as possible. The 3 caps on AVDD are used due to noise
MAX 1166 ADC
SN74LS06D (14)
SN74LS32D (14)
PHOENIX 8PIN
PHOENIX 4PIN
Title
Size
B
Number
Revision
Date
28-Feb-2007
Sheet of
File


Calibration Screen
Reading : 1 [10mV +/- 1mV]
Reading : 2 [20mV +/- 1mV]
Reading : 3 [30mV +/- 1mV]
Reading : 4 [40mV +/- 1mV]
Reading : 5 [50mV +/- 1mV]
Reading : 6 [60mV +/- 1mV]
Reading : 7 [70mV +/- 1mV]
Reading : 8 [80mV +/- 1mV]
Reading : 9 [90mV +/- 1mV]
Reading : 10 [100mV +/- 1mV]
Reading : 11 [110mV +/- 1mV]
Reading : 12 [120mV +/- 1mV]
Reading : 13 [130mV +/- 1mV]
Reading : 14 [140mV +/- 1mV]
Reading : 15 [150mV +/- 1mV]
Reading : 16 [160mV +/- 1mV]
Reading : 17 [170mV +/- 1mV]
Reading : 18 [180mV +/- 1mV]
Reading : 19 [190mV +/- 1mV]
Reading : 20 [200mV +/- 1mV]
Reading : 21 [210mV +/- 1mV]
Reading : 22 [220mV +/- 1mV]
Reading : 23 [230mV +/- 1mV]
Reading : 24 [240mV +/- 1mV]
Reading : 25 [250mV +/- 1mV]
Reading : 26 [260mV +/- 1mV]
Reading : 27 [270mV +/- 1mV]
Reading : 28 [280mV +/- 1mV]
Reading : 29 [290mV +/- 1mV]
Reading : 30 [300mV +/- 1mV]
Reading : 31 [310mV +/- 1mV]
Reading : 32 [320mV +/- 1mV]
Reading : 33 [330mV +/- 1mV]
Reading : 34 [340mV +/- 1mV]
Reading : 35 [350mV +/- 1mV]
Reading : 36 [360mV +/- 1mV]
Reading : 37 [370mV +/- 1mV]
Reading : 38 [380mV +/- 1mV]
Reading : 39 [390mV +/- 1mV]
Reading : 40 [400mV +/- 1mV]
Close Calibration Screen
View Spread Sheet
Re-Take Reading(s)
Calculate And Save

National Semiconductor

June 1989

54LS00/DM54LS00/DM74LS00 Quad 2-Input NAND Gates

General Description

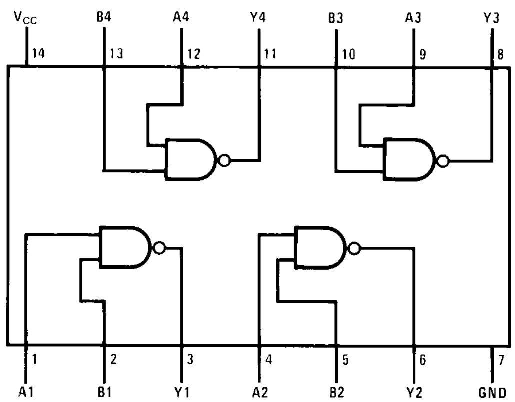
This device contains four independent gates each of which performs the logic NAND function.

Features

- Alternate Military/Aerospace device (54LS00) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6439–1

Order Number 54LS00DMQB, 54LS00FMQB, 54LS00LMQB, DM54LS00J, DM54LS00W, DM74LS00M or DM74LS00N
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

$$Y = \overline{AB}$$

Inputs		Output
A	**B**	**Y**
L	L	H
L	H	H
H	L	H
H	H	L

H = High Logic Level
L = Low Logic Level

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS00			DM74LS00			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max, V_{IL} = Max	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IH} = Min	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.36	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CCH}	Supply Current with Outputs High	V_{CC} = Max			0.8	1.6	mA
I_{CCL}	Supply Current with Outputs Low	V_{CC} = Max			2.4	4.4	mA

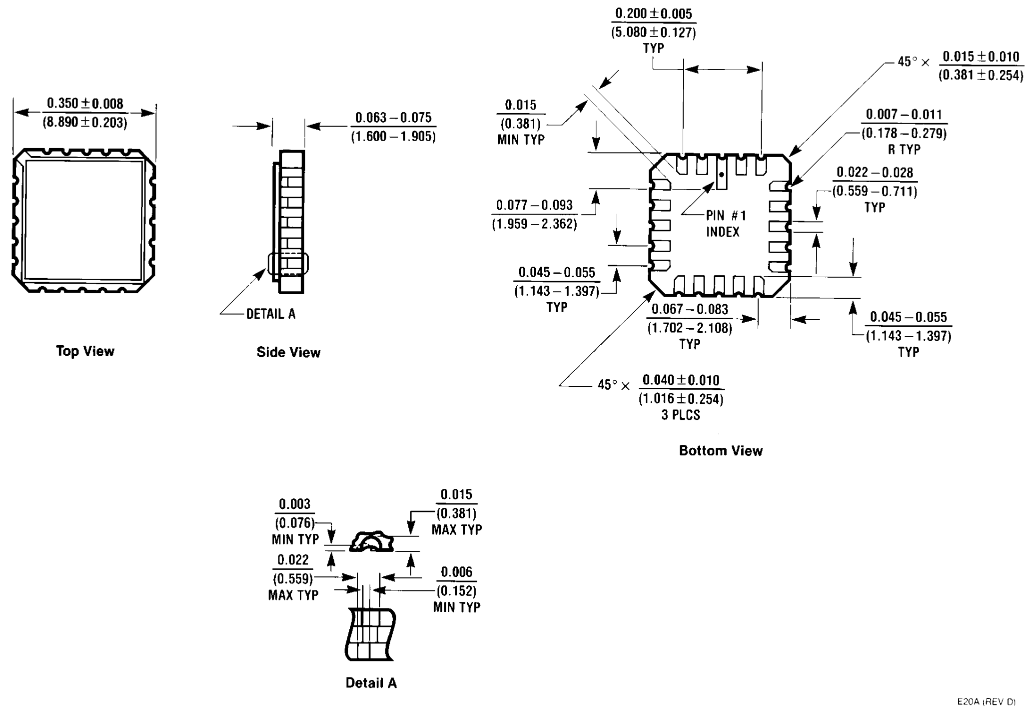
Switching Characteristics at V_{CC} = 5V and T_A = 25°C (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	3	10	4	15	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	3	10	4	15	ns

Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

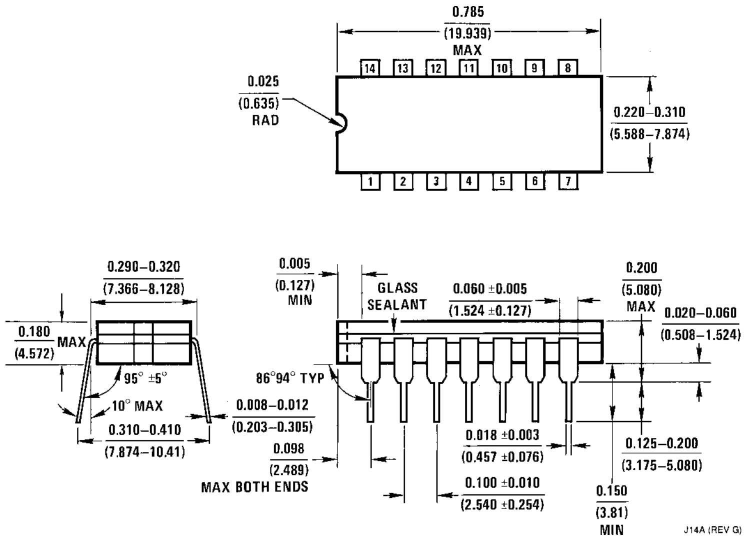
Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Physical Dimensions inches (millimeters)

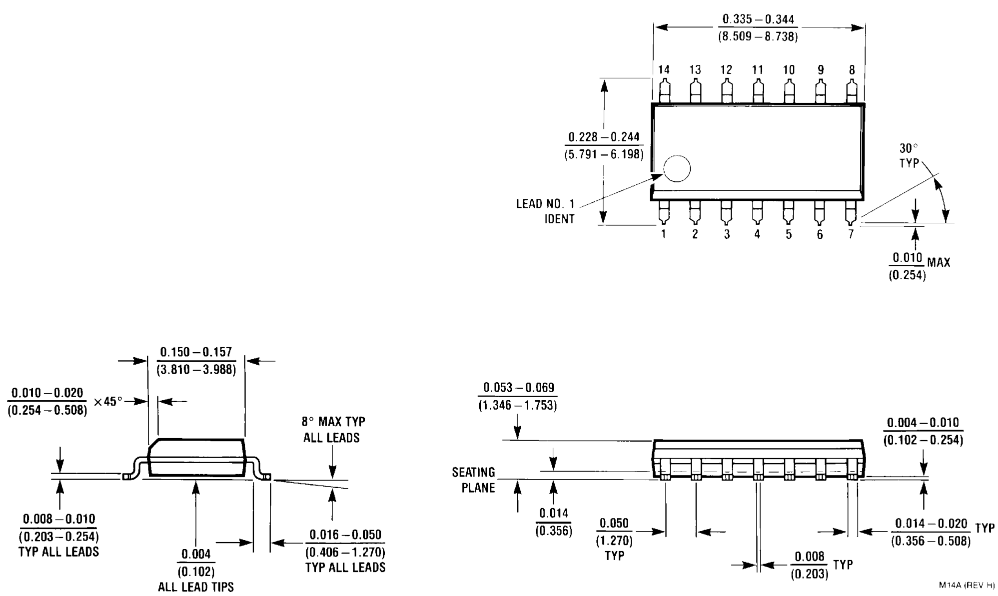


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS00LMQB
NS Package Number E20A

Physical Dimensions inches (millimeters)

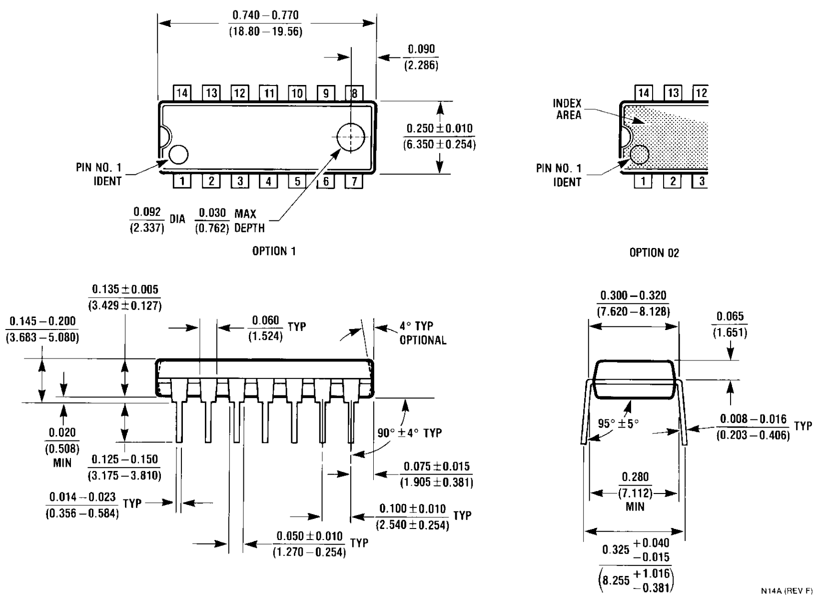


14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS00DMQB or DM54LS00J
NS Package Number J14A



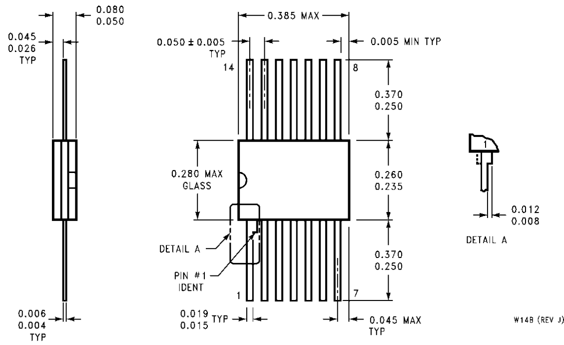
14-Lead Small Outline Molded Package (M)
Order Number DM74LS00M
NS Package Number M14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS00N
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS00FMQB or DM54LS00W
NS Package Number W14B

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

FAIRCHILD SEMICONDUCTOR™

May 1986
Revised March 2000

DM74LS02
Quad 2-Input NOR Gate

General Description

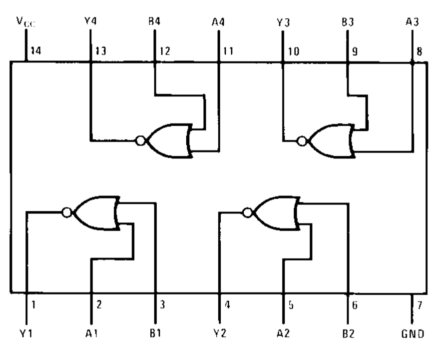
This device contains four independent gates each of which performs the logic NOR function.

Ordering Code:

Order Number	Package Number	Package Description
DM74LS02M	M14A	14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150 Narrow
DM74LS02SJ	M14D	14-Lead Small Outline Package (SOP), EIAJ TYPE II, 5.3mm Wide
DM74LS02N	N14A	14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300 Wide

Devices also available in Tape and Reel. Specify by appending the suffix letter "X" to the ordering code.

Connection Diagram



Function Table

$$Y = \overline{A + B}$$

Inputs		Output
A	**B**	**Y**
L	L	H
L	H	L
H	L	L
H	H	L

H = HIGH Logic Level
L = LOW Logic Level

Absolute Maximum Ratings(Note 1)

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	0°C to +70°C
Storage Temperature Range	–65°C to +150°C

Note 1: The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the Electrical Characteristics tables are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.

Recommended Operating Conditions

Symbol	Parameter	Min	Nom	Max	Units
V_{CC}	Supply Voltage	4.75	5	5.25	V
V_{IH}	HIGH Level Input Voltage	2			V
V_{IL}	LOW Level Input Voltage			0.8	V
I_{OH}	HIGH Level Output Current			–0.4	mA
I_{OL}	LOW Level Output Current			8	mA
T_A	Free Air Operating Temperature	0		70	°C

Electrical Characteristics

over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions	Min	Typ (Note 2)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = –18 mA			–1.5	V
V_{OH}	HIGH Level Output Voltage	V_{CC} = Min, I_{OH} = Max, V_{IL} = Max	2.7	3.4		V
V_{OL}	LOW Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IH} = Min		0.35	0.5	V
		I_{OL} = 4 mA, V_{CC} = Min		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V			0.1	mA
I_{IH}	HIGH Level Input Current	V_{CC} = Max, V_I = 2.7V			20	μA
I_{IL}	LOW Level Input Current	V_{CC} = Max, V_I = 0.4V			–0.40	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 3)	–20		–100	mA
I_{CCH}	Supply Current with Outputs HIGH	V_{CC} = Max		1.6	3.2	mA
I_{CCL}	Supply Current with Outputs LOW	V_{CC} = Max		2.8	5.4	mA

Note 2: All typicals are at V_{CC} = 5V, T_A = 25°C.

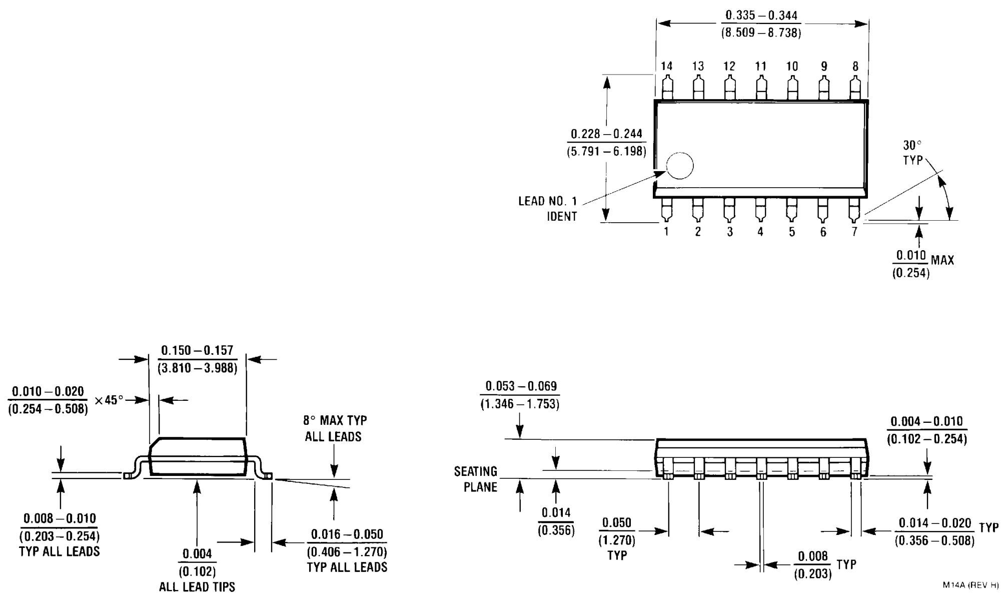
Note 3: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Switching Characteristics

at V_{CC} = 5V and T_A = 25°C

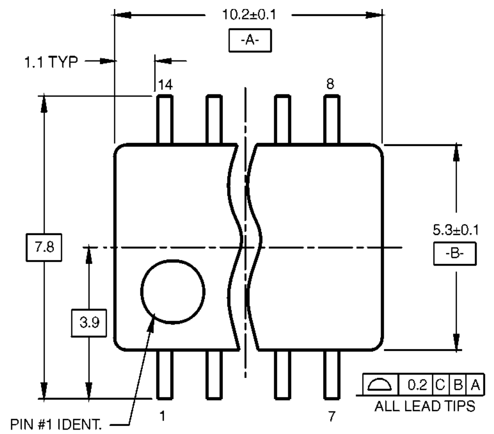
Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time LOW-to-HIGH Level Output		13		18	ns
t_{PHL}	Propagation Delay Time HIGH-to-LOW Level Output		10		15	ns

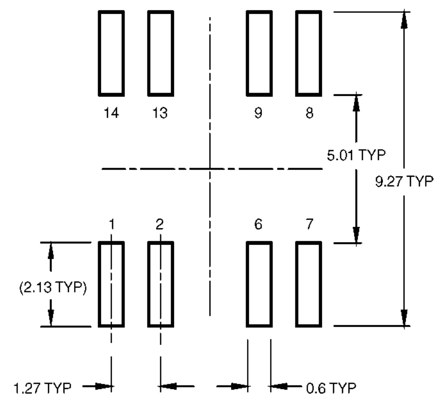
Physical Dimensions inches (millimeters) unless otherwise noted



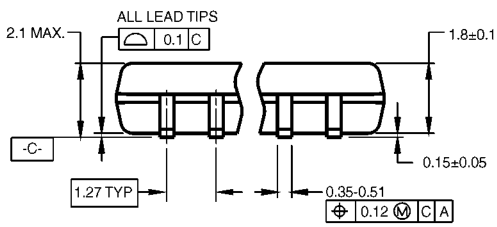
14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150 Narrow Package Number M14A

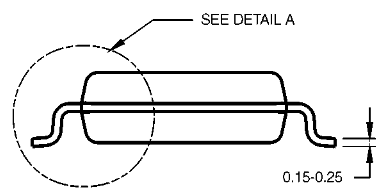
Physical Dimensions inches (millimeters) unless otherwise noted (Continued)





LAND PATTERN RECOMMENDATION

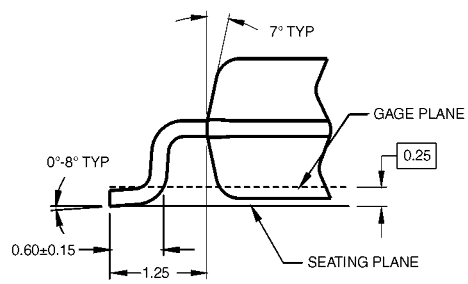




DIMENSIONS ARE IN MILLIMETERS

NOTES:
A. CONFORMS TO EIAJ EDR-7320 REGISTRATION, ESTABLISHED IN DECEMBER, 1998.
B. DIMENSIONS ARE IN MILLIMETERS.
C. DIMENSIONS ARE EXCLUSIVE OF BURRS, MOLD FLASH, AND TIE BAR EXTRUSIONS.

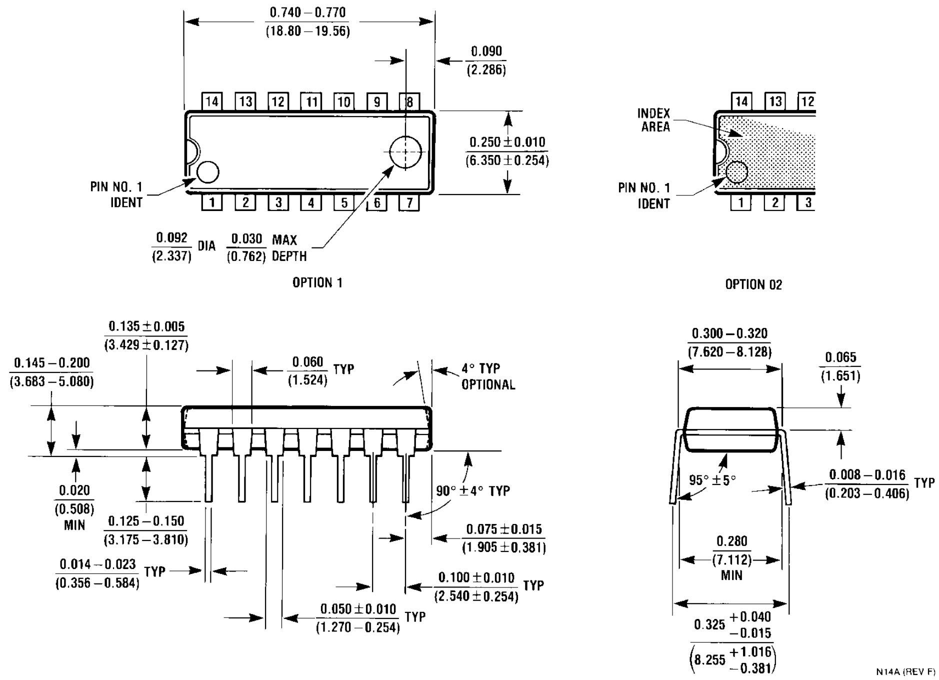
M14DRevB1



DETAIL A

14-Lead Small Outline Package (SOP), EIAJ TYPE II, 5.3mm Wide
Package Number M14D

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



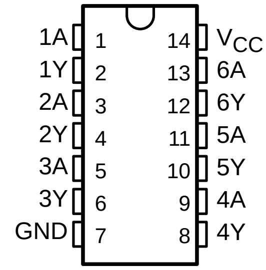
14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300 Wide
Package Number N14A

- **Dependable Texas Instruments Quality and Reliability**

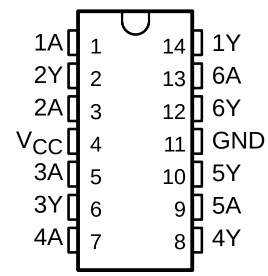
description

These devices contain six independent inverters.

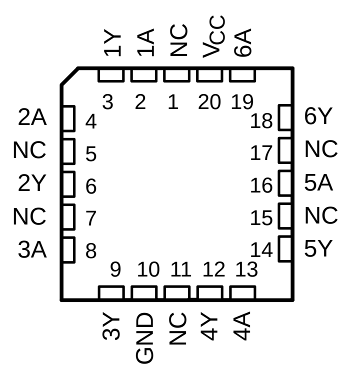
SN5404 . . . J PACKAGE
SN54LS04, SN54S04 . . . J OR W PACKAGE
SN7404 . . . D, N, OR NS PACKAGE
SN74LS04 . . . D, DB, N, OR NS PACKAGE
SN74S04 . . . D OR N PACKAGE
(TOP VIEW)



SN5404 . . . W PACKAGE
(TOP VIEW)



SN54LS04, SN54S04 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

ORDERING INFORMATION

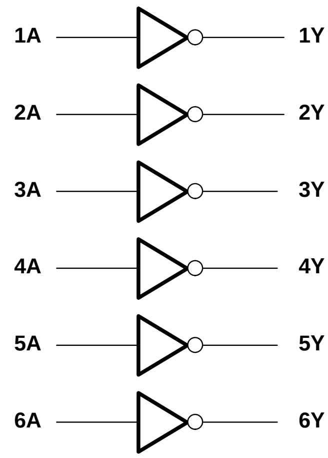
T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP – N	Tube	SN7404N	SN7404N
		Tube	SN74LS04N	SN74LS04N
		Tube	SN74S04N	SN74S04N
	SOIC – D	Tube	SN7404D	7404
		Tube	SN74LS04D	LS04
		Tape and reel	SN74LS04DR	
		Tube	SN74S04D	S04
		Tape and reel	SN74S04DR	
	SOP – NS	Tape and reel	SN7404NSR	SN7404
		Tape and reel	SN74LS04NSR	74LS04
	SSOP – DB	Tape and reel	SN74LS04DBR	LS04
–55°C to 125°C	CDIP – J	Tube	SN5404J	SN5404J
		Tube	SNJ5404J	SNJ5404J
		Tube	SN54LS04J	SN54LS04J
		Tube	SN54S04J	SN54S04J
		Tube	SNJ54LS04J	SNJ54LS04J
		Tube	SNJ54S04J	SNJ54S04J
	CFP – W	Tube	SNJ5404W	SNJ5404W
		Tube	SNJ54LS04W	SNJ54LS04W
		Tube	SNJ54S04W	SNJ54S04W
	LCCC – FK	Tube	SNJ54LS04FK	SNJ54LS04FK
		Tube	SNJ54S04FK	SNJ54S04FK

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

FUNCTION TABLE
(each inverter)

INPUT A	OUTPUT Y
H	L
L	H

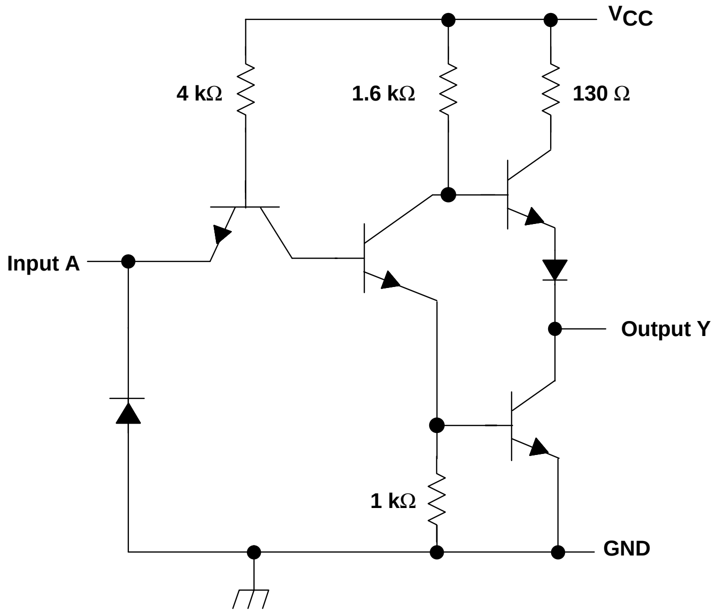
logic diagram (positive logic)



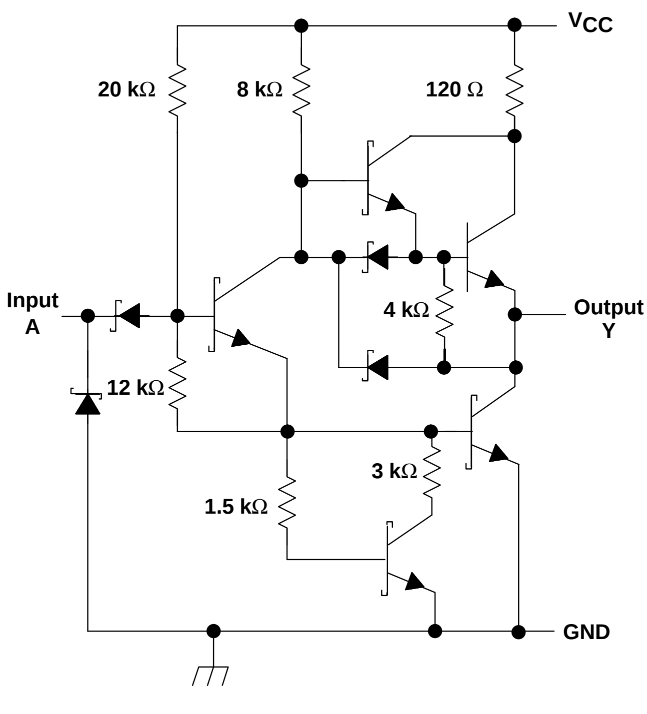
$Y = \overline{A}$

schematics (each gate)

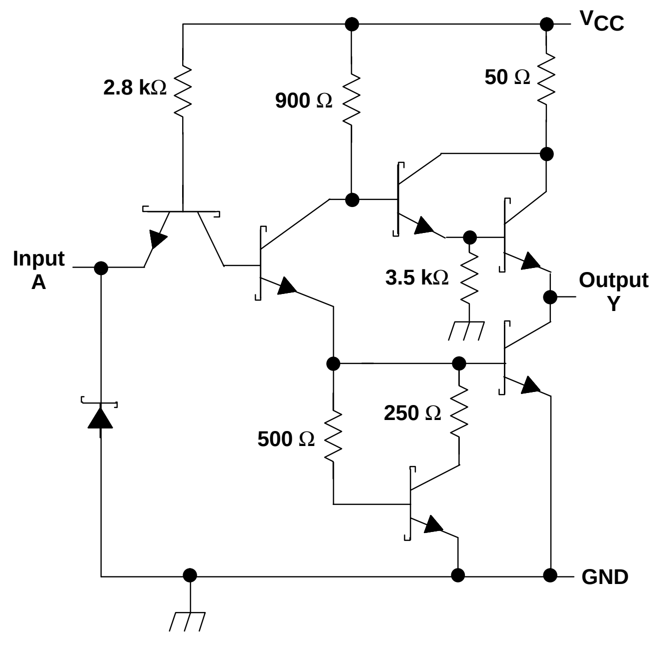
’04



’LS04



’S04



Resistor values shown are nominal.

TEXAS INSTRUMENTS
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absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{CC} (see Note 1) . . . . 7 V
Input voltage, V_I: '04, 'S04 . . . . 5.5 V
'LS04 . . . . 7 V
Package thermal impedance, θ_{JA} (see Note 2): D package . . . . 86°C/W
DB package . . . . 96°C/W
N package . . . . 80°C/W
NS package . . . . 76°C/W
Storage temperature range, T_{stg} . . . . –65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. This are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. Voltage values are with respect to network ground terminal.
2. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

		SN5404			SN7404			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.8			0.8	V
I_{OH}	High-level output current			–0.4			–0.4	mA
I_{OL}	Low-level output current			16			16	mA
T_A	Operating free-air temperature	–55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS‡			SN5404			SN7404			UNIT
				MIN	TYP§	MAX	MIN	TYP§	MAX	
V_{IK}	V_{CC} = MIN,	I_I = –12 mA				–1.5			–1.5	V
V_{OH}	V_{CC} = MIN,	V_{IL} = 0.8 V,	I_{OH} = –0.4 mA	2.4	3.4		2.4	3.4		V
V_{OL}	V_{CC} = MIN,	V_{IH} = 2 V,	I_{OL} = 16 mA		0.2	0.4		0.2	0.4	V
I_I	V_{CC} = MAX,	V_I = 5.5 V				1			1	mA
I_{IH}	V_{CC} = MAX,	V_I = 2.4 V				40			40	µA
I_{IL}	V_{CC} = MAX,	V_I = 0.4 V				–1.6			–1.6	mA
I_{OS}¶	V_{CC} = MAX			–20		–55	–18		–55	mA
I_{CCH}	V_{CC} = MAX,	V_I = 0 V			6	12		6	12	mA
I_{CCL}	V_{CC} = MAX,	V_I = 4.5 V			18	33		18	33	mA

‡ For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
§ All typical values are at V_{CC} = 5 V, T_A = 25°C.
¶ Not more than one output should be shorted at a time.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 1)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS		SN5404 SN7404			UNIT
					MIN	TYP	MAX	
t_{PLH}	A	Y	R_L = 400 Ω,	C_L = 15 pF		12	22	ns
t_{PHL}						8	15	

recommended operating conditions

		SN54LS04			SN74LS04			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.7			0.8	V
I_{OH}	High-level output current			–0.4			–0.4	mA
I_{OL}	Low-level output current			4			8	mA
T_A	Operating free-air temperature	–55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS†			SN54LS04			SN74LS04			UNIT
				MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IK}	V_{CC} = MIN,	I_I = –18 mA				–1.5			–1.5	V
V_{OH}	V_{CC} = MIN,	V_{IL} = MAX,	I_{OH} = –0.4 mA	2.5	3.4		2.7	3.4		V
V_{OL}	V_{CC} = MIN,	V_{IH} = 2 V	I_{OL} = 4 mA		0.25	0.4			0.4	V
			I_{OL} = 8 mA					0.25	0.5	
I_I	V_{CC} = MAX,	V_I = 7 V				0.1			0.1	mA
I_{IH}	V_{CC} = MAX,	V_I = 2.7 V				20			20	µA
I_{IL}	V_{CC} = MAX,	V_I = 0.4 V				–0.4			–0.4	mA
I_{OS}§	V_{CC} = MAX			–20		–100	–20		–100	mA
I_{CCH}	V_{CC} = MAX,	V_I = 0 V			1.2	2.4		1.2	2.4	mA
I_{CCL}	V_{CC} = MAX,	V_I = 4.5 V			3.6	6.6		3.6	6.6	mA

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡ All typical values are at V_{CC} = 5 V, T_A = 25°C.
§ Not more than one output should be shorted at a time and the duration of the short-circuit should not exceed one second.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 2)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS		SN54LS04 SN74LS04			UNIT
					MIN	TYP	MAX	
t_{PLH}	A	Y	R_L = 2 kΩ,	C_L = 15 pF		9	15	ns
t_{PHL}						10	15	

recommended operating conditions

		SN54S04			SN74S04			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.8			0.8	V
I_{OH}	High-level output current			–1			–1	mA
I_{OL}	Low-level output current			20			20	mA
T_A	Operating free-air temperature	–55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

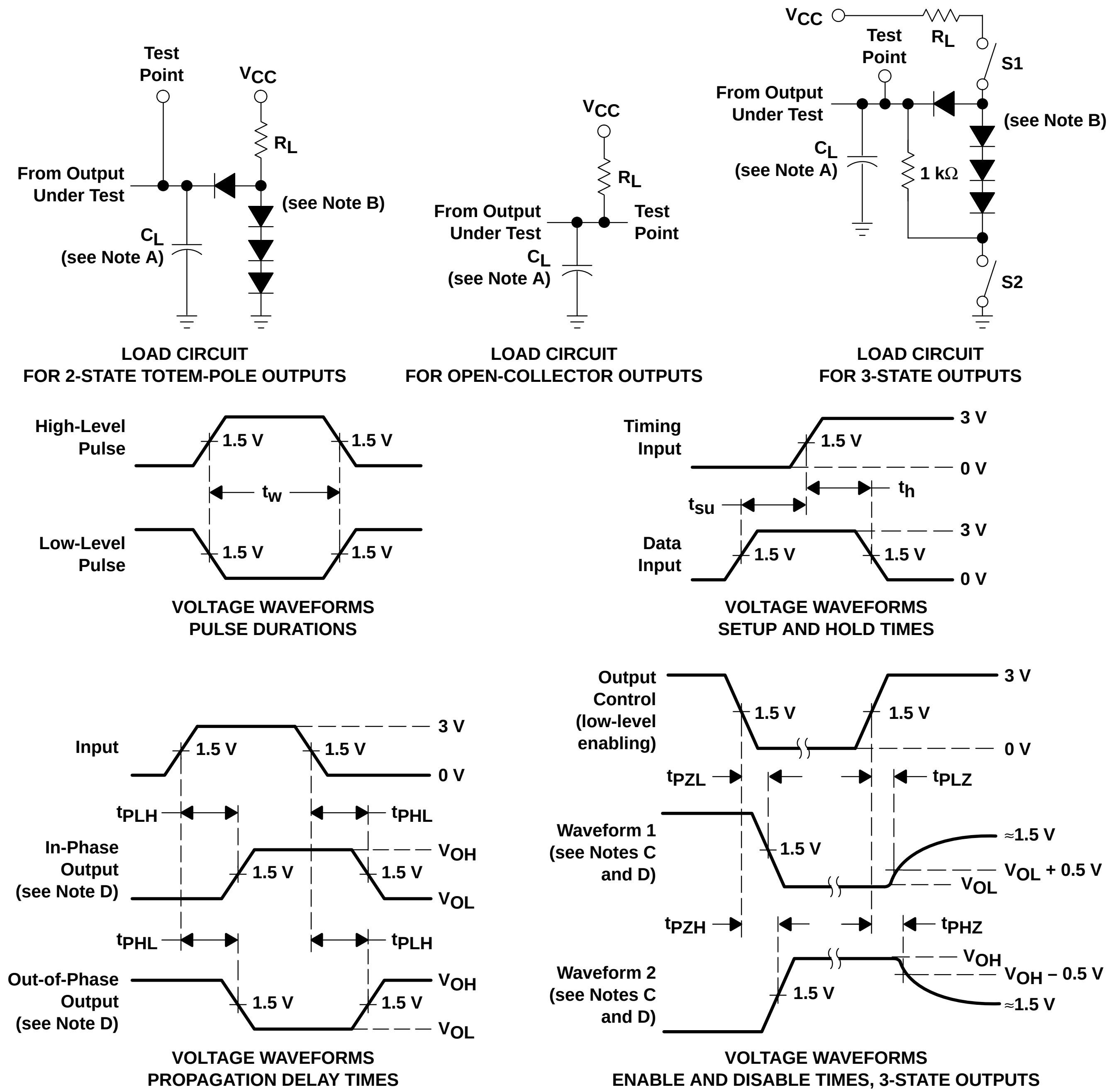
PARAMETER	TEST CONDITIONS†			SN54S04			SN74S04			UNIT
				MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IK}	V_{CC} = MIN,	I_I = –18 mA				–1.2			–1.2	V
V_{OH}	V_{CC} = MIN,	V_{IL} = 0.8 V,	I_{OH} = –1 mA	2.5	3.4		2.7	3.4		V
V_{OL}	V_{CC} = MIN,	V_{IH} = 2 V,	I_{OL} = 20 mA			0.5			0.5	V
I_I	V_{CC} = MAX,	V_I = 5.5 V				1			1	mA
I_{IH}	V_{CC} = MAX,	V_I = 2.7 V				50			50	µA
I_{IL}	V_{CC} = MAX,	V_I = 0.5 V				–2			–2	mA
I_{OS}§	V_{CC} = MAX			–40		–100	–40		–100	mA
I_{CCH}	V_{CC} = MAX,	V_I = 0 V			15	24		15	24	mA
I_{CCL}	V_{CC} = MAX,	V_I = 4.5 V			30	54		30	54	mA

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡ All typical values are at V_{CC} = 5 V, T_A = 25°C.
§ Not more than one output should be shorted at a time and the duration of the short-circuit should not exceed one second.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 1)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	TEST CONDITIONS		SN54S04 SN74S04			UNIT
					MIN	TYP	MAX	
t_{PLH}	A	Y	R_L = 280 Ω,	C_L = 15 pF		3	4.5	ns
t_{PHL}						3	5	
t_{PLH}	A	Y	R_L = 280 Ω,	C_L = 50 pF		4.5		ns
t_{PHL}						5		

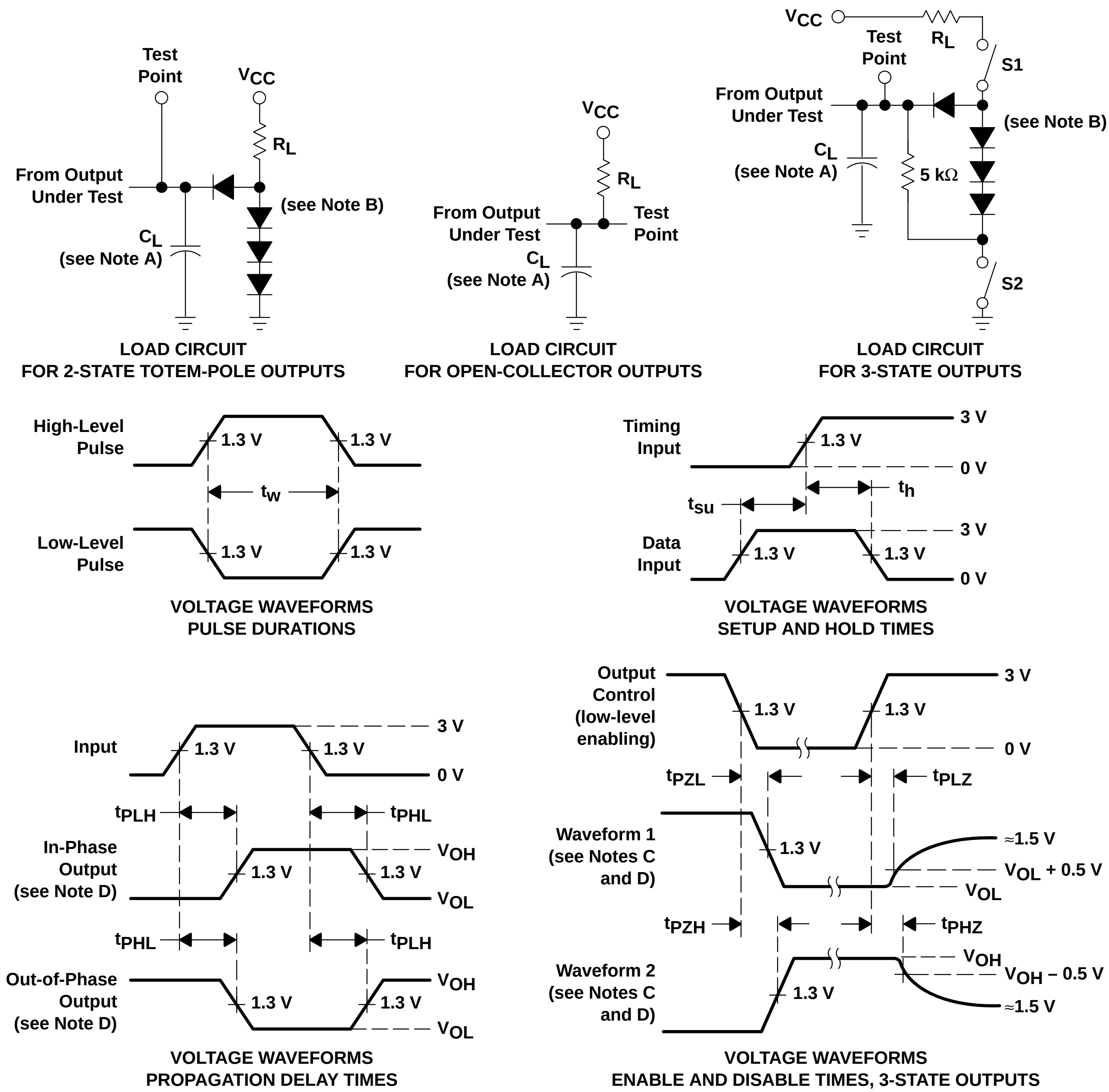
PARAMETER MEASUREMENT INFORMATION
SERIES 54/74 AND 54S/74S DEVICES



NOTES: A. C_L includes probe and jig capacitance.
B. All diodes are 1N3064 or equivalent.
C. Waveform 1 is for an output with internal conditions such that the output is low except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is high except when disabled by the output control.
D. S1 and S2 are closed for t_{PLH}, t_{PHL}, t_{PHZ}, and t_{PLZ}; S1 is open and S2 is closed for t_{PZH}; S1 is closed and S2 is open for t_{PZL}.
E. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, $Z_O \approx 50\ \Omega$; t_r and $t_f \leq 7$ ns for Series 54/74 devices and t_r and $t_f \leq 2.5$ ns for Series 54S/74S devices.
F. The outputs are measured one at a time with one input transition per measurement.

Figure 1. Load Circuits and Voltage Waveforms

PARAMETER MEASUREMENT INFORMATION
SERIES 54LS/74LS DEVICES



NOTES:
- A. C_L includes probe and jig capacitance.
- B. All diodes are 1N3064 or equivalent.
- C. Waveform 1 is for an output with internal conditions such that the output is low except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is high except when disabled by the output control.
- D. S1 and S2 are closed for t_{PLH}, t_{PHL}, t_{PHZ}, and t_{PLZ}; S1 is open and S2 is closed for t_{PZH}; S1 is closed and S2 is open for t_{PZL}.
- E. Phase relationships between inputs and outputs have been chosen arbitrarily for these examples.
- F. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, $Z_O \approx 50\ \Omega$, $t_r \le 1.5$ ns, $t_f \le 2.6$ ns.
- G. The outputs are measured one at a time with one input transition per measurement.

Figure 2. Load Circuits and Voltage Waveforms

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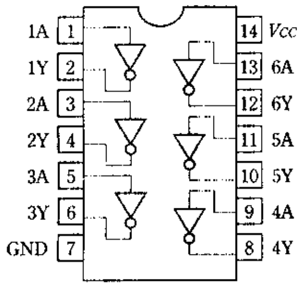
■ PIN ARRANGEMENT



(Top View)

■ ABSOLUTE MAXIMUM RATINGS

Item	Symbol	Ratings	Unit
Supply voltage	V_{CC}	7.0	V
Input voltage	V_{IN}	7.0	V
Output voltage	V_{out}	30	V
Operating temperature range	T_{opr}	–20 ~ +75	°C
Storage temperature range	T_{stg}	–65 ~ +150	°C

■ RECOMMENDED OPERATING CONDITIONS

Item	Symbol	min	typ	max	Unit
Supply voltage	V_{CC}	4.75	5.00	5.25	V
High level output voltage	V_{OH}	–	–	30	V
Low level output current	I_{OL}	–	–	48	mA
Operating temperature range	T_{opr}	–20	25	75	°C

■ ELECTRICAL CHARACTERISTICS (Ta = –20 ~ +75°C)

Item	Symbol	Test Conditions			min	typ*	max	Unit
Input voltage	V_{IH}				2.0	–	–	V
	V_{IL}				–	–	0.8	V
Output voltage	V_{OL}	V_{CC} = 4.75V,	V_{IH} = 2V	I_{OL} = 24mA	–	–	0.4	V
				I_{OL} = 48mA	–	–	0.5	V
Input current	I_{IH}	V_{CC} = 5.25V	V_I = 2.7V		–	–	20	µA
	I_{IL}	V_{CC} = 5.25V,	V_I = 0.4V		–	–	–0.4	mA
	I_I	V_{CC} = 5.25V,	V_I = 7V		–	–	0.1	mA
Output current	I_{OH}	V_{CC} = 4.75V,	V_{IL} = 0.8V,	V_{OH} = 30V	–	–	250	µA
Supply current	I_{CCH}	V_{CC} = 5.25V			–	23	48	mA
	I_{CCL}	V_{CC} = 5.25V			–	21	51	mA
Input clamp voltage	V_{IK}	V_{CC} = 4.75V,	I_{IN} = –18mA		–	–	–1.5	V

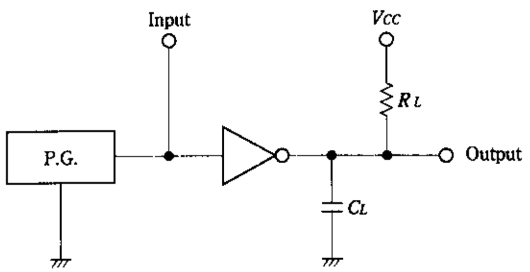
*V_{CC} = 5V, Ta = 25°C

■ SWITCHING CHARACTERISTICS (V_{CC} = 5V, Ta = 25°C)

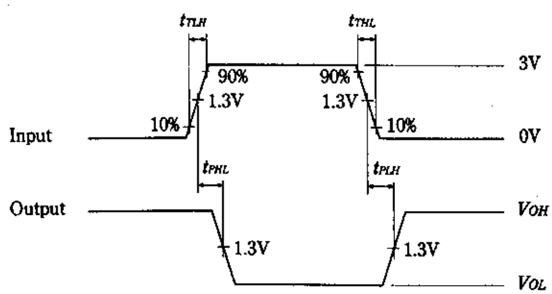
Item	Symbol	Test Conditions	min	typ	max	Unit
Propagation delay time	t_{PLH}	C_L = 15pF, R_L = 110Ω	–	10	15	ns
	t_{PHL}		–	15	23	ns

■ TESTING METHOD

Test Circuit

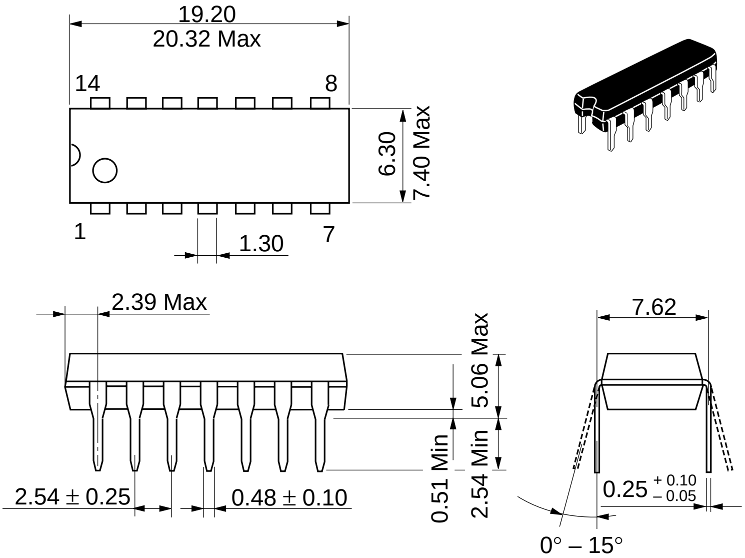


Waveform

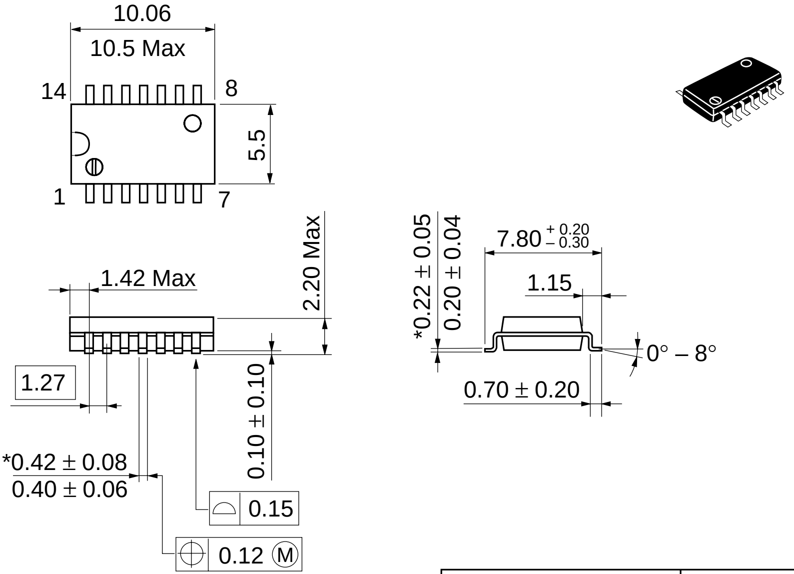


Notes) 1. Input pulse: PRR = 1MHz, duty cycle 50%, Zout = 50Ω, t_{TLH}≤15ns, t_{THL}≤6ns
2. C_L includes probe and jig capacitance.
3. All diodes are 1S2074(H)

Unit: mm



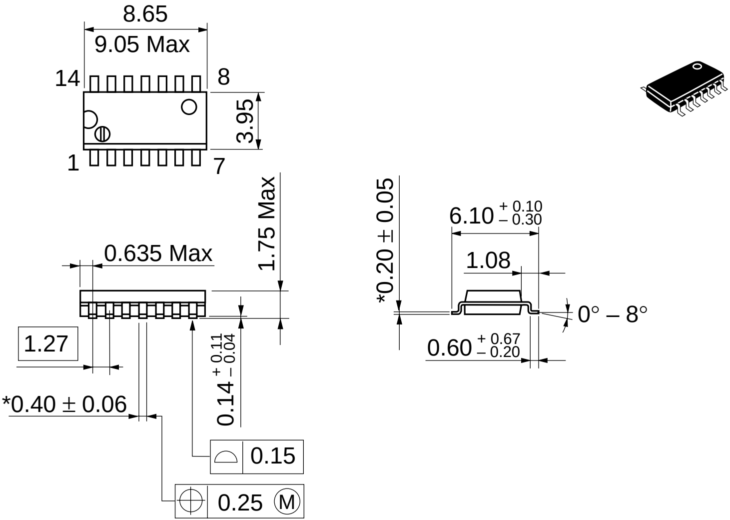
Hitachi Code	DP-14
JEDEC	Conforms
EIAJ	Conforms
Weight (reference value)	0.97 g



*Dimension including the plating thickness
Base material dimension

Hitachi Code	FP-14DA
JEDEC	—
EIAJ	Conforms
Weight (reference value)	0.23 g

Unit: mm



Hitachi Code	FP-14DN
JEDEC	Conforms
EIAJ	Conforms
Weight (reference value)	0.13 g

*Pd plating

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For further information write to:

Hitachi Semiconductor
(America) Inc.
179 East Tasman Drive,
San Jose,CA 95134
Tel: <1> (408) 433-1990
Fax: <1>(408) 433-0223

Hitachi Europe GmbH
Electronic components Group
Dornacher Stra§e 3
D-85622 Feldkirchen, Munich
Germany
Tel: <49> (89) 9 9180-0
Fax: <49> (89) 9 29 30 00

Hitachi Europe Ltd.
Electronic Components Group.
Whitebrook Park
Lower Cookham Road
Maidenhead
Berkshire SL6 8YA, United Kingdom
Tel: <44> (1628) 585000
Fax: <44> (1628) 778322

Hitachi Asia Pte. Ltd.
16 Collyer Quay #20-00
Hitachi Tower
Singapore 049318
Tel: 535-2100
Fax: 535-1533

Hitachi Asia Ltd.
Taipei Branch Office
3F, Hung Kuo Building. No.167,
Tun-Hwa North Road, Taipei (105)
Tel: <886> (2) 2718-3666
Fax: <886> (2) 2718-8180

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Group III (Electronic Components)
7/F., North Tower, World Finance Centre,
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National Semiconductor

June 1989

54LS08/DM54LS08/DM74LS08 Quad 2-Input AND Gates

General Description

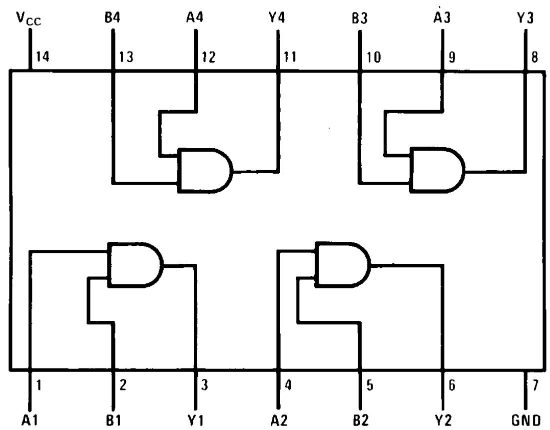
This device contains four independent gates each of which performs the logic AND function.

Features

- Alternate Military/Aerospace device (54LS08) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6347–1

Order Number 54LS08DMQB, 54LS08FMQB, 54LS08LMQB, DM54LS08J, DM54LS08W, DM74LS08M or DM74LS08N
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

Y = AB

Inputs		Output
A	**B**	**Y**
L	L	L
L	H	L
H	L	L
H	H	H

H = High Logic Level
L = Low Logic Level

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS08			DM74LS08			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max, V_{IH} = Min	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IL} = Max	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.36	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CCH}	Supply Current with Outputs High	V_{CC} = Max			2.4	4.8	mA
I_{CCL}	Supply Current with Outputs Low	V_{CC} = Max			4.4	8.8	mA

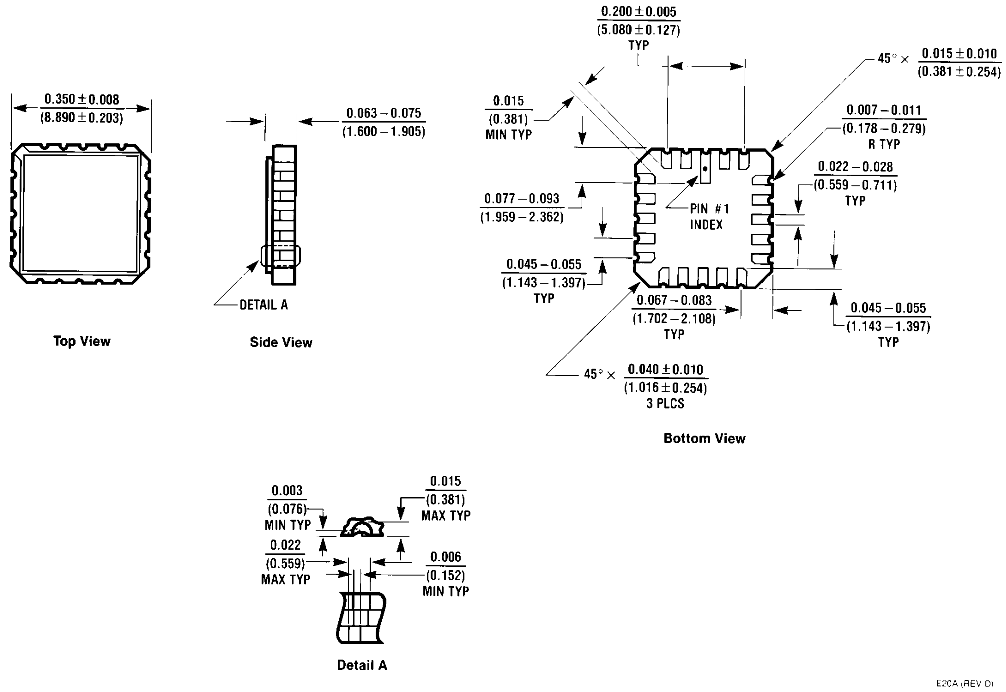
Switching Characteristics at V_{CC} = 5V and T_A = 25°C (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	4	13	6	18	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	3	11	5	18	ns

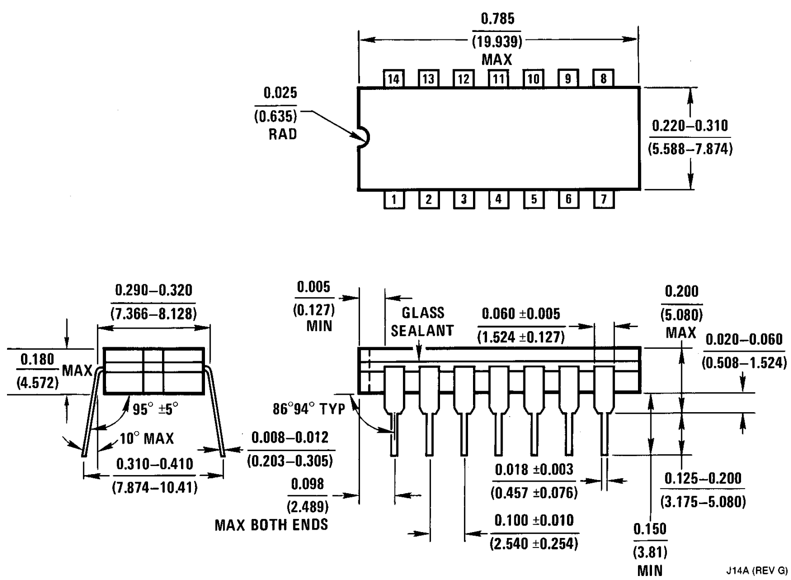
Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Physical Dimensions inches (millimeters)

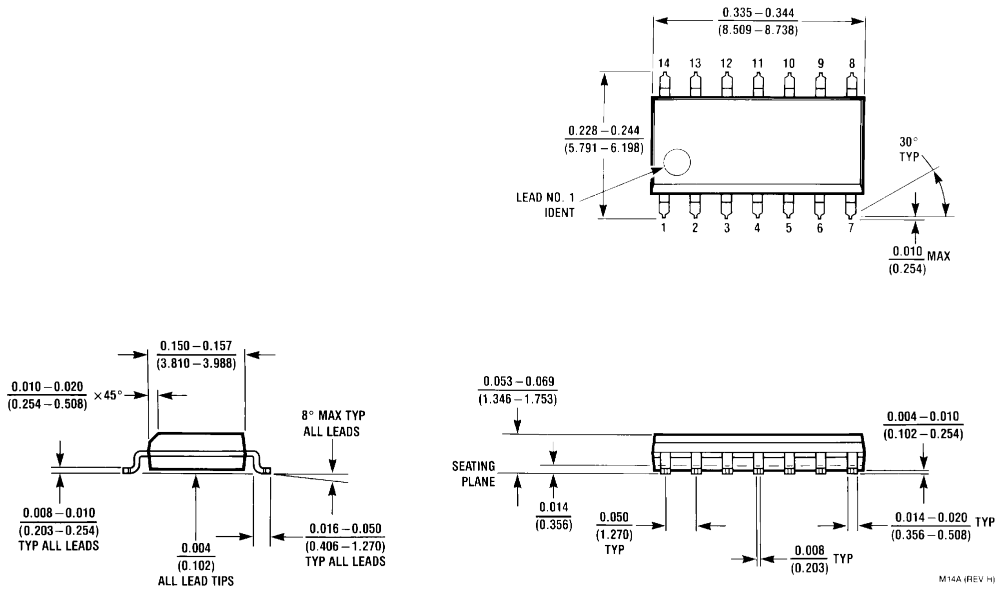


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS08LMQB
NS Package Number E20A

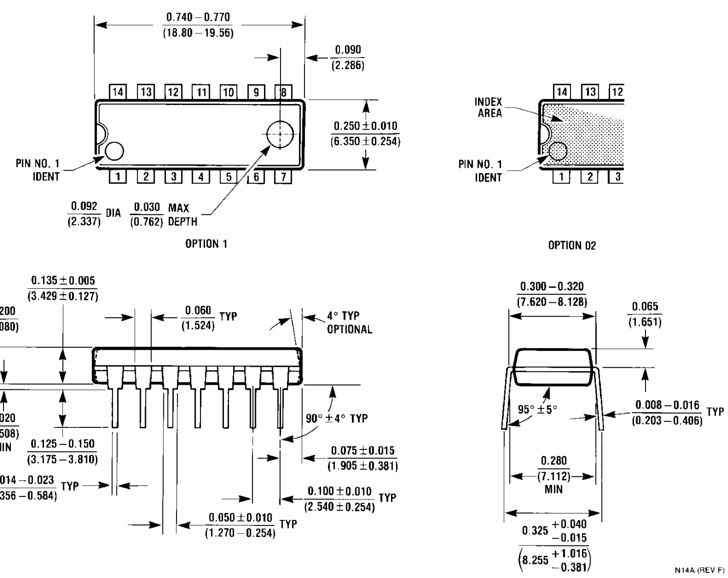


14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS08DMQB or DM54LS08J
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

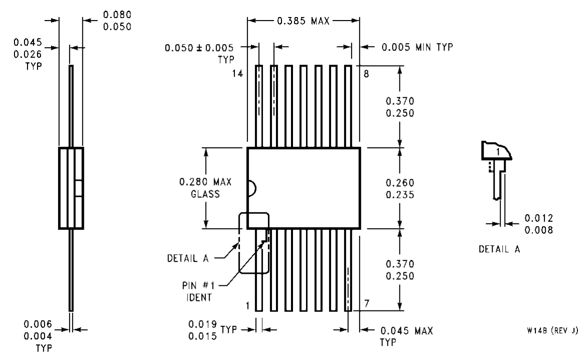


14-Lead Small Outline Molded Package (M)
Order Number DM74LS08M
NS Package Number M14A



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS08N
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS08FMQB or DM54LS08W
NS Package Number W14B

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Fax: 1(800) 737-7018

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Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
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Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
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National Semiconductor

May 1989

54LS32/DM54LS32/DM74LS32 Quad 2-Input OR Gates

General Description

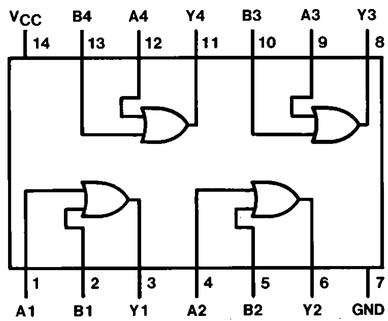
This device contains four independent gates each of which performs the logic OR function.

Features

- Alternate Military/Aerospace device (54LS32) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6361–1

Order Number 54LS32DMQB, 54LS32FMQB, 54LS32LMQB, DM54LS32J, DM54LS32W, DM74LS32M or DM74LS32N
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

Y = A + B

Inputs		Output
A	**B**	**Y**
L	L	L
L	H	H
H	L	H
H	H	H

H = High Logic Level
L = Low Logic Level

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS32			DM74LS32			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max, V_{IH} = Min	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IL} = Max	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.36	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CCH}	Supply Current with Outputs High	V_{CC} = Max			3.1	6.2	mA
I_{CCL}	Supply Current with Outputs Low	V_{CC} = Max			4.9	9.8	mA

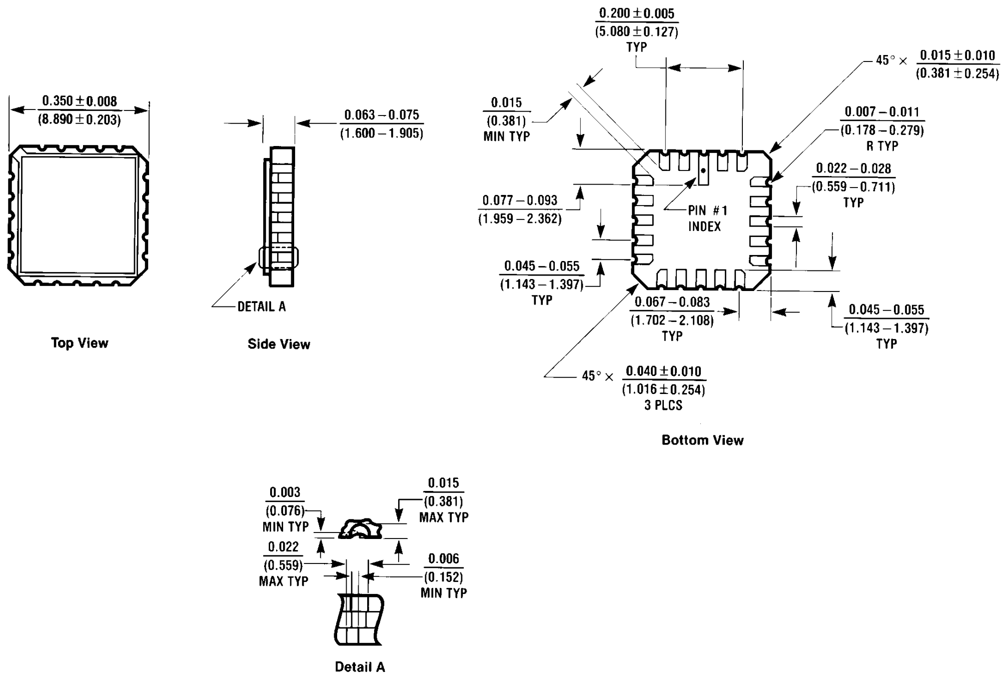
Switching Characteristics at V_{CC} = 5V and T_A = 25°C (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	R_L = 2 kΩ				Units
		C_L = 15 pF		C_L = 50 pF		
		Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	3	11	4	15	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	3	11	4	15	ns

Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

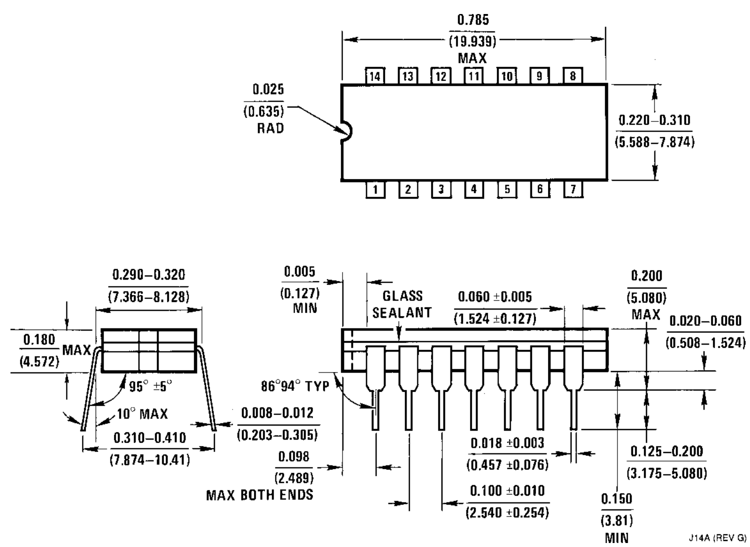
Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Physical Dimensions inches (millimeters)



E20A (REV D)

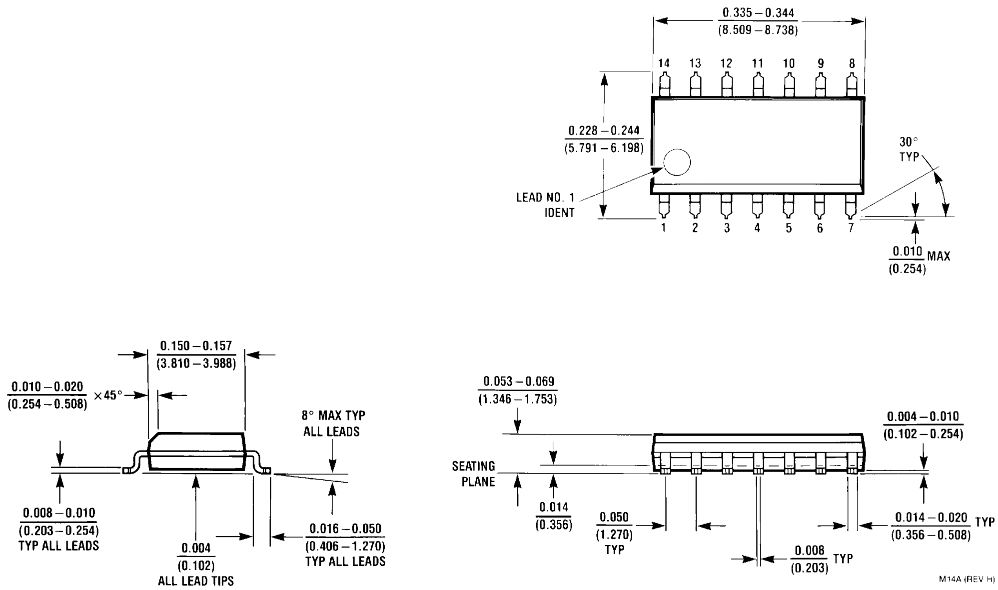
Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS32LMQB
NS Package Number E20A



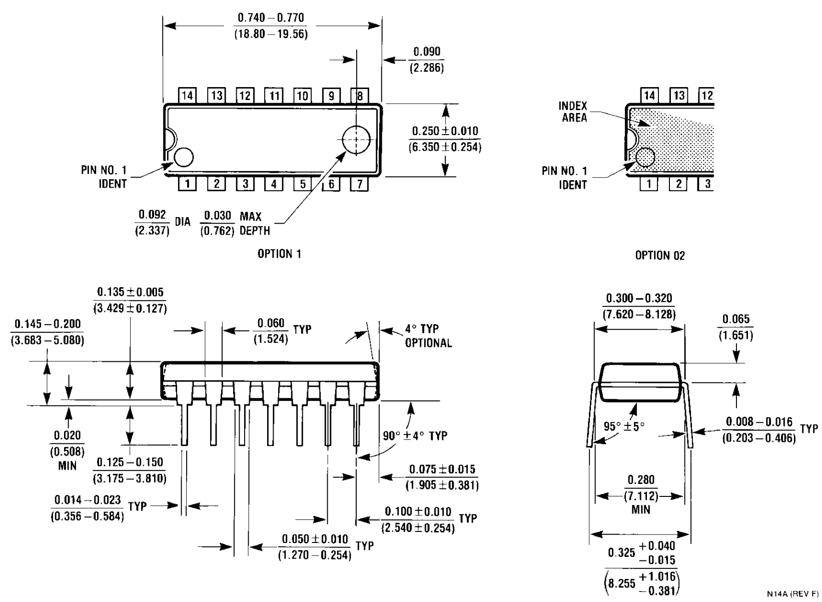
J14A (REV G)

14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS32DMQB or DM54LS32J
NS Package Number J14A

Physical Dimensions inches (millimeters)

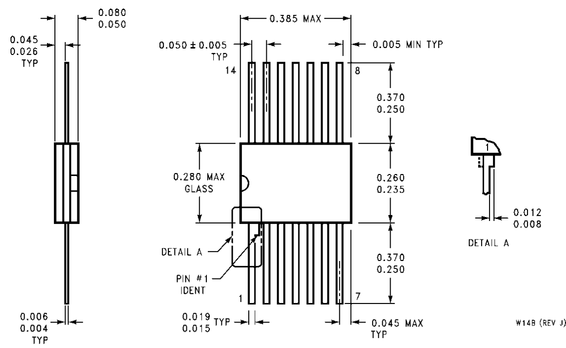


14-Lead Small Outline Molded Package (M)
Order Number DM74LS32M
NS Package Number M14A



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS32N
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS32FMQB or DM54LS32W
NS Package Number W14B

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

National Semiconductor

May 1989

54LS279/DM54LS279/DM74LS279 Quad $\overline{S}$-$\overline{R}$ Latches

General Description

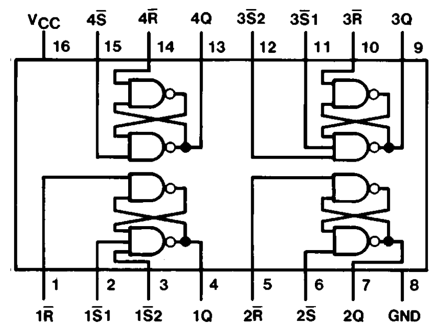
The ’LS279 consists of four individual and independent Set-Reset Latches with active low inputs. Two of the four latches have an additonal $\overline{S}$ input ANDed with the primary $\overline{S}$ input. A low on any $\overline{S}$ input while the $\overline{R}$ input is high will be stored in the latch and appear on the corresponding Q output as a high. A low on the $\overline{R}$ input while the $\overline{S}$ input is high will clear the Q output to a low. Simultaneous transistion of the $\overline{R}$ and $\overline{S}$ inputs from low to high will cause the Q output to be indeterminate. Both inputs are voltage level triggered and are not affected by transition time of the input data.

Features

- Alternate military/aerospace device (54LS279) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6420–1

Order Number 54LS279DMQB, 54LS279FMQB, 54LS279LMQB, DM54LS279J, DM74LS279M or DM74LS279N
See NS Package Number E20A, J16A, M16A, N16E or W16A

Function Table

Inputs		Output
$\overline{S}$(1)	$\overline{R}$	Q
L	L	H*
L	H	H
H	L	L
H	H	Q_0

H = High Level

L = Low Level

Q_0 = The Level of Q before the indicated input conditions were established.

*This output level is pseudo stable; that is, it may not persist when the $\overline{S}$ and $\overline{R}$ inputs return to their inactive (high) level.

Note 1: For latches with double $\overline{S}$ inputs:

H = both $\overline{S}$ inputs high

L = one or both $\overline{S}$ inputs low

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter	DM54LS279			DM74LS279			Units
		Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage	2			2			V
V_{IL}	Low Level Input Voltage			0.7			0.8	V
I_{OH}	High Level Output Current			−0.4			−0.4	mA
I_{OL}	Low Level Output Current			4			8	mA
T_A	Free Air Operating Temperature	−55		125	0		70	°C

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −18 mA				−1.5	V
V_{OH}	High Level Output Voltage	V_{CC} = Min, I_{OH} = Max	DM54	2.5	3.5		V
		V_{IL} = Max, V_{IH} = Min	DM74	2.7	3.5		
V_{OL}	Low Level Output Voltage	V_{CC} = Min, I_{OL} = Max V_{IL} = Max, V_{IH} = Min	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		I_{OL} = 4 mA, V_{CC} = Min	DM74		0.25	0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 7V				0.1	mA
I_{IH}	High Level Input Current	V_{CC} = Max, V_I = 2.7V				20	μA
I_{IL}	Low Level Input Current	V_{CC} = Max, V_I = 0.4V				−0.4	mA
I_{OS}	Short Circuit Output Current	V_{CC} = Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CC}	Supply Current	V_{CC} = Max (Note 3)			3.8	7	mA

Note 1: All typicals are at V_{CC} = 5V, T_A = 25°C.

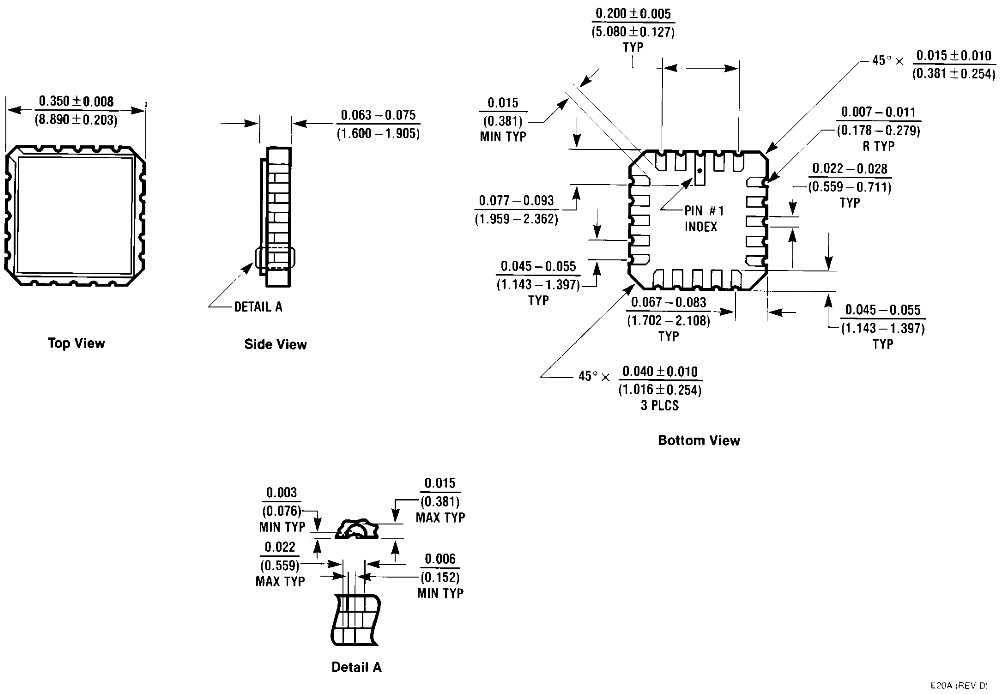
Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second.

Note 3: I_{CC} is measured with all $\overline{R}$ inputs grounded, all $\overline{S}$ inputs at 4.5V and all outputs open.

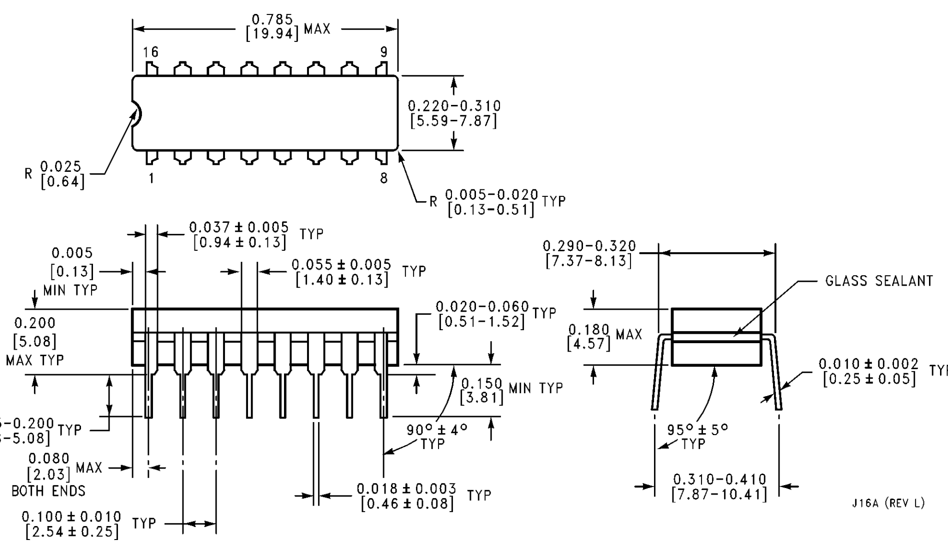
Switching Characteristics at $V_{CC} = 5V$ and $T_A = 25°C$ (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	From (Input) To (Output)	$R_L = 2\ k\Omega$				Units
			$C_L = 15\ pF$		$C_L = 50\ pF$		
			Min	Max	Min	Max	
t_{PLH}	Propagation Delay Time Low to High Level Output	$\overline{S}$ to Q		22		25	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	$\overline{S}$ to Q		15		23	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	$\overline{R}$ to Q		27		33	ns

Physical Dimensions inches (millimeters)

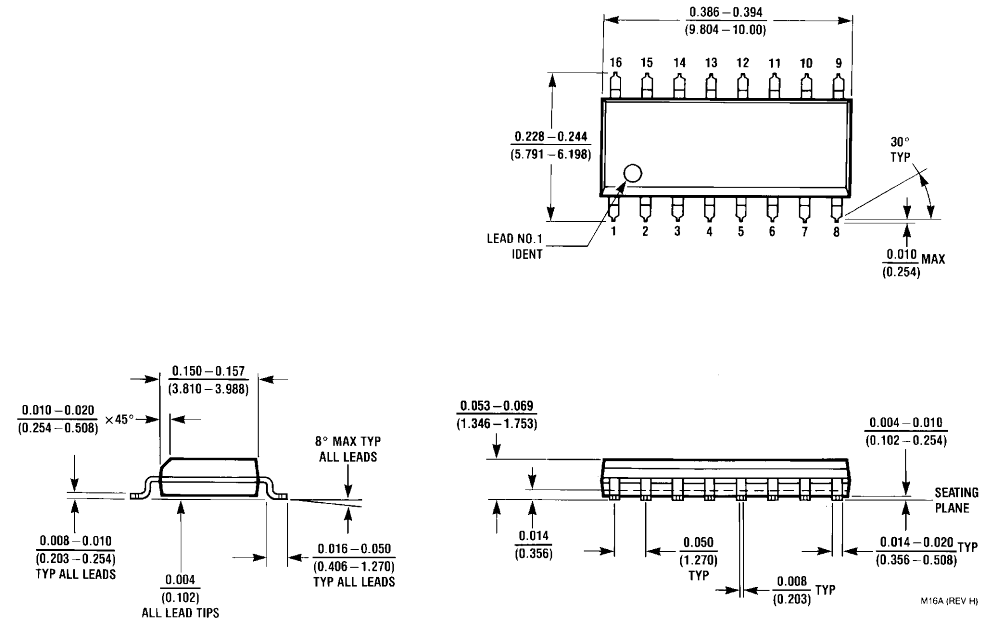


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS279LMQB
NS Package Number E20A

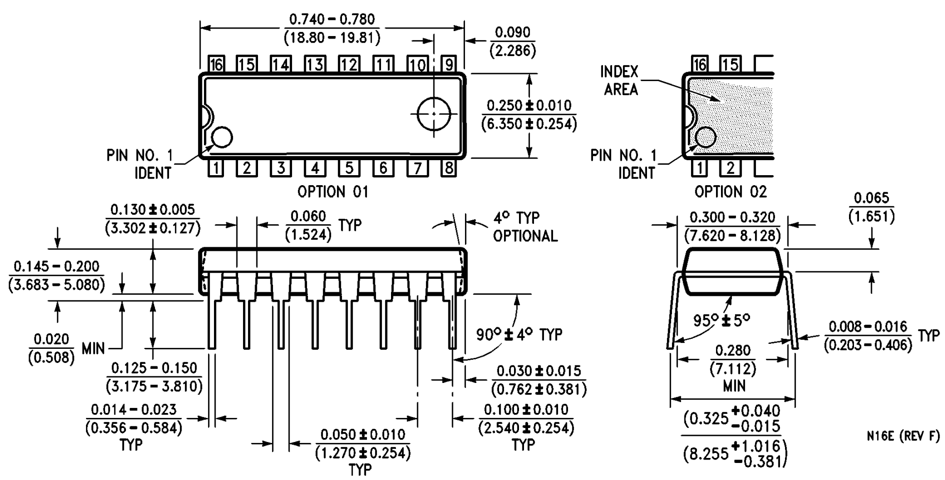


16-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS279DMQB or DM54LS279J
NS Package Number J16A

Physical Dimensions inches (millimeters) (Continued)

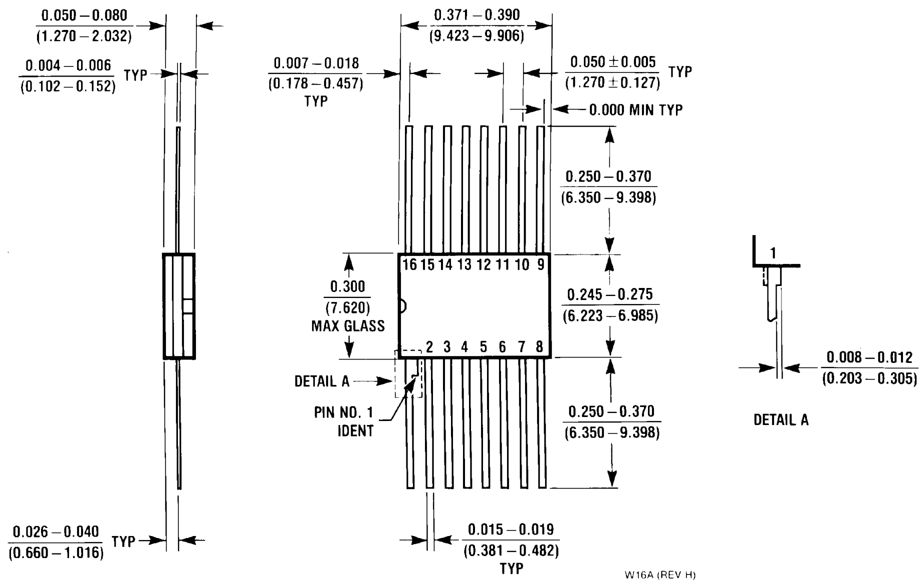


16-Lead Small Outline Molded Package (M)
Order Number DM74LS279M
NS Package Number M16A



16-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS279N
NS Package Number N16E

Physical Dimensions inches (millimeters) (Continued)



16-Lead Ceramic Flat Package (W)
Order Number 54LS279FMQB or DM54LS279W
NS Package Number W16A

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

Features

- Compatible with MCS®-51 Products
- 4K Bytes of In-System Programmable (ISP) Flash Memory
  - Endurance: 1000 Write/Erase Cycles
- 4.0V to 5.5V Operating Range
- Fully Static Operation: 0 Hz to 33 MHz
- Three-level Program Memory Lock
- 128 x 8-bit Internal RAM
- 32 Programmable I/O Lines
- Two 16-bit Timer/Counters
- Six Interrupt Sources
- Full Duplex UART Serial Channel
- Low-power Idle and Power-down Modes
- Interrupt Recovery from Power-down Mode
- Watchdog Timer
- Dual Data Pointer
- Power-off Flag
- Fast Programming Time
- Flexible ISP Programming (Byte and Page Mode)

Description

The AT89S51 is a low-power, high-performance CMOS 8-bit microcontroller with 4K bytes of In-System Programmable Flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology and is compatible with the industry-standard 80C51 instruction set and pinout. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with In-System Programmable Flash on a monolithic chip, the Atmel AT89S51 is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications.

The AT89S51 provides the following standard features: 4K bytes of Flash, 128 bytes of RAM, 32 I/O lines, Watchdog timer, two data pointers, two 16-bit timer/counters, a five-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry. In addition, the AT89S51 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port, and interrupt system to continue functioning. The Power-down mode saves the RAM contents but freezes the oscillator, disabling all other chip functions until the next external interrupt or hardware reset.

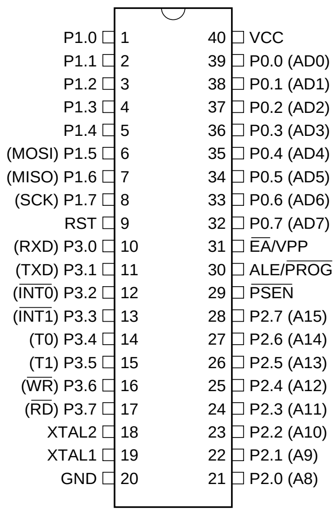
8-bit Microcontroller with 4K Bytes In-System Programmable Flash

AT89S51

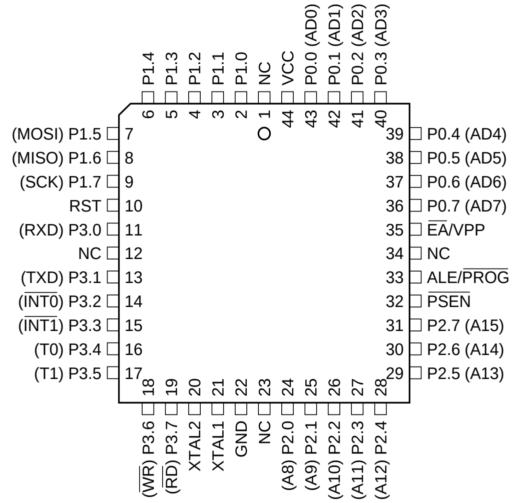
2487B–MICRO–12/03

Pin Configurations

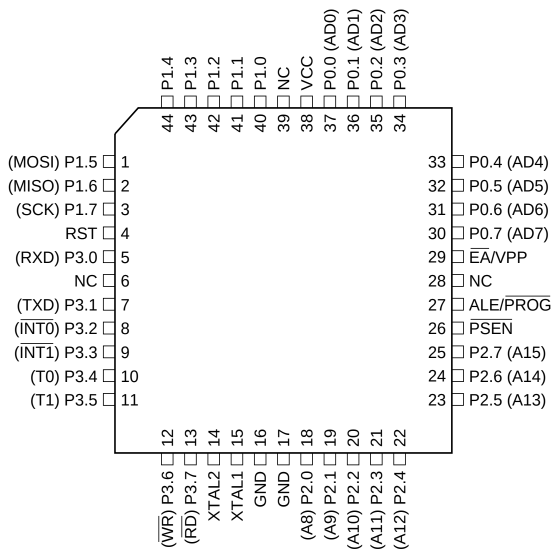
PDIP



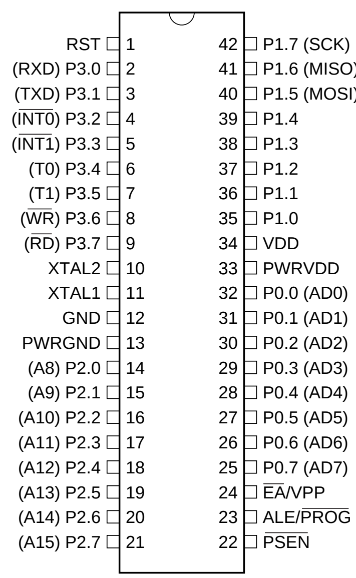
PLCC



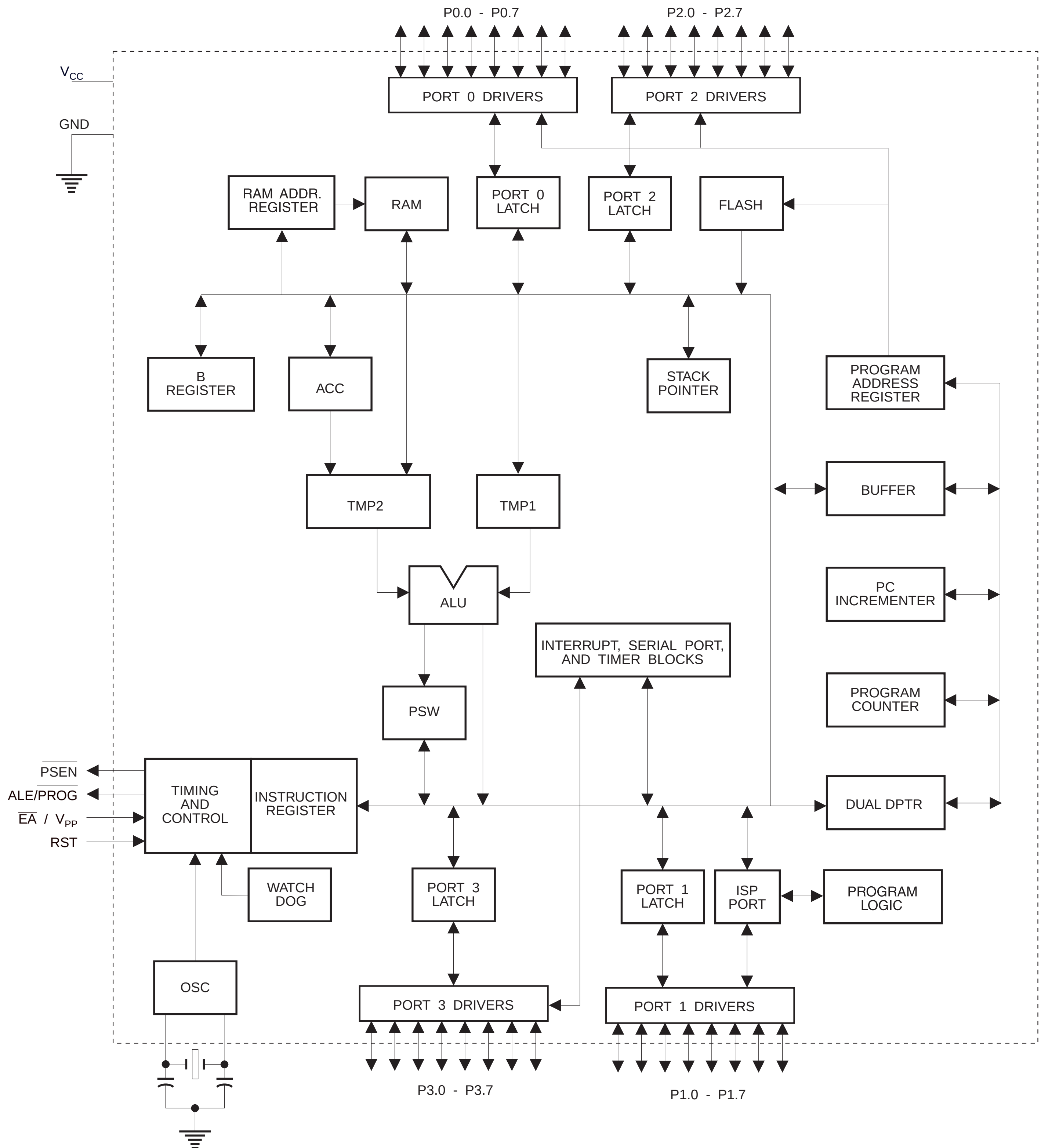
TQFP



PDIP



Block Diagram



Pin Description

VCC

Supply voltage (all packages except 42-PDIP).

GND

Ground (all packages except 42-PDIP; for 42-PDIP GND connects only the logic core and the embedded program memory).

VDD

Supply voltage for the 42-PDIP which connects only the logic core and the embedded program memory.

PWRVDD

Supply voltage for the 42-PDIP which connects only the I/O Pad Drivers. The application board **MUST** connect both VDD and PWRVDD to the board supply voltage.

PWRGND

Ground for the 42-PDIP which connects only the I/O Pad Drivers. PWRGND and GND are weakly connected through the common silicon substrate, but not through any metal link. The application board **MUST** connect both GND and PWRGND to the board ground.

Port 0

Port 0 is an 8-bit open drain bi-directional I/O port. As an output port, each pin can sink eight TTL inputs. When 1s are written to port 0 pins, the pins can be used as high-impedance inputs.

Port 0 can also be configured to be the multiplexed low-order address/data bus during accesses to external program and data memory. In this mode, P0 has internal pull-ups.

Port 0 also receives the code bytes during Flash programming and outputs the code bytes during program verification. **External pull-ups are required during program verification**.

Port 1

Port 1 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 1 output buffers can sink/source four TTL inputs. When 1s are written to Port 1 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 1 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

Port 1 also receives the low-order address bytes during Flash programming and verification.

Port Pin	Alternate Functions
P1.5	MOSI (used for In-System Programming)
P1.6	MISO (used for In-System Programming)
P1.7	SCK (used for In-System Programming)

Port 2

Port 2 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 2 output buffers can sink/source four TTL inputs. When 1s are written to Port 2 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 2 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

Port 2 emits the high-order address byte during fetches from external program memory and during accesses to external data memory that use 16-bit addresses (MOVX @ DPTR). In this application, Port 2 uses strong internal pull-ups when emitting 1s. During accesses to external data memory that use 8-bit addresses (MOVX @ RI), Port 2 emits the contents of the P2 Special Function Register.

Port 2 also receives the high-order address bits and some control signals during Flash programming and verification.

Port 3

Port 3 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 3 output buffers can sink/source four TTL inputs. When 1s are written to Port 3 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 3 pins that are externally being pulled low will source current (I_{IL}) because of the pull-ups.

Port 3 receives some control signals for Flash programming and verification.

Port 3 also serves the functions of various special features of the AT89S51, as shown in the following table.

Port Pin	Alternate Functions
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{\text{INT0}}$ (external interrupt 0)
P3.3	$\overline{\text{INT1}}$ (external interrupt 1)
P3.4	T0 (timer 0 external input)
P3.5	T1 (timer 1 external input)
P3.6	$\overline{\text{WR}}$ (external data memory write strobe)
P3.7	$\overline{\text{RD}}$ (external data memory read strobe)

RST

Reset input. A high on this pin for two machine cycles while the oscillator is running resets the device. This pin drives High for 98 oscillator periods after the Watchdog times out. The DISRTO bit in SFR AUXR (address 8EH) can be used to disable this feature. In the default state of bit DISRTO, the RESET HIGH out feature is enabled.

ALE/$\overline{\text{PROG}}$

Address Latch Enable (ALE) is an output pulse for latching the low byte of the address during accesses to external memory. This pin is also the program pulse input ($\overline{\text{PROG}}$) during Flash programming.

In normal operation, ALE is emitted at a constant rate of 1/6 the oscillator frequency and may be used for external timing or clocking purposes. Note, however, that one ALE pulse is skipped during each access to external data memory.

If desired, ALE operation can be disabled by setting bit 0 of SFR location 8EH. With the bit set, ALE is active only during a MOVX or MOVC instruction. Otherwise, the pin is weakly pulled high. Setting the ALE-disable bit has no effect if the microcontroller is in external execution mode.

$\overline{\text{PSEN}}$

Program Store Enable ($\overline{\text{PSEN}}$) is the read strobe to external program memory.

When the AT89S51 is executing code from external program memory, $\overline{\text{PSEN}}$ is activated twice each machine cycle, except that two $\overline{\text{PSEN}}$ activations are skipped during each access to external data memory.

$\overline{\text{EA}}$/VPP

External Access Enable. $\overline{\text{EA}}$ must be strapped to GND in order to enable the device to fetch code from external program memory locations starting at 0000H up to FFFFH. Note, however, that if lock bit 1 is programmed, $\overline{\text{EA}}$ will be internally latched on reset.

$\overline{\text{EA}}$ should be strapped to V_{CC} for internal program executions.

This pin also receives the 12-volt programming enable voltage (V_{PP}) during Flash programming.

XTAL1

Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the inverting oscillator amplifier

Special Function Registers

A map of the on-chip memory area called the Special Function Register (SFR) space is shown in Table 1.

Note that not all of the addresses are occupied, and unoccupied addresses may not be implemented on the chip. Read accesses to these addresses will in general return random data, and write accesses will have an indeterminate effect.

Table 1. AT89S51 SFR Map and Reset Values

0F8H									0FFH
0F0H	B 00000000								0F7H
0E8H									0EFH
0E0H	ACC 00000000								0E7H
0D8H									0DFH
0D0H	PSW 00000000								0D7H
0C8H									0CFH
0C0H									0C7H
0B8H	IP XX000000								0BFH
0B0H	P3 11111111								0B7H
0A8H	IE 0X000000								0AFH
0A0H	P2 11111111		AUXR1 XXXXXXX0				WDTRST XXXXXXXX		0A7H
98H	SCON 00000000	SBUF XXXXXXXX							9FH
90H	P1 11111111								97H
88H	TCON 00000000	TMOD 00000000	TL0 00000000	TL1 00000000	TH0 00000000	TH1 00000000	AUXR XXX00XX0		8FH
80H	P0 11111111	SP 00000111	DP0L 00000000	DP0H 00000000	DP1L 00000000	DP1H 00000000		PCON 0XXX0000	87H

User software should not write 1s to these unlisted locations, since they may be used in future products to invoke new features. In that case, the reset or inactive values of the new bits will always be 0.

Interrupt Registers: The individual interrupt enable bits are in the IE register. Two priorities can be set for each of the five interrupt sources in the IP register.

Table 2. AUXR: Auxiliary Register

AUXR Address = 8EH Reset Value = XXX00XX0B

Not Bit Addressable

	–	–	–	WDIDLE	DISRTO	–	–	DISALE
Bit	7	6	5	4	3	2	1	0

–	Reserved for future expansion	
DISALE	Disable/Enable ALE	
	DISALE Operating Mode	
	0	ALE is emitted at a constant rate of 1/6 the oscillator frequency
	1	ALE is active only during a MOVX or MOVC instruction
DISRTO	Disable/Enable Reset-out	
	DISRTO	
	0	Reset pin is driven High after WDT times out
	1	Reset pin is input only
WDIDLE	Disable/Enable WDT in IDLE mode	
WDIDLE		
0	WDT continues to count in IDLE mode	
1	WDT halts counting in IDLE mode	

Dual Data Pointer Registers: To facilitate accessing both internal and external data memory, two banks of 16-bit Data Pointer Registers are provided: DP0 at SFR address locations 82H-83H and DP1 at 84H-85H. Bit DPS = 0 in SFR AUXR1 selects DP0 and DPS = 1 selects DP1. The user should **ALWAYS** initialize the DPS bit to the appropriate value before accessing the respective Data Pointer Register.

Power Off Flag: The Power Off Flag (POF) is located at bit 4 (PCON.4) in the PCON SFR. POF is set to “1” during power up. It can be set and rest under software control and is not affected by reset.

Table 3. AUXR1: Auxiliary Register 1

AUXR1 Address = A2H Reset Value = XXXXXXX0B

Not Bit Addressable

	–	–	–	–	–	–	–	DPS
Bit	7	6	5	4	3	2	1	0

– Reserved for future expansion

DPS Data Pointer Register Select

DPS	
0	Selects DPTR Registers DP0L, DP0H
1	Selects DPTR Registers DP1L, DP1H

Memory Organization

MCS-51 devices have a separate address space for Program and Data Memory. Up to 64K bytes each of external Program and Data Memory can be addressed.

Program Memory

If the $\overline{EA}$ pin is connected to GND, all program fetches are directed to external memory.

On the AT89S51, if $\overline{EA}$ is connected to V_{CC}, program fetches to addresses 0000H through FFFH are directed to internal memory and fetches to addresses 1000H through FFFFH are directed to external memory.

Data Memory

The AT89S51 implements 128 bytes of on-chip RAM. The 128 bytes are accessible via direct and indirect addressing modes. Stack operations are examples of indirect addressing, so the 128 bytes of data RAM are available as stack space.

Watchdog Timer (One-time Enabled with Reset-out)

The WDT is intended as a recovery method in situations where the CPU may be subjected to software upsets. The WDT consists of a 14-bit counter and the Watchdog Timer Reset (WDTRST) SFR. The WDT is defaulted to disable from exiting reset. To enable the WDT, a user must write 01EH and 0E1H in sequence to the WDTRST register (SFR location 0A6H). When the WDT is enabled, it will increment every machine cycle while the oscillator is running. The WDT timeout period is dependent on the external clock frequency. There is no way to disable the WDT except through reset (either hardware reset or WDT overflow reset). When WDT overflows, it will drive an output RESET HIGH pulse at the RST pin.

Using the WDT

To enable the WDT, a user must write 01EH and 0E1H in sequence to the WDTRST register (SFR location 0A6H). When the WDT is enabled, the user needs to service it by writing 01EH and 0E1H to WDTRST to avoid a WDT overflow. The 14-bit counter overflows when it reaches 16383 (3FFFH), and this will reset the device. When the WDT is enabled, it will increment every machine cycle while the oscillator is running. This means the user must reset the WDT at least every 16383 machine cycles. To reset the WDT the user must write 01EH and 0E1H to WDTRST. WDTRST is a write-only register. The WDT counter cannot be read or written. When WDT overflows, it will generate an output RESET pulse at the RST pin. The RESET pulse duration is 98xTOSC, where TOSC = 1/FOSC. To make the best use of the WDT, it should be serviced in those sections of code that will periodically be executed within the time required to prevent a WDT reset.

WDT During Power-down and Idle

In Power-down mode the oscillator stops, which means the WDT also stops. While in Power-down mode, the user does not need to service the WDT. There are two methods of exiting Power-down mode: by a hardware reset or via a level-activated external interrupt, which is enabled prior to entering Power-down mode. When Power-down is exited with hardware reset, servicing the WDT should occur as it normally does whenever the AT89S51 is reset. Exiting Power-down with an interrupt is significantly different. The interrupt is held low long enough for the oscillator to stabilize. When the interrupt is brought high, the interrupt is serviced. To prevent the WDT from resetting the device while the interrupt pin is held low, the WDT is not started until the interrupt is pulled high. It is suggested that the WDT be reset during the interrupt service for the interrupt used to exit Power-down mode.

To ensure that the WDT does not overflow within a few states of exiting Power-down, it is best to reset the WDT just before entering Power-down mode.

Before going into the IDLE mode, the WDIDLE bit in SFR AUXR is used to determine whether the WDT continues to count if enabled. The WDT keeps counting during IDLE (WDIDLE bit = 0) as the default state. To prevent the WDT from resetting the AT89S51 while in IDLE mode, the user should always set up a timer that will periodically exit IDLE, service the WDT, and reenter IDLE mode.

With WDIDLE bit enabled, the WDT will stop to count in IDLE mode and resumes the count upon exit from IDLE.

UART

The UART in the AT89S51 operates the same way as the UART in the AT89C51. For further information on the UART operation, refer to the Atmel Web site (http://www.atmel.com). From the home page, select “Products”, then “Microcontrollers”, then “8051-Architecture”, then “Documentation”, and “Other Documents”. Open the Adobe® Acrobat® file “AT89 Series Hardware Description”.

Timer 0 and 1

Timer 0 and Timer 1 in the AT89S51 operate the same way as Timer 0 and Timer 1 in the AT89C51. For further information on the timers’ operation, refer to the Atmel Web site (http://www.atmel.com). From the home page, select “Products”, then “Microcontrollers”, then “8051-Architecture”, then “Documentation”, and “Other Documents”. Open the Adobe Acrobat file “AT89 Series Hardware Description”.

Interrupts

The AT89S51 has a total of five interrupt vectors: two external interrupts ($\overline{\text{INT0}}$ and $\overline{\text{INT1}}$), two timer interrupts (Timers 0 and 1), and the serial port interrupt. These interrupts are all shown in Figure 1.

Each of these interrupt sources can be individually enabled or disabled by setting or clearing a bit in Special Function Register IE. IE also contains a global disable bit, EA, which disables all interrupts at once.

Note that Table 4 shows that bit positions IE.6 and IE.5 are unimplemented. User software should not write 1s to these bit positions, since they may be used in future AT89 products.

The Timer 0 and Timer 1 flags, TF0 and TF1, are set at S5P2 of the cycle in which the timers overflow. The values are then polled by the circuitry in the next cycle.

Table 4. Interrupt Enable (IE) Register

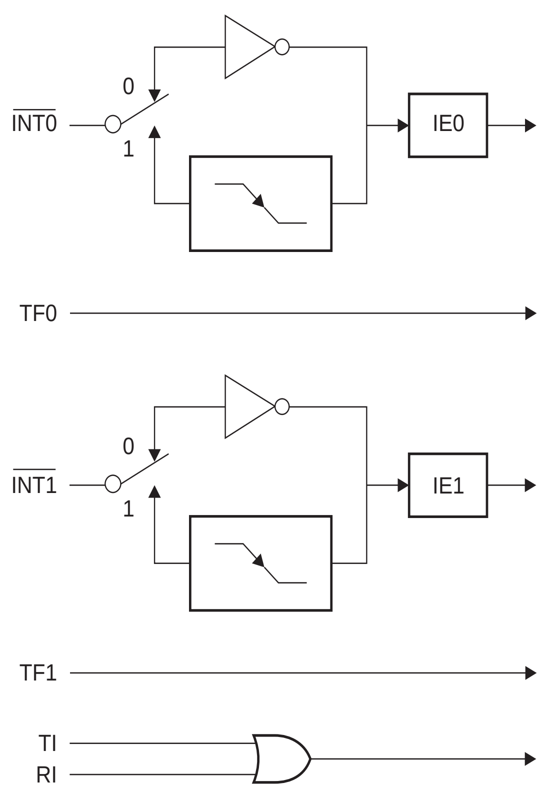
(MSB)							(LSB)
EA	–	–	ES	ET1	EX1	ET0	EX0

Enable Bit = 1 enables the interrupt.

Enable Bit = 0 disables the interrupt.

Symbol	Position	Function
EA	IE.7	Disables all interrupts. If EA = 0, no interrupt is acknowledged. If EA = 1, each interrupt source is individually enabled or disabled by setting or clearing its enable bit.
–	IE.6	Reserved
–	IE.5	Reserved
ES	IE.4	Serial Port interrupt enable bit
ET1	IE.3	Timer 1 interrupt enable bit
EX1	IE.2	External interrupt 1 enable bit
ET0	IE.1	Timer 0 interrupt enable bit
EX0	IE.0	External interrupt 0 enable bit
User software should never write 1s to reserved bits, because they may be used in future AT89 products.		

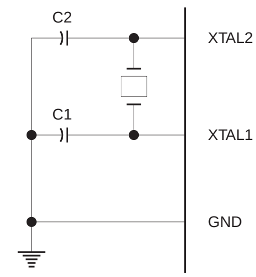
Figure 1. Interrupt Sources



Oscillator Characteristics

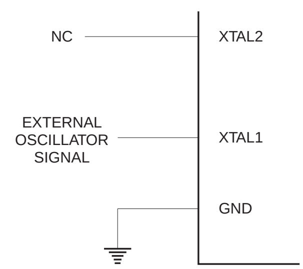
XTAL1 and XTAL2 are the input and output, respectively, of an inverting amplifier that can be configured for use as an on-chip oscillator, as shown in Figure 2. Either a quartz crystal or ceramic resonator may be used. To drive the device from an external clock source, XTAL2 should be left unconnected while XTAL1 is driven, as shown in Figure 3. There are no requirements on the duty cycle of the external clock signal, since the input to the internal clocking circuitry is through a divide-by-two flip-flop, but minimum and maximum voltage high and low time specifications must be observed.

Figure 2. Oscillator Connections



Note: C1, C2 = 30 pF ± 10 pF for Crystals
= 40 pF ± 10 pF for Ceramic Resonators

Figure 3. External Clock Drive Configuration



Idle Mode

In idle mode, the CPU puts itself to sleep while all the on-chip peripherals remain active. The mode is invoked by software. The content of the on-chip RAM and all the special function registers remain unchanged during this mode. The idle mode can be terminated by any enabled interrupt or by a hardware reset.

Note that when idle mode is terminated by a hardware reset, the device normally resumes program execution from where it left off, up to two machine cycles before the internal reset algorithm takes control. On-chip hardware inhibits access to internal RAM in this event, but access to the port pins is not inhibited. To eliminate the possibility of an unexpected write to a port pin when idle mode is terminated by a reset, the instruction following the one that invokes idle mode should not write to a port pin or to external memory.

Power-down Mode

In the Power-down mode, the oscillator is stopped, and the instruction that invokes Power-down is the last instruction executed. The on-chip RAM and Special Function Registers retain their values until the Power-down mode is terminated. Exit from Power-down mode can be initiated either by a hardware reset or by activation of an enabled external interrupt ($\overline{\text{INT0}}$ or $\overline{\text{INT1}}$). Reset redefines the SFRs but does not change the on-chip RAM. The reset should not be activated before V_{CC} is restored to its normal operating level and must be held active long enough to allow the oscillator to restart and stabilize.

Table 5. Status of External Pins During Idle and Power-down Modes

Mode	Program Memory	ALE	$\overline{\text{PSEN}}$	PORT0	PORT1	PORT2	PORT3
Idle	Internal	1	1	Data	Data	Data	Data
Idle	External	1	1	Float	Data	Address	Data
Power-down	Internal	0	0	Data	Data	Data	Data
Power-down	External	0	0	Float	Data	Data	Data

Program Memory Lock Bits

The AT89S51 has three lock bits that can be left unprogrammed (U) or can be programmed (P) to obtain the additional features listed in the following table.

Table 6. Lock Bit Protection Modes

	Program Lock Bits			
	LB1	LB2	LB3	Protection Type
1	U	U	U	No program lock features
2	P	U	U	MOVC instructions executed from external program memory are disabled from fetching code bytes from internal memory, $\overline{\text{EA}}$ is sampled and latched on reset, and further programming of the Flash memory is disabled
3	P	P	U	Same as mode 2, but verify is also disabled
4	P	P	P	Same as mode 3, but external execution is also disabled

When lock bit 1 is programmed, the logic level at the $\overline{\text{EA}}$ pin is sampled and latched during reset. If the device is powered up without a reset, the latch initializes to a random value and holds that value until reset is activated. The latched value of $\overline{\text{EA}}$ must agree with the current logic level at that pin in order for the device to function properly.

Programming the Flash – Parallel Mode

The AT89S51 is shipped with the on-chip Flash memory array ready to be programmed. The programming interface needs a high-voltage (12-volt) program enable signal and is compatible with conventional third-party Flash or EPROM programmers.

The AT89S51 code memory array is programmed byte-by-byte.

Programming Algorithm: Before programming the AT89S51, the address, data, and control signals should be set up according to the Flash Programming Modes table (Table 7) and Figures 4 and 5. To program the AT89S51, take the following steps:

1. Input the desired memory location on the address lines.
2. Input the appropriate data byte on the data lines.
3. Activate the correct combination of control signals.
4. Raise $\overline{\text{EA}}/V_{PP}$ to 12V.
5. Pulse ALE/$\overline{\text{PROG}}$ once to program a byte in the Flash array or the lock bits. The byte-write cycle is self-timed and typically takes no more than 50 µs. Repeat steps 1 through 5, changing the address and data for the entire array or until the end of the object file is reached.

$\overline{\text{Data}}$ Polling: The AT89S51 features $\overline{\text{Data}}$ Polling to indicate the end of a byte write cycle. During a write cycle, an attempted read of the last byte written will result in the complement of the written data on P0.7. Once the write cycle has been completed, true data is valid on all outputs, and the next cycle may begin. $\overline{\text{Data}}$ Polling may begin any time after a write cycle has been initiated.

Ready/$\overline{\text{Busy}}$: The progress of byte programming can also be monitored by the RDY/$\overline{\text{BSY}}$ output signal. P3.0 is pulled low after ALE goes high during programming to indicate $\overline{\text{BUSY}}$. P3.0 is pulled high again when programming is done to indicate READY.

Program Verify: If lock bits LB1 and LB2 have not been programmed, the programmed code data can be read back via the address and data lines for verification. **The status of the individual lock bits can be verified directly by reading them back.**

Reading the Signature Bytes: The signature bytes are read by the same procedure as a normal verification of locations 000H, 100H, and 200H, except that P3.6 and P3.7 must be pulled to a logic low. The values returned are as follows.

(000H) = 1EH indicates manufactured by Atmel
(100H) = 51H indicates AT89S51
(200H) = 06H

Chip Erase: In the parallel programming mode, a chip erase operation is initiated by using the proper combination of control signals and by pulsing ALE/$\overline{\text{PROG}}$ low for a duration of 200 ns - 500 ns.

In the serial programming mode, a chip erase operation is initiated by issuing the Chip Erase instruction. In this mode, chip erase is self-timed and takes about 500 ms.

During chip erase, a serial read from any address location will return 00H at the data output.

Programming the Flash – Serial Mode

The Code memory array can be programmed using the serial ISP interface while RST is pulled to V_{CC}. The serial interface consists of pins SCK, MOSI (input) and MISO (output). After RST is set high, the Programming Enable instruction needs to be executed first before other operations can be executed. Before a reprogramming sequence can occur, a Chip Erase operation is required.

The Chip Erase operation turns the content of every memory location in the Code array into FFH.

Either an external system clock can be supplied at pin XTAL1 or a crystal needs to be connected across pins XTAL1 and XTAL2. The maximum serial clock (SCK) frequency should be less than 1/16 of the crystal frequency. With a 33 MHz oscillator clock, the maximum SCK frequency is 2 MHz.

Serial Programming Algorithm

To program and verify the AT89S51 in the serial programming mode, the following sequence is recommended:

1. Power-up sequence:

   Apply power between VCC and GND pins.

   Set RST pin to “H”.

   If a crystal is not connected across pins XTAL1 and XTAL2, apply a 3 MHz to 33 MHz clock to XTAL1 pin and wait for at least 10 milliseconds.
2. Enable serial programming by sending the Programming Enable serial instruction to pin MOSI/P1.5. The frequency of the shift clock supplied at pin SCK/P1.7 needs to be less than the CPU clock at XTAL1 divided by 16.
3. The Code array is programmed one byte at a time in either the Byte or Page mode. The write cycle is self-timed and typically takes less than 0.5 ms at 5V.
4. Any memory location can be verified by using the Read instruction that returns the content at the selected address at serial output MISO/P1.6.
5. At the end of a programming session, RST can be set low to commence normal device operation.

Power-off sequence (if needed):

Set XTAL1 to “L” (if a crystal is not used).

Set RST to “L”.

Turn V_{CC} power off.

$\overline{\text{Data}}$ Polling: The $\overline{\text{Data}}$ Polling feature is also available in the serial mode. In this mode, during a write cycle an attempted read of the last byte written will result in the complement of the MSB of the serial output byte on MISO.

Serial Programming Instruction Set

The Instruction Set for Serial Programming follows a 4-byte protocol and is shown in Table 8.

Programming Interface – Parallel Mode

Every code byte in the Flash array can be programmed by using the appropriate combination of control signals. The write operation cycle is self-timed and once initiated, will automatically time itself to completion.

Most major worldwide programming vendors offer worldwide support for the Atmel AT89 microcontroller series. Please contact your local programming vendor for the appropriate software revision.

Table 7. Flash Programming Modes

Mode	V_{CC}	RST	$\overline{\text{PSEN}}$	ALE/ $\overline{\text{PROG}}$	$\overline{\text{EA}}$/ V_{PP}	P2.6	P2.7	P3.3	P3.6	P3.7	P0.7-0 Data	P2.3-0	P1.7-0
												Address	
Write Code Data	5V	H	L	(2)	12V	L	H	H	H	H	D_{IN}	A11-8	A7-0
Read Code Data	5V	H	L	H	H	L	L	L	H	H	D_{OUT}	A11-8	A7-0
Write Lock Bit 1	5V	H	L	(3)	12V	H	H	H	H	H	X	X	X
Write Lock Bit 2	5V	H	L	(3)	12V	H	H	H	L	L	X	X	X
Write Lock Bit 3	5V	H	L	(3)	12V	H	L	H	H	L	X	X	X
Read Lock Bits 1, 2, 3	5V	H	L	H	H	H	H	L	H	L	P0.2, P0.3, P0.4	X	X
Chip Erase	5V	H	L	(1)	12V	H	L	H	L	L	X	X	X
Read Atmel ID	5V	H	L	H	H	L	L	L	L	L	1EH	0000	00H
Read Device ID	5V	H	L	H	H	L	L	L	L	L	51H	0001	00H
Read Device ID	5V	H	L	H	H	L	L	L	L	L	06H	0010	00H

Notes:
1. Each $\overline{\text{PROG}}$ pulse is 200 ns - 500 ns for Chip Erase.
2. Each $\overline{\text{PROG}}$ pulse is 200 ns - 500 ns for Write Code Data.
3. Each $\overline{\text{PROG}}$ pulse is 200 ns - 500 ns for Write Lock Bits.
4. RDY/$\overline{\text{BSY}}$ signal is output on P3.0 during programming.
5. X = don’t care.

Figure 4. Programming the Flash Memory (Parallel Mode)

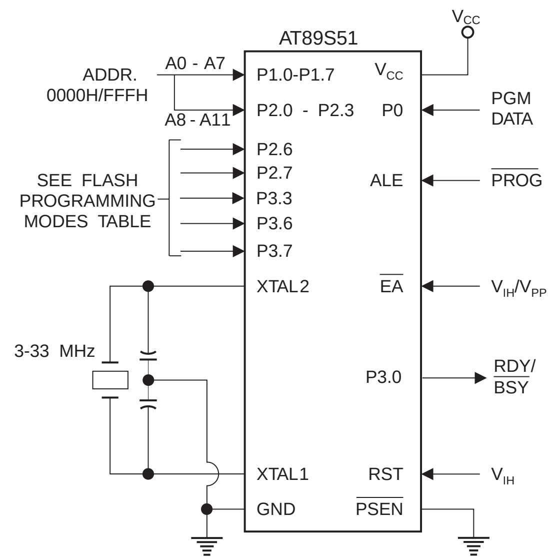
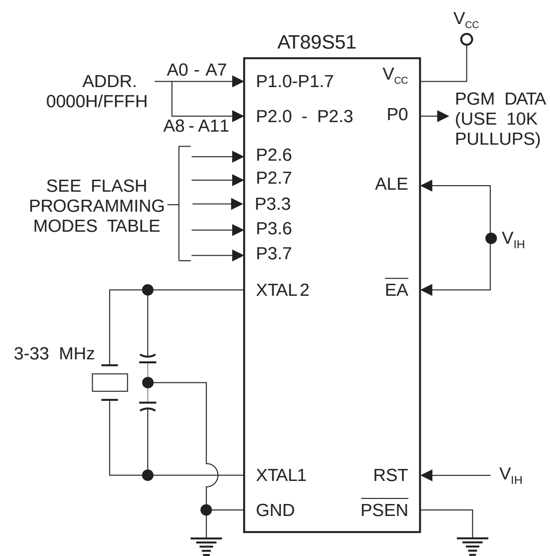


Figure 5. Verifying the Flash Memory (Parallel Mode)



Flash Programming and Verification Characteristics (Parallel Mode)

T_A = 20°C to 30°C, V_{CC} = 4.5 to 5.5V

Symbol	Parameter	Min	Max	Units
V_{PP}	Programming Supply Voltage	11.5	12.5	V
I_{PP}	Programming Supply Current		10	mA
I_{CC}	V_{CC} Supply Current		30	mA
$1/t_{CLCL}$	Oscillator Frequency	3	33	MHz
t_{AVGL}	Address Setup to $\overline{\text{PROG}}$ Low	$48t_{CLCL}$		
t_{GHAX}	Address Hold After $\overline{\text{PROG}}$	$48t_{CLCL}$		
t_{DVGL}	Data Setup to $\overline{\text{PROG}}$ Low	$48t_{CLCL}$		
t_{GHDX}	Data Hold After $\overline{\text{PROG}}$	$48t_{CLCL}$		
t_{EHSH}	P2.7 ($\overline{\text{ENABLE}}$) High to V_{PP}	$48t_{CLCL}$		
t_{SHGL}	V_{PP} Setup to $\overline{\text{PROG}}$ Low	10		µs
t_{GHSL}	V_{PP} Hold After $\overline{\text{PROG}}$	10		µs
t_{GLGH}	$\overline{\text{PROG}}$ Width	0.2	1	µs
t_{AVQV}	Address to Data Valid		$48t_{CLCL}$	
t_{ELQV}	$\overline{\text{ENABLE}}$ Low to Data Valid		$48t_{CLCL}$	
t_{EHQZ}	Data Float After $\overline{\text{ENABLE}}$	0	$48t_{CLCL}$	
t_{GHBL}	$\overline{\text{PROG}}$ High to $\overline{\text{BUSY}}$ Low		1.0	µs
t_{WC}	Byte Write Cycle Time		50	µs

Figure 6. Flash Programming and Verification Waveforms – Parallel Mode

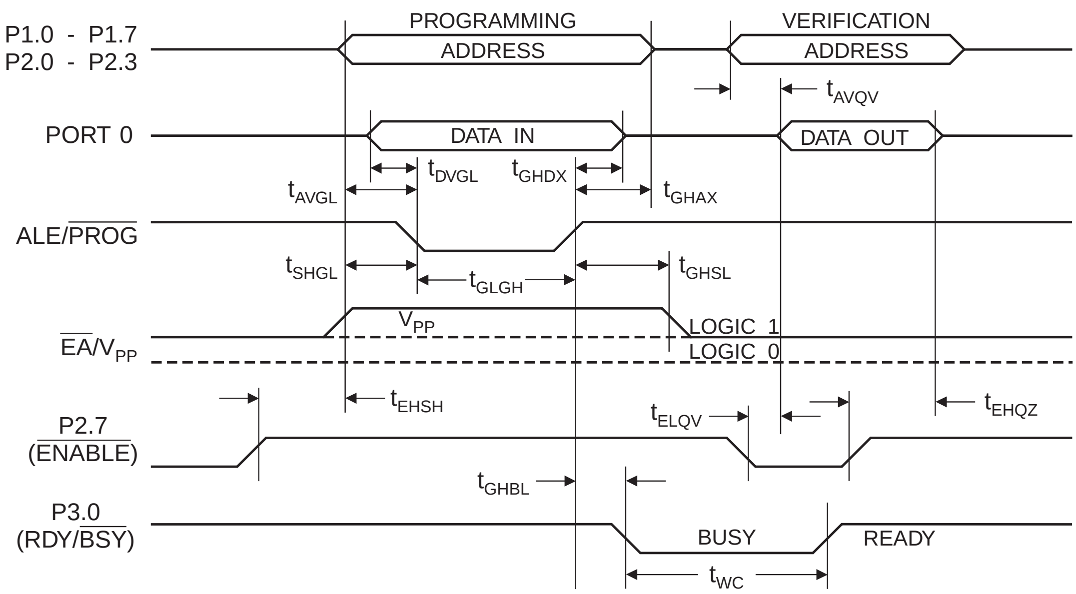
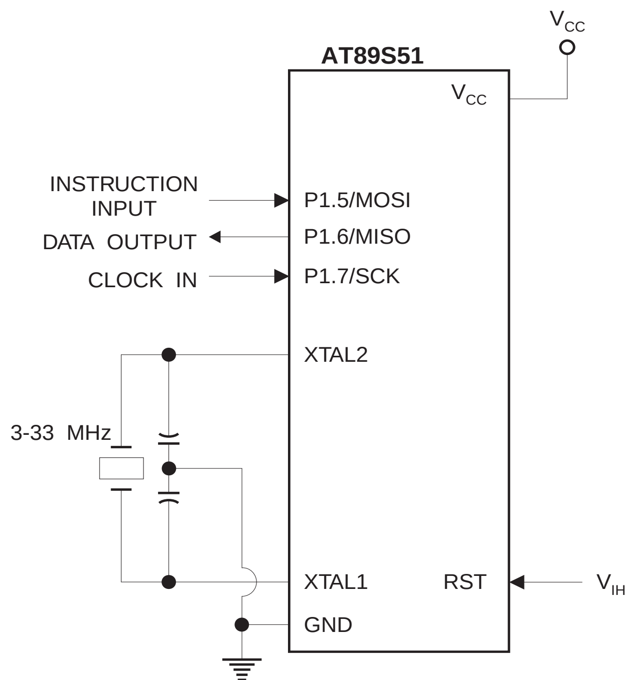


Figure 7. Flash Memory Serial Downloading



Flash Programming and Verification Waveforms – Serial Mode

Figure 8. Serial Programming Waveforms

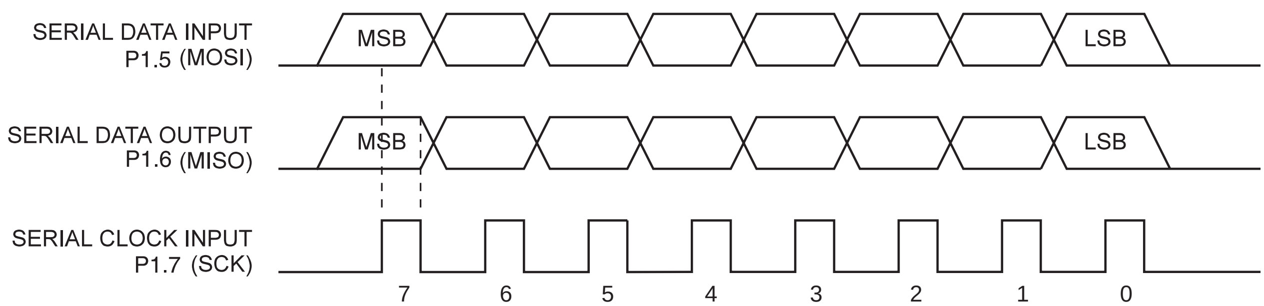


Table 8. Serial Programming Instruction Set

Instruction	Instruction Format Byte 1	Byte 2	Byte 3	Byte 4	Operation
Programming Enable	1010 1100	0101 0011	xxxx xxxx	xxxx xxxx 0110 1001 (Output on MISO)	Enable Serial Programming while RST is high
Chip Erase	1010 1100	100x xxxx	xxxx xxxx	xxxx xxxx	Chip Erase Flash memory array
Read Program Memory (Byte Mode)	0010 0000	xxxx A11 A10 A9 A8	A7 A6 A5 A4 A3 A2 A1 A0	D7 D6 D5 D4 D3 D2 D1 D0	Read data from Program memory in the byte mode
Write Program Memory (Byte Mode)	0100 0000	xxxx A11 A10 A9 A8	A7 A6 A5 A4 A3 A2 A1 A0	D7 D6 D5 D4 D3 D2 D1 D0	Write data to Program memory in the byte mode
Write Lock Bits[(1)]	1010 1100	1110 00 B1 B2	xxxx xxxx	xxxx xxxx	Write Lock bits. See Note (1).
Read Lock Bits	0010 0100	xxxx xxxx	xxxx xxxx	xxx LB3 LB2 LB1 xx	Read back current status of the lock bits (a programmed lock bit reads back as a "1")
Read Signature Bytes	0010 1000	xxxx A11 A10 A9 A8	A7 xxx xxx0	Signature Byte	Read Signature Byte
Read Program Memory (Page Mode)	0011 0000	xxxx A11 A10 A9 A8	Byte 0	Byte 1... Byte 255	Read data from Program memory in the Page Mode (256 bytes)
Write Program Memory (Page Mode)	0101 0000	xxxx A11 A10 A9 A8	Byte 0	Byte 1... Byte 255	Write data to Program memory in the Page Mode (256 bytes)

Note: 1. B1 = 0, B2 = 0 → Mode 1, no lock protection
B1 = 0, B2 = 1 → Mode 2, lock bit 1 activated
B1 = 1, B2 = 0 → Mode 3, lock bit 2 activated
B1 = 1, B2 = 1 → Mode 4, lock bit 3 activated
} Each of the lock bit modes need to be activated sequentially before Mode 4 can be executed.

After Reset signal is high, SCK should be low for at least 64 system clocks before it goes high to clock in the enable data bytes. No pulsing of Reset signal is necessary. SCK should be no faster than 1/16 of the system clock at XTAL1.

For Page Read/Write, the data always starts from byte 0 to 255. After the command byte and upper address byte are latched, each byte thereafter is treated as data until all 256 bytes are shifted in/out. Then the next instruction will be ready to be decoded.

Serial Programming Characteristics

Figure 9. Serial Programming Timing

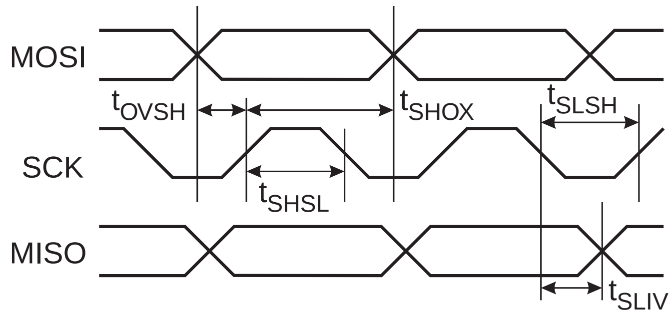


Table 9. Serial Programming Characteristics, T_A = -40° C to 85° C, V_{CC} = 4.0 - 5.5V (Unless Otherwise Noted)

Symbol	Parameter	Min	Typ	Max	Units
$1/t_{CLCL}$	Oscillator Frequency	3		33	MHz
t_{CLCL}	Oscillator Period	30			ns
t_{SHSL}	SCK Pulse Width High	8 t_{CLCL}			ns
t_{SLSH}	SCK Pulse Width Low	8 t_{CLCL}			ns
t_{OVSH}	MOSI Setup to SCK High	t_{CLCL}			ns
t_{SHOX}	MOSI Hold after SCK High	2 t_{CLCL}			ns
t_{SLIV}	SCK Low to MISO Valid	10	16	32	ns
t_{ERASE}	Chip Erase Instruction Cycle Time			500	ms
t_{SWC}	Serial Byte Write Cycle Time			64 t_{CLCL} + 400	µs

Absolute Maximum Ratings*

Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C
Voltage on Any Pin with Respect to Ground	-1.0V to +7.0V
Maximum Operating Voltage	6.6V
DC Output Current	15.0 mA

*NOTICE: Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC Characteristics

The values shown in this table are valid for T_A = -40°C to 85°C and V_{CC} = 4.0V to 5.5V, unless otherwise noted.

Symbol	Parameter	Condition	Min	Max	Units
V_{IL}	Input Low Voltage	(Except $\overline{EA}$)	-0.5	0.2 V_{CC}-0.1	V
V_{IL1}	Input Low Voltage ($\overline{EA}$)		-0.5	0.2 V_{CC}-0.3	V
V_{IH}	Input High Voltage	(Except XTAL1, RST)	0.2 V_{CC}+0.9	V_{CC}+0.5	V
V_{IH1}	Input High Voltage	(XTAL1, RST)	0.7 V_{CC}	V_{CC}+0.5	V
V_{OL}	Output Low Voltage(1) (Ports 1,2,3)	I_{OL} = 1.6 mA		0.45	V
V_{OL1}	Output Low Voltage(1) (Port 0, ALE, $\overline{PSEN}$)	I_{OL} = 3.2 mA		0.45	V
V_{OH}	Output High Voltage (Ports 1,2,3, ALE, $\overline{PSEN}$)	I_{OH} = -60 µA, V_{CC} = 5V ±10%	2.4		V
		I_{OH} = -25 µA	0.75 V_{CC}		V
		I_{OH} = -10 µA	0.9 V_{CC}		V
V_{OH1}	Output High Voltage (Port 0 in External Bus Mode)	I_{OH} = -800 µA, V_{CC} = 5V ±10%	2.4		V
		I_{OH} = -300 µA	0.75 V_{CC}		V
		I_{OH} = -80 µA	0.9 V_{CC}		V
I_{IL}	Logical 0 Input Current (Ports 1,2,3)	V_{IN} = 0.45V		-50	µA
I_{TL}	Logical 1 to 0 Transition Current (Ports 1,2,3)	V_{IN} = 2V, V_{CC} = 5V ±10%		-650	µA
I_{LI}	Input Leakage Current (Port 0, $\overline{EA}$)	0.45 < V_{IN} < V_{CC}		±10	µA
RRST	Reset Pulldown Resistor		50	300	KΩ
C_{IO}	Pin Capacitance	Test Freq. = 1 MHz, T_A = 25°C		10	pF
I_{CC}	Power Supply Current	Active Mode, 12 MHz		25	mA
		Idle Mode, 12 MHz		6.5	mA
	Power-down Mode(2)	V_{CC} = 5.5V		50	µA

Notes:
1. Under steady state (non-transient) conditions, I_{OL} must be externally limited as follows:
   Maximum I_{OL} per port pin: 10 mA
   Maximum I_{OL} per 8-bit port:
   Port 0: 26 mA Ports 1, 2, 3: 15 mA
   Maximum total I_{OL} for all output pins: 71 mA
   If I_{OL} exceeds the test condition, V_{OL} may exceed the related specification. Pins are not guaranteed to sink current greater than the listed test conditions.
2. Minimum V_{CC} for Power-down is 2V.

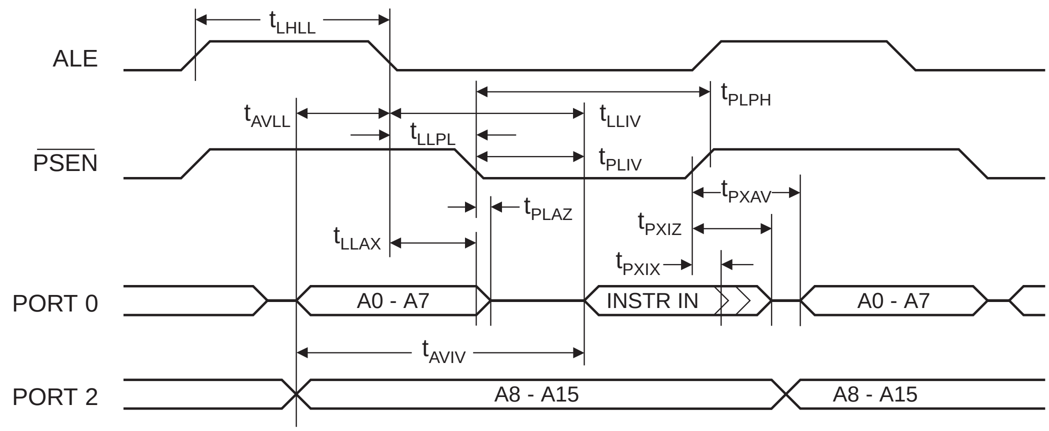
AC Characteristics

Under operating conditions, load capacitance for Port 0, ALE/$\overline{PROG}$, and $\overline{PSEN}$ = 100 pF; load capacitance for all other outputs = 80 pF.

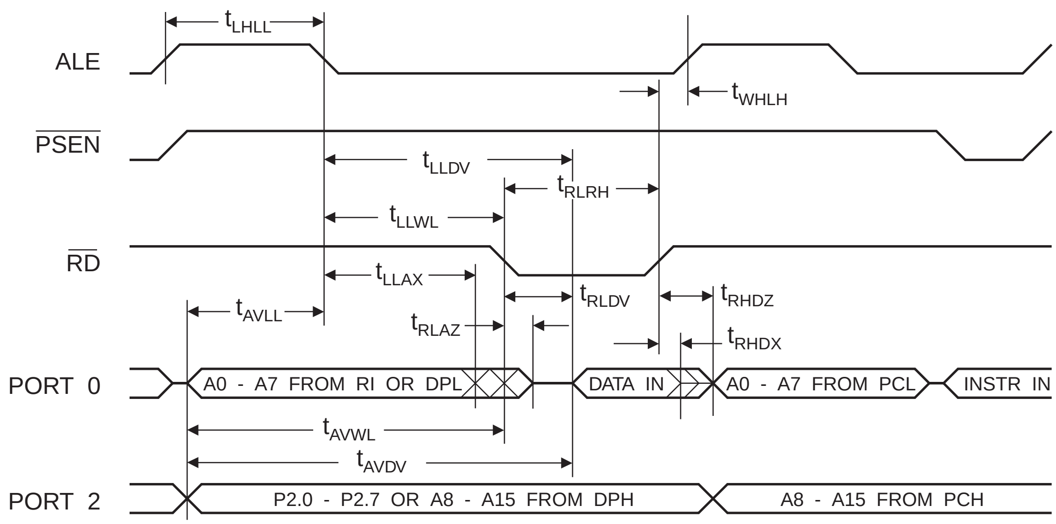
External Program and Data Memory Characteristics

Symbol	Parameter	12 MHz Oscillator		Variable Oscillator		Units
		Min	Max	Min	Max	
$1/t_{CLCL}$	Oscillator Frequency			0	33	MHz
t_{LHLL}	ALE Pulse Width	127		$2t_{CLCL}$-40		ns
t_{AVLL}	Address Valid to ALE Low	43		t_{CLCL}-25		ns
t_{LLAX}	Address Hold After ALE Low	48		t_{CLCL}-25		ns
t_{LLIV}	ALE Low to Valid Instruction In		233		$4t_{CLCL}$-65	ns
t_{LLPL}	ALE Low to $\overline{PSEN}$ Low	43		t_{CLCL}-25		ns
t_{PLPH}	$\overline{PSEN}$ Pulse Width	205		$3t_{CLCL}$-45		ns
t_{PLIV}	$\overline{PSEN}$ Low to Valid Instruction In		145		$3t_{CLCL}$-60	ns
t_{PXIX}	Input Instruction Hold After $\overline{PSEN}$	0		0		ns
t_{PXIZ}	Input Instruction Float After $\overline{PSEN}$		59		t_{CLCL}-25	ns
t_{PXAV}	$\overline{PSEN}$ to Address Valid	75		t_{CLCL}-8		ns
t_{AVIV}	Address to Valid Instruction In		312		$5t_{CLCL}$-80	ns
t_{PLAZ}	$\overline{PSEN}$ Low to Address Float		10		10	ns
t_{RLRH}	$\overline{RD}$ Pulse Width	400		$6t_{CLCL}$-100		ns
t_{WLWH}	$\overline{WR}$ Pulse Width	400		$6t_{CLCL}$-100		ns
t_{RLDV}	$\overline{RD}$ Low to Valid Data In		252		$5t_{CLCL}$-90	ns
t_{RHDX}	Data Hold After $\overline{RD}$	0		0		ns
t_{RHDZ}	Data Float After $\overline{RD}$		97		$2t_{CLCL}$-28	ns
t_{LLDV}	ALE Low to Valid Data In		517		$8t_{CLCL}$-150	ns
t_{AVDV}	Address to Valid Data In		585		$9t_{CLCL}$-165	ns
t_{LLWL}	ALE Low to $\overline{RD}$ or $\overline{WR}$ Low	200	300	$3t_{CLCL}$-50	$3t_{CLCL}$+50	ns
t_{AVWL}	Address to $\overline{RD}$ or $\overline{WR}$ Low	203		$4t_{CLCL}$-75		ns
t_{QVWX}	Data Valid to $\overline{WR}$ Transition	23		t_{CLCL}-30		ns
t_{QVWH}	Data Valid to $\overline{WR}$ High	433		$7t_{CLCL}$-130		ns
t_{WHQX}	Data Hold After $\overline{WR}$	33		t_{CLCL}-25		ns
t_{RLAZ}	$\overline{RD}$ Low to Address Float		0		0	ns
t_{WHLH}	$\overline{RD}$ or $\overline{WR}$ High to ALE High	43	123	t_{CLCL}-25	t_{CLCL}+25	ns

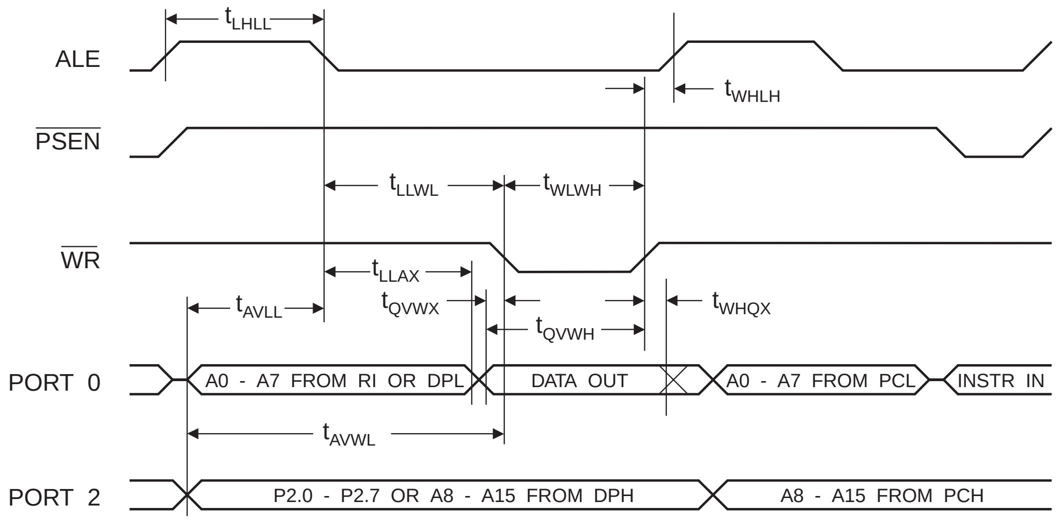
External Program Memory Read Cycle



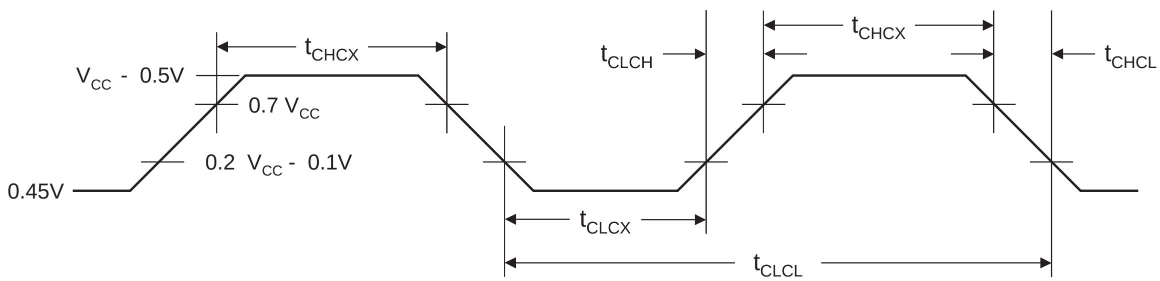
External Data Memory Read Cycle



External Data Memory Write Cycle



External Clock Drive Waveforms



External Clock Drive

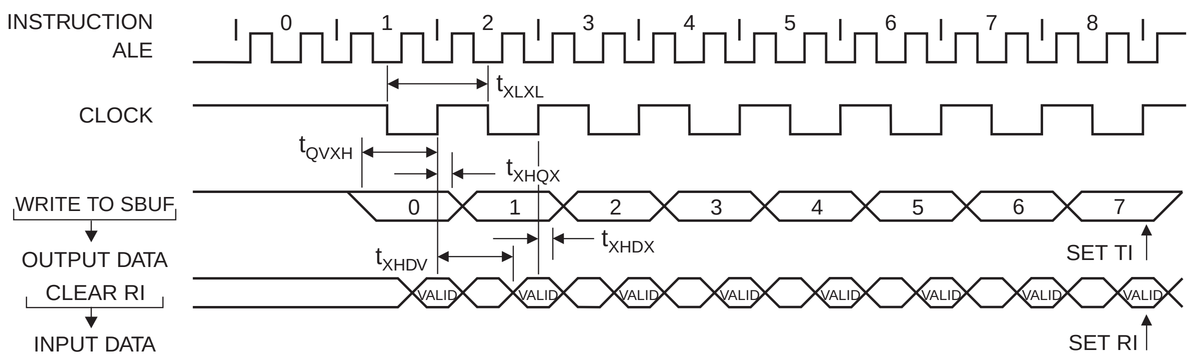
Symbol	Parameter	Min	Max	Units
$1/t_{CLCL}$	Oscillator Frequency	0	33	MHz
t_{CLCL}	Clock Period	30		ns
t_{CHCX}	High Time	12		ns
t_{CLCX}	Low Time	12		ns
t_{CLCH}	Rise Time		5	ns
t_{CHCL}	Fall Time		5	ns

Serial Port Timing: Shift Register Mode Test Conditions

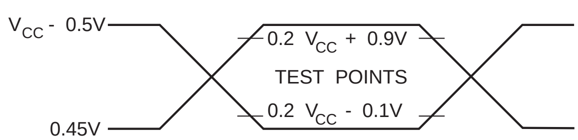
The values in this table are valid for V_{CC} = 4.0V to 5.5V and Load Capacitance = 80 pF.

Symbol	Parameter	12 MHz Osc		Variable Oscillator		Units
		Min	Max	Min	Max	
t_{XLXL}	Serial Port Clock Cycle Time	1.0		$12t_{CLCL}$		µs
t_{QVXH}	Output Data Setup to Clock Rising Edge	700		$10t_{CLCL}$-133		ns
t_{XHQX}	Output Data Hold After Clock Rising Edge	50		$2t_{CLCL}$-80		ns
t_{XHDX}	Input Data Hold After Clock Rising Edge	0		0		ns
t_{XHDV}	Clock Rising Edge to Input Data Valid		700		$10t_{CLCL}$-133	ns

Shift Register Mode Timing Waveforms

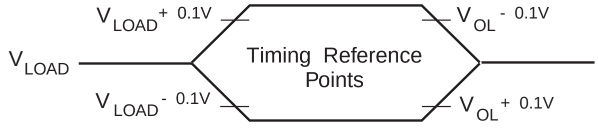


AC Testing Input/Output Waveforms(1)



Note: 1. AC Inputs during testing are driven at V_{CC} - 0.5V for a logic 1 and 0.45V for a logic 0. Timing measurements are made at V_{IH} min. for a logic 1 and V_{IL} max. for a logic 0.

Float Waveforms(1)



Note: 1. For timing purposes, a port pin is no longer floating when a 100 mV change from load voltage occurs. A port pin begins to float when a 100 mV change from the loaded V_{OH}/V_{OL} level occurs.

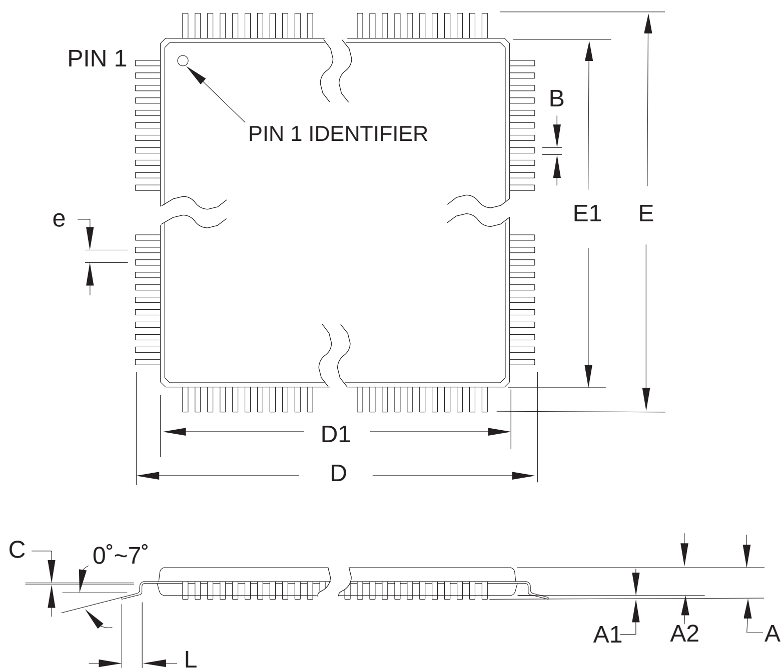
Ordering Information

Speed (MHz)	Power Supply	Ordering Code	Package	Operation Range
24	4.0V to 5.5V	AT89S51-24AC AT89S51-24JC AT89S51-24PC AT89S51-24SC	44A 44J 40P6 42PS6	Commercial (0° C to 70° C)
		AT89S51-24AI AT89S51-24JI AT89S51-24PI AT89S51-24SI	44A 44J 40P6 42PS6	Industrial (-40° C to 85° C)
33	4.5V to 5.5V	AT89S51-33AC AT89S51-33JC AT89S51-33PC AT89S51-33SC	44A 44J 40P6 42PS6	Commercial (0° C to 70° C)

Package Type	
44A	44-lead, Thin Plastic Gull Wing Quad Flatpack (TQFP)
44J	44-lead, Plastic J-leaded Chip Carrier (PLCC)
40P6	40-pin, 0.600" Wide, Plastic Dual Inline Package (PDIP)
42PS6	42-pin, 0.600" Wide, Plastic Dual Inline Package (PDIP)

Packaging Information

44A – TQFP



COMMON DIMENSIONS
(Unit of Measure = mm)

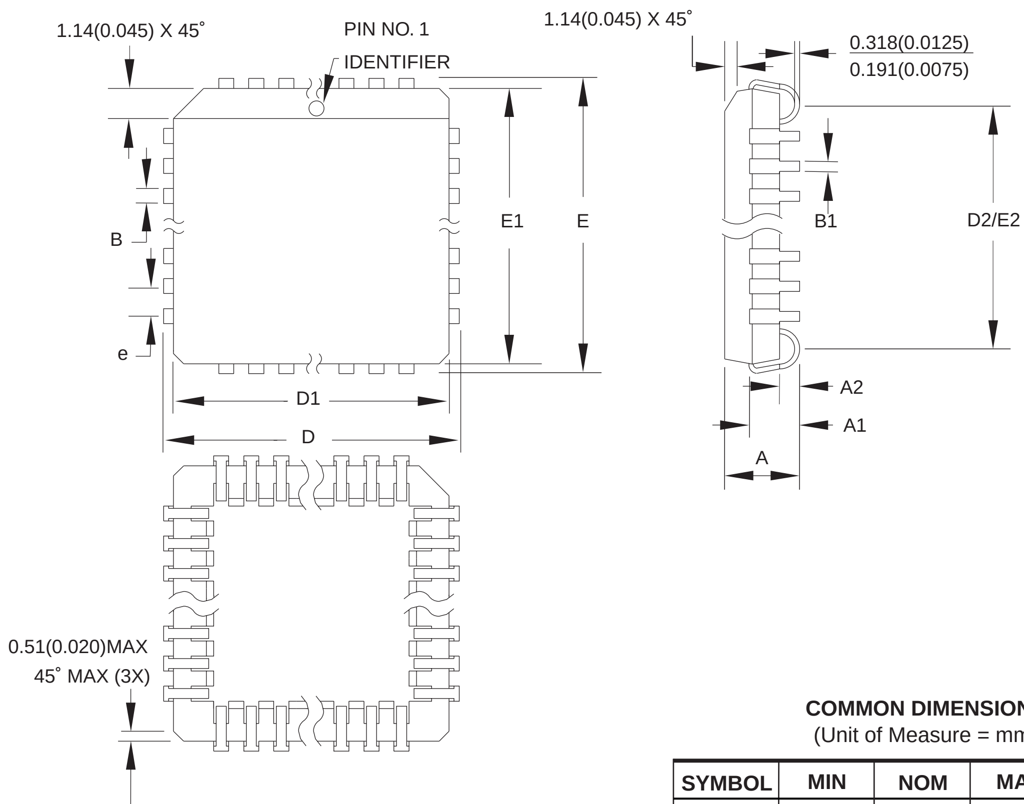
SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	1.20	
A1	0.05	–	0.15	
A2	0.95	1.00	1.05	
D	11.75	12.00	12.25	
D1	9.90	10.00	10.10	Note 2
E	11.75	12.00	12.25	
E1	9.90	10.00	10.10	Note 2
B	0.30	–	0.45	
C	0.09	–	0.20	
L	0.45	–	0.75	
e	0.80 TYP			

Notes:
1. This package conforms to JEDEC reference MS-026, Variation ACB.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25 mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10 mm maximum.

10/5/2001

	TITLE	DRAWING NO.	REV.
ATMEL 2325 Orchard Parkway San Jose, CA 95131	**44A,** 44-lead, 10 x 10 mm Body Size, 1.0 mm Body Thickness, 0.8 mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP)	44A	B

44J – PLCC



COMMON DIMENSIONS
(Unit of Measure = mm)

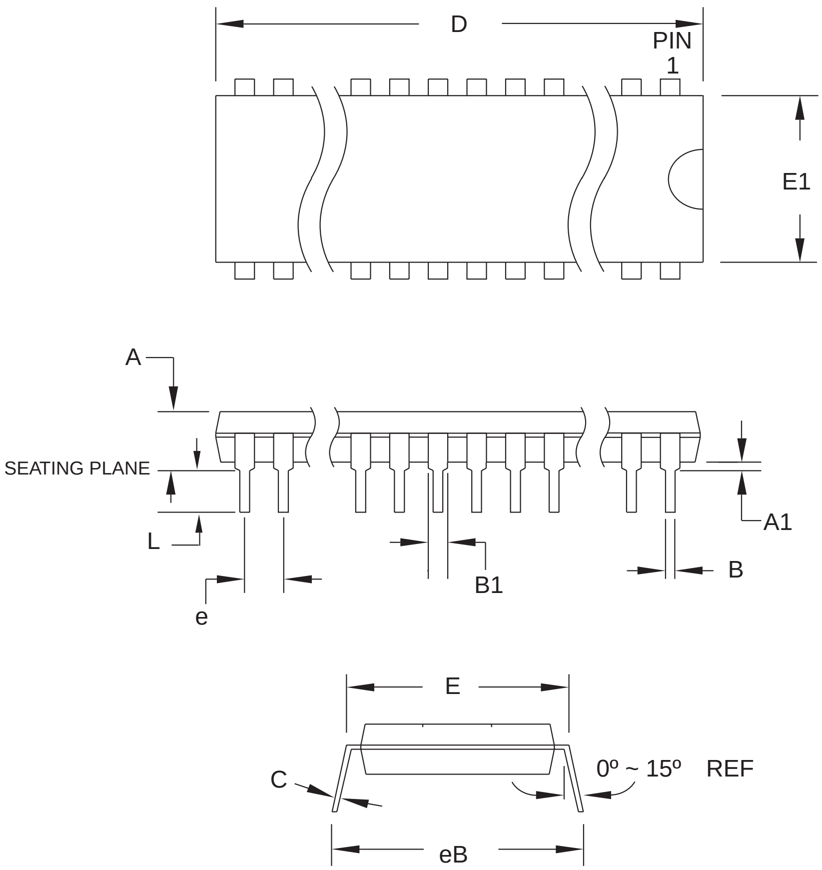
SYMBOL	MIN	NOM	MAX	NOTE
A	4.191	–	4.572	
A1	2.286	–	3.048	
A2	0.508	–	–	
D	17.399	–	17.653	
D1	16.510	–	16.662	Note 2
E	17.399	–	17.653	
E1	16.510	–	16.662	Note 2
D2/E2	14.986	–	16.002	
B	0.660	–	0.813	
B1	0.330	–	0.533	
e	1.270 TYP			

Notes:
1. This package conforms to JEDEC reference MS-018, Variation AC.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is .010"(0.254 mm) per side. Dimension D1 and E1 include mold mismatch and are measured at the extreme material condition at the upper or lower parting line.
3. Lead coplanarity is 0.004" (0.102 mm) maximum.

10/04/01

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**44J**, 44-lead, Plastic J-leaded Chip Carrier (PLCC)	44J	B

40P6 – PDIP



COMMON DIMENSIONS
(Unit of Measure = mm)

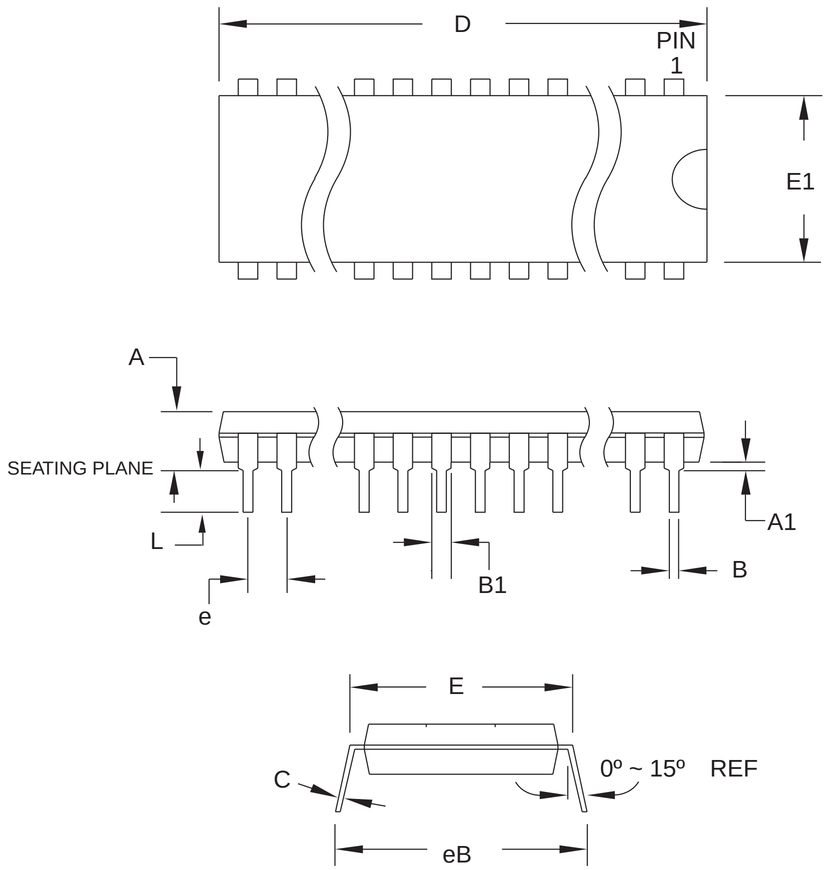
SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.826	
A1	0.381	–	–	
D	52.070	–	52.578	Note 2
E	15.240	–	15.875	
E1	13.462	–	13.970	Note 2
B	0.356	–	0.559	
B1	1.041	–	1.651	
L	3.048	–	3.556	
C	0.203	–	0.381	
eB	15.494	–	17.526	
e	2.540 TYP			

Notes:
1. This package conforms to JEDEC reference MS-011, Variation AC.
2. Dimensions D and E1 do not include mold Flash or Protrusion. Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

09/28/01

	TITLE	DRAWING NO.	REV.
ATMEL 2325 Orchard Parkway San Jose, CA 95131	**40P6**, 40-lead (0.600"/15.24 mm Wide) Plastic Dual Inline Package (PDIP)	40P6	B

42PS6 – PDIP



COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.83	
A1	0.51	–	–	
D	36.70	–	36.96	Note 2
E	15.24	–	15.88	
E1	13.46	–	13.97	Note 2
B	0.38	–	0.56	
B1	0.76	–	1.27	
L	3.05	–	3.43	
C	0.20	–	0.30	
eB	–	–	18.55	
e	1.78 TYP			

Notes:
1. This package conforms to JEDEC reference MS-011, Variation AC.
2. Dimensions D and E1 do not include mold Flash or Protrusion. Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

11/6/03

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**42PS6**, 42-lead (0.600"/15.24 mm Wide) Plastic Dual Inline Package (PDIP)	42PS6	A

Atmel Corporation

2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 487-2600

Regional Headquarters

Europe
Atmel Sarl
Route des Arsenaux 41
Case Postale 80
CH-1705 Fribourg
Switzerland
Tel: (41) 26-426-5555
Fax: (41) 26-426-5500

Asia
Room 1219
Chinachem Golden Plaza
77 Mody Road Tsimshatsui
East Kowloon
Hong Kong
Tel: (852) 2721-9778
Fax: (852) 2722-1369

Japan
9F, Tonetsu Shinkawa Bldg.
1-24-8 Shinkawa
Chuo-ku, Tokyo 104-0033
Japan
Tel: (81) 3-3523-3551
Fax: (81) 3-3523-7581

Atmel Operations

Memory
2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

Microcontrollers
2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

La Chantrerie
BP 70602
44306 Nantes Cedex 3, France
Tel: (33) 2-40-18-18-18
Fax: (33) 2-40-18-19-60

ASIC/ASSP/Smart Cards
Zone Industrielle
13106 Rousset Cedex, France
Tel: (33) 4-42-53-60-00
Fax: (33) 4-42-53-60-01

1150 East Cheyenne Mtn. Blvd.
Colorado Springs, CO 80906, USA
Tel: 1(719) 576-3300
Fax: 1(719) 540-1759

Scottish Enterprise Technology Park
Maxwell Building
East Kilbride G75 0QR, Scotland
Tel: (44) 1355-803-000
Fax: (44) 1355-242-743

RF/Automotive
Theresienstrasse 2
Postfach 3535
74025 Heilbronn, Germany
Tel: (49) 71-31-67-0
Fax: (49) 71-31-67-2340

1150 East Cheyenne Mtn. Blvd.
Colorado Springs, CO 80906, USA
Tel: 1(719) 576-3300
Fax: 1(719) 540-1759

Biometrics/Imaging/Hi-Rel MPU/
High Speed Converters/RF Datacom
Avenue de Rochepleine
BP 123
38521 Saint-Egreve Cedex, France
Tel: (33) 4-76-58-30-00
Fax: (33) 4-76-58-34-80

Literature Requests
www.atmel.com/literature

2487B–MICRO–12/03

National Semiconductor

February 1995

LM555/LM555C Timer

General Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200 mA or drive TTL circuits.

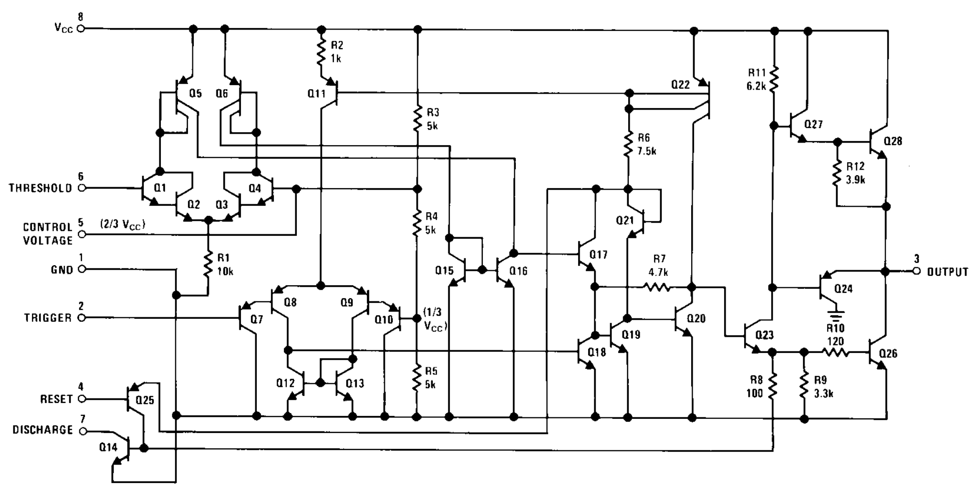
Features

- Direct replacement for SE555/NE555
- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- Output can source or sink 200 mA
- Output and supply TTL compatible
- Temperature stability better than 0.005% per °C
- Normally on and normally off output

Applications

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation
- Pulse position modulation
- Linear ramp generator

Schematic Diagram



TL/H/7851–1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	+18V
Power Dissipation (Note 1)	
LM555H, LM555CH	760 mW
LM555, LM555CN	1180 mW
Operating Temperature Ranges	
LM555C	0°C to +70°C
LM555	−55°C to + 125°C
Storage Temperature Range	−65°C to +150°C
Soldering Information	
Dual-In-Line Package	
Soldering (10 Seconds)	260°C
Small Outline Package	
Vapor Phase (60 Seconds)	215°C
Infrared (15 Seconds)	220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

Electrical Characteristics (T_A = 25°C, V_{CC} = +5V to +15V, unless othewise specified)

Parameter	Conditions	Limits						Units
		LM555			LM555C			
		Min	Typ	Max	Min	Typ	Max	
Supply Voltage		4.5		18	4.5		16	V
Supply Current	V_{CC} = 5V, R_L = ∞ V_{CC} = 15V, R_L = ∞ (Low State) (Note 2)		3 10	5 12		3 10	6 15	mA mA
Timing Error, Monostable Initial Accuracy Drift with Temperature Accuracy over Temperature Drift with Supply	 R_A = 1k to 100 kΩ, C = 0.1 μF, (Note 3)		 0.5 30 1.5 0.05			 1 50 1.5 0.1		 % ppm/°C % %/V
Timing Error, Astable Initial Accuracy Drift with Temperature Accuracy over Temperature Drift with Supply	 R_A, R_B = 1k to 100 kΩ, C = 0.1 μF, (Note 3)		 1.5 90 2.5 0.15			 2.25 150 3.0 0.30		 % ppm/°C % %/V
Threshold Voltage			0.667			0.667		x V_{CC}
Trigger Voltage	V_{CC} = 15V V_{CC} = 5V	4.8 1.45	5 1.67	5.2 1.9		5 1.67		V V
Trigger Current			0.01	0.5		0.5	0.9	μA
Reset Voltage		0.4	0.5	1	0.4	0.5	1	V
Reset Current			0.1	0.4		0.1	0.4	mA
Threshold Current	(Note 4)		0.1	0.25		0.1	0.25	μA
Control Voltage Level	V_{CC} = 15V V_{CC} = 5V	9.6 2.9	10 3.33	10.4 3.8	9 2.6	10 3.33	11 4	V V
Pin 7 Leakage Output High			1	100		1	100	nA
Pin 7 Sat (Note 5) Output Low Output Low	 V_{CC} = 15V, I_7 = 15 mA V_{CC} = 4.5V, I_7 = 4.5 mA		 150 70	 100		 180 80	 200	 mV mV

Electrical Characteristics $T_A = 25°C$, $V_{CC} = +5V$ to $+15V$, (unless othewise specified) (Continued)

Parameter	Conditions	Limits						Units
		LM555			LM555C			
		Min	Typ	Max	Min	Typ	Max	
Output Voltage Drop (Low)	$V_{CC} = 15V$							
	$I_{SINK} = 10$ mA		0.1	0.15		0.1	0.25	V
	$I_{SINK} = 50$ mA		0.4	0.5		0.4	0.75	V
	$I_{SINK} = 100$ mA		2	2.2		2	2.5	V
	$I_{SINK} = 200$ mA		2.5			2.5		V
	$V_{CC} = 5V$							
	$I_{SINK} = 8$ mA		0.1	0.25				V
	$I_{SINK} = 5$ mA					0.25	0.35	V
Output Voltage Drop (High)	$I_{SOURCE} = 200$ mA, $V_{CC} = 15V$		12.5			12.5		V
	$I_{SOURCE} = 100$ mA, $V_{CC} = 15V$	13	13.3		12.75	13.3		V
	$V_{CC} = 5V$	3	3.3		2.75	3.3		V
Rise Time of Output			100			100		ns
Fall Time of Output			100			100		ns

Note 1: For operating at elevated temperatures the device must be derated above 25°C based on a +150°C maximum junction temperature and a thermal resistance of 164°c/w (T0-5), 106°c/w (DIP) and 170°c/w (S0-8) junction to ambient.

Note 2: Supply current when output high typically 1 mA less at $V_{CC} = 5V$.

Note 3: Tested at $V_{CC} = 5V$ and $V_{CC} = 15V$.

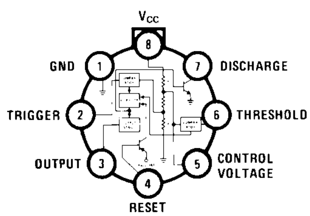
Note 4: This will determine the maximum value of $R_A + R_B$ for 15V operation. The maximum total $(R_A + R_B)$ is 20 MΩ.

Note 5: No protection against excessive pin 7 current is necessary providing the package dissipation rating will not be exceeded.

Note 6: Refer to RETS555X drawing of military LM555H and LM555J versions for specifications.

Connection Diagrams

Metal Can Package

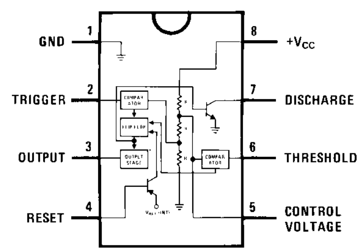


TL/H/7851–2

Top View

Order Number LM555H or LM555CH
See NS Package Number H08C

Dual-In-Line and Small Outline Packages



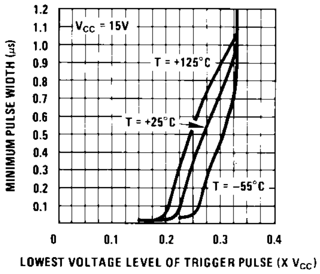
TL/H/7851–3

Top View

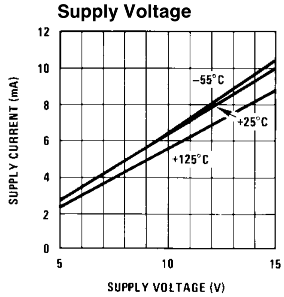
Order Number LM555J, LM555CJ, LM555CM or LM555CN
See NS Package Number J08A, M08A or N08E

Typical Performance Characteristics

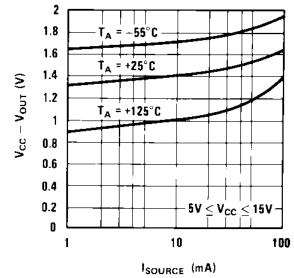
Minimuim Pulse Width Required for Triggering



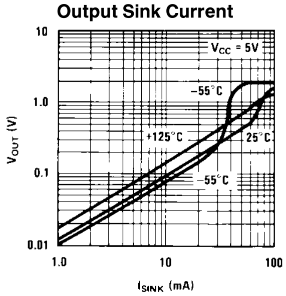
Supply Current vs Supply Voltage



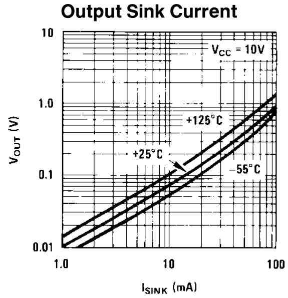
High Output Voltage vs Output Source Current



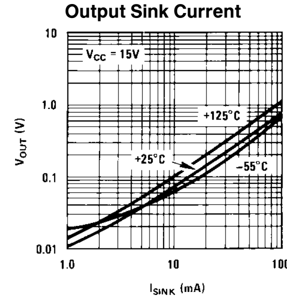
Low Output Voltage vs Output Sink Current



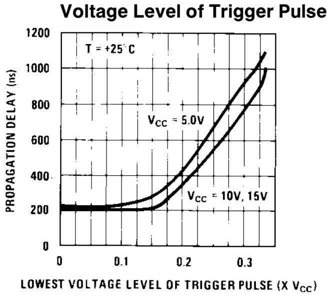
Low Output Voltage vs Output Sink Current



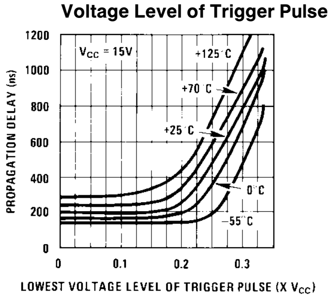
Low Output Voltage vs Output Sink Current



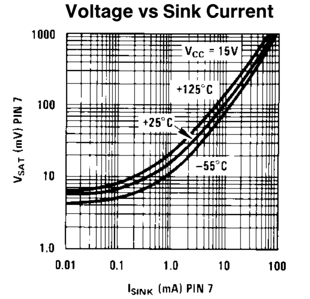
Output Propagation Delay vs Voltage Level of Trigger Pulse



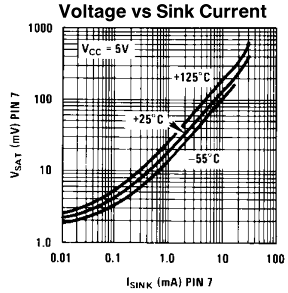
Output Propagation Delay vs Voltage Level of Trigger Pulse



Discharge Transistor (Pin 7) Voltage vs Sink Current



Discharge Transistor (Pin 7) Voltage vs Sink Current

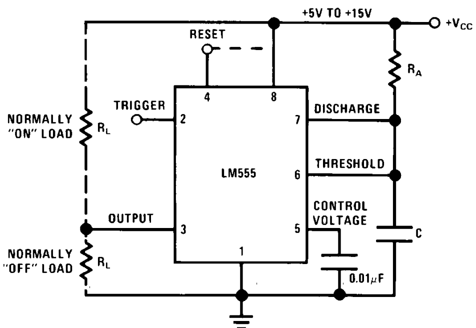


TL/H/7851–4

Applications Information

MONOSTABLE OPERATION

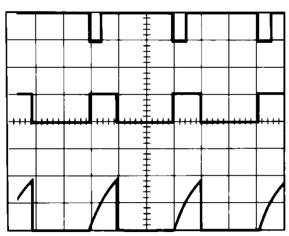
In this mode of operation, the timer functions as a one-shot *(Figure 1)*. The external capacitor is initially held discharged by a transistor inside the timer. Upon application of a negative trigger pulse of less than 1/3 V_{CC} to pin 2, the flip-flop is set which both releases the short circuit across the capacitor and drives the output high.



TL/H/7851–5

FIGURE 1. Monostable

The voltage across the capacitor then increases exponentially for a period of t = 1.1 R_A C, at the end of which time the voltage equals 2/3 V_{CC}. The comparator then resets the flip-flop which in turn discharges the capacitor and drives the output to its low state. *Figure 2* shows the waveforms generated in this mode of operation. Since the charge and the threshold level of the comparator are both directly proportional to supply voltage, the timing internal is independent of supply.



TL/H/7851–6

V_{CC} = 5V Top Trace: Input 5V/Div.
TIME = 0.1 ms/DIV. Middle Trace: Output 5V/Div.
R_A = 9.1 kΩ Bottom Trace: Capacitor Voltage 2V/Div.
C = 0.01 μF

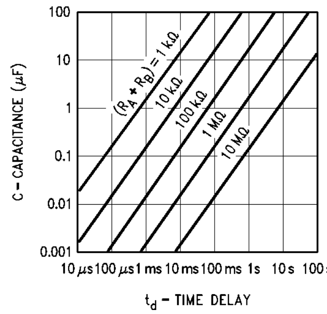
FIGURE 2. Monostable Waveforms

During the timing cycle when the output is high, the further application of a trigger pulse will not effect the circuit so long as the trigger input is returned high at least 10 μs before the end of the timing interval. However the circuit can be reset during this time by the application of a negative pulse to the reset terminal (pin 4). The output will then remain in the low state until a trigger pulse is again applied.

When the reset function is not in use, it is recommended that it be connected to V_{CC} to avoid any possibility of false triggering.

Figure 3 is a nomograph for easy determination of R, C values for various time delays.

NOTE: In monostable operation, the trigger should be driven high before the end of timing cycle.

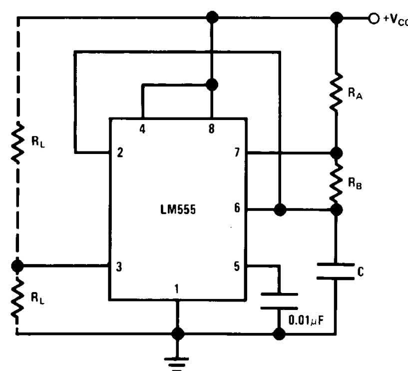


TL/H/7851–7

FIGURE 3. Time Delay

ASTABLE OPERATION

If the circuit is connected as shown in *Figure 4* (pins 2 and 6 connected) it will trigger itself and free run as a multivibrator. The external capacitor charges through $R_A + R_B$ and discharges through R_B. Thus the duty cycle may be precisely set by the ratio of these two resistors.



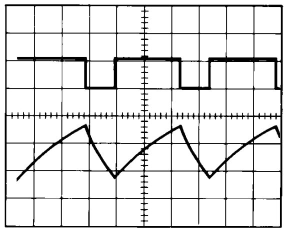
TL/H/7851–8

FIGURE 4. Astable

In this mode of operation, the capacitor charges and discharges between 1/3 V_{CC} and 2/3 V_{CC}. As in the triggered mode, the charge and discharge times, and therefore the frequency are independent of the supply voltage.

Applications Information (Continued)

Figure 5 shows the waveforms generated in this mode of operation.



TL/H/7851–9

V_{CC} = 5V Top Trace: Output 5V/Div.
TIME = 20 μs/DIV. Bottom Trace: Capacitor Voltage 1V/Div.
R_A = 3.9 kΩ
R_B = 3 kΩ
C = 0.01 μF

FIGURE 5. Astable Waveforms

The charge time (output high) is given by:

$$t_1 = 0.693\ (R_A + R_B)\ C$$

And the discharge time (output low) by:

$$t_2 = 0.693\ (R_B)\ C$$

Thus the total period is:

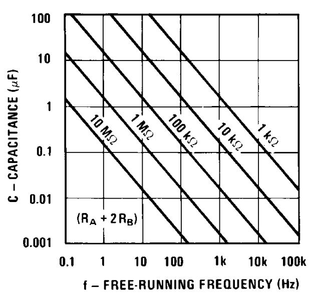
$$T = t_1 + t_2 = 0.693\ (R_A + 2R_B)\ C$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2\,R_B)\ C}$$

Figure 6 may be used for quick determination of these RC values.

The duty cycle is: $D = \dfrac{R_B}{R_A + 2R_B}$

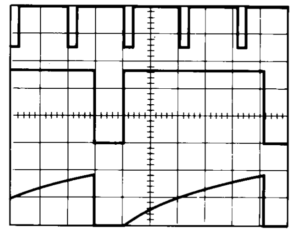


TL/H/7851–10

FIGURE 6. Free Running Frequency

FREQUENCY DIVIDER

The monostable circuit of *Figure 1* can be used as a frequency divider by adjusting the length of the timing cycle. *Figure 7* shows the waveforms generated in a divide by three circuit.



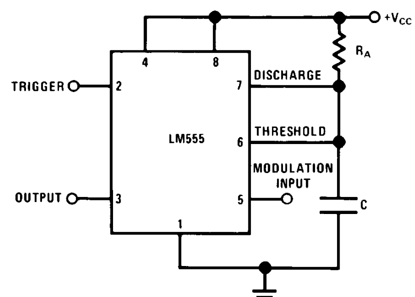
TL/H/7851–11

V_{CC} = 5V Top Trace: Input 4V/Div.
TIME = 20 μs/DIV. Middle Trace: Output 2V/Div.
R_A = 9.1 kΩ Bottom Trace: Capacitor 2V/Div.
C = 0.01 μF

FIGURE 7. Frequency Divider

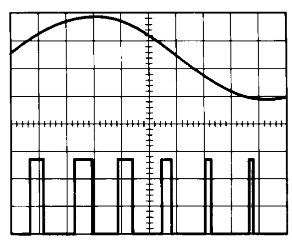
PULSE WIDTH MODULATOR

When the timer is connected in the monostable mode and triggered with a continuous pulse train, the output pulse width can be modulated by a signal applied to pin 5. *Figure 8* shows the circuit, and in *Figure 9* are some waveform examples.



TL/H/7851–12

FIGURE 8. Pulse Width Modulator



TL/H/7851–13

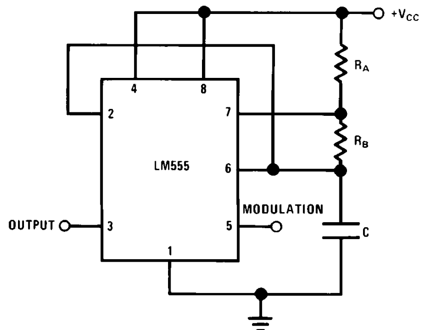
V_{CC} = 5V Top Trace: Modulation 1V/Div.
TIME = 0.2 ms/DIV. Bottom Trace: Output Voltage 2V/Div.
R_A = 9.1 kΩ
C = 0.01 μF

FIGURE 9. Pulse Width Modulator

PULSE POSITION MODULATOR

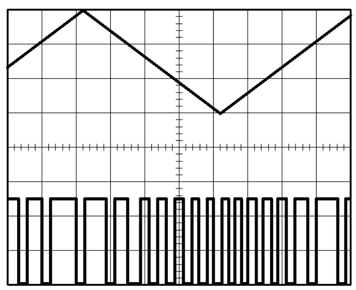
This application uses the timer connected for astable operation, as in *Figure 10,* with a modulating signal again applied to the control voltage terminal. The pulse position varies with the modulating signal, since the threshold voltage and hence the time delay is varied. *Figure 11* shows the waveforms generated for a triangle wave modulation signal.

Applications Information (Continued)



TL/H/7851–14

FIGURE 10. Pulse Position Modulator



TL/H/7851–15

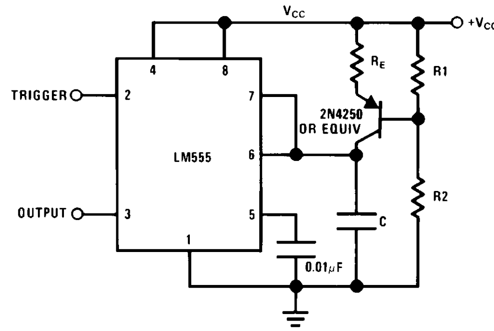
V_{CC} = 5V
TIME = 0.1 ms/DIV.
R_A = 3.9 kΩ
R_B = 3 kΩ
C = 0.01 μF

Top Trace: Modulation Input 1V/Div.
Bottom Trace: Output 2V/Div.

FIGURE 11. Pulse Position Modulator

LINEAR RAMP

When the pullup resistor, R_A, in the monostable circuit is replaced by a constant current source, a linear ramp is generated. *Figure 12* shows a circuit configuration that will perform this function.



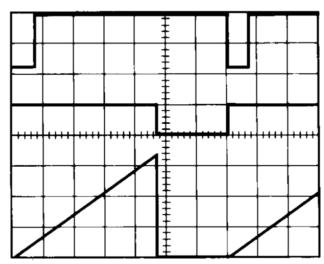
TL/H/7851–16

FIGURE 12

Figure 13 shows waveforms generated by the linear ramp. The time interval is given by:

$$T = \frac{2/3\ V_{CC}\ R_E\ (R_1 + R_2)\ C}{R_1\ V_{CC} - V_{BE}\ (R_1 + R_2)}$$

$$V_{BE} \cong 0.6V$$



TL/H/7851–17

V_{CC} = 5V
TIME = 20 μs/DIV.
R_1 = 47 kΩ
R_2 = 100 kΩ
R_E = 2.7 kΩ
C = 0.01 μF

Top Trace: Input 3V/Div.
Middle Trace: Output 5V/Div.
Bottom Trace: Capacitor Voltage 1V/Div.

FIGURE 13. Linear Ramp

50% DUTY CYCLE OSCILLATOR

For a 50% duty cycle, the resistors R_A and R_B may be connected as in *Figure 14.* The time period for the out-

Applications Information (Continued)

put high is the same as previous, $t_1 = 0.693\ R_A\ C$. For the output low it is $t_2 =$

$$\left[(R_A\ R_B)/(R_A + R_B)\right] C\ \ell n \left[\frac{R_B - 2R_A}{2R_B - R_A}\right]$$

Thus the frequency of oscillation is $f = \dfrac{1}{t_1 + t_2}$

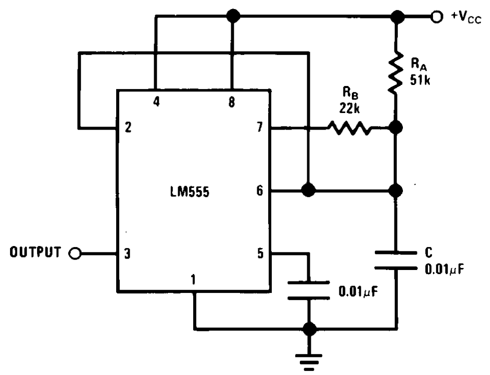


FIGURE 14. 50% Duty Cycle Oscillator

Note that this circuit will not oscillate if R_B is greater than 1/2 R_A because the junction of R_A and R_B cannot bring pin 2 down to 1/3 V_{CC} and trigger the lower comparator.

ADDITIONAL INFORMATION

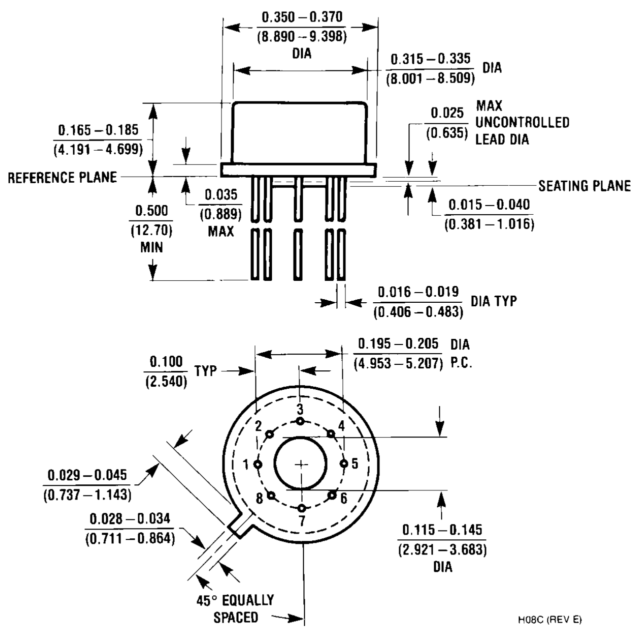
Adequate power supply bypassing is necessary to protect associated circuitry. Minimum recommended is 0.1 μF in parallel with 1 μF electrolytic.

Lower comparator storage time can be as long as 10 μs when pin 2 is driven fully to ground for triggering. This limits the monostable pulse width to 10 μs minimum.

Delay time reset to output is 0.47 μs typical. Minimum reset pulse width must be 0.3 μs, typical.

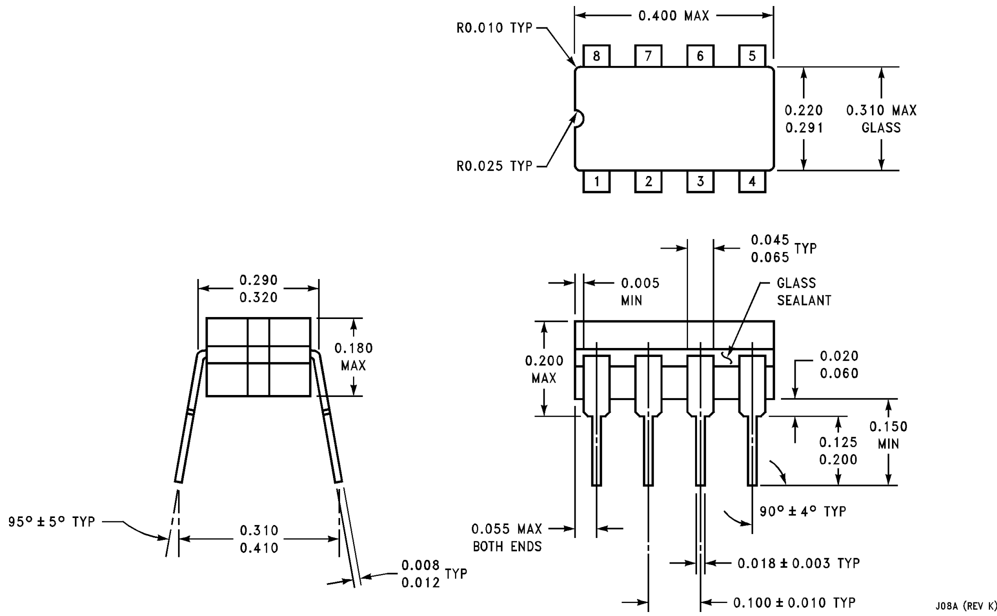
Pin 7 current switches within 30 ns of the output (pin 3) voltage.

Physical Dimensions inches (millimeters)

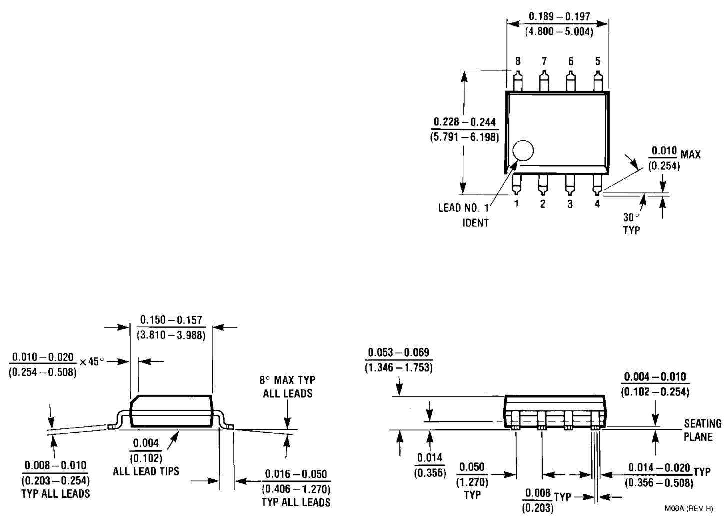


Metal Can Package (H)
Order Number LM555H or LM555CH
NS Package Number H08C

Physical Dimensions inches (millimeters) (Continued)

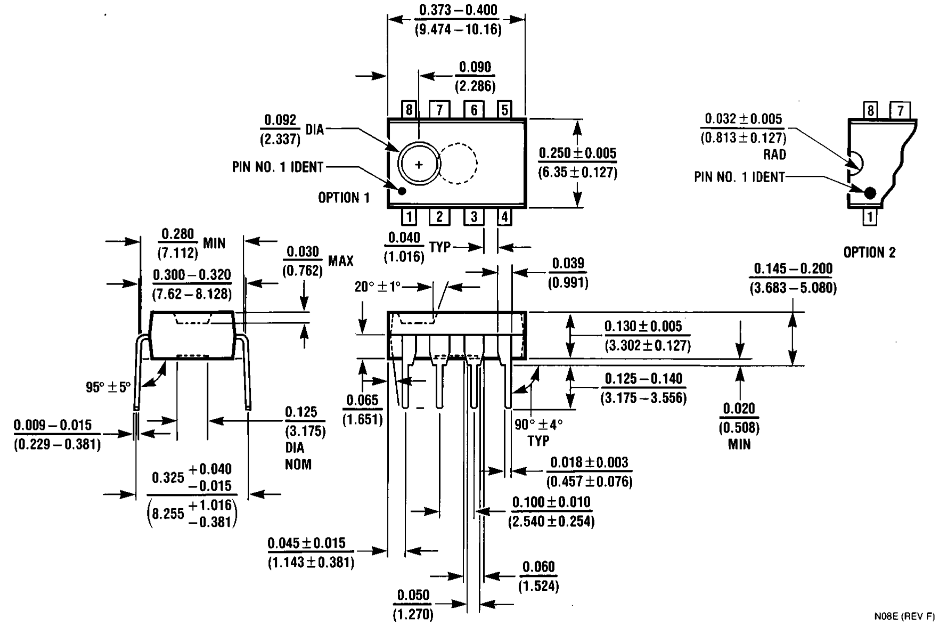


Ceramic Dual-In-Line Package (J)
Order Number LM555J or LM555CJ
NS Package Number J08A



Small Outline Package (M)
Order Number LM555CM
NS Package Number M08A

Physical Dimensions inches (millimeters) (Continued)



Molded Dual-In-Line Package (N)
Order Number LM555CN
NS Package Number N08E

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

National Semiconductor

June 1989

54LS74/DM54LS74A/DM74LS74A Dual Positive-Edge-Triggered D Flip-Flops with Preset, Clear and Complementary Outputs

General Description

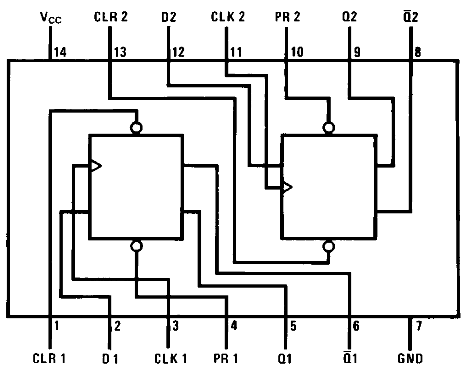
This device contains two independent positive-edge-triggered D flip-flops with complementary outputs. The information on the D input is accepted by the flip-flops on the positive going edge of the clock pulse. The triggering occurs at a voltage level and is not directly related to the transition time of the rising edge of the clock. The data on the D input may be changed while the clock is low or high without affecting the outputs as long as the data setup and hold times are not violated. A low logic level on the preset or clear inputs will set or reset the outputs regardless of the logic levels of the other inputs.

Features

- Alternate military/aerospace device (54LS74) is available. Contact a National Semiconductor Sales Office/Distributor for specifications.

Connection Diagram

Dual-In-Line Package



TL/F/6373–1

Order Number 54LS74DMQB, 54LS74FMQB, 54LS74LMQB, DM54LS74AJ, DM54LS74AW, DM74LS74AM or DM74LS74AN
See NS Package Number E20A, J14A, M14A, N14A or W14B

Function Table

Inputs				Outputs	
PR	CLR	CLK	D	Q	$\overline{Q}$
L	H	X	X	H	L
H	L	X	X	L	H
L	L	X	X	H*	H*
H	H	↑	H	H	L
H	H	↑	L	L	H
H	H	L	X	Q_0	$\overline{Q}_0$

H = High Logic Level

X = Either Low or High Logic Level

L = Low Logic Level

↑ = Positive-going Transition

* = This configuration is nonstable; that is, it will not persist when either the preset and/or clear inputs return to their inactive (high) level.

Q_0 = The output logic level of Q before the indicated input conditions were established.

 TL/F/6373

RRD-B30M105/Printed in U. S. A.

Absolute Maximum Ratings (Note)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	7V
Operating Free Air Temperature Range	
DM54LS and 54LS	−55°C to +125°C
DM74LS	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note: *The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the "Electrical Characteristics" table are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.*

Recommended Operating Conditions

Symbol	Parameter		DM54LS74A			DM74LS74A			Units
			Min	Nom	Max	Min	Nom	Max	
V_{CC}	Supply Voltage		4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High Level Input Voltage		2			2			V
V_{IL}	Low Level Input Voltage				0.7			0.8	V
I_{OH}	High Level Output Current				−0.4			−0.4	mA
I_{OL}	Low Level Output Current				4			8	mA
f_{CLK}	Clock Frequency (Note 2)		0		25	0		25	MHz
f_{CLK}	Clock Frequency (Note 3)		0		20	0		20	MHz
t_W	Pulse Width (Note 2)	Clock High	18			18			ns
		Preset Low	15			15			
		Clear Low	15			15			
t_W	Pulse Width (Note 3)	Clock High	25			25			ns
		Preset Low	20			20			
		Clear Low	20			20			
t_{SU}	Setup Time (Notes 1 and 2)		20↑			20↑			ns
t_{SU}	Setup Time (Notes 1 and 3)		25↑			25↑			ns
t_H	Hold Time (Note 1 and 4)		0↑			0↑			ns
T_A	Free Air Operating Temperature		−55		125	0		70	°C

Note 1: The symbol (↑) indicates the rising edge of the clock pulse is used for reference.

Note 2: C_L = 15 pF, R_L = 2 kΩ, T_A = 25°C, and V_{CC} = 5V.

Note 3: C_L = 50 pF, R_L = 2 kΩ, T_A = 25°C, and V_{CC} = 5V.

Note 4: T_A = 25°C and V_{CC} = 5V.

Electrical Characteristics over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions		Min	Typ (Note 1)	Max	Units
V_I	Input Clamp Voltage	$V_{CC} = $ Min, $I_I = -18$ mA				−1.5	V
V_{OH}	High Level Output Voltage	$V_{CC} = $ Min, $I_{OH} = $ Max $V_{IL} = $ Max, $V_{IH} = $ Min	DM54	2.5	3.4		V
			DM74	2.7	3.4		
V_{OL}	Low Level Output Voltage	$V_{CC} = $ Min, $I_{OL} = $ Max $V_{IL} = $ Max, $V_{IH} = $ Min	DM54		0.25	0.4	V
			DM74		0.35	0.5	
		$I_{OL} = 4$ mA, $V_{CC} = $ Min	DM74		0.25	0.4	
I_I	Input Current @Max Input Voltage	$V_{CC} = $ Max $V_I = 7V$	Data			0.1	mA
			Clock			0.1	
			Preset			0.2	
			Clear			0.2	
I_{IH}	High Level Input Current	$V_{CC} = $ Max $V_I = 2.7V$	Data			20	μA
			Clock			20	
			Clear			40	
			Preset			40	
I_{IL}	Low Level Input Current	$V_{CC} = $ Max $V_I = 0.4V$	Data			−0.4	mA
			Clock			−0.4	
			Preset			−0.8	
			Clear			−0.8	
I_{OS}	Short Circuit Output Current	$V_{CC} = $ Max (Note 2)	DM54	−20		−100	mA
			DM74	−20		−100	
I_{CC}	Supply Current	$V_{CC} = $ Max (Note 3)			4	8	mA

Note 1: All typicals are at $V_{CC} = 5V$, $T_A = 25°C$.

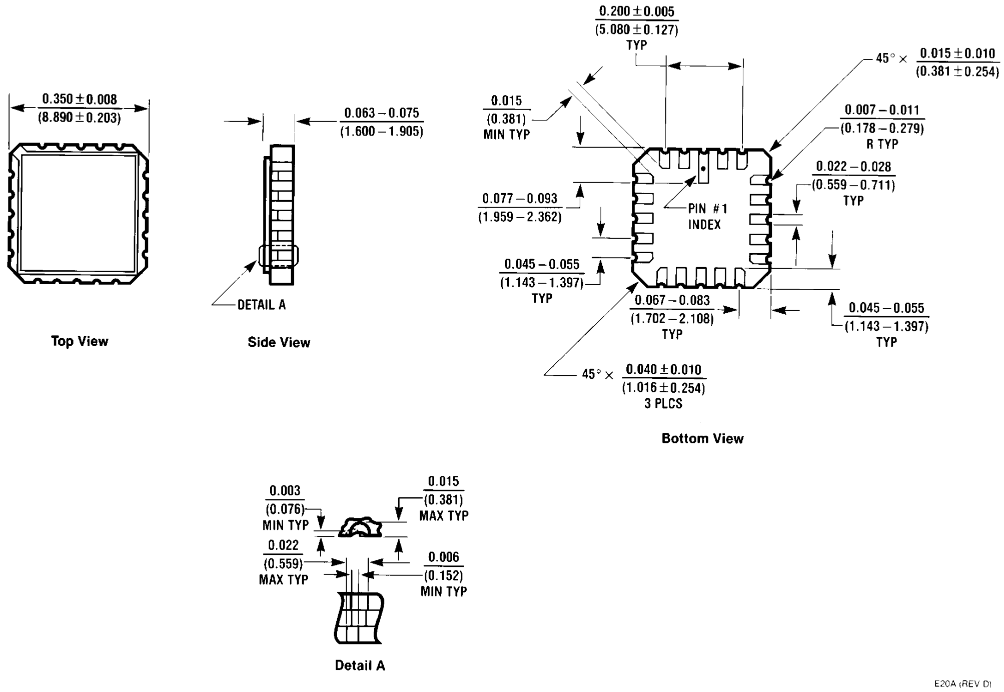
Note 2: Not more than one output should be shorted at a time, and the duration should not exceed one second. For devices, with feedback from the outputs, where shorting the outputs to ground may cause the outputs to change logic state an equivalent test may be performed where $V_O = 2.25V$ and 2.125V for DM54 and DM74 series, respectively, with the minimum and maximum limits reduced by one half from their stated values. This is very useful when using automatic test equipment.

Note 3: With all outputs open, I_{CC} is measured with CLOCK grounded after setting the Q and $\overline{Q}$ outputs high in turn.

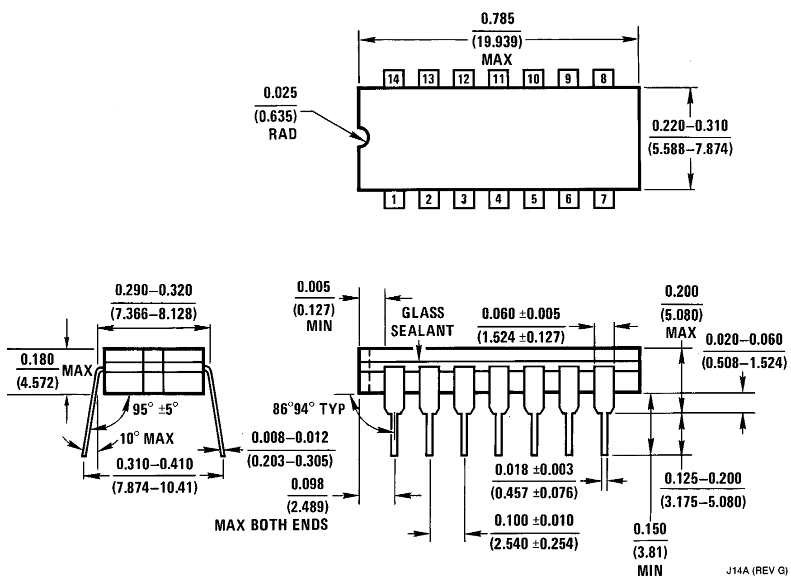
Switching Characteristics at $V_{CC} = 5V$ and $T_A = 25°C$ (See Section 1 for Test Waveforms and Output Load)

Symbol	Parameter	From (Input) To (Output)	$R_L = 2$ kΩ				Units
			$C_L = 15$ pF		$C_L = 50$ pF		
			Min	Max	Min	Max	
f_{MAX}	Maximum Clock Frequency		25		20		MHz
t_{PLH}	Propagation Delay Time Low to High Level Output	Clock to Q or $\overline{Q}$		25		35	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	Clock to Q or $\overline{Q}$		30		35	ns
t_{PLH}	Propagation Delay Time Low to High Level Output	Preset to Q		25		35	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	Preset to $\overline{Q}$		30		35	ns
t_{PLH}	Propagation Delay Time Low to High Level Output	Clear to $\overline{Q}$		25		35	ns
t_{PHL}	Propagation Delay Time High to Low Level Output	Clear to Q		30		35	ns

Physical Dimensions inches (millimeters)

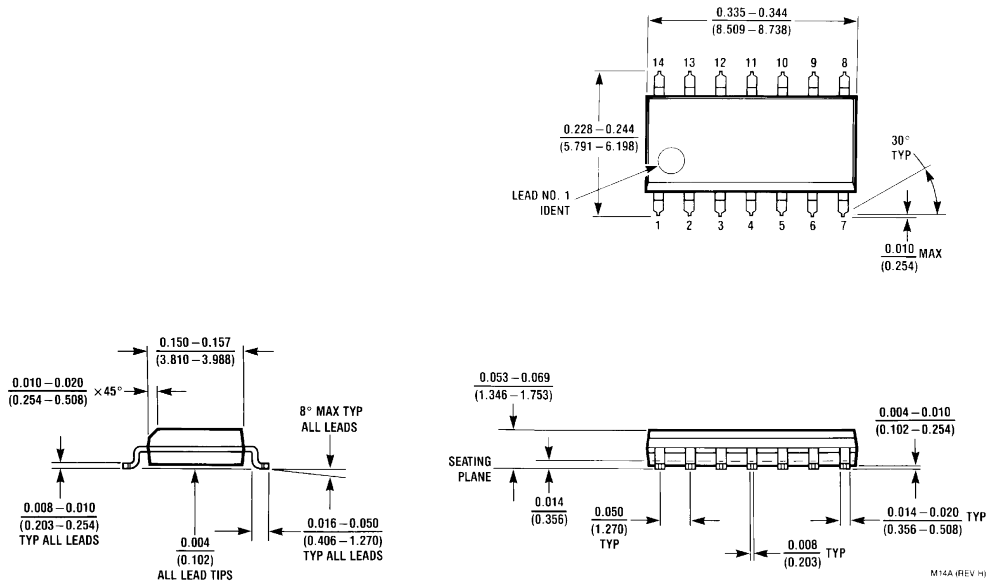


Ceramic Leadless Chip Carrier Package (E)
Order Number 54LS74LMQB
NS Package Number E20A

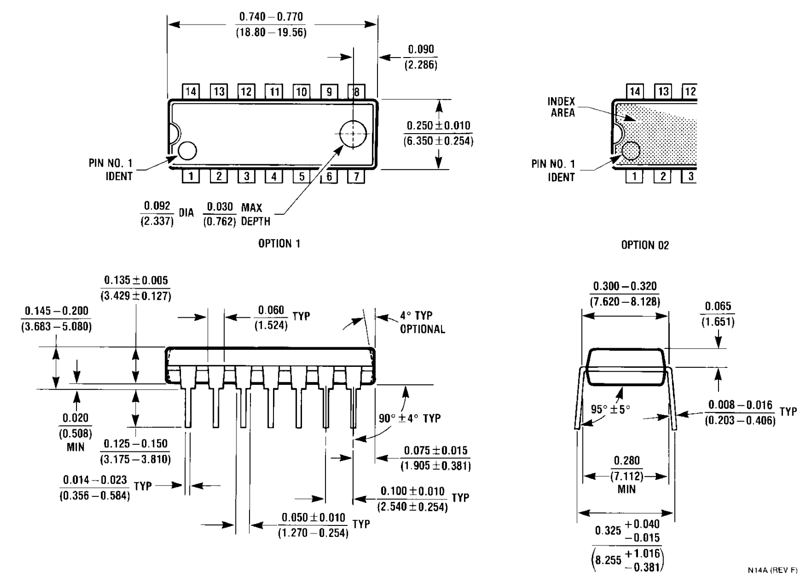


14-Lead Ceramic Dual-In-Line Package (J)
Order Number 54LS74DMQB or DM54LS74AJ
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

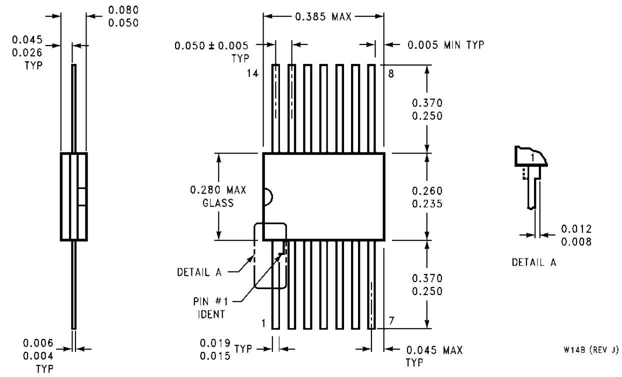


14-Lead Small Outline Molded Package (M)
Order Number DM74LS74AM
NS Package Number M14A



14-Lead Molded Dual-In-Line Package (N)
Order Number DM74LS74AN
NS Package Number N14A

Physical Dimensions inches (millimeters) (Continued)



14-Lead Ceramic Flat Package (W)
Order Number 54LS74FMQB or DM54LS74AW
NS Package Number W14B

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

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Tel: 81-043-299-2309
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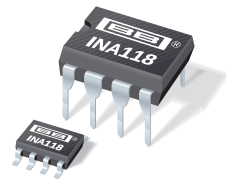


INA118

Precision, Low Power INSTRUMENTATION AMPLIFIER

FEATURES

- LOW OFFSET VOLTAGE: 50μV max
- LOW DRIFT: 0.5μV/°C max
- LOW INPUT BIAS CURRENT: 5nA max
- HIGH CMR: 110dB min
- INPUTS PROTECTED TO ±40V
- WIDE SUPPLY RANGE: ±1.35 to ±18V
- LOW QUIESCENT CURRENT: 350μA
- 8-PIN PLASTIC DIP, SO-8

APPLICATIONS

- BRIDGE AMPLIFIER
- THERMOCOUPLE AMPLIFIER
- RTD SENSOR AMPLIFIER
- MEDICAL INSTRUMENTATION
- DATA ACQUISITION

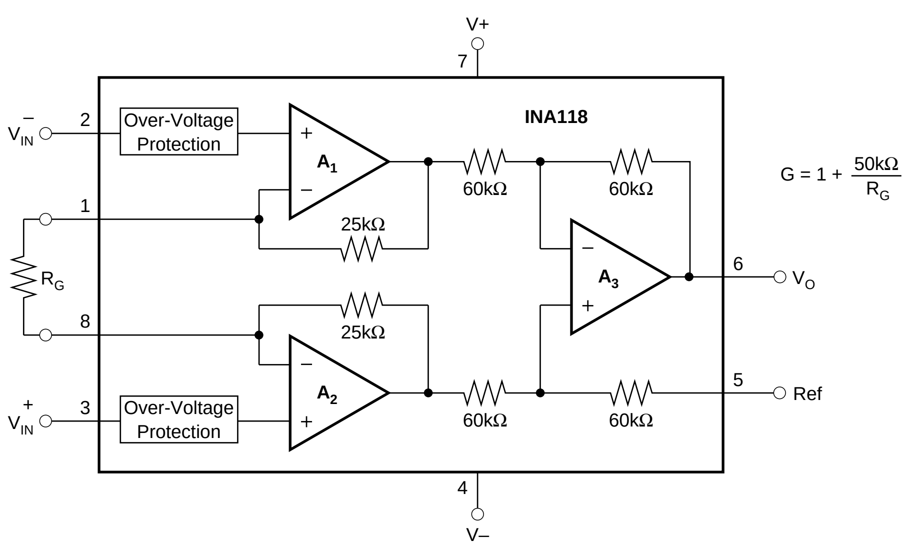
DESCRIPTION

The INA118 is a low power, general purpose instrumentation amplifier offering excellent accuracy. Its versatile 3-op amp design and small size make it ideal for a wide range of applications. Current-feedback input circuitry provides wide bandwidth even at high gain (70kHz at G = 100).

A single external resistor sets any gain from 1 to 10,000. Internal input protection can withstand up to ±40V without damage.

The INA118 is laser trimmed for very low offset voltage (50μV), drift (0.5μV/°C) and high common-mode rejection (110dB at G = 1000). It operates with power supplies as low as ±1.35V, and quiescent current is only 350μA—ideal for battery operated systems.

The INA118 is available in 8-pin plastic DIP, and SO-8 surface-mount packages, specified for the –40°C to +85°C temperature range.



International Airport Industrial Park • Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111 • Twx: 910-952-1111
Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

PDS-1199D Printed in U.S.A. April, 1998

SPECIFICATIONS

ELECTRICAL

At T_A = +25°C, V_S = ±15V, R_L = 10kΩ unless otherwise noted.

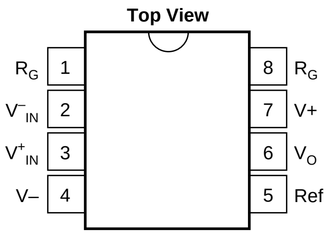
		INA118PB, UB			INA118P, U			
PARAMETER	**CONDITIONS**	**MIN**	**TYP**	**MAX**	**MIN**	**TYP**	**MAX**	**UNITS**
INPUT								
Offset Voltage, RTI								
Initial	T_A = +25°C		±10 ± 50/G	±50 ± 500/G		±25 ±100/G	±125±1000/G	µV
vs Temperature	$T_A = T_{MIN}$ to T_{MAX}		±0.2 ± 2/G	±0.5 ± 20/G		±0.2 ± 5/G	±1 ± 20/G	µV/°C
vs Power Supply	V_S = ±1.35V to ±18V		±1 ±10/G	±5 ± 100/G		*	±10 ±100/G	µV/V
Long-Term Stability			±0.4 ±5/G			*		µV/mo
Impedance, Differential			$10^{10} \parallel 1$			*		Ω ∥ pF
Common-Mode			$10^{10} \parallel 4$			*		Ω ∥ pF
Linear Input Voltage Range		(V+) – 1	(V+) – 0.65		*	*		V
		(V–) + 1.1	(V–) + 0.95		*	*		V
Safe Input Voltage				±40			*	V
Common-Mode Rejection	V_{CM} = ±10V, ΔR_S = 1kΩ							
	G = 1	80	90		73	*		dB
	G = 10	97	110		89	*		dB
	G = 100	107	120		98	*		dB
	G = 1000	110	125		100	*		dB
BIAS CURRENT			±1	±5		*	±10	nA
vs Temperature			±40			*		pA/°C
OFFSET CURRENT			±1	±5		*	±10	nA
vs Temperature			±40			*		pA/°C
NOISE VOLTAGE, RTI	G = 1000, R_S = 0Ω							
f = 10Hz			11			*		nV/√Hz
f = 100Hz			10			*		nV/√Hz
f = 1kHz			10			*		nV/√Hz
f_B = 0.1Hz to 10Hz			0.28			*		µVp-p
Noise Current								
f=10Hz			2.0			*		pA/√Hz
f=1kHz			0.3			*		pA/√Hz
f_B = 0.1Hz to 10Hz			80			*		pAp-p
GAIN								
Gain Equation			1 + (50kΩ/R_G)			*		V/V
Range of Gain		1		10000	*		*	V/V
Gain Error	G = 1		±0.01	±0.024		*	±0.1	%
	G = 10		±0.02	±0.4		*	±0.5	%
	G = 100		±0.05	±0.5		*	±0.7	%
	G = 1000		±0.5	±1		*	±2	%
Gain vs Temperature	G = 1		±1	±10		*	±10	ppm/°C
50kΩ Resistance(1)			±25	±100		*	*	ppm/°C
Nonlinearity	G = 1		±0.0003	±0.001		*	±0.002	% of FSR
	G = 10		±0.0005	±0.002		*	±0.004	% of FSR
	G = 100		±0.0005	±0.002		*	±0.004	% of FSR
	G = 1000		±0.002	±0.01		*	±0.02	% of FSR
OUTPUT								
Voltage: Positive	R_L = 10kΩ	(V+) – 1	(V+) – 0.8		*	*		V
Negative	R_L = 10kΩ	(V–) + 0.35	(V–) + 0.2		*	*		V
Single Supply High	V_S = +2.7V/0V(2), R_L = 10kΩ	1.8	2.0		*	*		V
Single Supply Low	V_S = +2.7V/0V(2), R_L = 10kΩ	60	35		*	*		mV
Load Capacitance Stability			1000			*		pF
Short Circuit Current			+5/–12			*		mA
FREQUENCY RESPONSE								
Bandwidth, –3dB	G = 1		800			*		kHz
	G = 10		500			*		kHz
	G = 100		70			*		kHz
	G = 1000		7			*		kHz
Slew Rate	V_O = ±10V, G = 10		0.9			*		V/µs
Settling Time, 0.01%	G = 1		15			*		µs
	G = 10		15			*		µs
	G = 100		21			*		µs
	G = 1000		210			*		µs
Overload Recovery	50% Overdrive		20			*		µs
POWER SUPPLY								
Voltage Range		±1.35	±15	±18	*	*	*	V
Current	V_{IN} = 0V		±350	±385		*	*	µA
TEMPERATURE RANGE								
Specification		–40		85	*		*	°C
Operating		–40		125	*		*	°C
θ_{JA}			80			*		°C/W

* Specification same as INA118PB, UB.

NOTE: (1) Temperature coefficient of the "50kΩ" term in the gain equation. (2) Common-mode input voltage range is limited. See text for discussion of low power supply and single power supply operation.

PIN CONFIGURATION

8-Pin DIP and SO-8



ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±18V
Analog Input Voltage Range	±40V
Output Short-Circuit (to ground)	Continuous
Operating Temperature	–40°C to +125°C
Storage Temperature	–40°C to +125°C
Junction Temperature	+150°C
Lead Temperature (soldering, 10s)	+300°C

ORDERING INFORMATION

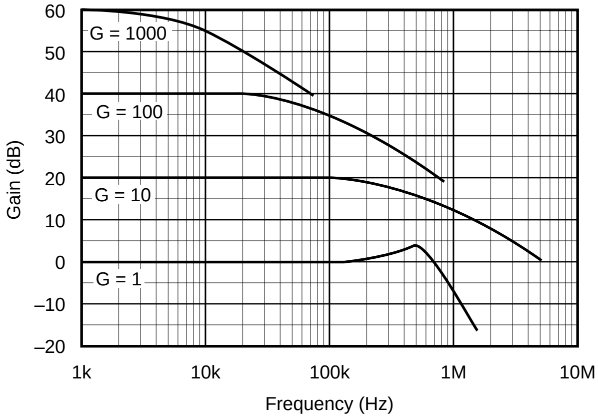
PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER(1)	TEMPERATURE RANGE
INA118P	8-Pin Plastic DIP	006	–40°C to +85°C
INA118PB	8-Pin Plastic DIP	006	–40°C to +85°C
INA118U	SO-8 Surface-Mount	182	–40°C to +85°C
INA118UB	SO-8 Surface-Mount	182	–40°C to +85°C

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

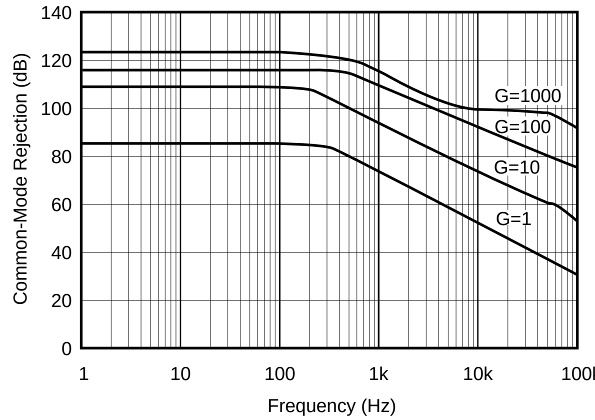
TYPICAL PERFORMANCE CURVES

At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.

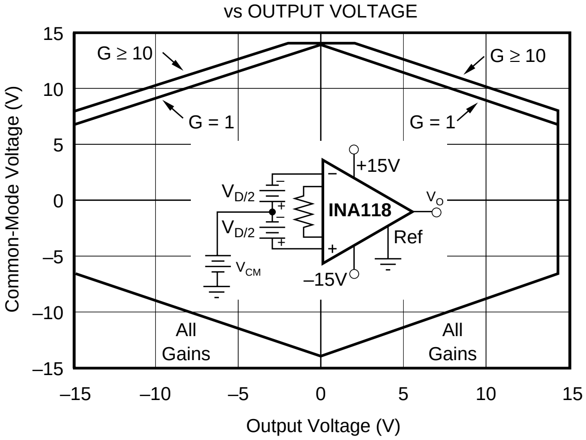
GAIN vs FREQUENCY



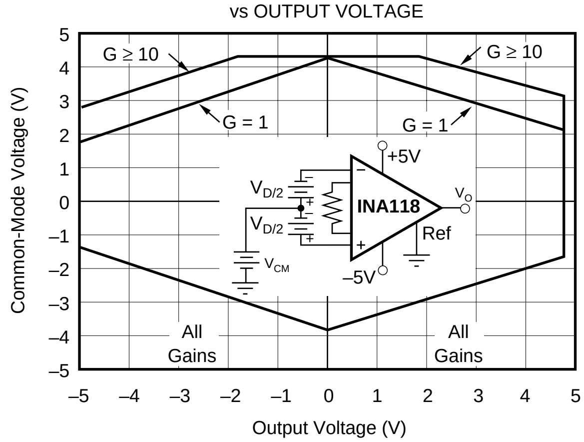
COMMON-MODE REJECTION vs FREQUENCY



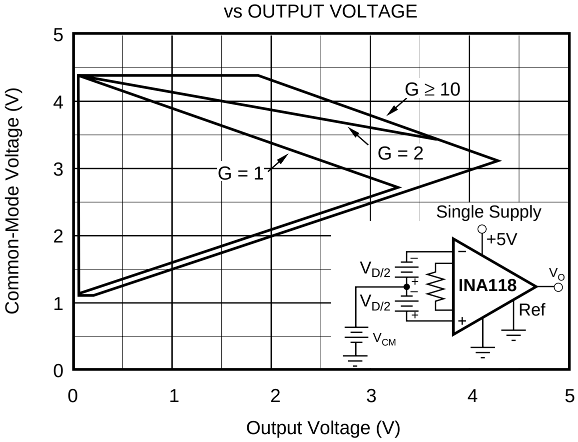
INPUT COMMON-MODE RANGE vs OUTPUT VOLTAGE



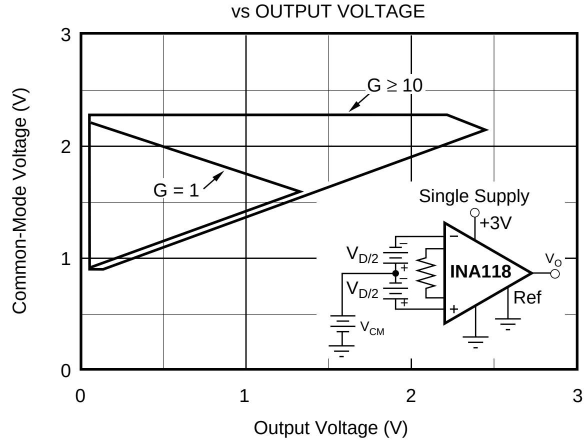
INPUT COMMON-MODE RANGE vs OUTPUT VOLTAGE



INPUT COMMON-MODE RANGE vs OUTPUT VOLTAGE



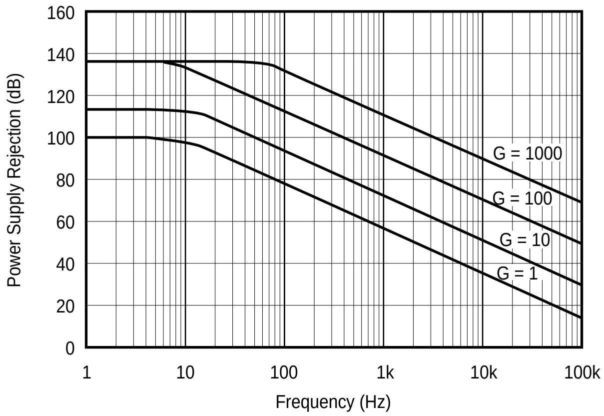
INPUT COMMON-MODE RANGE vs OUTPUT VOLTAGE



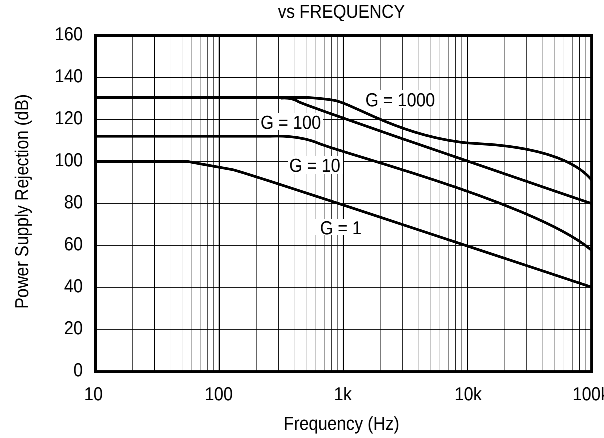
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.

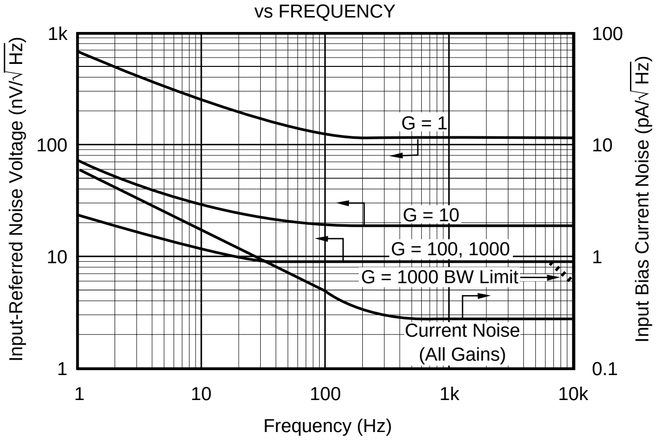
POSITIVE POWER SUPPLY REJECTION
vs FREQUENCY



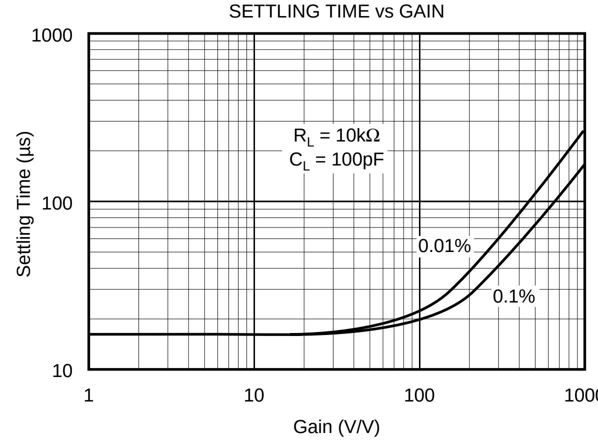
NEGATIVE POWER SUPPLY REJECTION
vs FREQUENCY



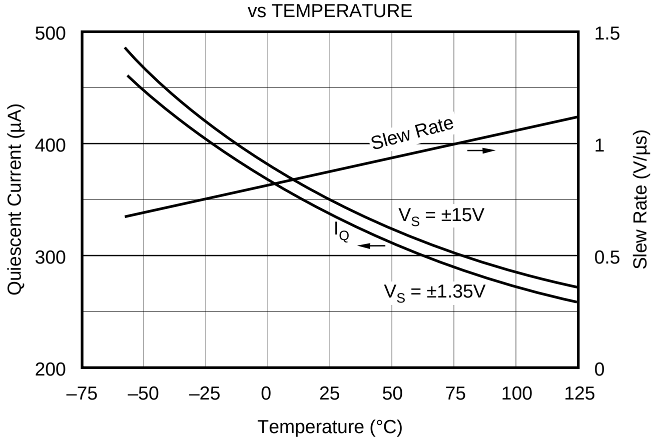
INPUT- REFERRED NOISE VOLTAGE
vs FREQUENCY



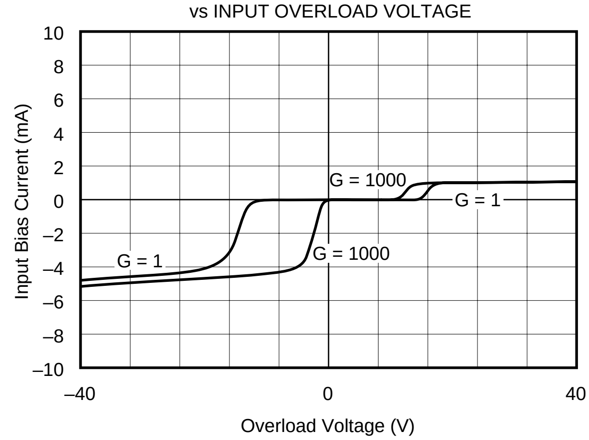
SETTLING TIME vs GAIN



QUIESCENT CURRENT and SLEW RATE
vs TEMPERATURE



INPUT BIAS CURRENT
vs INPUT OVERLOAD VOLTAGE



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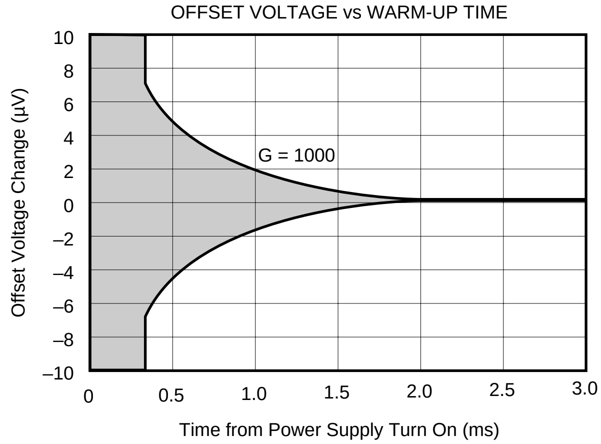
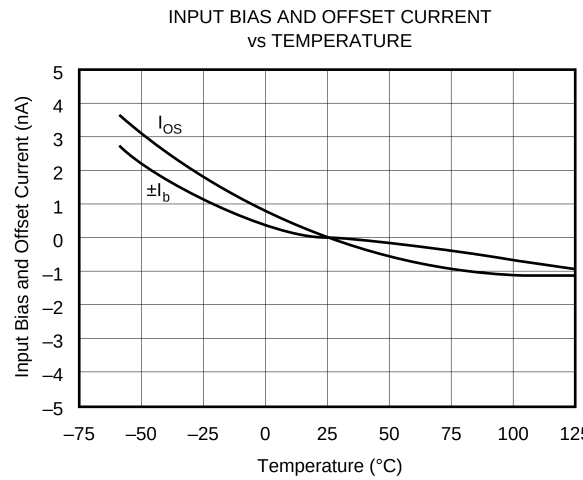
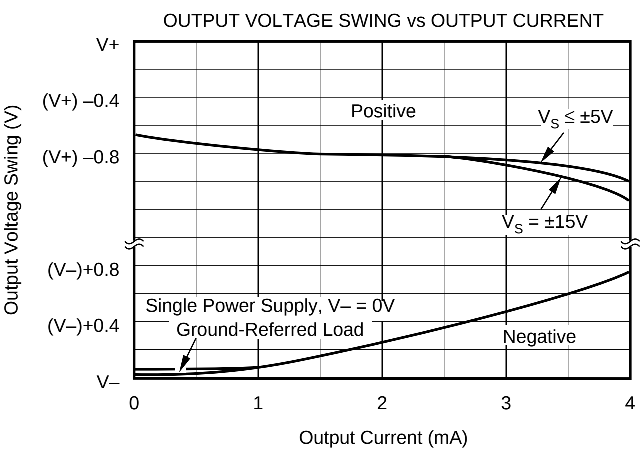
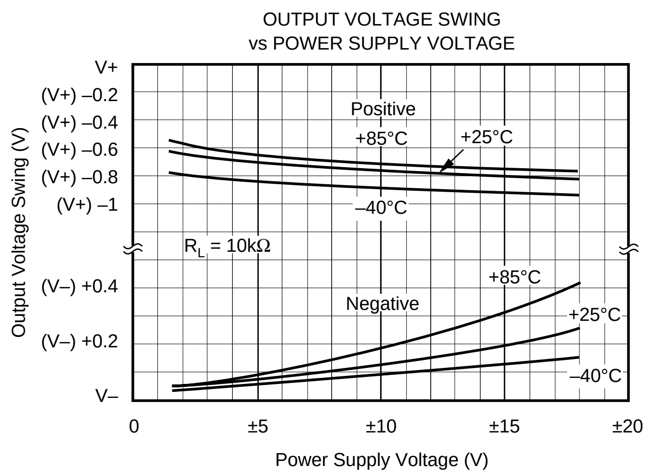
TYPICAL PERFORMANCE CURVES (CONT)

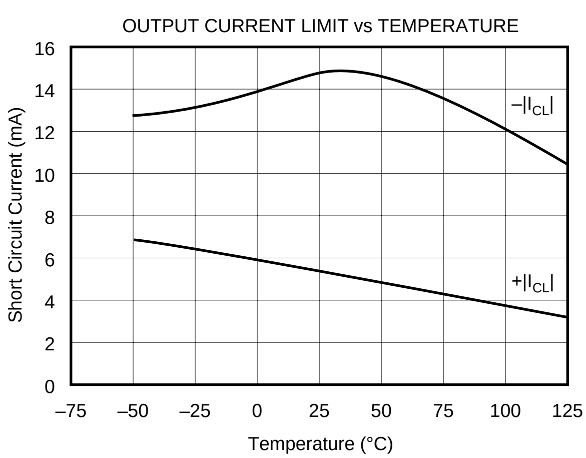
At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.

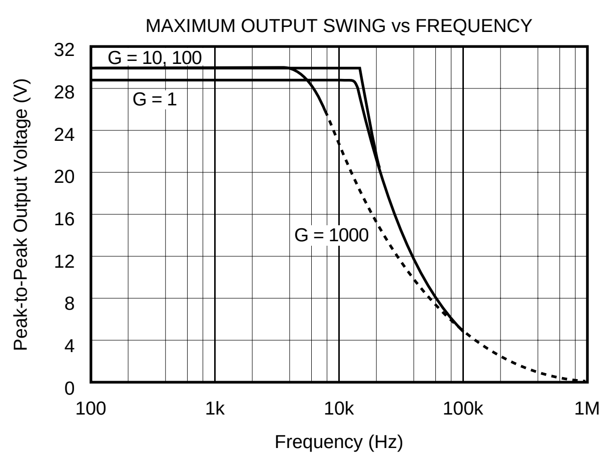








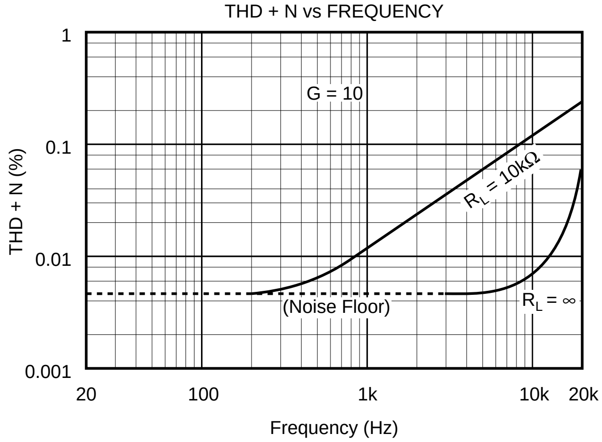




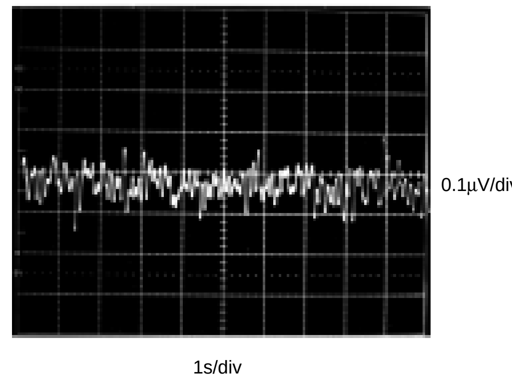
TYPICAL PERFORMANCE CURVES (CONT)

At T_A = +25°C, V_S = ±15V, unless otherwise noted.

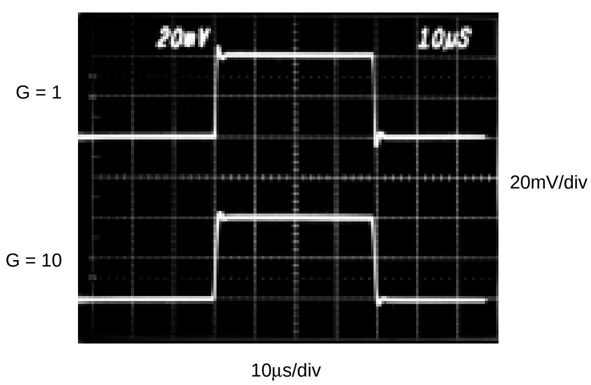
THD + N vs FREQUENCY



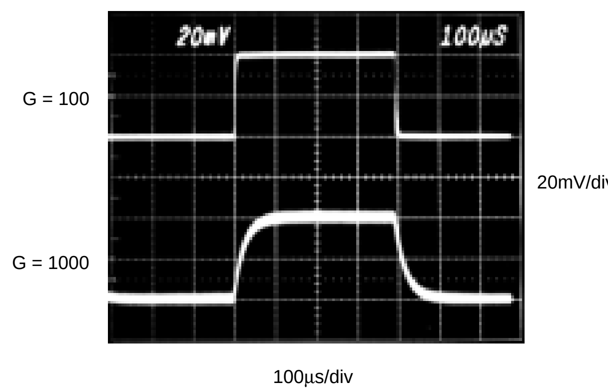
INPUT-REFERRED NOISE, 0.1Hz to 10Hz



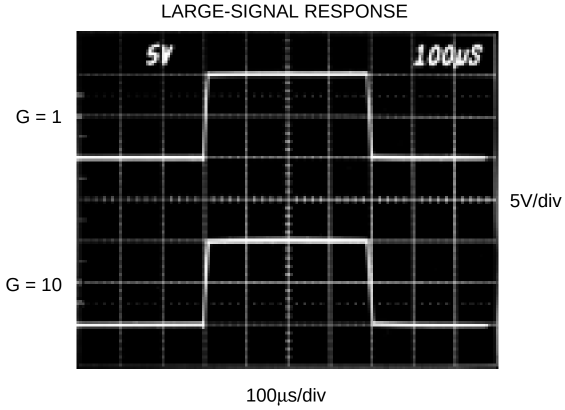
SMALL-SIGNAL RESPONSE



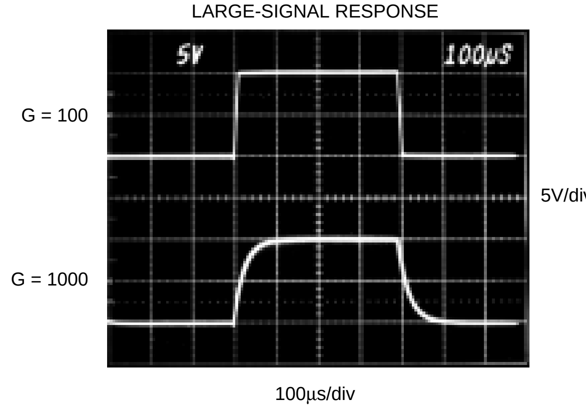
SMALL-SIGNAL RESPONSE



LARGE-SIGNAL RESPONSE



LARGE-SIGNAL RESPONSE



APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA118. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins as shown.

The output is referred to the output reference (Ref) terminal which is normally grounded. This must be a low-impedance connection to assure good common-mode rejection. A resistance of 12Ω in series with the Ref pin will cause a typical device to degrade to approximately 80dB CMR (G = 1).

SETTING THE GAIN

Gain of the INA118 is set by connecting a single external resistor, R_G, connected between pins 1 and 8:

$$G = 1 + \frac{50\,k\Omega}{R_G} \qquad (1)$$

Commonly used gains and resistor values are shown in Figure 1.

The 50kΩ term in Equation 1 comes from the sum of the two internal feedback resistors of A_1 and A_2. These on-chip metal film resistors are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these resistors are included in the gain accuracy and drift specifications of the INA118.

The stability and temperature drift of the external gain setting resistor, R_G, also affects gain. R_G's contribution to gain accuracy and drift can be directly inferred from the gain equation (1). Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance which will contribute additional gain error (possibly an unstable gain error) in gains of approximately 100 or greater.

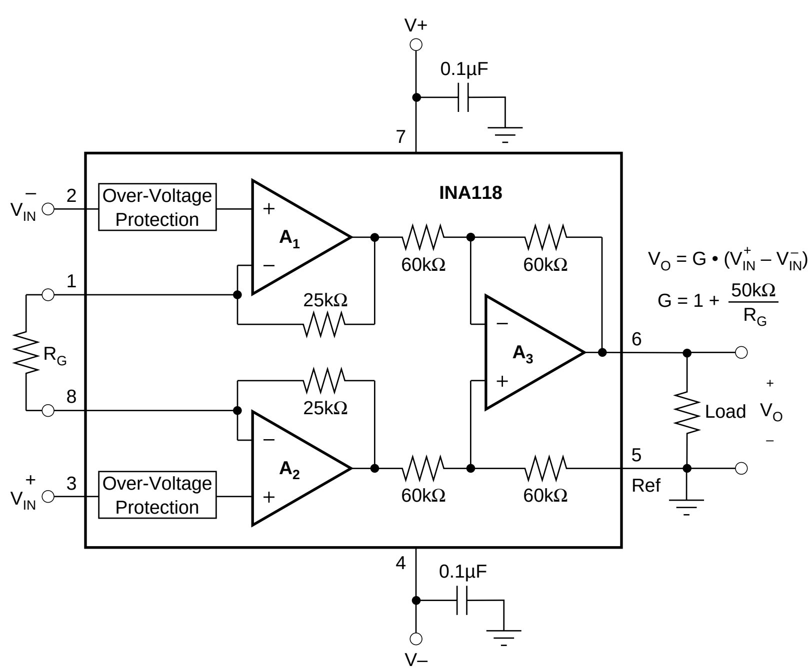
DYNAMIC PERFORMANCE

The typical performance curve "Gain vs Frequency" shows that, despite its low quiescent current, the INA118 achieves wide bandwidth, even at high gain. This is due to the current-feedback topology of the INA118. Settling time also remains excellent at high gain.

The INA118 exhibits approximately 3dB peaking at 500kHz in unity gain. This is a result of its current-feedback topology and is not an indication of instability. Unlike an op amp with poor phase margin, the rise in response is a predictable +6dB/octave due to a response zero. A simple pole at 300kHz or lower will produce a flat passband unity gain response.

DESIRED GAIN	R_G (Ω)	NEAREST 1% R_G (Ω)
1	NC	NC
2	50.00k	49.9k
5	12.50k	12.4k
10	5.556k	5.62k
20	2.632k	2.61k
50	1.02k	1.02k
100	505.1	511
200	251.3	249
500	100.2	100
1000	50.05	49.9
2000	25.01	24.9
5000	10.00	10
10000	5.001	4.99

NC: No Connection.



Also drawn in simplified form:

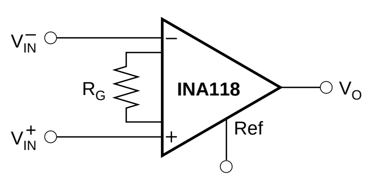


FIGURE 1. Basic Connections.

NOISE PERFORMANCE

The INA118 provides very low noise in most applications. For differential source impedances less than 1kΩ, the INA103 may provide lower noise. For source impedances greater than 50kΩ, the INA111 FET-Input Instrumentation Amplifier may provide lower noise.

Low frequency noise of the INA118 is approximately 0.28µVp-p measured from 0.1 to 10Hz (G≥100). This provides dramatically improved noise when compared to state-of-the-art chopper-stabilized amplifiers.

OFFSET TRIMMING

The INA118 is laser trimmed for low offset voltage and drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to Ref terminal is summed at the output. The op amp buffer provides low impedance at the Ref terminal to preserve good common-mode rejection.

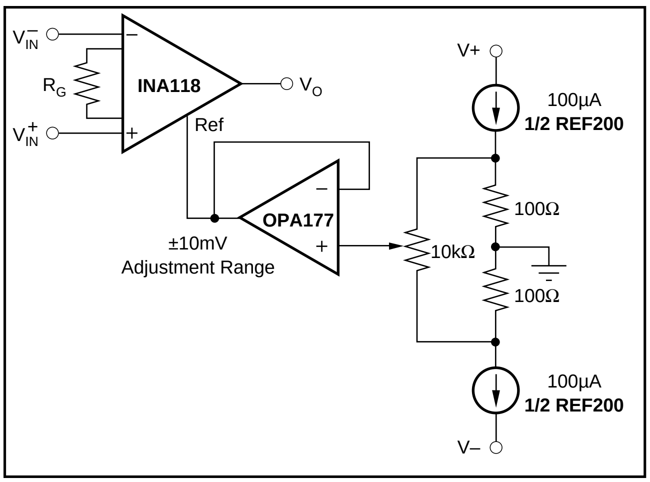


FIGURE 2. Optional Trimming of Output Offset Voltage.

INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA118 is extremely high—approximately $10^{10}Ω$. However, a path must be provided for the input bias current of both inputs. This input bias current is approximately ±5nA. High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. Figure 3 shows various provisions for an input bias current path. Without a bias current path, the inputs will float to a potential which exceeds the common-mode range of the INA118 and the input amplifiers will saturate.

If the differential source resistance is low, the bias current return path can be connected to one input (see the thermocouple example in Figure 3). With higher source impedance, using two equal resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better high-frequency common-mode rejection.

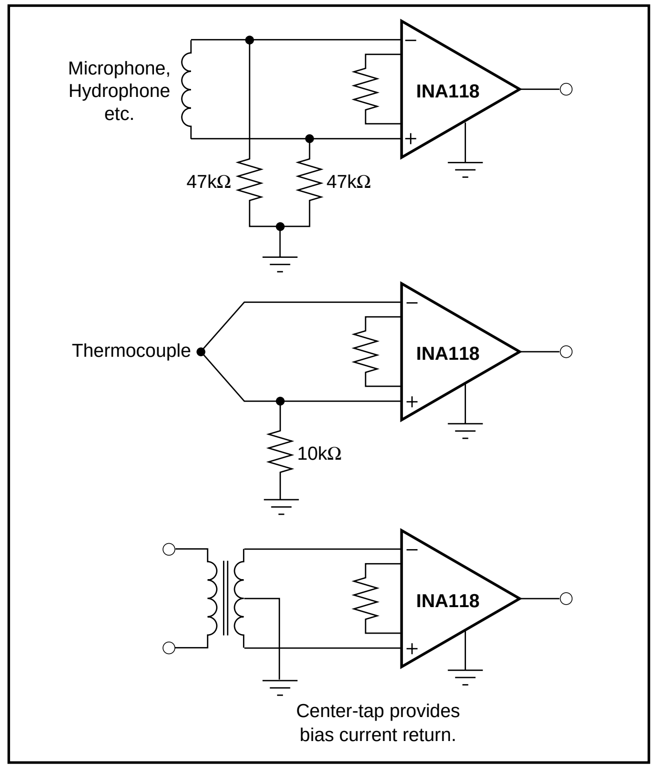


FIGURE 3. Providing an Input Common-Mode Current Path.

INPUT COMMON-MODE RANGE

The linear input voltage range of the input circuitry of the INA118 is from approximately 0.6V below the positive supply voltage to 1V above the negative supply. As a differential input voltage causes the output voltage to increase, however, the linear input range will be limited by the output voltage swing of amplifiers A_1 and A_2. Thus, the linear common-mode input range is related to the output voltage of the complete amplifier. This behavior also depends on supply voltage—see performance curves "Input Common-Mode Range vs Output Voltage".

Input-overload can produce an output voltage that appears normal. For example, if an input overload condition drives both input amplifiers to their positive output swing limit, the difference voltage measured by the output amplifier will be near zero. The output of the INA118 will be near 0V even though both inputs are overloaded.

LOW VOLTAGE OPERATION

The INA118 can be operated on power supplies as low as ±1.35V. Performance of the INA118 remains excellent with power supplies ranging from ±1.35V to ±18V. Most parameters vary only slightly throughout this supply voltage range—see typical performance curves. Operation at very low supply voltage requires careful attention to assure that the input voltages remain within their linear range. Voltage swing requirements of internal nodes limit the input common-mode range with low power supply voltage. Typical performance curves, "Input Common-Mode Range vs Output Voltage" show the range of linear operation for a various supply voltages and gains.

SINGLE SUPPLY OPERATION

The INA118 can be used on single power supplies of +2.7V to +36V. Figure 5 shows a basic single supply circuit. The output Ref terminal is connected to ground. Zero differential input voltage will demand an output voltage of 0V (ground). Actual output voltage swing is limited to approximately 35mV above ground, when the load is referred to ground as shown. The typical performance curve "Output Voltage vs Output Current" shows how the output voltage swing varies with output current.

With single supply operation, V_{IN}^{+} and V_{IN}^{-} must both be 0.98V above ground for linear operation. You cannot, for instance, connect the inverting input to ground and measure a voltage connected to the non-inverting input.

To illustrate the issues affecting low voltage operation, consider the circuit in Figure 5. It shows the INA118, operating from a single 3V supply. A resistor in series with the low side of the bridge assures that the bridge output voltage is within the common-mode range of the amplifier's inputs. Refer to the typical performance curve "Input Common-Mode Range vs Output Voltage" for 3V single supply operation.

INPUT PROTECTION

The inputs of the INA118 are individually protected for voltages up to ±40V. For example, a condition of –40V on one input and +40V on the other input will not cause damage. Internal circuitry on each input provides low series impedance under normal signal conditions. To provide equivalent protection, series input resistors would contribute excessive noise. If the input is overloaded, the protection circuitry limits the input current to a safe value of approximately 1.5 to 5mA. The typical performance curve "Input Bias Current vs Input Overload Voltage" shows this input current limit behavior. The inputs are protected even if the power supplies are disconnected or turned off.

INSIDE THE INA118

Figure 1 shows a simplified representation of the INA118. The more detailed diagram shown here provides additional insight into its operation.

Each input is protected by two FET transistors that provide a low series resistance under normal signal conditions, preserving excellent noise performance. When excessive voltage is applied, these transistors limit input current to approximately 1.5 to 5mA.

The differential input voltage is buffered by Q_1 and Q_2 and impressed across R_G, causing a signal current to flow through R_G, R_1 and R_2. The output difference amp, A_3, removes the common-mode component of the input signal and refers the output signal to the Ref terminal.

Equations in the figure describe the output voltages of A_1 and A_2. The V_{BE} and IR drop across R_1 and R_2 produce output voltages on A_1 and A_2 that are approximately 1V lower than the input voltages.

A_1 Out = $V_{CM} - V_{BE} - (10\mu A \bullet 25k\Omega) - V_O/2$
A_2 Out = $V_{CM} - V_{BE} - (10\mu A \bullet 25k\Omega) + V_O/2$
Output Swing Range A_1, A_2; (V+) – 0.65V to (V–) + 0.06V
Amplifier Linear Input Range: (V+) – 0.65V to (V–) + 0.98V

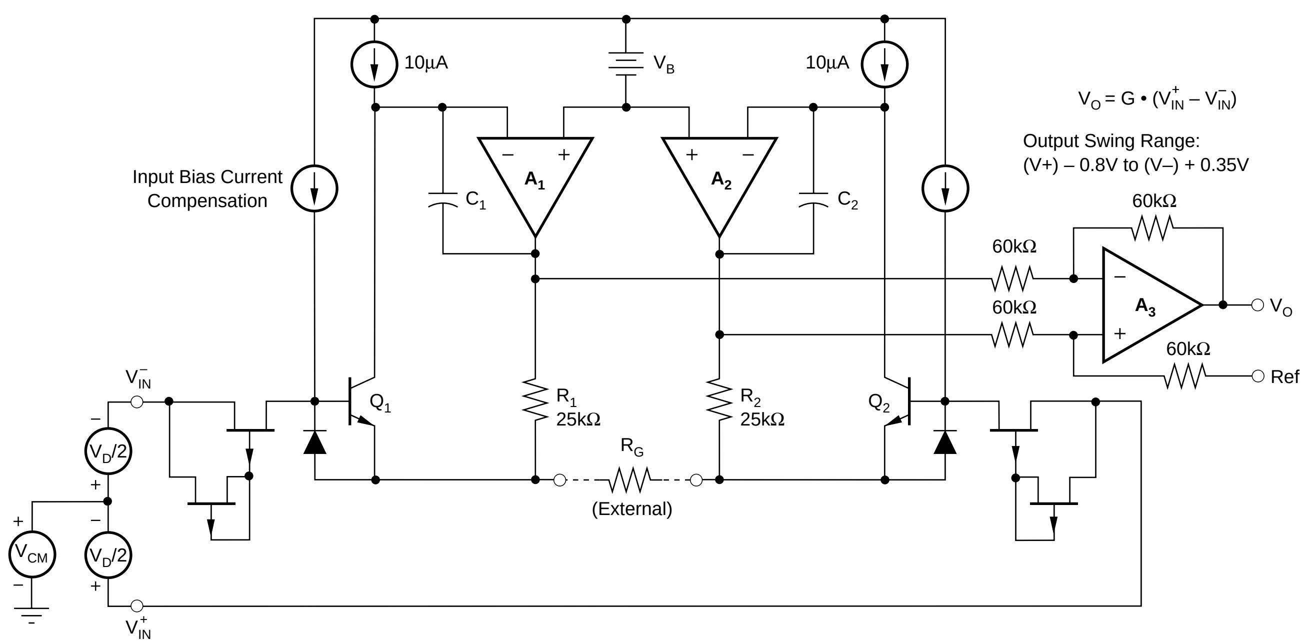


FIGURE 4. INA118 Simplified Circuit Diagram.

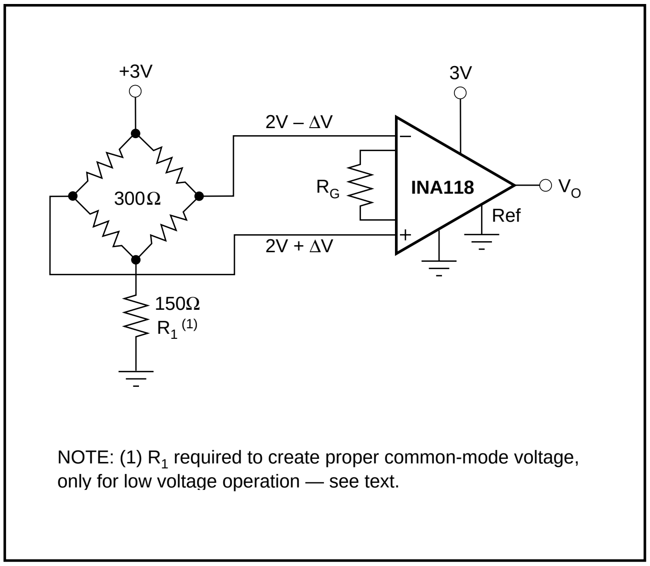


FIGURE 5. Single-Supply Bridge Amplifier.

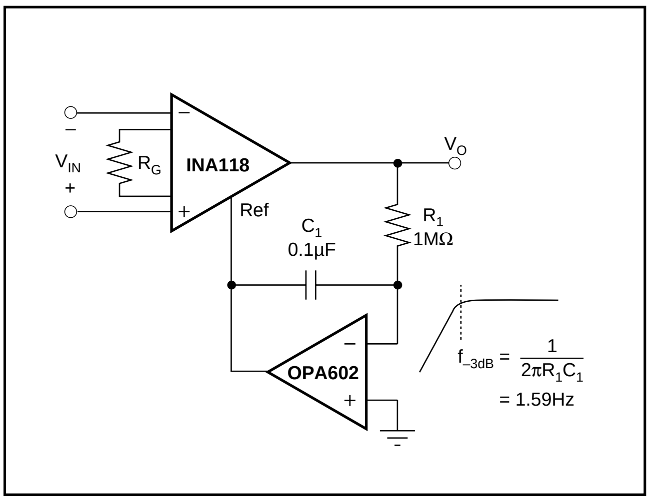
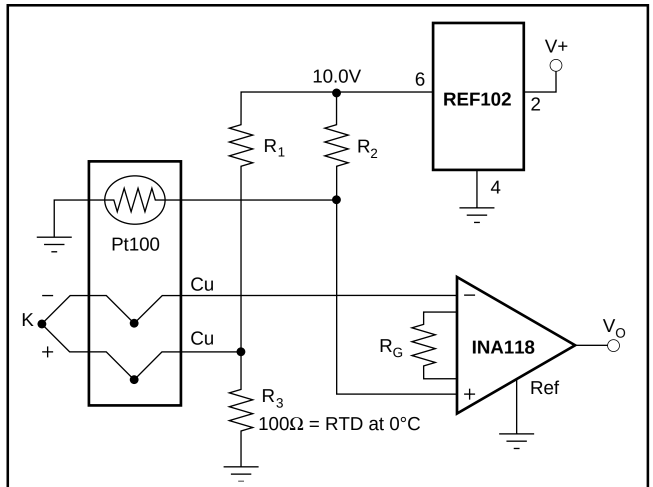
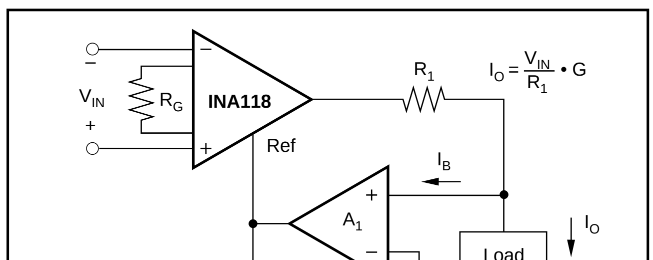


FIGURE 6. AC-Coupled Instrumentation Amplifier.



ISA TYPE	MATERIAL	SEEBECK COEFFICIENT (µV/°C)	R_1, R_2
E	+ Chromel – Constantan	58.5	66.5kΩ
J	+ Iron – Constantan	50.2	76.8kΩ
K	+ Chromel – Alumel	39.4	97.6kΩ
T	+ Copper – Constantan	38.0	102kΩ

FIGURE 7. Thermocouple Amplifier With Cold Junction Compensation.



A_1	I_B Error
OPA177	±1.5nA
OPA602	±1pA
OPA128	±75fA

FIGURE 8. Differential Voltage to Current Converter.

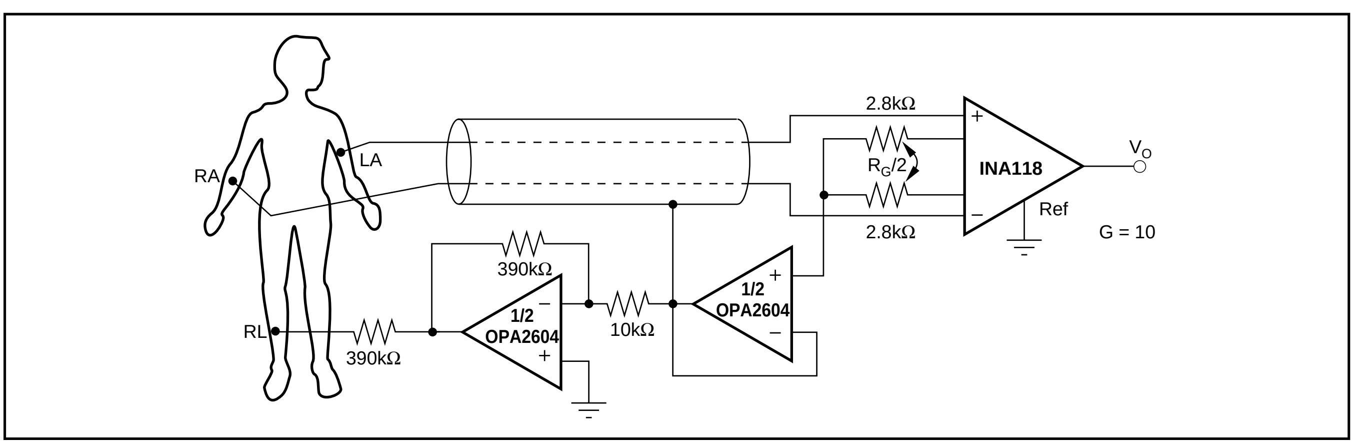


FIGURE 9. ECG Amplifier With Right-Leg Drive.

Appendix O - Index

Document/File	Description
Presentation	A PowerPoint presentation designed to lead the reader/viewer into some of the more critical screens that will seen on the GUI. Screen captures of the Remote GUI (RGUI) as well as the Acebus - 8051 Microconrtoller Family Development Environment - are also included in this presentation. Each slide/screen capture is accompanied by a brief explanation and notes.
System Evaluation	A spreadsheet containing injection, and system acquired data, using the Calibration Screen. This data is used to evaluate the accuracy of the data acquisition hardware as well as the GUI data evaluation and calculation algorithms. Graphs are plotted graphically display the test results.
Repeatability Test As Recorded	A spreadsheet containing the raw system acquired and evaluated date for the repeatability test.
Repeatability Test with Highlights	A spreadsheet containing the same data as displayed in the file mentioned above “Repeatability Test As Recorded”, with the highest and lowest recorded being highlighted. Also displayed is the Forty Point Average and the Difference Between The Averaged Maximum And Minimum Acquired Values. Graphs are plotted graphically display the test results.
Test Results 1 2006-4-12 13H11M2	Test results captured and stored for a simulated 10 pair bar test. This spreadsheet displays a typical test recording with all possible faults taking into account.
Test Results 2006-4-12 13H53M53	Another set of test results captured and stored for a simulated 10 pair bar test. This spreadsheet displays a typical test recording with all possible faults taking into account. Note that in this spreadsheet there are only 9 recordings of 100 successive readings. This is because an Emergency Stop was invoked on the last pair of bars.
All Component Datasheets	Datasheets

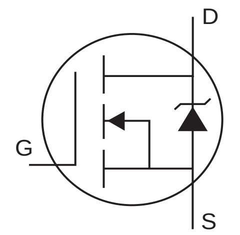
International
IOR Rectifier

PD - 91541B

IRLR/U120N

HEXFET® Power MOSFET

- Surface Mount (IRLR120N)
- Straight Lead (IRLU120N)
- Advanced Process Technology
- Fast Switching
- Fully Avalanche Rated



V_{DSS} = 100V

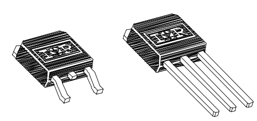
$R_{DS(on)}$ = 0.185Ω

I_D = 10A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve the lowest possible on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient device for use in a wide variety of applications.

The D-PAK is designed for surface mounting using vapor phase, infrared, or wave soldering techniques. The straight lead version (IRFU series) is for through-hole mounting applications. Power dissipation levels up to 1.5 watts are possible in typical surface mount applications.



D-PAK TO-252AA

I-PAK TO-251AA

Absolute Maximum Ratings

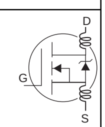
	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	10	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	7.0	
I_{DM}	Pulsed Drain Current ①⑥	35	
P_D @T_C = 25°C	Power Dissipation	48	W
	Linear Derating Factor	0.32	W/°C
V_{GS}	Gate-to-Source Voltage	± 16	V
E_{AS}	Single Pulse Avalanche Energy②⑥	85	mJ
I_{AR}	Avalanche Current①⑥	6.0	A
E_{AR}	Repetitive Avalanche Energy①⑥	4.8	mJ
dv/dt	Peak Diode Recovery dv/dt ③	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	

Thermal Resistance

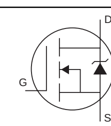
	Parameter	Typ.	Max.	Units
$R_{θJC}$	Junction-to-Case	——	3.1	°C/W
$R_{θJA}$	Junction-to-Ambient (PCB mount) **	——	50	
$R_{θJA}$	Junction-to-Ambient	——	110	

5/11/98

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	100	——	——	V	V_{GS} = 0V, I_D = 250µA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	——	0.12	——	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	——	——	0.185	W	V_{GS} = 10V, I_D = 6.0A ④
		——	——	0.225		V_{GS} = 5.0V, I_D = 6.0A ④
		——	——	0.265		V_{GS} = 4.0V, I_D = 5.0A ④
$V_{GS(th)}$	Gate Threshold Voltage	1.0	——	2.0	V	V_{DS} = V_{GS}, I_D = 250µA
g_{fs}	Forward Transconductance	3.1	——	——	S	V_{DS} = 25V, I_D = 6.0A⑥
I_{DSS}	Drain-to-Source Leakage Current	——	——	25	µA	V_{DS} = 100V, V_{GS} = 0V
		——	——	250		V_{DS} = 80V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	——	——	100	nA	V_{GS} = 16V
	Gate-to-Source Reverse Leakage	——	——	-100		V_{GS} = -16V
Q_g	Total Gate Charge	——	——	20	nC	I_D = 6.0A
Q_{gs}	Gate-to-Source Charge	——	——	4.6		V_{DS} = 80V
Q_{gd}	Gate-to-Drain ("Miller") Charge	——	——	10		V_{GS} = 5.0V, See Fig. 6 and 13 ④⑥
$t_{d(on)}$	Turn-On Delay Time	——	4.0	——	ns	V_{DD} = 50V
t_r	Rise Time	——	35	——		I_D = 6.0A
$t_{d(off)}$	Turn-Off Delay Time	——	23	——		R_G = 11Ω, V_{GS} = 5.0V
t_f	Fall Time		22			R_D = 8.2Ω, See Fig. 10 ④⑥
L_D	Internal Drain Inductance	——	4.5	——	nH	Between lead, 6mm (0.25in.) from package and center of die contact⑤ 
L_S	Internal Source Inductance	——	7.5	——		
C_{iss}	Input Capacitance	——	440	——	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	——	97	——		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	——	50	——		f = 1.0MHz, See Fig. 5⑥

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	——	——	10	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①⑥	——	——	35		
V_{SD}	Diode Forward Voltage	——	——	1.3	V	T_J = 25°C, I_S = 6.0A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	——	110	160	ns	T_J = 25°C, I_F =6.0A
Q_{rr}	Reverse RecoveryCharge	——	410	620	nC	di/dt = 100A/µs ④⑥
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11)

② V_{DD} = 25V, starting T_J = 25°C, L = 4.7mH R_G = 25Ω, I_{AS} = 6.0A. (See Figure 12)

③ $I_{SD} \le$ 6.0A, di/dt ≤ 340A/µs, $V_{DD} \le V_{(BR)DSS}$, $T_J \le$ 175°C

④ Pulse width ≤ 300µs; duty cycle ≤ 2%.

⑤ This is applied for I-PAK, L_S of D-PAK is measured between lead and center of die contact

⑥ Uses IRL520N data and test conditions.

** When mounted on 1" square PCB (FR-4 or G-10 Material) .
For recommended footprint and soldering techniques refer to application note #AN-994

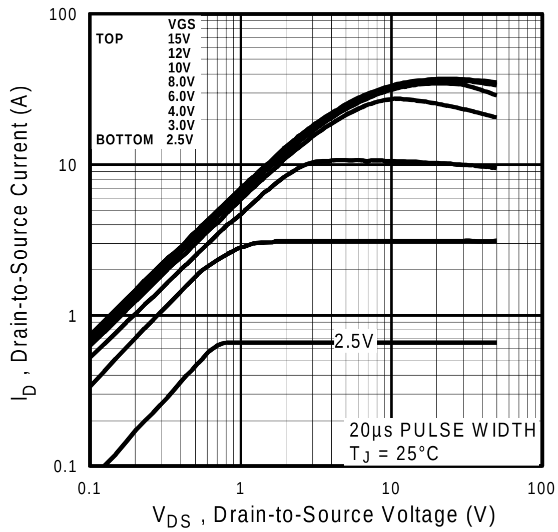


Fig 1. Typical Output Characteristics

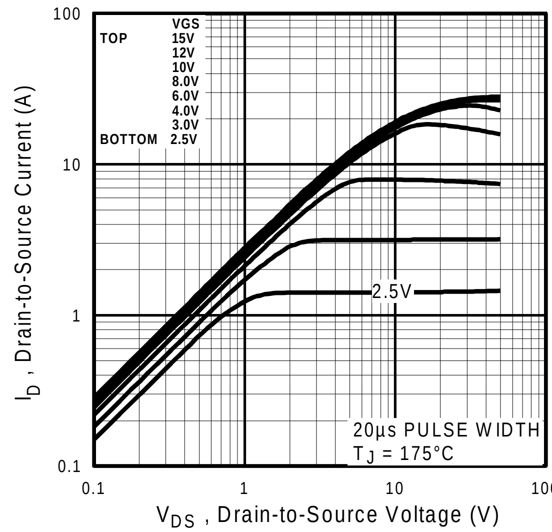


Fig 2. Typical Output Characteristics

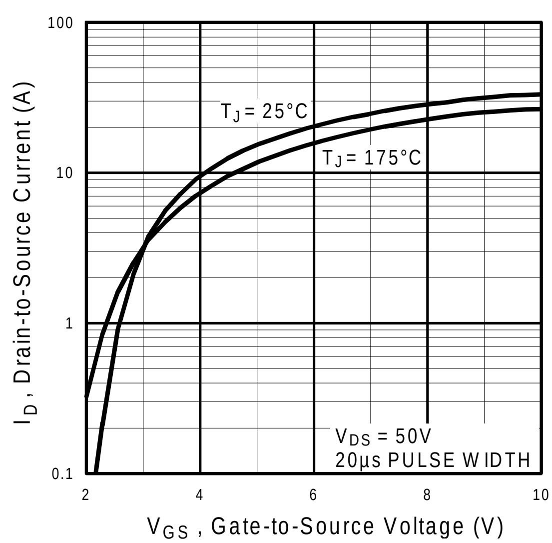


Fig 3. Typical Transfer Characteristics

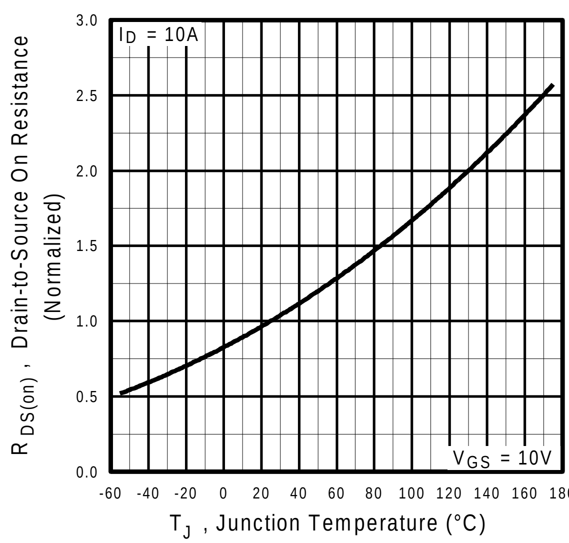


Fig 4. Normalized On-Resistance
Vs. Temperature

and

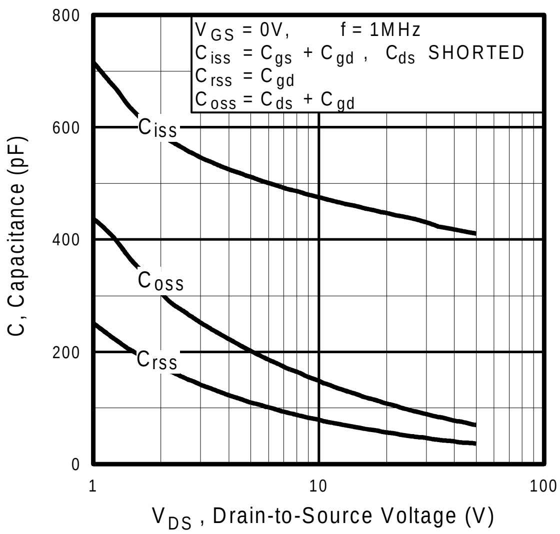


Fig 5. Typical Capacitance Vs. Drain-to-Source Voltage

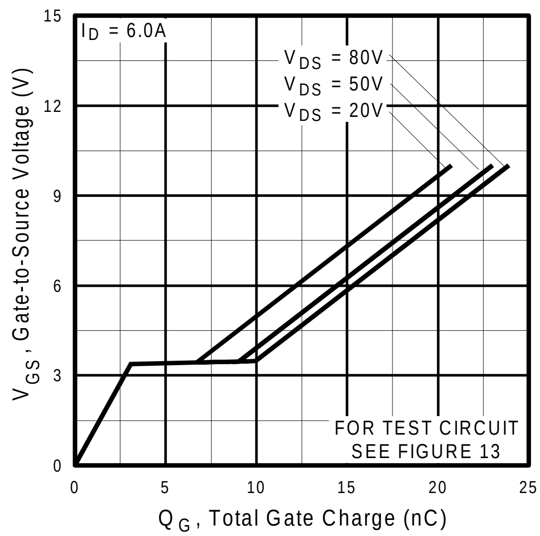


Fig 6. Typical Gate Charge Vs. Gate-to-Source Voltage

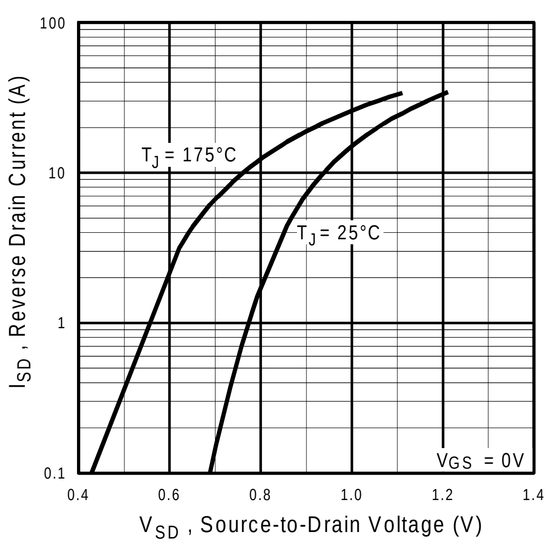


Fig 7. Typical Source-Drain Diode Forward Voltage

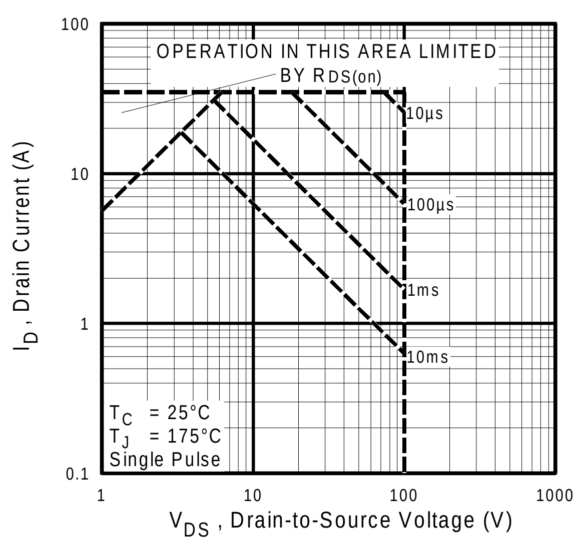


Fig 8. Maximum Safe Operating Area

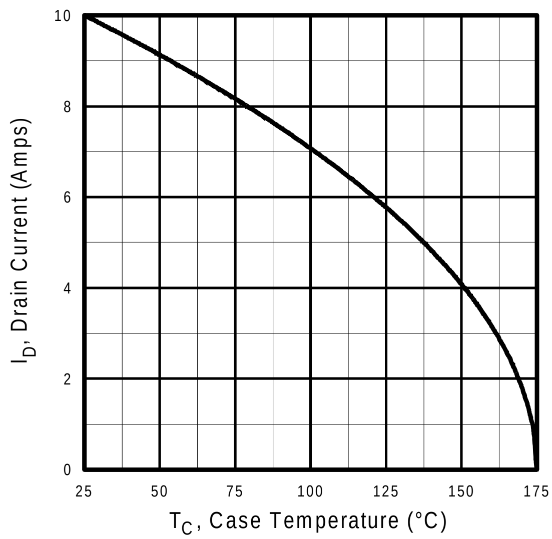


Fig 9. Maximum Drain Current Vs. Case Temperature

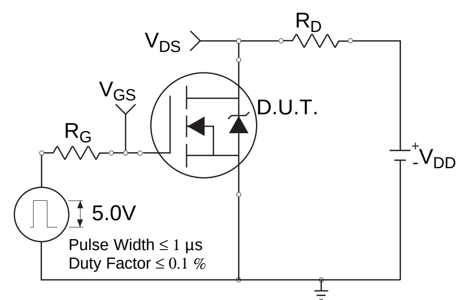


Fig 10a. Switching Time Test Circuit

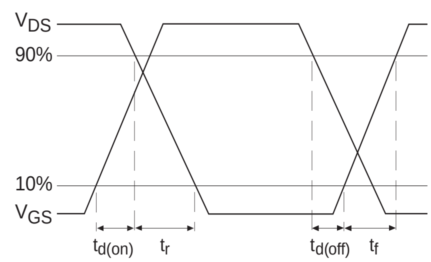


Fig 10b. Switching Time Waveforms

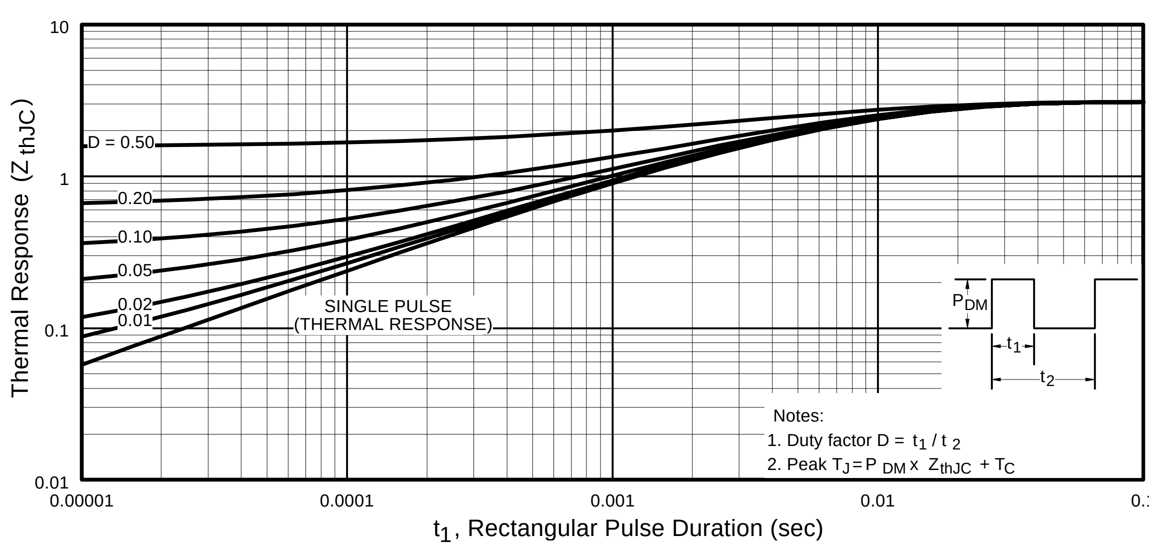


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

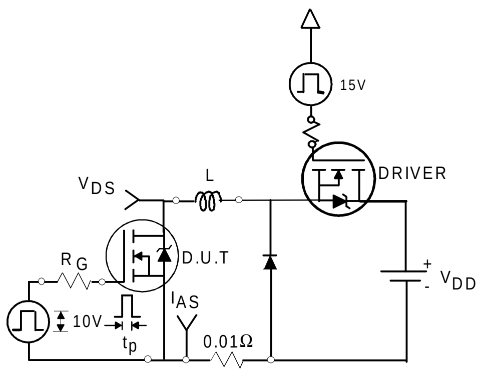


Fig 12a. Unclamped Inductive Test Circuit

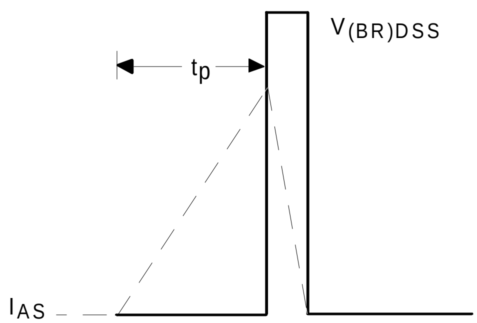


Fig 12b. Unclamped Inductive Waveforms

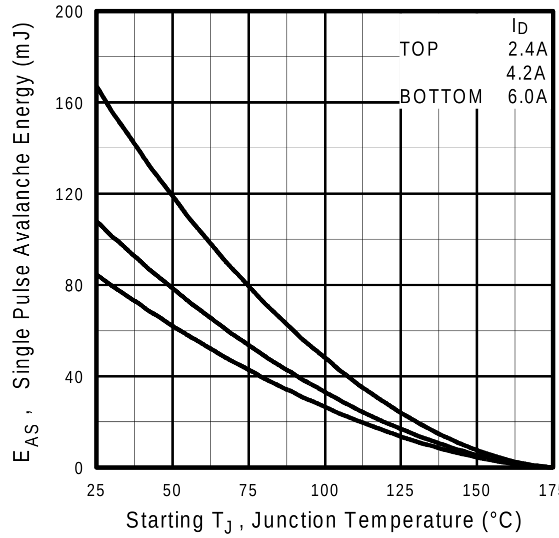


Fig 12c. Maximum Avalanche Energy Vs. Drain Current

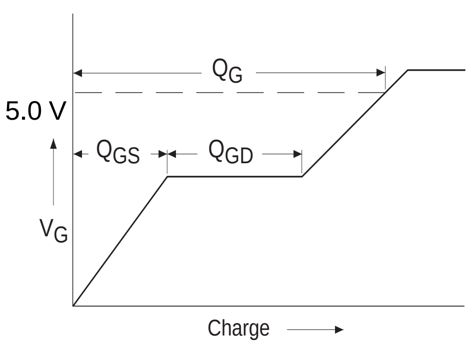


Fig 13a. Basic Gate Charge Waveform

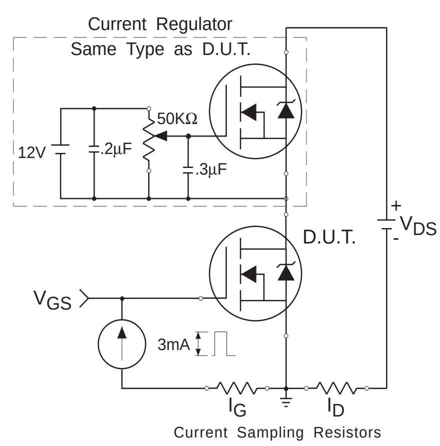
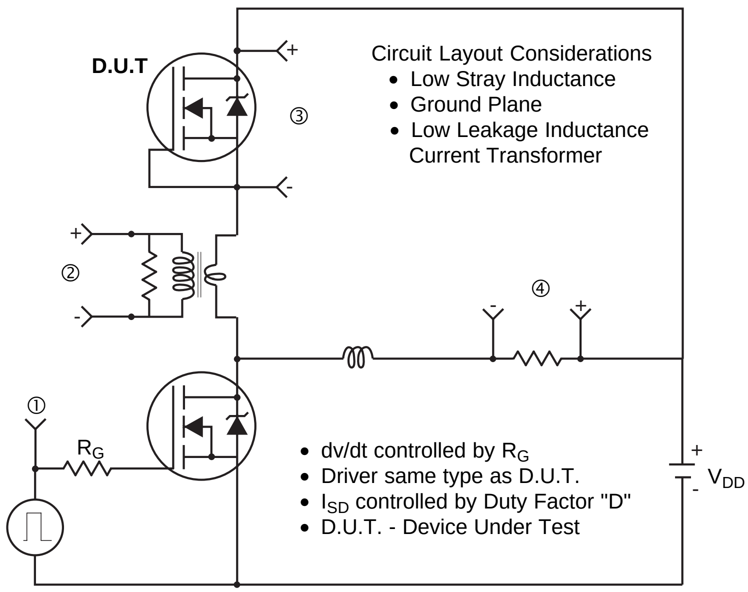
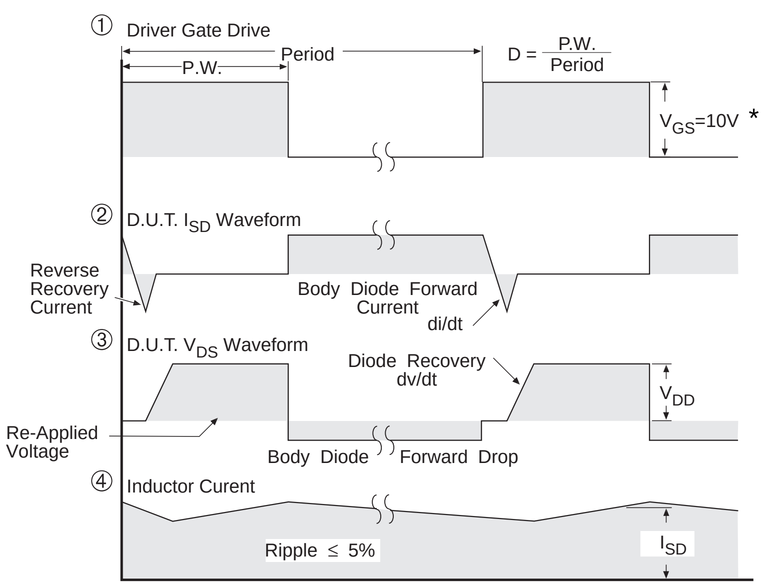


Fig 13b. Gate Charge Test Circuit

Peak Diode Recovery dv/dt Test Circuit



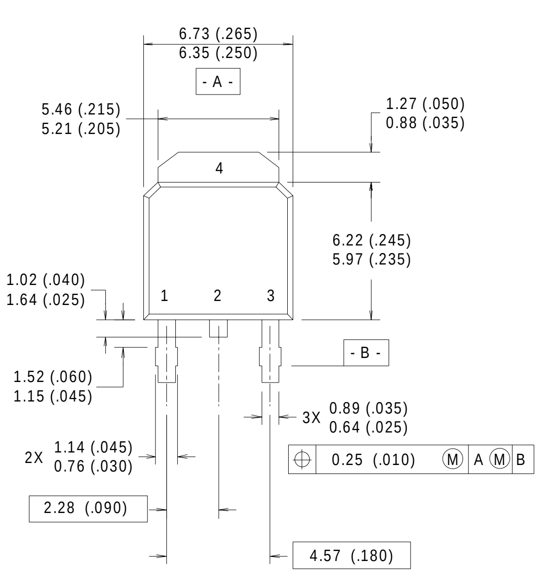


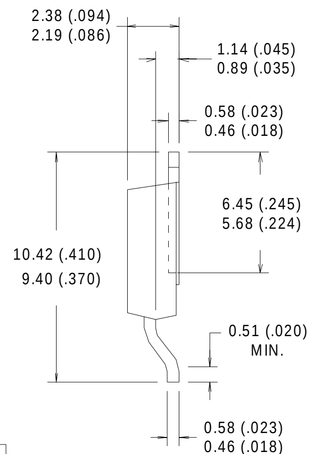
* V_{GS} = 5V for Logic Level Devices

Fig 14. For N-Channel HEXFETS

Package Outline

TO-252AA Outline
Dimensions are shown in millimeters (inches)





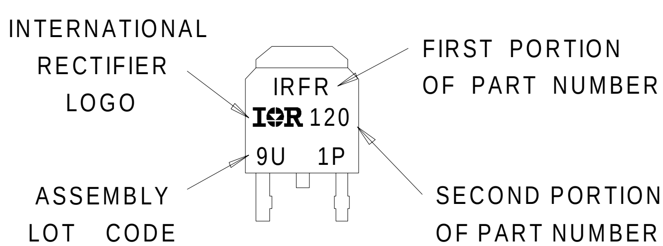
LEAD ASSIGNMENTS
1 - GATE
2 - DRAIN
3 - SOURCE
4 - DRAIN

NOTES:
1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION : INCH.
3 CONFORMS TO JEDEC OUTLINE TO-252AA.
4 DIMENSIONS SHOWN ARE BEFORE SOLDER DIP, SOLDER DIP MAX. +0.16 (.006).

Part Marking Information

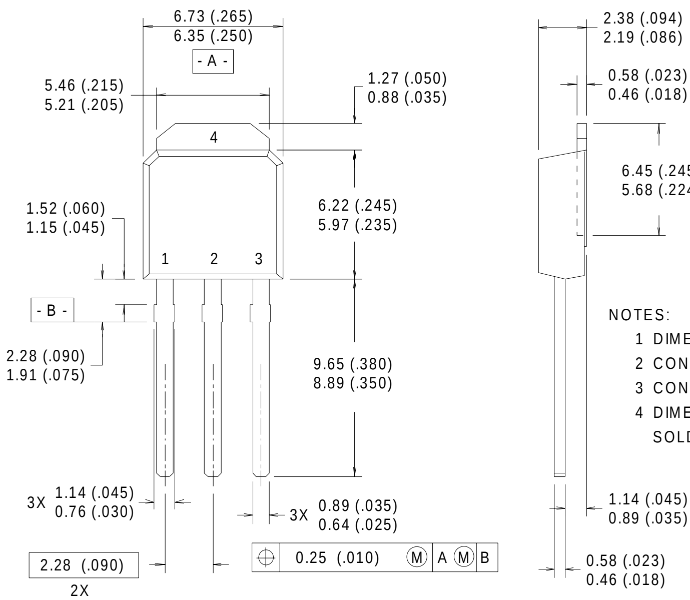
TO-252AA (D-PARK)

EXAMPLE : THIS IS AN IRFR120
WITH ASSEMBLY
LOT CODE 9U1P



Package Outline

TO-251AA Outline
Dimensions are shown in millimeters (inches)



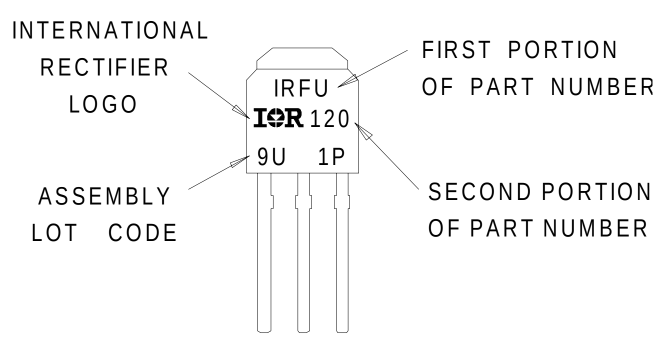
LEAD ASSIGNMENTS
1 - GATE
2 - DRAIN
3 - SOURCE
4 - DRAIN

NOTES:
1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION : INCH.
3 CONFORMS TO JEDEC OUTLINE TO-252AA.
4 DIMENSIONS SHOWN ARE BEFORE SOLDER DIP, SOLDER DIP MAX. +0.16 (.006).

Part Marking Information

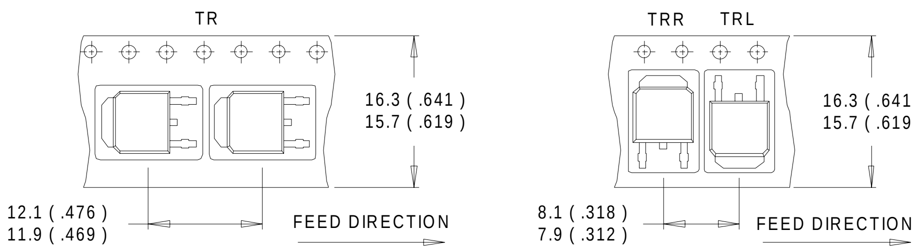
TO-251AA (I-PARK)

EXAMPLE : THIS IS AN IRFU120
WITH ASSEMBLY
LOT CODE 9U1P

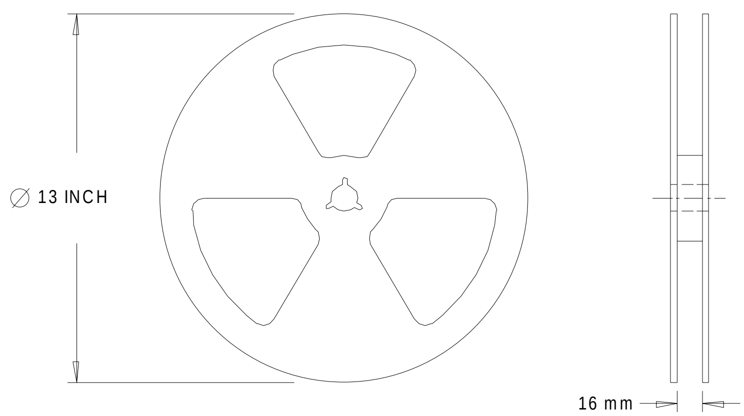


Tape & Reel Information

TO-252AA



NOTES :
1. CONTROLLING DIMENSION : MILLIMETER.
2. ALL DIMENSIONS ARE SHOWN IN MILLIMETERS (INCHES).
3. OUTLINE CONFORMS TO EIA-481 & EIA-541.



NOTES :
1. OUTLINE CONFORMS TO EIA-481.

International IOR Rectifier

WORLD HEADQUARTERS: 233 Kansas St., El Segundo, California 90245, Tel: (310) 322 3331
EUROPEAN HEADQUARTERS: Hurst Green, Oxted, Surrey RH8 9BB, UK Tel: ++ 44 1883 732020
IR CANADA: 15 Lincoln Court, Brampton, Ontario L6T 3Z2, Tel: (905) 453 2200
IR GERMANY: Saalburgstrasse 157, 61350 Bad Homburg Tel: ++ 49 6172 96590
IR ITALY: Via Liguria 49, 10071 Borgaro, Torino Tel: ++ 39 11 451 0111
IR FAR EAST: 171 (K&H Bldg.) 30-4 Nishi-ikebukuro 3-chome, Toshima-ku, Tokyo Japan Tel: 81 33 983 0086
IR SOUTHEAST ASIA: 315 Outram Road, #10-02 Tan Boon Liat Building, Singapore 16907 Tel: 65 221 8371

Data and specifications subject to change without notice. *5/98*

National Semiconductor

November 1994

LM741 Operational Amplifier

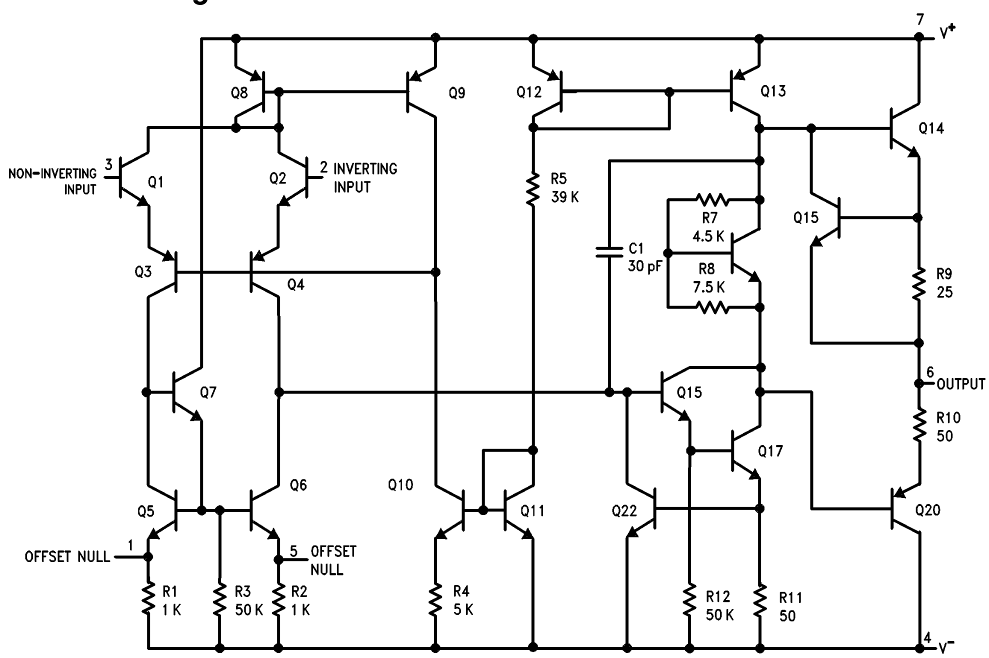
General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

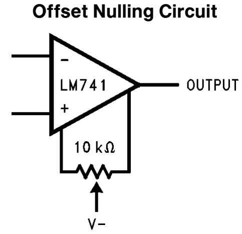
The LM741C/LM741E are identical to the LM741/LM741A except that the LM741C/LM741E have their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Schematic Diagram



TL/H/9341–1

Offset Nulling Circuit



TL/H/9341–7

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.
(Note 5)

	LM741A	LM741E	LM741	LM741C
Supply Voltage	±22V	±22V	±22V	±18V
Power Dissipation (Note 1)	500 mW	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V	±30V
Input Voltage (Note 2)	±15V	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	0°C to +70°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	100°C	150°C	100°C
Soldering Information				
N-Package (10 seconds)	260°C	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C	300°C
M-Package				
Vapor Phase (60 seconds)	215°C	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C	215°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

	LM741A	LM741E	LM741	LM741C
ESD Tolerance (Note 6)	400V	400V	400V	400V

Electrical Characteristics (Note 3)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	$T_A = 25°C, V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25°C, V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Input Voltage Range	$T_A = 25°C$							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V
Large Signal Voltage Gain	$T_A = 25°C, R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V, V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V, V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $R_L \geq 2\ k\Omega$,										
	$V_S = \pm 20V, V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V, V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V, V_O = \pm 2V$	10									V/mV

Electrical Characteristics (Note 3) (Continued)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit Current	$T_A = 25°C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB
Supply Voltage Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$ to $V_S = \pm 5V$										
	$R_S \leq 50\Omega$	86	96								dB
	$R_S \leq 10\ k\Omega$				77	96		77	96		dB
Transient Response	$T_A = 25°C$, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		μs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 4)	$T_A = 25°C$	0.437	1.5								MHz
Slew Rate	$T_A = 25°C$, Unity Gain	0.3	0.7			0.5			0.5		V/μs
Supply Current	$T_A = 25°C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25°C$										
	$V_S = \pm 20V$		80	150							mW
	$V_S = \pm 15V$					50	85		50	85	mW
LM741A	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741E	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			150							mW
	$T_A = T_{AMAX}$			150							mW
LM741	$V_S = \pm 15V$										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 1: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 2: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 3: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \leq T_A \leq +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \leq T_A \leq +70°C$.

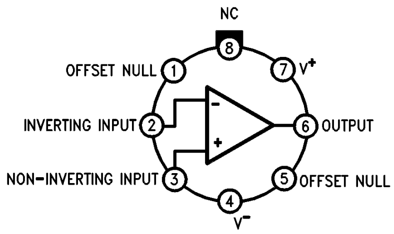
Note 4: Calculated value from: BW (MHz) = 0.35/Rise Time(μs).

Note 5: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 6: Human body model, 1.5 kΩ in series with 100 pF.

Connection Diagrams

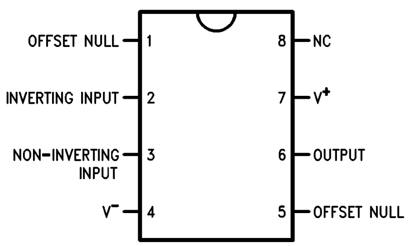
Metal Can Package



TL/H/9341–2

Order Number LM741H, LM741H/883*, LM741AH/883 or LM741CH
See NS Package Number H08C

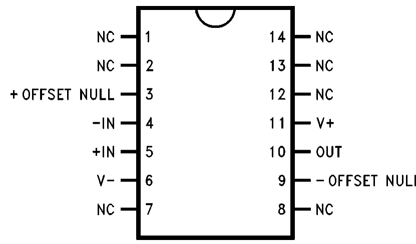
Dual-In-Line or S.O. Package



TL/H/9341–3

Order Number LM741J, LM741J/883, LM741CM, LM741CN or LM741EN
See NS Package Number J08A, M08A or N08E

Ceramic Dual-In-Line Package

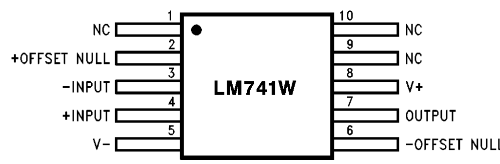


TL/H/9341–5

Order Number LM741J-14/883*, LM741AJ-14/883**
See NS Package Number J14A

*also available per JM38510/10101
**also available per JM38510/10102

Ceramic Flatpak

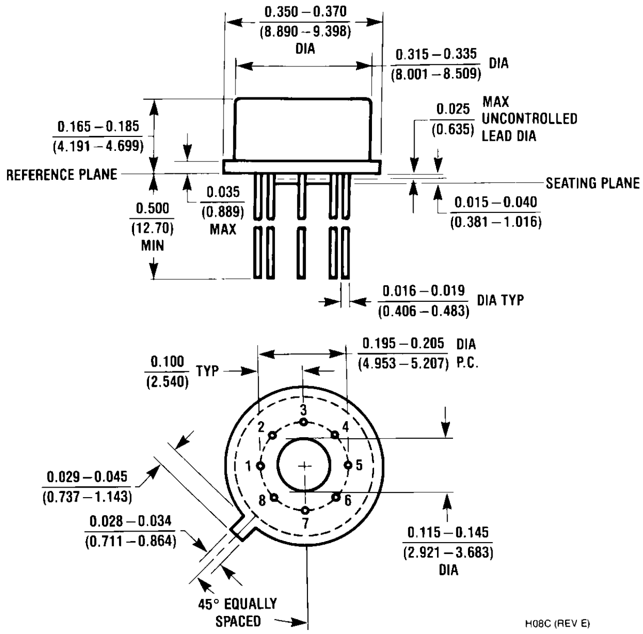


TL/H/9341–6

Order Number LM741W/883
See NS Package Number W10A

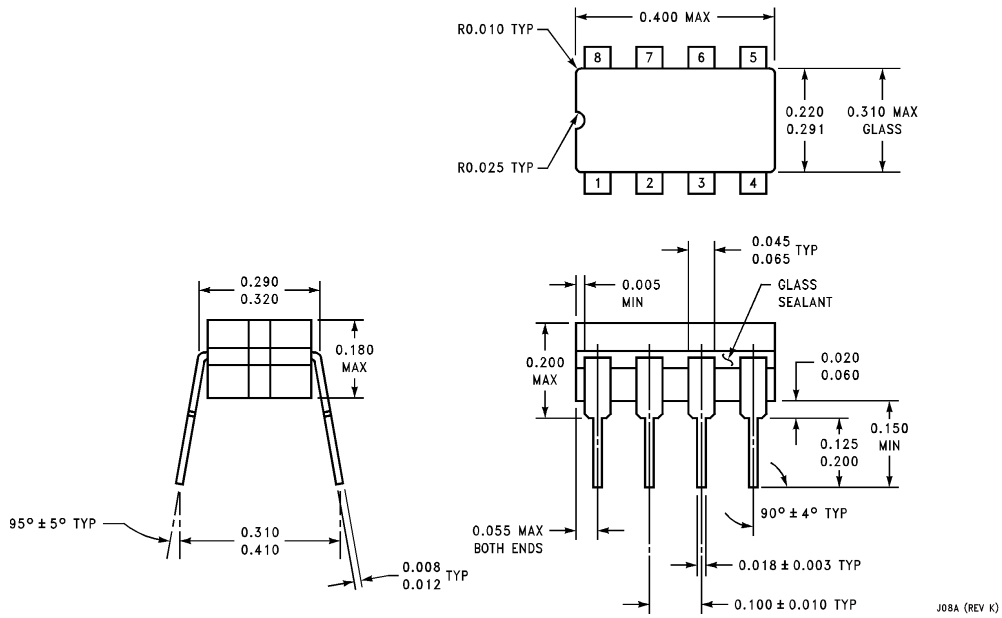
*LM741H is available per JM38510/10101

Physical Dimensions inches (millimeters)

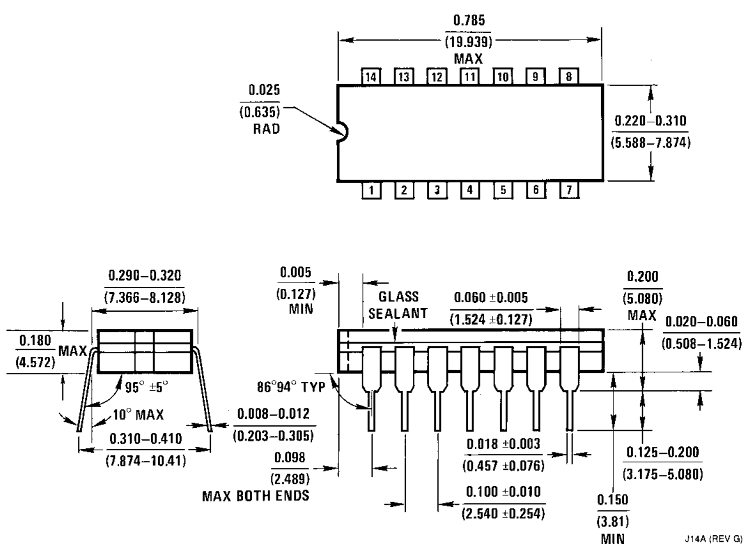


Metal Can Package (H)
Order Number LM741H, LM741H/883, LM741AH/883, LM741CH or LM741EH
NS Package Number H08C

Physical Dimensions inches (millimeters) (Continued)

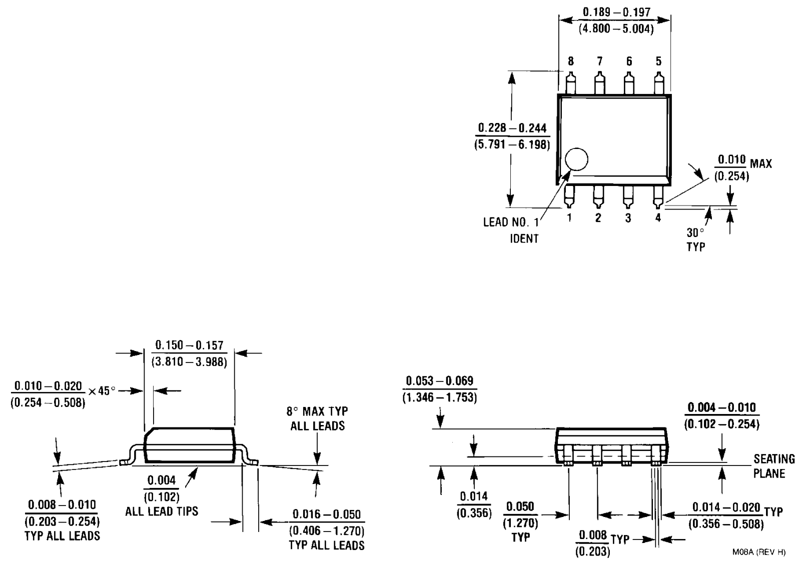


Ceramic Dual-In-Line Package (J)
Order Number LM741CJ or LM741J/883
NS Package Number J08A

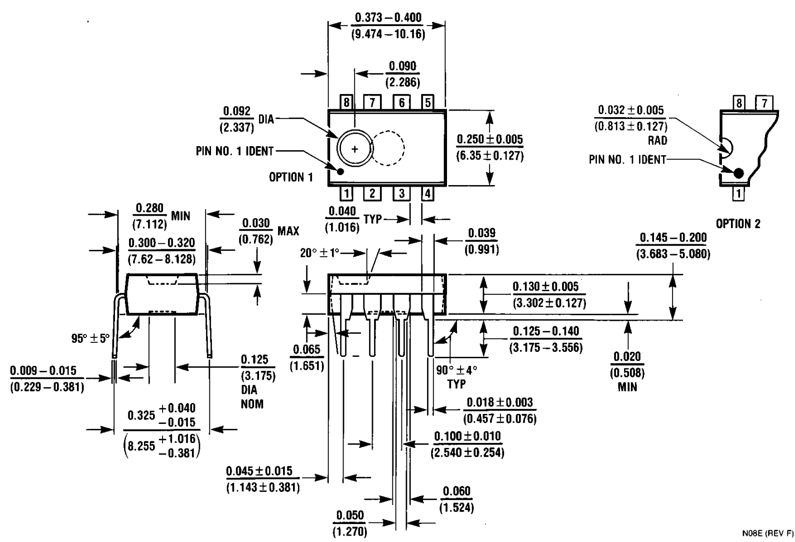


Ceramic Dual-In-Line Package (J)
Order Number LM741J-14/883 or LM741AJ-14/883
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

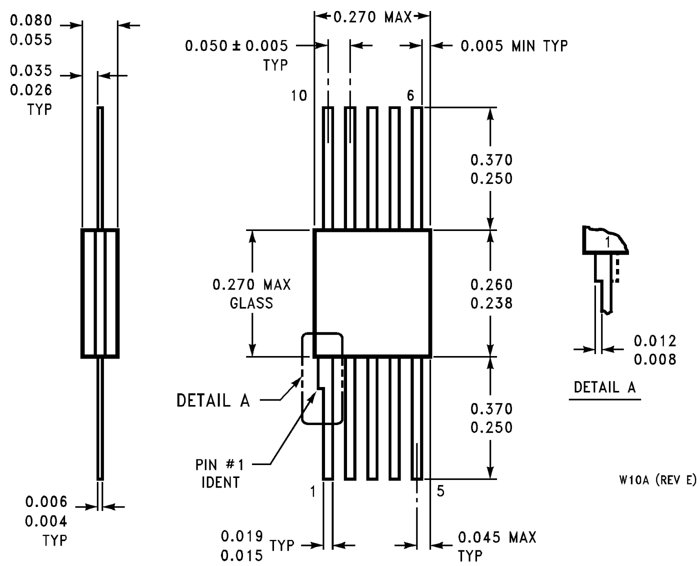


Small Outline Package (M)
Order Number LM741CM
NS Package Number M08A



Dual-In-Line Package (N)
Order Number LM741CN or LM741EN
NS Package Number N08E

Physical Dimensions inches (millimeters) (Continued)



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883
NS Package Number W10A

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

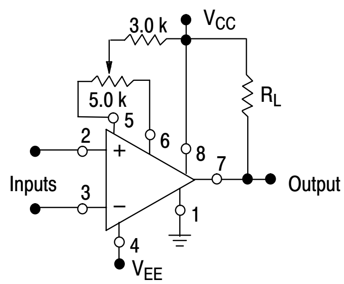
National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

Single Comparators

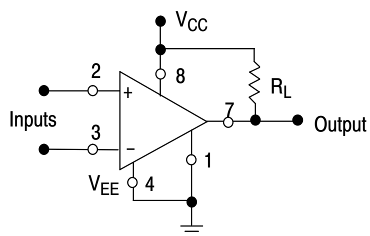
The ability to operate from a single power supply of 5.0 V to 30 V or ±15 V split supplies, as commonly used with operational amplifiers, makes the LM211/LM311 a truly versatile comparator. Moreover, the inputs of the device can be isolated from system ground while the output can drive loads referenced either to ground, the V_{CC} or the V_{EE} supply. This flexibility makes it possible to drive DTL, RTL, TTL, or MOS logic. The output can also switch voltages to 50 V at currents to 50 mA, therefore, the LM211/LM311 can be used to drive relays, lamps or solenoids.

Features

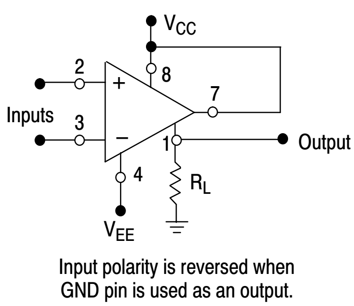
- Pb−Free Packages are Available



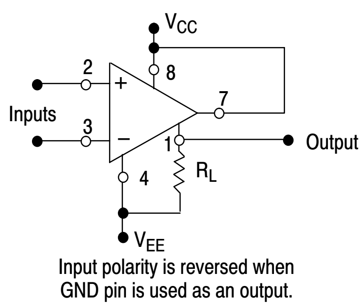
Split Power Supply with Offset Balance



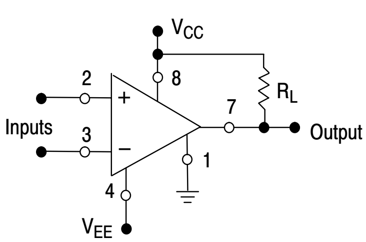
Single Supply



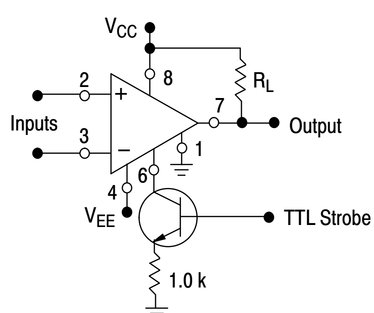
Ground−Referred Load



Load Referred to Negative Supply



Load Referred to Positive Supply



Strobe Capability

Figure 1. Typical Comparator Design Configurations

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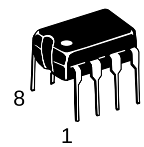
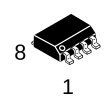
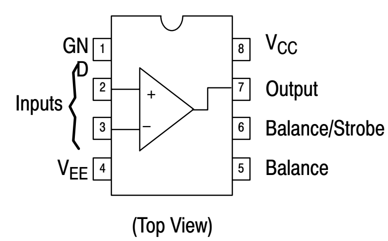


PDIP−8
N SUFFIX
CASE 626



SOIC−8
D SUFFIX
CASE 751

PIN CONNECTIONS



ORDERING & DEVICE MARKING INFORMATION

See detailed ordering and shipping information and marking information in the package dimensions section on page 7 of this data sheet.

MAXIMUM RATINGS (T_A = +25°C, unless otherwise noted.)

Rating	Symbol	LM211	LM311	Unit
Total Supply Voltage	$V_{CC} + \lvert V_{EE} \rvert$	36	36	Vdc
Output to Negative Supply Voltage	$V_O - V_{EE}$	50	40	Vdc
Ground to Negative Supply Voltage	V_{EE}	30	30	Vdc
Input Differential Voltage	V_{ID}	±30	±30	Vdc
Input Voltage (Note 2)	V_{in}	±15	±15	Vdc
Voltage at Strobe Pin	−	V_{CC} to $V_{CC}−5$	V_{CC} to $V_{CC}−5$	Vdc
Power Dissipation and Thermal Characteristics Plastic DIP Derate Above T_A = +25°C	 P_D $R_{\theta JA}$	 625 5.0		 mW mW/°C
Operating Ambient Temperature Range	T_A	−25 to +85	0 to +70	°C
Operating Junction Temperature	$T_{J(max)}$	+150	+150	°C
Storage Temperature Range	T_{stg}	−65 to +150	−65 to +150	°C

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

ELECTRICAL CHARACTERISTICS (V_{CC} = +15 V, V_{EE} = −15 V, T_A = 25°C, unless otherwise noted) Note 1

Characteristic	Symbol	LM211			LM311			Unit
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage (Note 3) $R_S \le$ 50 kΩ, T_A = +25°C $R_S \le$ 50 kΩ, $T_{low} \le T_A \le T_{high}$*	V_{IO}	 − −	 0.7 −	 3.0 4.0	 − −	 2.0 −	 7.5 10	mV
Input Offset Current (Note 3) T_A = +25°C $T_{low} \le T_A \le T_{high}$*	I_{IO}	− −	1.7 −	10 20	− −	1.7 −	50 70	nA
Input Bias Current T_A = +25°C $T_{low} \le T_A \le T_{high}$*	I_{IB}	− −	45 −	100 150	− −	45 −	250 300	nA
Voltage Gain	A_V	40	200	−	40	200	−	V/mV
Response Time (Note 4)		−	200	−	−	200	−	ns
Saturation Voltage $V_{ID} \le$ −5.0 mV, I_O = 50 mA, T_A = 25°C $V_{ID} \le$ −10 mV, I_O = 50 mA, T_A = 25°C $V_{CC} \ge$ 4.5 V, V_{EE} = 0, $T_{low} \le T_A \le T_{high}$* $V_{ID} \angle\le$ 6.0 mV, $I_{sink} \le$ 8.0 mA $V_{ID} \angle\le$ 10 mV, $I_{sink} \le$ 8.0 mA	V_{OL}	 − − − −	 0.75 − 0.23 −	 1.5 − 0.4 −	 − − − −	 − 0.75 − 0.23	 − 1.5 − 0.4	V
Strobe ”On” Current (Note 5)	I_S	−	3.0	−	−	3.0	−	mA
Output Leakage Current $V_{ID} \ge$ 5.0 mV, V_O= 35 V, T_A = 25°C, I_{strobe}= 3.0 mA $V_{ID \ge 10\ mV}$, V_O= 35 V, T_A = 25°C, I_{strobe}= 3.0 mA $V_{ID \ge 5.0\ mV}$, V_O= 35 V, $T_{low} \le T_A \le T_{high}$*		 − − −	 0.2 − 0.1	 10 − 0.5	 − − −	 − 0.2 −	 − 50 −	 nA nA μA
Input Voltage Range ($T_{low} \le T_A \le T_{high}$*)	V_{ICR}	−14.5	−14.7 to 13.8	+13.0	−14.5	−14.7 to 13.8	+13.0	V
Positive Supply Current	I_{CC}	−	+2.4	+6.0	−	+2.4	+7.5	mA
Negative Supply Current	I_{EE}	−	−1.3	−5.0	−	−1.3	−5.0	mA

* LM211: T_{low} = −25°C, T_{high} = +85°C
LM311: T_{low} = 0°C, T_{high} = +70°C

1. Offset voltage, offset current and bias current specifications apply for a supply voltage range from a single 5.0 V supply up to ±15 V supplies.
2. This rating applies for ±15 V supplies. The positive input voltage limit is 30 V above the negative supply. The negative input voltage limit is equal to the negative supply voltage or 30 V below the positive supply, whichever is less.
3. The offset voltages and offset currents given are the maximum values required to drive the output within a volt of either supply with a 1.0 mA load. Thus, these parameters define an error band and take into account the “worst case” effects of voltage gain and input impedance.
4. The response time specified is for a 100 mV input step with 5.0 mV overdrive.
5. Do not short the strobe pin to ground; it should be current driven at 3.0 mA to 5.0 mA.

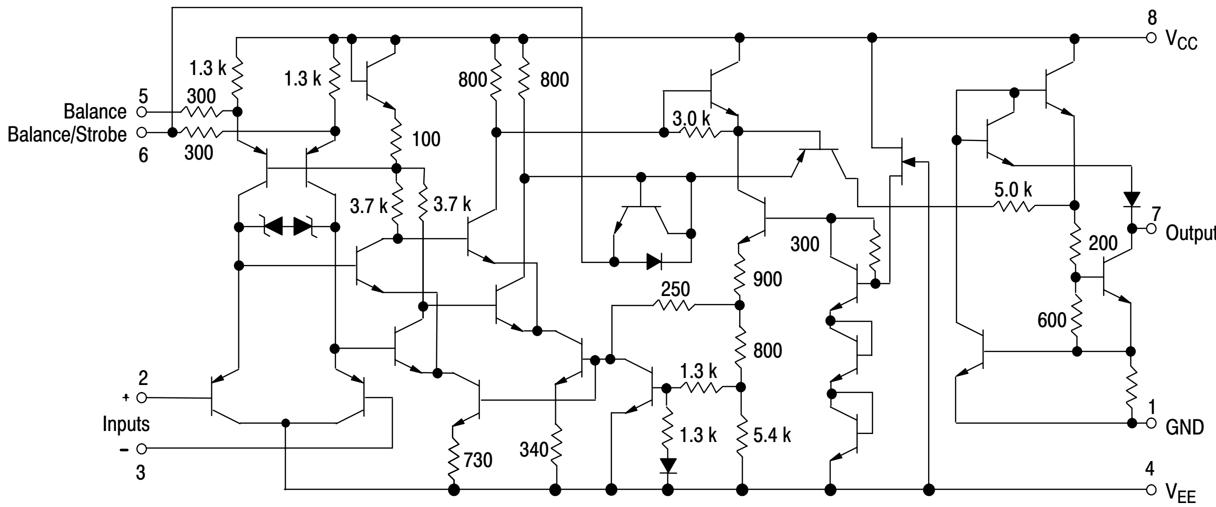


Figure 2. Circuit Schematic

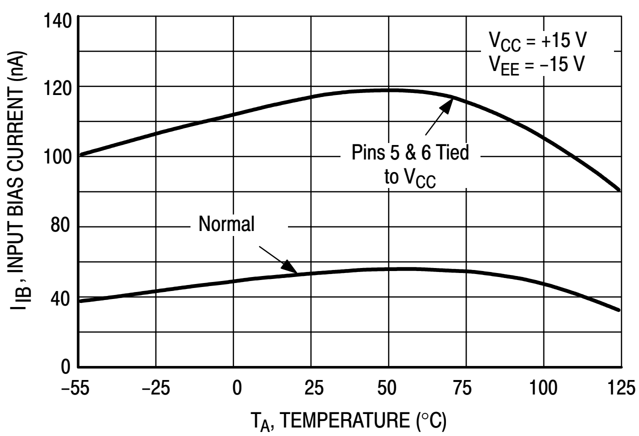


Figure 3. Input Bias Current versus Temperature

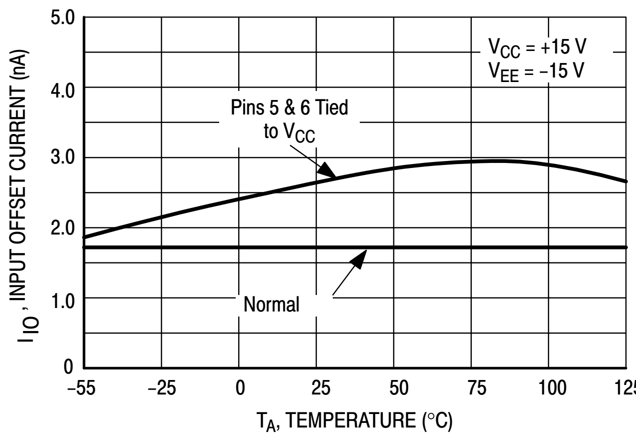


Figure 4. Input Offset Current versus Temperature

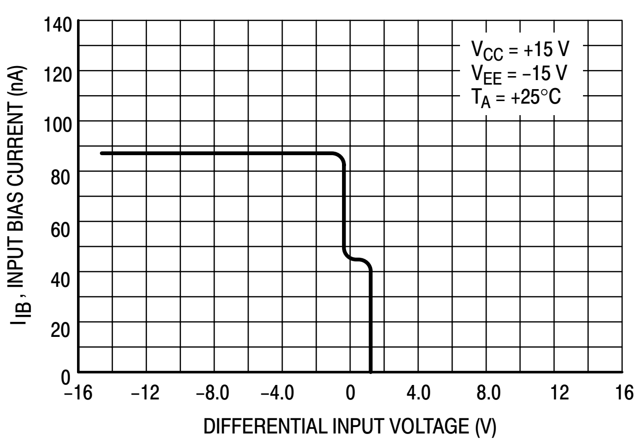


Figure 5. Input Bias Current versus Differential Input Voltage

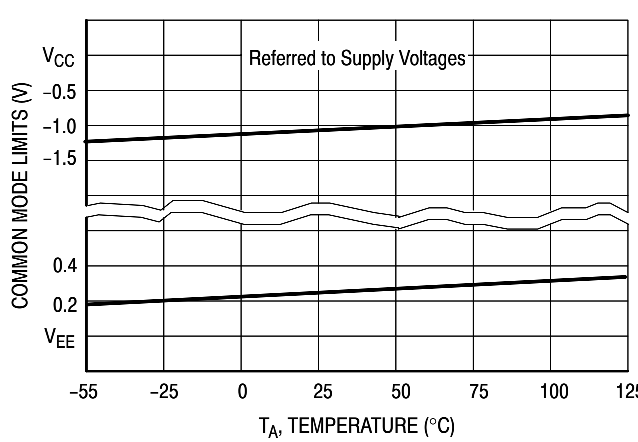


Figure 6. Common Mode Limits versus Temperature

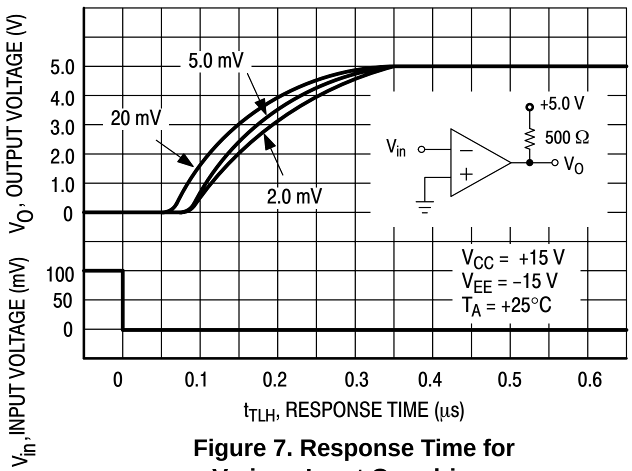


Figure 7. Response Time for Various Input Overdrives

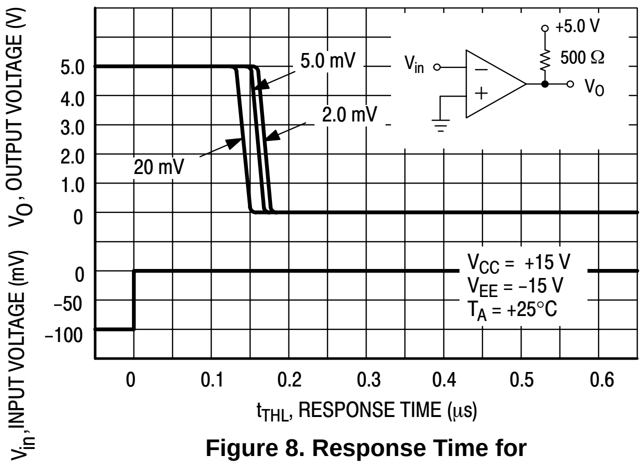


Figure 8. Response Time for Various Input Overdrives

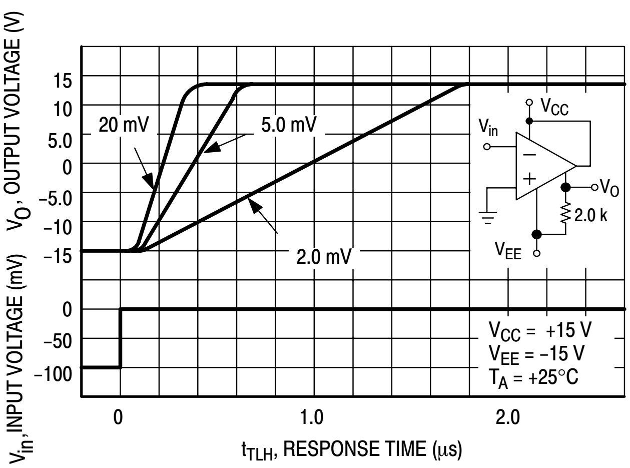


Figure 9. Response Time for Various Input Overdrives

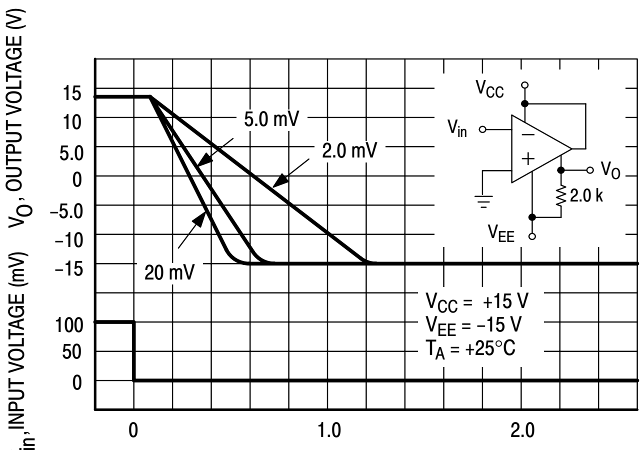


Figure 10. Response Time for Various Input Overdrives

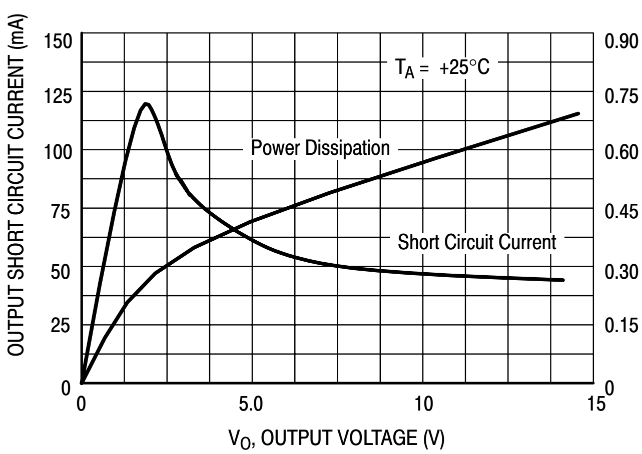


Figure 11. Output Short Circuit Current Characteristics and Power Dissipation

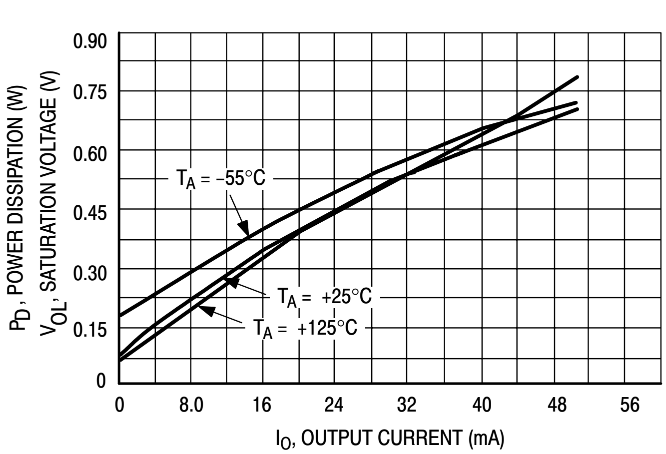


Figure 12. Output Saturation Voltage versus Output Current

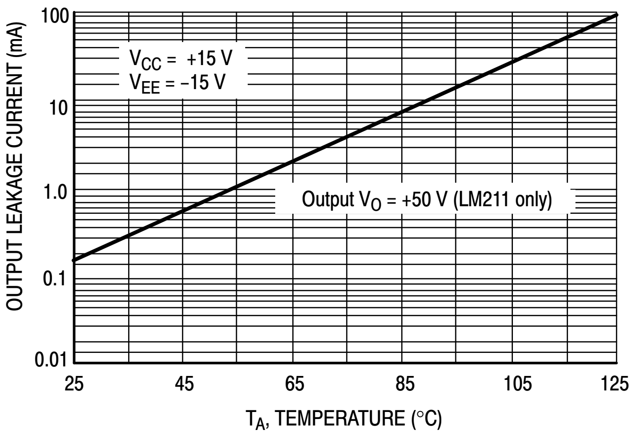


Figure 13. Output Leakage Current versus Temperature

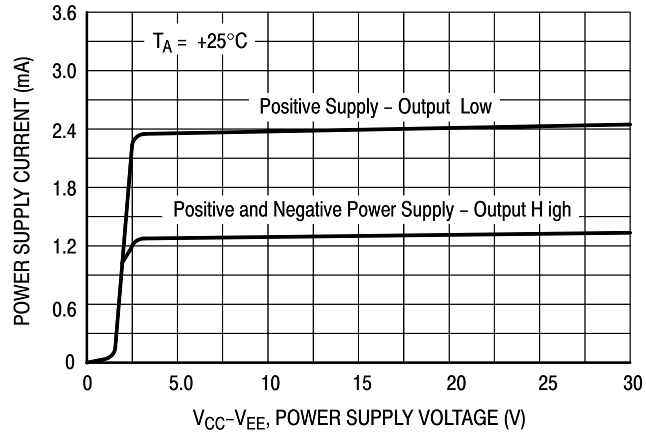


Figure 14. Power Supply Current versus Supply Voltage

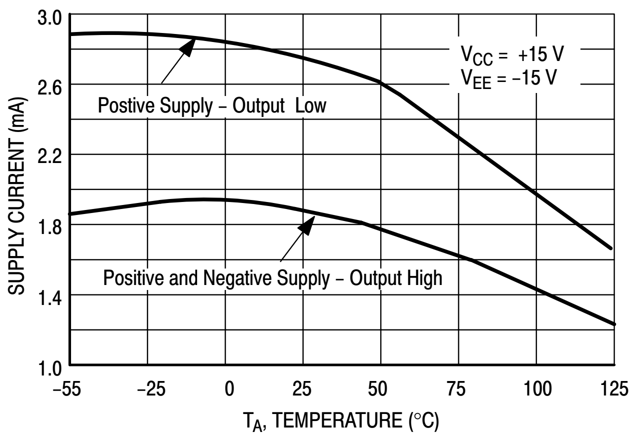


Figure 15. Power Supply Current versus Temperature

APPLICATIONS INFORMATION

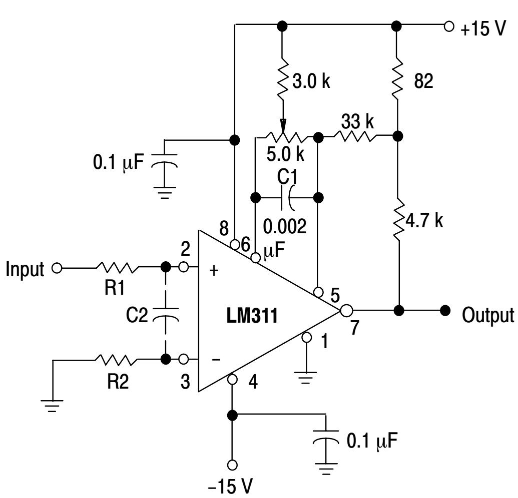


Figure 16. Improved Method of Adding Hysteresis Without Applying Positive Feedback to the Inputs

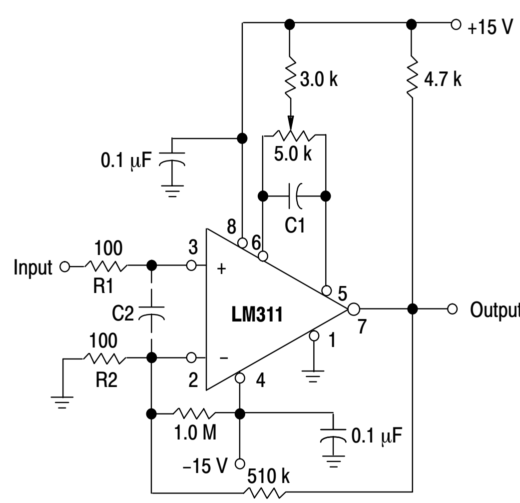


Figure 17. Conventional Technique for Adding Hysteresis

TECHNIQUES FOR AVOIDING OSCILLATIONS IN COMPARATOR APPLICATIONS

When a high speed comparator such as the LM211 is used with high speed input signals and low source impedances, the output response will normally be fast and stable, providing the power supplies have been bypassed (with 0.1 μF disc capacitors), and that the output signal is routed well away from the inputs (Pins 2 and 3) and also away from Pins 5 and 6.

However, when the input signal is a voltage ramp or a slow sine wave, or if the signal source impedance is high (1.0 kΩ to 100 kΩ), the comparator may burst into oscillation near the crossing−point. This is due to the high gain and wide bandwidth of comparators like the LM211 series. To avoid oscillation or instability in such a usage, several precautions are recommended, as shown in Figure 16.

The trim pins (Pins 5 and 6) act as unwanted auxiliary inputs. If these pins are not connected to a trim−pot, they should be shorted together. If they are connected to a trim−pot, a 0.01 μF capacitor (C1) between Pins 5 and 6 will minimize the susceptibility to AC coupling. A smaller capacitor is used if Pin 5 is used for positive feedback as in Figure 16. For the fastest response time, tie both balance pins to V_{CC}.

Certain sources will produce a cleaner comparator output waveform if a 100 pF to 1000 pF capacitor (C2) is connected directly across the input pins. When the signal source is applied through a resistive network, R1, it is usually advantageous to choose R2 of the same value, both for DC and for dynamic (AC) considerations. Carbon, tin−oxide, and metal−film resistors have all been used with good results in comparator input circuitry, but inductive wirewound resistors should be avoided.

When comparator circuits use input resistors (e.g., summing resistors), their value and placement are particularly important. In all cases the body of the resistor should be close to the device or socket. In other words, there should be a very short lead length or printed−circuit foil run between comparator and resistor to radiate or pick up signals. The same applies to capacitors, pots, etc. For example, if R1 = 10 kΩ, as little as 5 inches of lead between the resistors and the input pins can result in oscillations that are very hard to dampen. Twisting these input leads tightly is the best alternative to placing resistors close to the comparator.

Since feedback to almost any pin of a comparator can result in oscillation, the printed−circuit layout should be engineered thoughtfully. Preferably there should be a groundplane under the LM211 circuitry (e.g., one side of a double layer printed circuit board). Ground, positive supply or negative supply foil should extend between the output and the inputs to act as a guard. The foil connections for the inputs should be as small and compact as possible, and should be essentially surrounded by ground foil on all sides to guard against capacitive coupling from any fast high−level signals (such as the output). If Pins 5 and 6 are not used, they should be shorted together. If they are connected to a trim−pot, the trim−pot should be located no more than a few inches away from the LM211, and a 0.01 μF capacitor should be installed across Pins 5 and 6. If this capacitor cannot be used, a shielding printed−circuit foil may be advisable between Pins 6 and 7. The power supply bypass capacitors should be located within a couple inches of the LM211.

A standard procedure is to add hysteresis to a comparator to prevent oscillation, and to avoid excessive noise on the output. In the circuit of Figure 17, the feedback resistor of 510 kΩ from the output to the positive input will cause about 3.0 mV of hysteresis. However, if R2 is larger than 100 Ω, such as 50 kΩ, it would not be practical to simply increase the value of the positive feedback resistor proportionally above 510 kΩ to maintain the same amount of hysteresis.

When both inputs of the LM211 are connected to active signals, or if a high−impedance signal is driving the positive input of the LM211 so that positive feedback would be disruptive, the circuit of Figure 16 is ideal. The positive feedback is applied to Pin 5 (one of the offset adjustment pins). This will be sufficient to cause 1.0 mV to 2.0 mV hysteresis and sharp transitions with input triangle waves from a few Hz to hundreds of kHz. The positive−feedback signal across the 82 Ω resistor swings 240 mV below the positive supply. This signal is centered around the nominal voltage at Pin 5, so this feedback does not add to the offset voltage of the comparator. As much as 8.0 mV of offset voltage can be trimmed out, using the 5.0 kΩ pot and 3.0 kΩ resistor as shown.

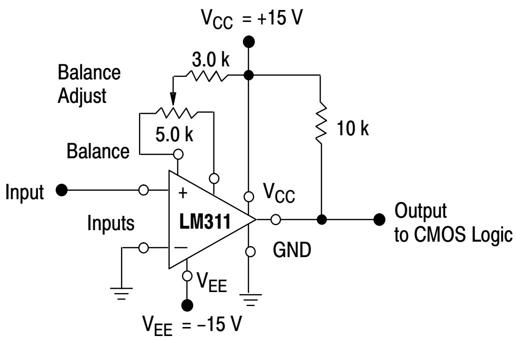


Figure 18. Zero−Crossing Detector Driving CMOS Logic

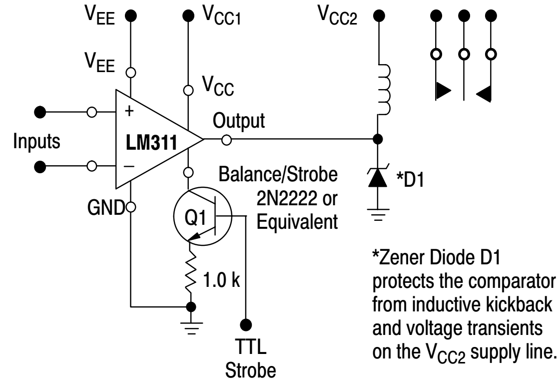


Figure 19. Relay Driver with Strobe Capability

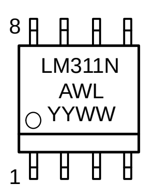
ORDERING INFORMATION

Device	Package	Shipping†
LM211D	SOIC−8	98 Units / Rail
LM211DR2	SOIC−8	
LM211DR2G	SOIC−8 (Pb−Free)	
LM311D	SOIC−8	2500 Units / Reel
LM311DG	SOIC−8 (Pb−Free)	98 Units / Rail
LM311DR2	SOIC−8	2500 Units / Reel
LM311DR2G	SOIC−8 (Pb−Free)	
LM311N	PDIP−8	50 Units / Rail
LM311NG	PDIP−8 (Pb−Free)	

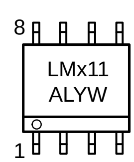
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

MARKING DIAGRAMS

PDIP−8
N SUFFIX
CASE 626



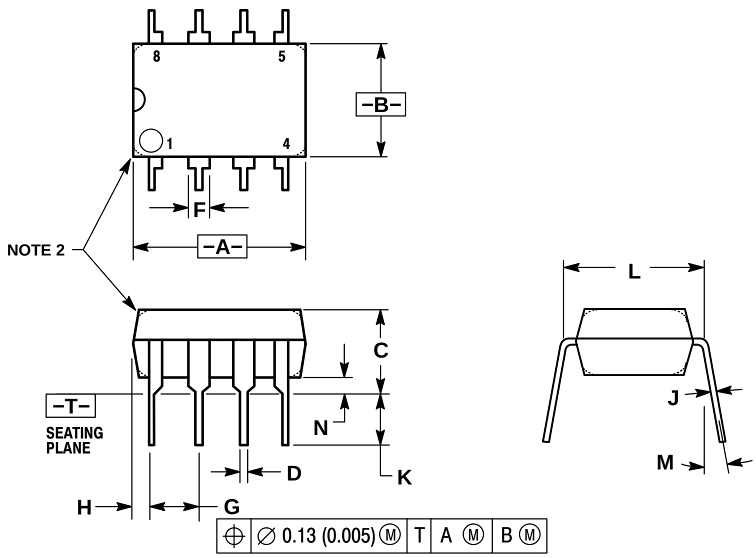
SOIC−8
D SUFFIX
CASE 751



x = 2 or 3
A = Assembly Location
WL, L = Wafer Lot
YY, Y = Year
WW, W = Work Week

PACKAGE DIMENSIONS

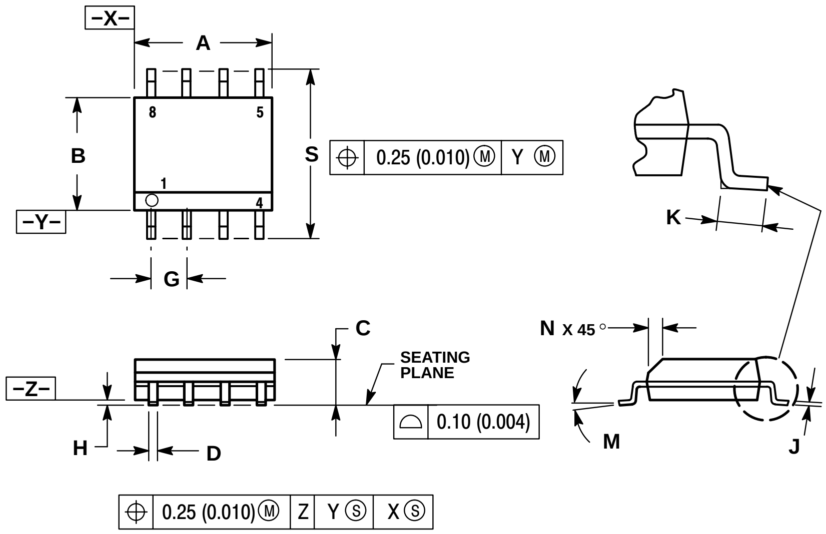
PDIP−8
N SUFFIX
CASE 626−05
ISSUE L



NOTES:
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	---	10°	---	10°
N	0.76	1.01	0.030	0.040

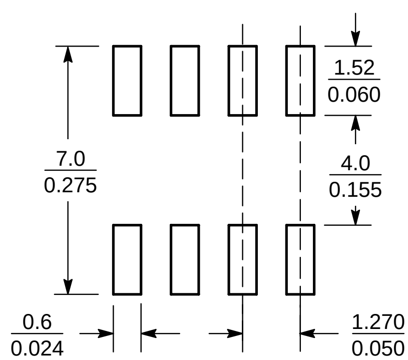
SOIC−8
D SUFFIX
CASE 751−07
ISSUE AC



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. 751−01 THRU 751−06 ARE OBSOLETE. NEW STANDARD IS 751−07.

	MILLIMETERS		INCHES	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	4.80	5.00	0.189	0.197
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.053	0.069
D	0.33	0.51	0.013	0.020
G	1.27 BSC		0.050 BSC	
H	0.10	0.25	0.004	0.010
J	0.19	0.25	0.007	0.010
K	0.40	1.27	0.016	0.050
M	0 °	8 °	0 °	8 °
N	0.25	0.50	0.010	0.020
S	5.80	6.20	0.228	0.244

SOLDERING FOOTPRINT*



SCALE 6:1 $\left(\frac{mm}{inches}\right)$

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 61312, Phoenix, Arizona 85082−1312 USA
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Fax: 480−829−7709 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

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Japan: ON Semiconductor, Japan Customer Focus Center
2−9−1 Kamimeguro, Meguro−ku, Tokyo, Japan 153−0051
Phone: 81−3−5773−3850

ON Semiconductor Website: http://onsemi.com

Order Literature: http://www.onsemi.com/litorder

For additional information, please contact your local Sales Representative.

MC78XX/LM78XX/MC78XXA

3-Terminal 1A Positive Voltage Regulator

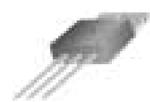
Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The MC78XX/LM78XX/MC78XXA series of three terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

TO-220



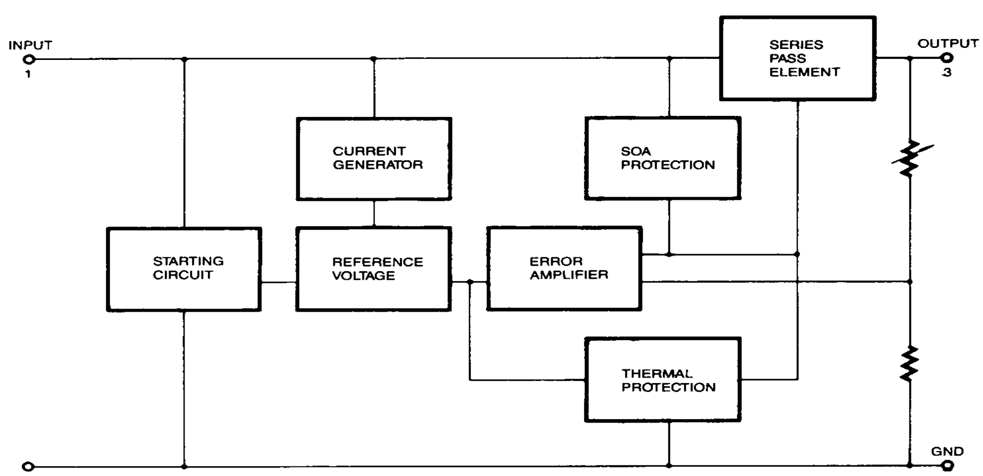
1

D-PAK

1

1. Input 2. GND 3. Output

Internal Block Digram



Rev. 1.0.1

Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	$^oC/W$
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	$^oC/W$
Operating Temperature Range	T_{OPR}	0 ~ +125	^oC
Storage Temperature Range	T_{STG}	-65 ~ +150	^oC

Electrical Characteristics (MC7805/LM7805)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I = 10V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7805/LM7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 ^oC		4.8	5.0	5.2	V
		5.0mA $\leq$ Io $\leq$ 1.0A, P_O $\leq$ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 ^oC	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 ^oC	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 ^oC		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/ ^oC
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 ^oC		-	42	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 ^oC		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 ^oC		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 ^oC		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7806)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =11V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7806 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		5.75	6.0	6.25	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 8.0V to 21V		5.7	6.0	6.3	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 8V to 25V	-	5	120	mV
			V_I = 9V to 13V	-	1.5	60	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O =5mA to 1.5A	-	9	120	mV
			I_O =250mA to750A	-	3	60	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8V to 25V		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	45	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 9V to 19V		59	75	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7808)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =14V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7808 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		7.7	8.0	8.3	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 10.5V to 23V		7.6	8.0	8.4	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 10.5V to 25V	-	5.0	160	mV
			V_I = 11.5V to 17V	-	2.0	80	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5.0mA to 1.5A	-	10	160	mV
			I_O= 250mA to 750mA	-	5.0	80	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.05	0.5	mA
		V_I = 10.5A to 25V		-	0.5	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	52	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, V_I= 11.5V to 21.5V		56	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7809)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =15V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7809 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25°C		8.65	9	9.35	V
		5.0mA≤ I_O ≤1.0A, P_O ≤15W V_I= 11.5V to 24V		8.6	9	9.4	
Line Regulation (Note1)	Regline	T_J=+25°C	V_I = 11.5V to 25V	-	6	180	mV
			V_I = 12V to 17V	-	2	90	
Load Regulation (Note1)	Regload	T_J=+25°C	I_O = 5mA to 1.5A	-	12	180	mV
			I_O = 250mA to 750mA	-	4	90	
Quiescent Current	I_Q	T_J=+25°C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	**mA**
		V_I = 11.5V to 26V		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	58	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 13V to 23V		56	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25°C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25°C		-	250	-	mA
Peak Current	I_{PK}	T_J= +25°C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7810)

(Refer to test circuit ,0°C< T_J < 125°C, I_O = 500mA, V_I =16V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7810 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		9.6	10	10.4	V
		5.0mA ≤ I_O≤1.0A, P_O ≤15W V_I = 12.5V to 25V		9.5	10	10.5	
Line Regulation (Note1)	Regline	T_J =+25°C	V_I = 12.5V to 25V	-	10	200	mV
			V_I = 13V to 25V	-	3	100	
Load Regulation (Note1)	Regload	T_J =+25°C	I_O = 5mA to 1.5A	-	12	200	mV
			I_O = 250mA to 750mA	-	4	400	
Quiescent Current	I_Q	T_J =+25°C		-	5.1	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 12.5V to 29V		-	-	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	58	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 13V to 23V		56	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7812)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =19V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7812 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		11.5	12	12.5	V
		5.0mA ≤ I_O≤1.0A, P_O≤15W V_I = 14.5V to 27V		11.4	12	12.6	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 14.5V to 30V	-	10	240	mV
			V_I = 16V to 22V	-	3.0	120	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	11	240	mV
			I_O = 250mA to 750mA	-	5.0	120	
Quiescent Current	I_Q	T_J =+25 °C		-	5.1	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.1	0.5	mA
		V_I = 14.5V to 30V		-	0.5	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	76	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 15V to 25V		55	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	18	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J = +25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7815)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =23V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7815			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		14.4	15	15.6	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 17.5V to 30V		14.25	15	15.75	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 17.5V to 30V	-	11	300	mV
			V_I = 20V to 26V	-	3	150	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	12	300	mV
			I_O = 250mA to 750mA	-	4	150	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 17.5V to 30V		-	-	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	90	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 18.5V to 28.5V		54	70	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7818)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =27V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7818 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		17.3	18	18.7	V
		5.0mA ≤ I_O ≤1.0A, P_O ≤15W V_I = 21V to 33V		17.1	18	18.9	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 21V to 33V	-	15	360	mV
			V_I = 24V to 30V	-	5	180	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	15	360	mV
			I_O = 250mA to 750mA	-	5.0	180	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 21V to 33V		-	-	1	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	110	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 22V to 32V		53	69	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	22	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7824)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =33V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7824 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		23	24	25	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 27V to 38V		22.8	24	25.25	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 27V to 38V	-	17	480	mV
			V_I = 30V to 36V	-	6	240	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	15	480	mV
			I_O = 250mA to 750mA	-	5.0	240	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.1	0.5	mA
		V_I = 27V to 38V		-	0.5	1	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1.5	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	60	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 28V to 38V		50	67	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	28	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7805A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_o =1A, V_I = 10V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 ^oC		4.9	5	5.1	V
		I_O = 5mA to 1A, $P_O \le$ 15W V_I = 7.5V to 20V		4.8	5	5.2	
Line Regulation (Note1)	Regline	V_I = 7.5V to 25V I_O = 500mA		-	5	50	mV
		V_I = 8V to 12V		-	3	50	
		T_J =+25 ^oC	V_I= 7.3V to 20V	-	5	50	
			V_I= 8V to 12V	-	1.5	25	
Load Regulation (Note1)	Regload	T_J =+25 ^oC I_O = 5mA to 1.5A		-	9	100	mV
		I_O = 5mA to 1A		-	9	100	
		I_O = 250mA to 750mA		-	4	50	
Quiescent Current	I_Q	T_J =+25 ^oC		-	5.0	6	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8 V to 25V, I_O = 500mA		-	-	0.8	
		V_I = 7.5V to 20V, T_J =+25 ^oC		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	Io = 5mA		-	-0.8	-	mV/ ^oC
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 ^oC		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 8V to 18V		-	68	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 ^oC		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 ^oC		-	250	-	mA
Peak Current	I_{PK}	T_J= +25 ^oC		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7806A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I =11V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		5.58	6	6.12	V
		I_O = 5mA to 1A, $P_O \leq$ 15W V_I = 8.6V to 21V		5.76	6	6.24	
Line Regulation (Note1)	Regline	V_I= 8.6V to 25V I_O = 500mA		-	5	60	mV
		V_I= 9V to 13V		-	3	60	
		T_J =+25 °C	V_I= 8.3V to 21V	-	5	60	
			V_I= 9V to 13V	-	1.5	30	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	9	100	mV
		I_O = 5mA to 1A		-	4	100	
		I_O = 250mA to 750mA		-	5.0	50	
Quiescent Current	I_Q	T_J =+25 °C		-	4.3	6	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 9V to 25V, I_O = 500mA		-	-	0.8	
		V_I= 8.5V to 21V, T_J =+25 °C		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 9V to 19V		-	65	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7808A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 14V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		7.84	8	8.16	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 10.6V to 23V		7.7	8	8.3	
Line Regulation (Note1)	Regline	V_I= 10.6V to 25V I_O = 500mA		-	6	80	mV
		V_I= 11V to 17V		-	3	80	
		T_J =+25 °C	V_I= 10.4V to 23V	-	6	80	
			V_I= 11V to 17V	-	2	40	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 11V to 25V, I_O = 500mA		-	-	0.8	
		V_I= 10.6V to 23V, T_J =+25 °C		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 11.5V to 21.5V		-	62	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	18	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7809A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 15V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25°C		8.82	9.0	9.18	V
		I_O = 5mA to 1A, P_O≤15W V_I = 11.2V to 24V		8.65	9.0	9.35	
Line Regulation (Note1)	Regline	V_I= 11.7V to 25V I_O = 500mA		-	6	90	mV
		V_I= 12.5V to 19V		-	4	45	
		T_J =+25°C	V_I= 11.5V to 24V	-	6	90	
			V_I= 12.5V to 19V	-	2	45	
Load Regulation (Note1)	Regload	T_J =+25°C I_O = 5mA to 1.0A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 11.7V to 25V, T_J=+25 °C		-	-	0.8	mA
		V_I = 12V to 25V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 12V to 22V		-	62	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25°C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant, junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7810A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 16V, C_I=0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25°C		9.8	10	10.2	V
		I_O = 5mA to 1A, $P_O \leq$ 15W V_I =12.8V to 25V		9.6	10	10.4	
Line Regulation (Note1)	Regline	V_I= 12.8V to 26V I_O = 500mA		-	8	100	mV
		V_I= 13V to 20V		-	4	50	
		T_J =+25 °C	V_I= 12.5V to 25V	-	8	100	
			V_I= 13V to 20V	-	3	50	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 13V to 26V, T_J=+25 °C		-	-	0.5	mA
		V_I = 12.8V to 25V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	μV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 14V to 24V		-	62	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25°C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7812A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 19V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		11.75	12	12.25	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 14.8V to 27V		11.5	12	12.5	
Line Regulation (Note1)	Regline	V_I= 14.8V to 30V I_O = 500mA		-	10	120	mV
		V_I= 16V to 22V		-	4	120	
		T_J =+25 °C	V_I= 14.5V to 27V	-	10	120	
			V_I= 16V to 22V	-	3	60	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25°C		-	5.1	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 15V to 30V, T_J=+25 °C		-		0.8	mA
		V_I = 14V to 27V, I_O = 500mA		-		0.8	
		I_O = 5mA to 1.0A		-		0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25°C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 14V to 24V		-	60	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25°C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	18	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7815A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I =23V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		14.7	15	15.3	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 17.7V to 30V		14.4	15	15.6	
Line Regulation (Note1)	Regline	V_I= 17.9V to 30V I_O = 500mA		-	10	150	mV
		V_I= 20V to 26V		-	5	150	
		T_J =+25°C	V_I= 17.5V to 30V	-	11	150	
			V_I= 20V to 26V	-	3	75	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	12	100	mV
		I_O = 5mA to 1.0A		-	12	100	
		I_O = 250mA to 750mA		-	5	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 17.5V to 30V, T_J =+25 °C		-	-	0.8	mA
		V_I = 17.5V to 30V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 18.5V to 28.5V		-	58	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25°C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7818A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 27V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		17.64	18	18.36	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 21V to 33V		17.3	18	18.7	
Line Regulation (Note1)	Regline	V_I= 21V to 33V I_O = 500mA		-	15	180	mV
		V_I= 21V to 33V		-	5	180	
		T_J =+25 °C	V_I= 20.6V to 33V	-	15	180	
			V_I= 24V to 30V	-	5	90	
Load Regulation (Note1)	Regload	T_J =+25°C I_O = 5mA to 1.5A		-	15	100	mV
		I_O = 5mA to 1.0A		-	15	100	
		I_O = 250mA to 750mA		-	7	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 21V to 33V, T_J=+25 °C		-	-	0.8	mA
		V_I = 21V to 33V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.0	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25°C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 22V to 32V		-	57	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25°C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25°C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7824A)

(Refer to the test circuits. 0°C < T_J < 125°C, I_O =1A, V_I = 33V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		23.5	24	24.5	V
		I_O = 5mA to 1A, P_O ≤15W V_I = 27.3V to 38V		23	24	25	
Line Regulation (Note1)	Regline	V_I= 27V to 38V I_O = 500mA		-	18	240	mV
		V_I= 21V to 33V		-	6	240	
		T_J =+25 °C	V_I= 26.7V to 38V	-	18	240	
			V_I= 30V to 36V	-	6	120	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	15	100	mV
		I_O = 5mA to 1.0A		-	15	100	
		I_O = 250mA to 750mA		-	7	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	6.0	mA
Quiescent Current Change	ΔI_Q	V_I = 27.3V to 38V, T_J =+25 °C		-	-	0.8	mA
		V_I = 27.3V to 38V, I_O = 500mA		-	-	0.8	
		I_O = 5mA to 1.0A		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-1.5	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A = 25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 28V to 38V		-	54	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2.0	-	V
Output Resistance	r_O	f = 1KHz		-	20	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Change in VO due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Typical Perfomance Characteristics

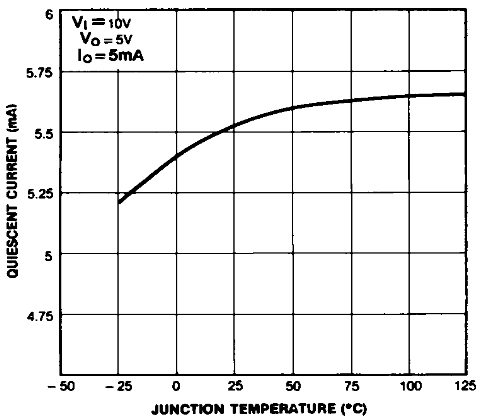


Figure 1. Quiescent Current

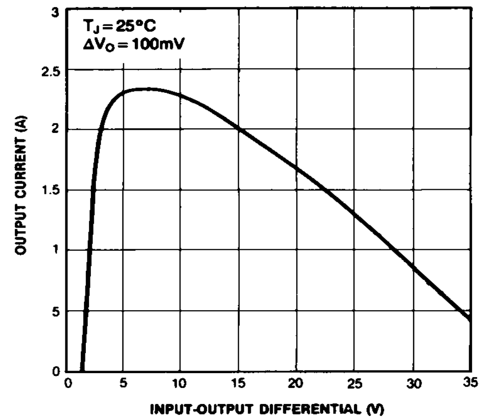


Figure 2. Peak Output Current

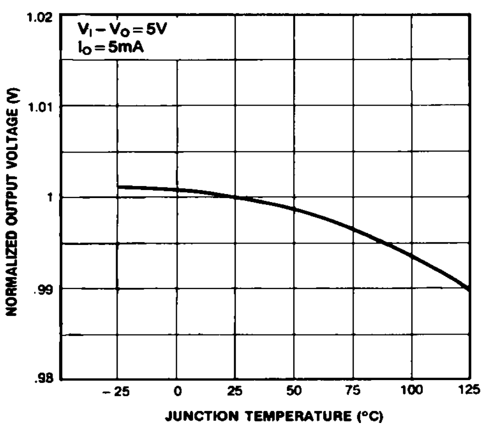


Figure 3. Output Voltage

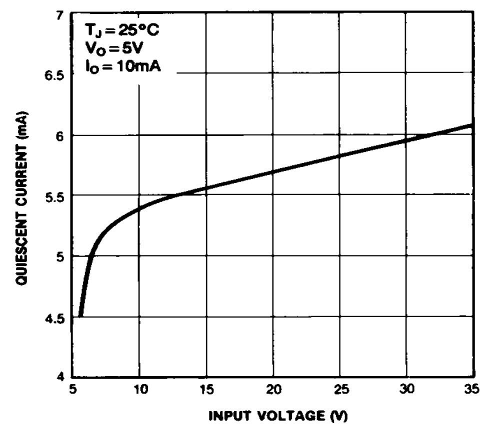


Figure 4. Quiescent Current

Typical Applications

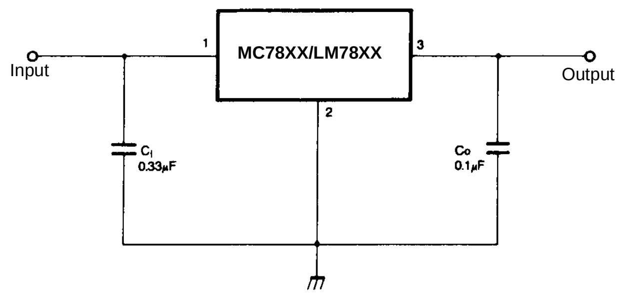


Figure 5. DC Parameters

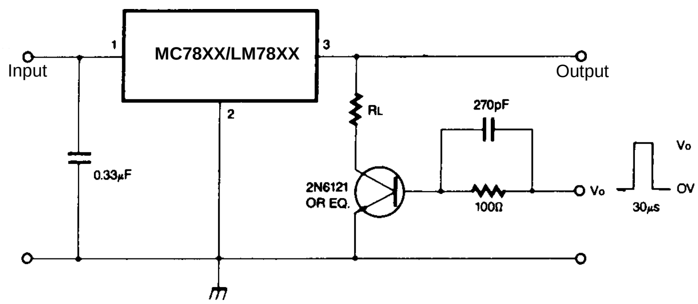


Figure 6. Load Regulation

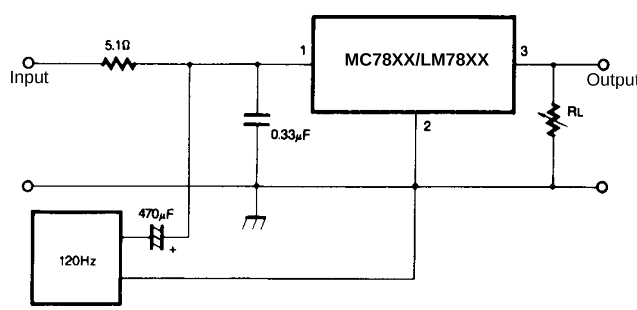


Figure 7. Ripple Rejection

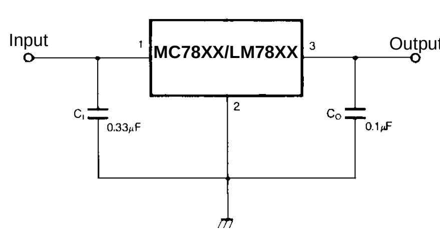
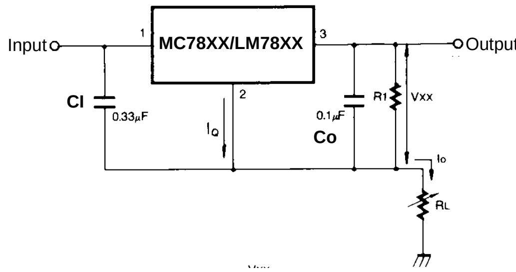


Figure 8. Fixed Output Regulator



$$I_o = \frac{V_{xx}}{R_1} + I_Q$$

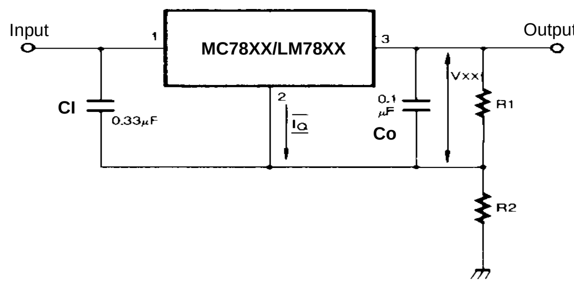
Figure 9. Constant Current Regulator

Notes:

(1) To specify an output voltage. substitute voltage value for "XX." A common ground is required between the input and the Output voltage. The input voltage must remain typically 2.0V above the output voltage even during the low point on the input ripple voltage.

(2) C_I is required if regulator is located an appreciable distance from power Supply filter.

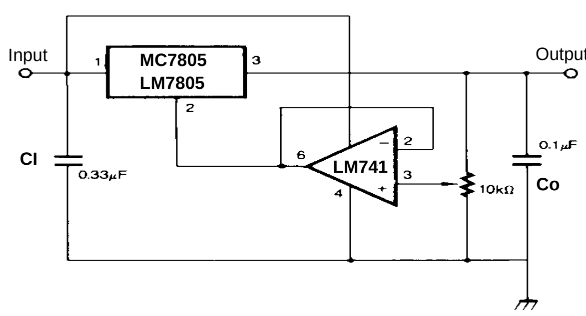
(3) C_O improves stability and transient response.



$$I_{RI} \geq 5I_Q$$

$$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$$

Figure 10. Circuit for Increasing Output Voltage



$$I_{RI} \geq 5\ I_Q$$

$$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$$

Figure 11. Adjustable Output Regulator (7 to 30V)

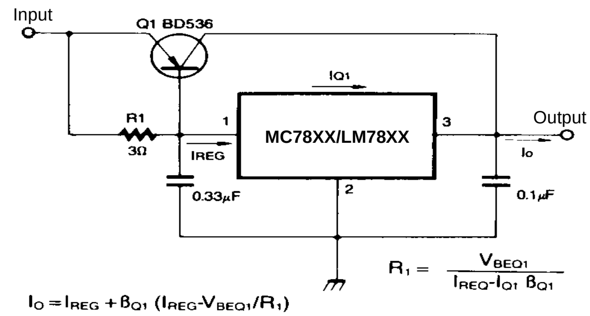


Figure 12. High Current Voltage Regulator

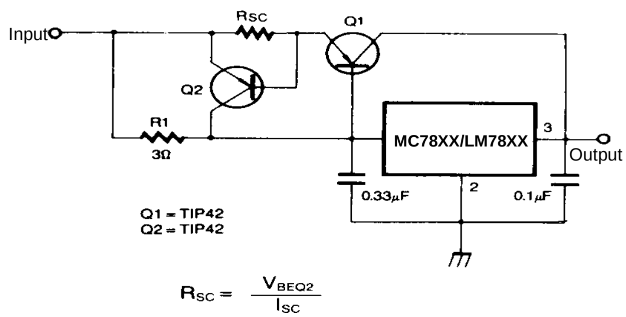


Figure 13. High Output Current with Short Circuit Protection

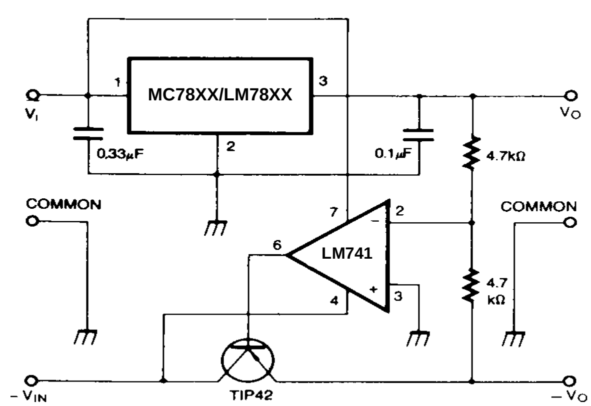


Figure 14. Tracking Voltage Regulator

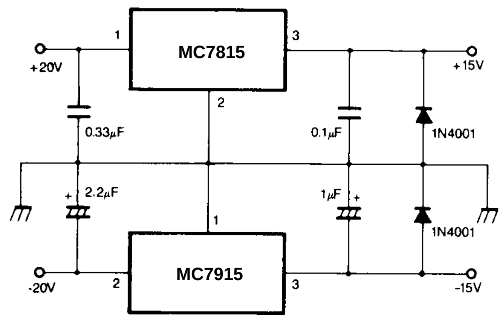


Figure 15. Split Power Supply (±15V-1A)

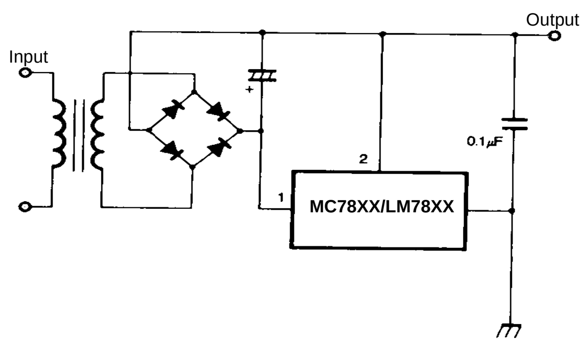


Figure 16. Negative Output Voltage Circuit

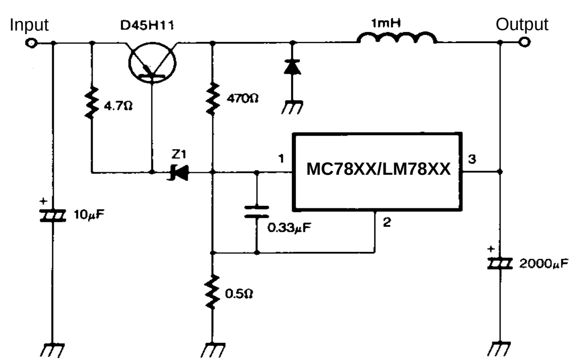
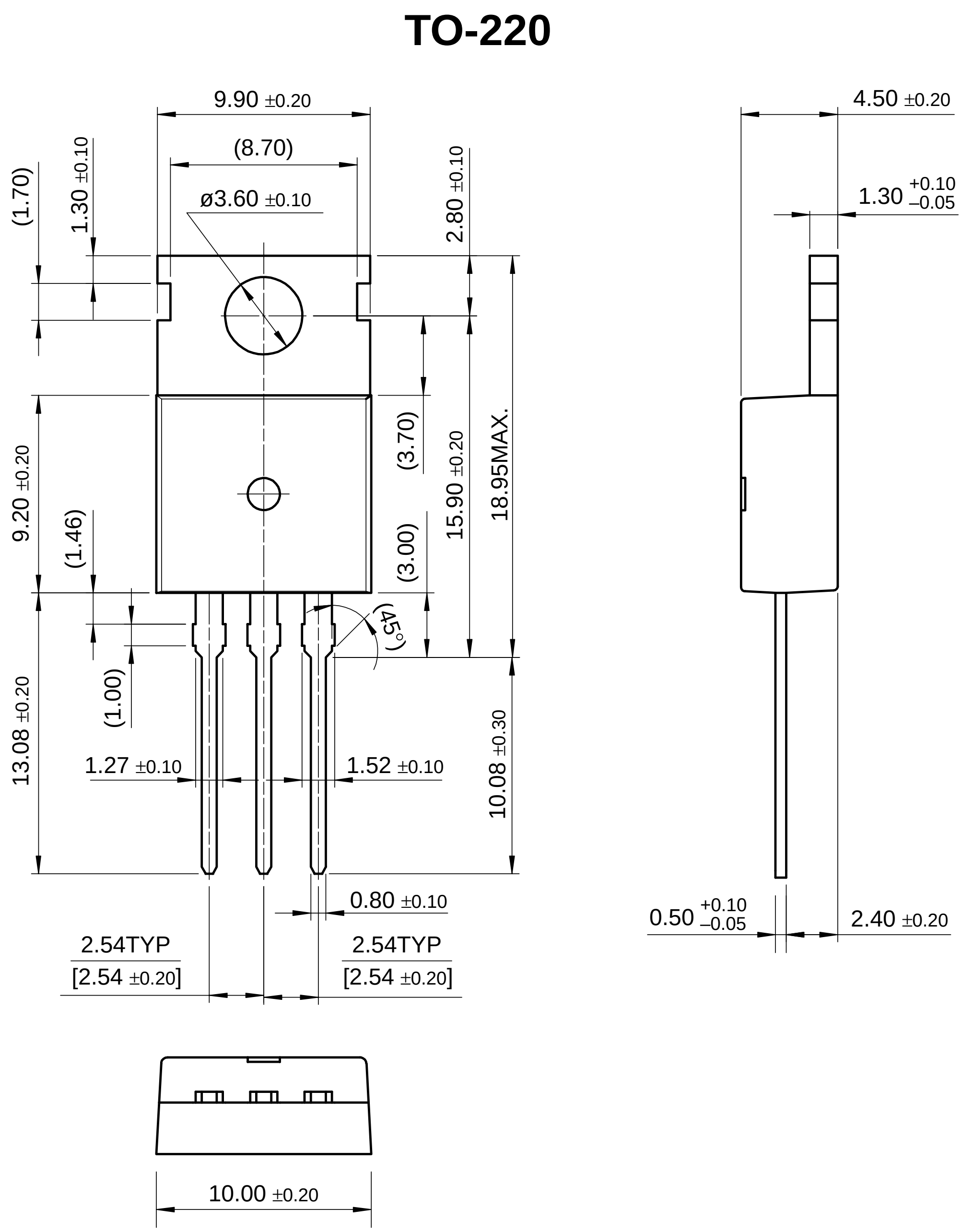


Figure 17. Switching Regulator

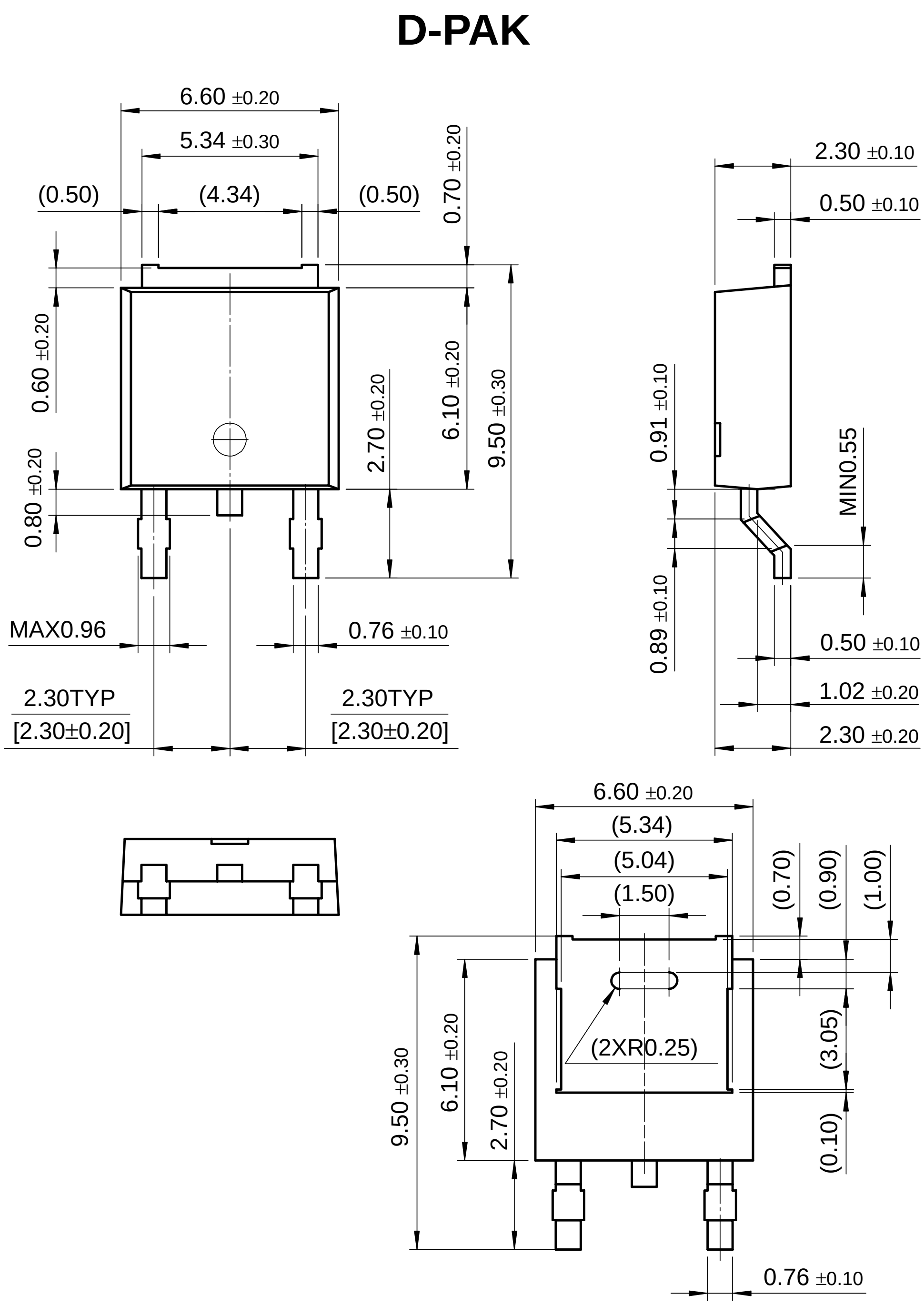
Mechanical Dimensions

Package



Mechancal Dimensions (Continued)

Package



Ordering Information

Product Number	Output Voltage Tolerance	Package	Operating Temperature
LM7805CT	±4%	TO-220	0 ~ + 125°C

Product Number	Output Voltage Tolerance	Package	Operating Temperature
MC7805CT	±4%	TO-220	0 ~ + 125°C
MC7806CT			
MC7808CT			
MC7809CT			
MC7810CT			
MC7812CT			
MC7815CT			
MC7818CT			
MC7824CT			
MC7805CDT		D-PAK	
MC7806CDT			
MC7808CDT			
MC7809CDT			
MC7810CDT			
MC7812CDT			
MC7805ACT	±2%	TO-220	
MC7806ACT			
MC7808ACT			
MC7809ACT			
MC7810ACT			
MC7812ACT			
MC7815ACT			
MC7818ACT			
MC7824ACT			

7/2/01 0.0m 001
Stock#DSxxxxxxxx

September 2001

National Semiconductor

LM79XX Series 3-Terminal Negative Regulators

General Description

The LM79XX series of 3-terminal regulators is available with fixed output voltages of −5V, −12V, and −15V. These devices need only one external component — a compensation capacitor at the output. The LM79XX series is packaged in the TO-220 power package and is capable of supplying 1.5A of output current.

These regulators employ internal current limiting safe area protection and thermal shutdown for protection against virtually all overload conditions.

Low ground pin current of the LM79XX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current drain of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

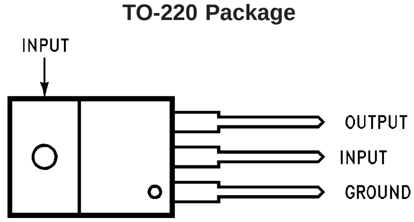
For applications requiring other voltages, see LM137 datasheet.

Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 1.5A output current
- 4% tolerance on preset output voltage

Connection Diagrams

TO-220 Package

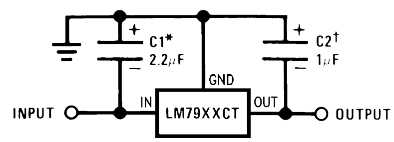


DS007340-14

Front View
Order Number LM7905CT, LM7912CT or LM7915CT
See NS Package Number TO3B

Typical Applications

Fixed Regulator



DS007340-3

*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100μF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_o = −5V)	−25V
(V_o = −12V and −15V)	−35V
Input-Output Differential	
(V_o = −5V)	25V
(V_o = −12V and −15V)	30V
Power Dissipation (Note 2)	Internally Limited
Operating Junction Temperature Range	0˚C to +125˚C
Storage Temperature Range	−65˚C to +150˚C
Lead Temperature (Soldering, 10 sec.)	230˚C

Electrical Characteristics

Conditions unless otherwise noted: I_{OUT} = 500mA, C_{IN} = 2.2µF, C_{OUT} = 1µF, 0˚C ≤ T_J ≤ +125˚C, Power Dissipation ≤ 1.5W.

Part Number			LM7905C			Units
Output Voltage			−5V			
Input Voltage (unless otherwise specified)			−10V			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	T_J = 25˚C	−4.8	−5.0	−5.2	V
		5mA ≤ I_{OUT} ≤ 1A,	−4.75		−5.25	V
		P ≤ 15W		(−20 ≤ V_{IN} ≤ −7)		V
ΔV_O	Line Regulation	T_J = 25˚C, (Note 3)		8	50	mV
				(−25 ≤ V_{IN} ≤ −7)		V
				2	15	mV
				(−12 ≤ V_{IN} ≤ −8)		V
ΔV_O	Load Regulation	T_J = 25˚C, (Note 3)				
		5mA ≤ I_{OUT} ≤ 1.5A		15	100	mV
		250mA ≤ I_{OUT} ≤ 750mA		5	50	mV
I_Q	Quiescent Current	T_J = 25˚C		1	2	mA
ΔI_Q	Quiescent Current Change	With Line			0.5	mA
				(−25 ≤ V_{IN} ≤ −7)		V
		With Load, 5mA ≤ I_{OUT} ≤ 1A			0.5	mA
V_n	Output Noise Voltage	T_A = 25˚C, 10Hz ≤ f ≤ 100Hz		125		µV
	Ripple Rejection	f = 120Hz	54	66		dB
				(−18 ≤ V_{IN} ≤ −8)		V
	Dropout Voltage	T_J = 25˚C, I_{OUT} = 1A		1.1		V
I_{OMAX}	Peak Output Current	T_J = 25˚C		2.2		A
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5mA, 0 C ≤ T_J ≤ 100˚C		0.4		mV/˚C

Electrical Characteristics

Conditions unless otherwise noted: I_{OUT} = 500mA, C_{IN} = 2.2µF, C_{OUT} = 1µF, 0˚C ≤ T_J ≤ +125˚C, Power Dissipation ≤ 1.5W.

Part Number			LM7912C			LM7915C			Units
Output Voltage			−12V			−15V			
Input Voltage (unless otherwise specified)			−19V			−23V			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	T_J = 25˚C	−11.5	−12.0	−12.5	−14.4	−15.0	−15.6	V
		5mA ≤ I_{OUT} ≤ 1A,	−11.4		−12.6	−14.25		−15.75	V
		P ≤ 15W		(−27 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)		V
ΔV_O	Line Regulation	T_J = 25˚C, (Note 3)		5	80		5	100	mV
				(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN}≤ −17.5)		V
				3	30		3	50	mV
				(−22 ≤ V_{IN} ≤ −16)			(−26 ≤ V_{IN} ≤−20)		V
ΔV_O	Load Regulation	T_J = 25˚C, (Note 3)							

Electrical Characteristics (Continued)

Conditions unless otherwise noted: I_{OUT} = 500mA, C_{IN} = 2.2µF, C_{OUT} = 1µF, 0˚C ≤ T_J ≤ +125˚C, Power Dissipation ≤ 1.5W.

Part Number			LM7912C			LM7915C			Units
Output Voltage			−12V			−15V			
Input Voltage (unless otherwise specified)			−19V			−23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	
		5mA ≤ I_{OUT} ≤ 1.5A		15	200		15	200	mV
		250mA ≤ I_{OUT} ≤ 750mA		5	75		5	75	mV
I_Q	Quiescent Current	T_J = 25˚C		1.5	3		1.5	3	mA
ΔI_Q	Quiescent Current Change	With Line			0.5			0.5	mA
				(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)		V
		With Load, 5mA ≤ I_{OUT} ≤ 1A			0.5			0.5	mA
V_n	Output Noise Voltage	T_A = 25˚C, 10Hz ≤ f ≤ 100Hz		300			375		µV
	Ripple Rejection	f = 120 Hz	54	70		54	70		dB
				(−25 ≤ V_{IN} ≤ −15)			(−30 ≤ V_{IN} ≤ −17.5)		V
	Dropout Voltage	T_J = 25˚C, I_{OUT} = 1A		1.1			1.1		V
I_{OMAX}	Peak Output Current	T_J = 25˚C		2.2			2.2		A
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5mA, 0 C ≤ T_J ≤ 100˚C		−0.8			−1.0		mV/˚C

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee Specific Performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Refer to Typical Performance Characteristics and Design Considerations for details.

Note 3: Regulation is measured at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

Design Considerations

The LM79XX fixed voltage regulator series has thermal overload protection from excessive power dissipation, internal short circuit protection which limits the circuit's maximum current, and output transistor safe-area compensation for reducing the output current as the voltage across the pass transistor is increased.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature (125˚C) in order to meet data sheet specifications. To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

Package	Typ θ_{JC} ˚C/W	Max θ_{JC} ˚C/W	Typ θ_{JA} ˚C/W	Max θ_{JA} ˚C/W
TO-220	3.0	5.0	60	40

$$P_{D\,MAX} = \frac{T_{J\,Max} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or } \frac{T_{J\,Max}\ \ T_A}{\theta_{JA}}$$

$$\theta_{CA} = \theta_{CS} + \theta_{SA} \text{ (without heat sink)}$$

Solving for T_J:

$T_J = T_A + P_D (\theta_{JC} + \theta_{CA})$ or

$= T_A + P_D\theta_{JA}$ (without heat sink)

Where:

T_J = Junction Temperature

T_A = Ambient Temperature

P_D = Power Dissipation

θ_{JA} = Junction-to-Ambient Thermal Resistance

θ_{JC} = Junction-to-Case Thermal Resistance

θ_{CA} = Case-to-Ambient Thermal Resistance

θ_{CS} = Case-to-Heat Sink Thermal Resistance

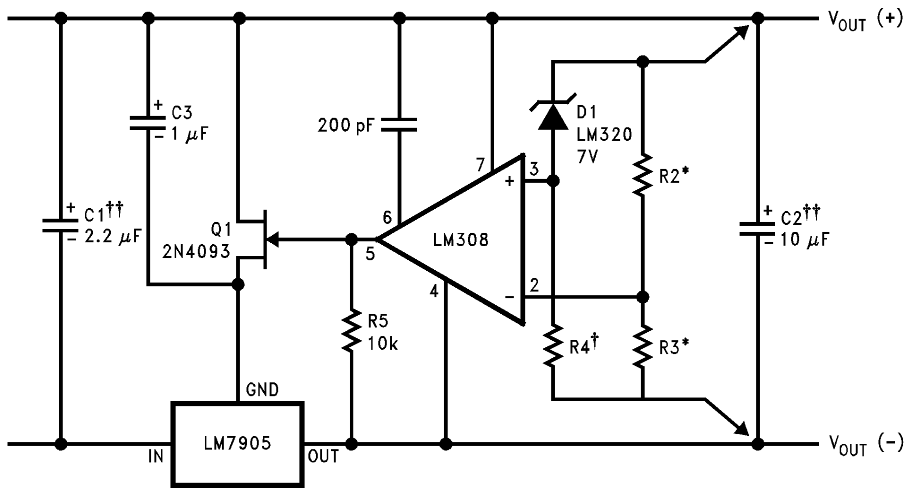
θ_{SA} = Heat Sink-to-Ambient Thermal Resistance

Typical Applications

Bypass capacitors are necessary for stable operation of the LM79XX series of regulators over the input voltage and output current ranges. Output bypass capacitors will improve the transient response by the regulator.

The bypass capacitors, (2.2µF on the input, 1.0µF on the output) should be ceramic or solid tantalum which have good high frequency characteristics. If aluminum electrolytics are used, their values should be 10µF or larger. The bypass capacitors should be mounted with the shortest leads, and if possible, directly across the regulator terminals.

High Stability 1 Amp Regulator



DS007340-5

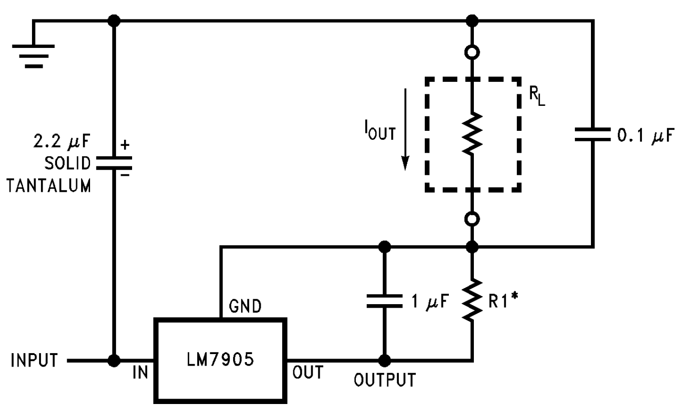
Load and line regulation < 0.01% temperature stability ≤ 0.2%

†Determine Zener current

††Solid tantalum

*Select resistors to set output voltage. 2 ppm/°C tracking suggested

Current Source

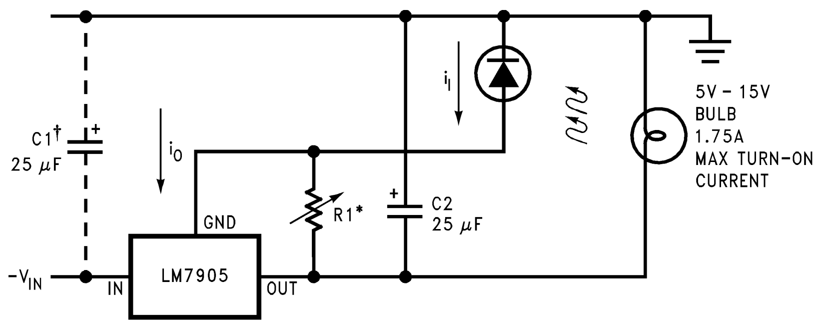


DS007340-7

$$^{*}I_{OUT} = 1\ \text{mA} + \frac{5V}{R1}$$

Typical Applications (Continued)

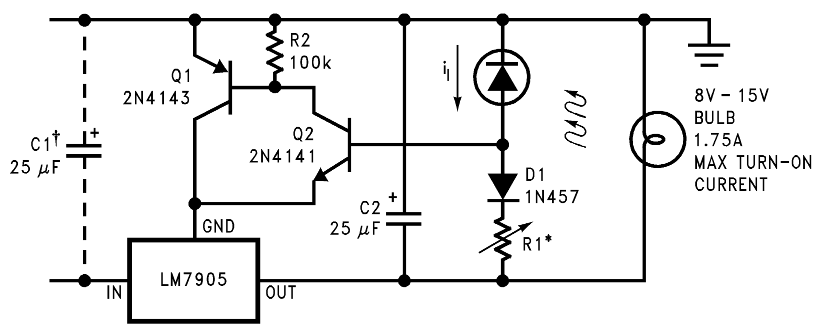
Light Controller Using Silicon Photo Cell



DS007340-8

*Lamp brightness increase until $i_l = i_Q$ (≈ 1 mA) + 5V/R1.
†Necessary only if raw supply filter capacitor is more that 2" from LM7905CT

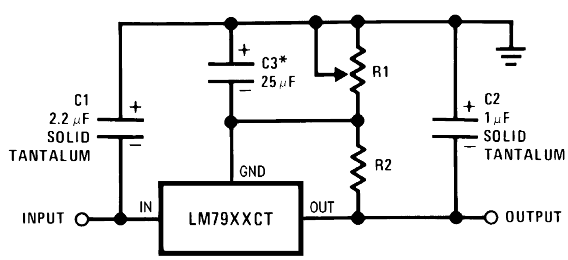
High-Sensitivity Light Controller



DS007340-9

*Lamp brightness increases until i_i = 5V/R1 (I_i can be set as low as 1 µA)
†Necessary only if raw supply filter capacitor is more that 2" from LM7905

Variable Output



DS007340-2

*Improves transient response and ripple rejection. Do not increase beyond 50 µF.

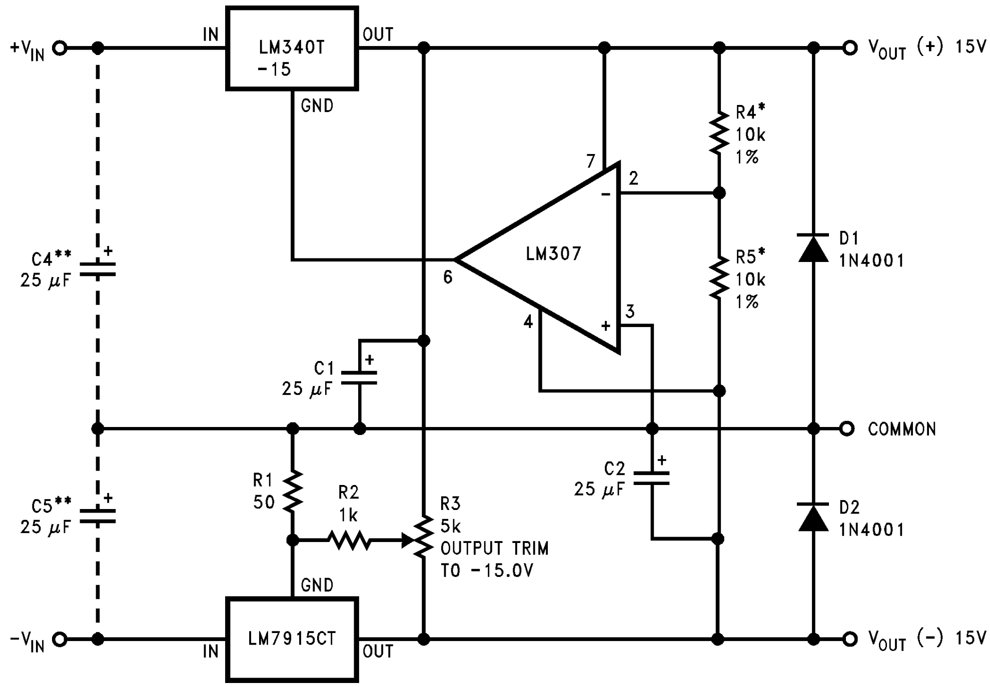
$$V_{OUT} = V_{SET}\left(\frac{R1 + R2}{R2}\right)$$

Select R2 as follows:

LM7905CT	300Ω
LM7912CT	750Ω
LM7915CT	1k

Typical Applications (Continued)

±15V, 1 Amp Tracking Regulators



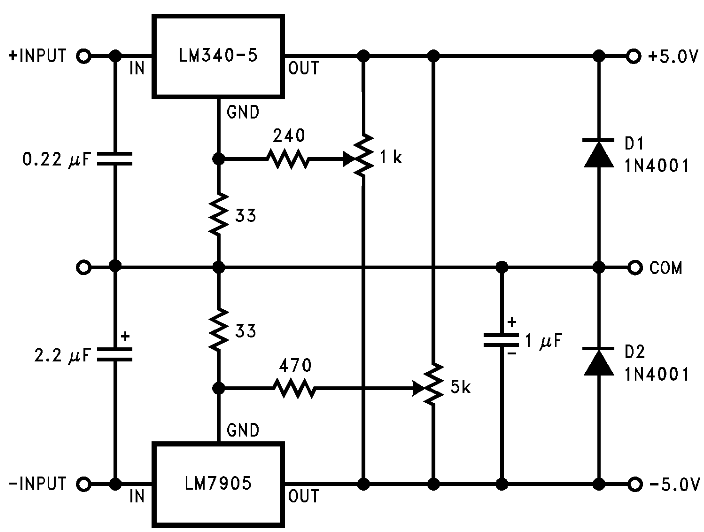
DS007340-1

	(-15)	(+15)
Load Regulation at ΔI_L = 1A	40mV	2mV
Output Ripple, C_{IN} = 3000µF, I_L = 1A	100 µVms	100 µVms
Temperature Stability	50mV	50mV
Output Noise 10Hz ≤ f ≤ 10kHz	150 µVms	150 µVms

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs.

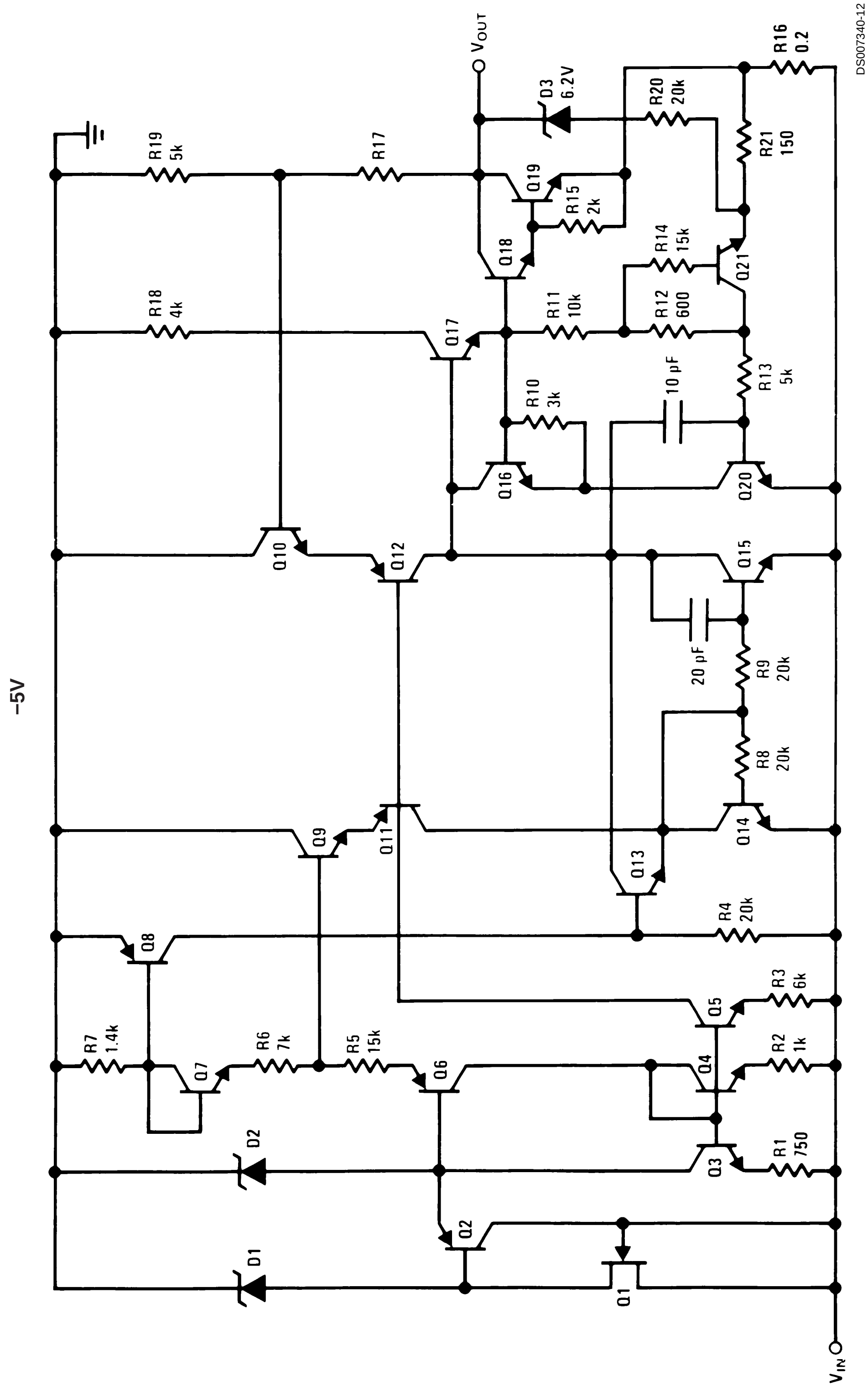
**Necessary only if raw supply filter capacitors are more than 3" from regulators.

Dual Trimmed Supply



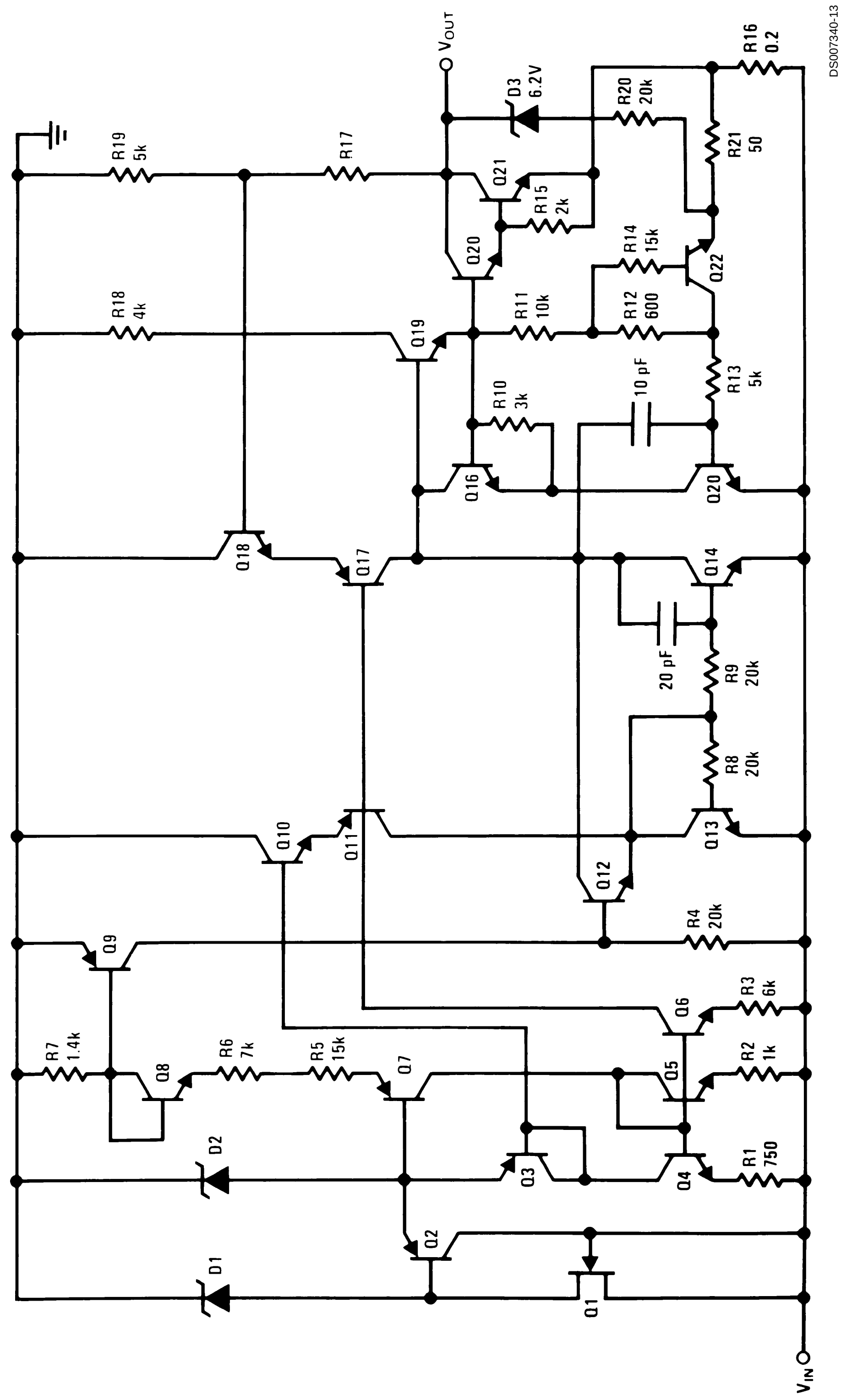
DS007340-4

Schematic Diagrams



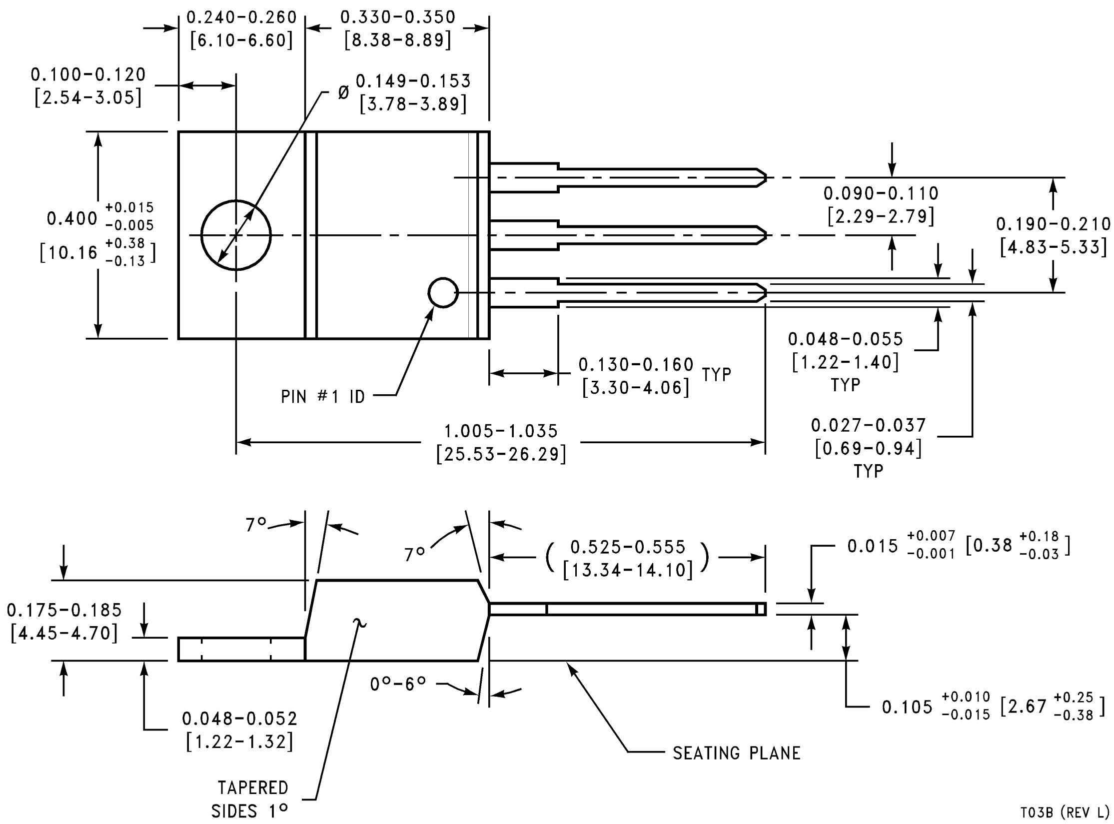
DS007340-12

Schematic Diagrams (Continued)



−12V and −15V

Physical Dimensions inches (millimeters) unless otherwise noted



TO-220 Outline Package (T)
Order Number LM7905CT, LM7912CT or LM7915CT
NS Package Number T03B

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National Semiconductor Corporation
Americas
Email: support@nsc.com

www.national.com

National Semiconductor Europe
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: ap.support@nsc.com

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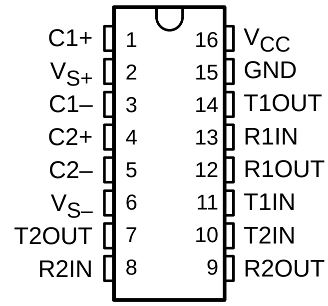
- **Meet or Exceed TIA/EIA-232-F and ITU Recommendation V.28**
- **Operate With Single 5-V Power Supply**
- **Operate Up to 120 kbit/s**
- **Two Drivers and Two Receivers**
- **±30-V Input Levels**
- **Low Supply Current . . . 8 mA Typical**
- **Designed to be Interchangeable With Maxim MAX232**
- **ESD Protection Exceeds JESD 22**
  – 2000-V Human-Body Model (A114-A)
- **Applications**
  TIA/EIA-232-F
  Battery-Powered Systems
  Terminals
  Modems
  Computers

MAX232 . . . D, DW, N, OR NS PACKAGE
MAX232I . . . D, DW, OR N PACKAGE
(TOP VIEW)



description/ordering information

The MAX232 is a dual driver/receiver that includes a capacitive voltage generator to supply EIA-232 voltage levels from a single 5-V supply. Each receiver converts EIA-232 inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V and a typical hysteresis of 0.5 V, and can accept ±30-V inputs. Each driver converts TTL/CMOS input levels into EIA-232 levels. The driver, receiver, and voltage-generator functions are available as cells in the Texas Instruments LinASIC™ library.

ORDERING INFORMATION

T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP (N)	Tube	MAX232N	MAX232N
	SOIC (D)	Tube	MAX232D	MAX232
		Tape and reel	MAX232DR	
	SOIC (DW)	Tube	MAX232DW	MAX232
		Tape and reel	MAX232DWR	
	SOP (NS)	Tape and reel	MAX232NSR	MAX232
–40°C to 85°C	PDIP (N)	Tube	MAX232IN	MAX232IN
	SOIC (D)	Tube	MAX232ID	MAX232I
		Tape and reel	MAX232IDR	
	SOIC (DW)	Tube	MAX232IDW	MAX232I
		Tape and reel	MAX232IDWR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

Function Tables

EACH DRIVER

INPUT TIN	OUTPUT TOUT
L	H
H	L

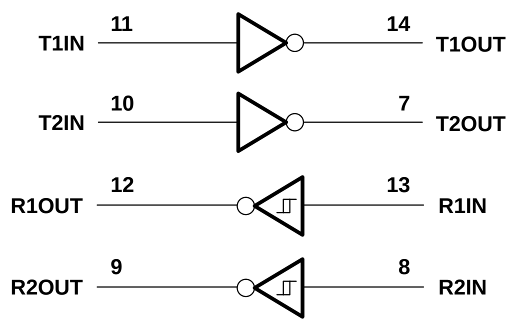
H = high level, L = low level

EACH RECEIVER

INPUT RIN	OUTPUT ROUT
L	H
H	L

H = high level, L = low level

logic diagram (positive logic)



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Input supply voltage range, V_{CC} (see Note 1) . . . . –0.3 V to 6 V
Positive output supply voltage range, V_{S+} . . . . V_{CC} – 0.3 V to 15 V
Negative output supply voltage range, $V_{S–}$ . . . . –0.3 V to –15 V
Input voltage range, V_I: Driver . . . . –0.3 V to V_{CC} + 0.3 V
Receiver . . . . ±30 V
Output voltage range, V_O: T1OUT, T2OUT . . . . $V_{S–}$ – 0.3 V to V_{S+} + 0.3 V
R1OUT, R2OUT . . . . –0.3 V to V_{CC} + 0.3 V
Short-circuit duration: T1OUT, T2OUT . . . . Unlimited
Package thermal impedance, θ_{JA} (see Note 2): D package . . . . 73°C/W
DW package . . . . 57°C/W
N package . . . . 67°C/W
NS package . . . . 64°C/W
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . 260°C
Storage temperature range, T_{stg} . . . . –65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to network ground terminal.
2. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

			MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage		4.5	5	5.5	V
V_{IH}	High-level input voltage (T1IN,T2IN)		2			V
V_{IL}	Low-level input voltage (T1IN, T2IN)				0.8	V
R1IN, R2IN	Receiver input voltage				±30	V
T_A	Operating free-air temperature	MAX232	0		70	°C
		MAX232I	–40		85	

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Note 3 and Figure 4)

PARAMETER		TEST CONDITIONS	MIN	TYP‡	MAX	UNIT
I_{CC}	Supply current	V_{CC} = 5.5 V, All outputs open, T_A = 25°C		8	10	mA

‡ All typical values are at V_{CC} = 5 V and T_A = 25°C.
NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

DRIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

PARAMETER			TEST CONDITIONS	MIN	TYP†	MAX	UNIT
V_{OH}	High-level output voltage	T1OUT, T2OUT	R_L = 3 kΩ to GND	5	7		V
V_{OL}	Low-level output voltage‡	T1OUT, T2OUT	R_L = 3 kΩ to GND		–7	–5	V
r_o	Output resistance	T1OUT, T2OUT	$V_{S+} = V_{S-} = 0$, $V_O = \pm 2$ V	300			Ω
I_{OS}§	Short-circuit output current	T1OUT, T2OUT	V_{CC} = 5.5 V, V_O = 0		±10		mA
I_{IS}	Short-circuit input current	T1IN, T2IN	V_I = 0			200	µA

† All typical values are at V_{CC} = 5 V, T_A = 25°C.
‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.
§ Not more than one output should be shorted at a time.
NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 3)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SR	Driver slew rate	R_L = 3 kΩ to 7 kΩ, See Figure 2			30	V/µs
SR(t)	Driver transition region slew rate	See Figure 3		3		V/µs
	Data rate	One TOUT switching		120		kbit/s

NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

RECEIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

PARAMETER			TEST CONDITIONS	MIN	TYP†	MAX	UNIT
V_{OH}	High-level output voltage	R1OUT, R2OUT	I_{OH} = –1 mA	3.5			V
V_{OL}	Low-level output voltage‡	R1OUT, R2OUT	I_{OL} = 3.2 mA			0.4	V
V_{IT+}	Receiver positive-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C		1.7	2.4	V
V_{IT-}	Receiver negative-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C	0.8	1.2		V
V_{hys}	Input hysteresis voltage	R1IN, R2IN	V_{CC} = 5 V	0.2	0.5	1	V
r_i	Receiver input resistance	R1IN, R2IN	V_{CC} = 5, T_A = 25°C	3	5	7	kΩ

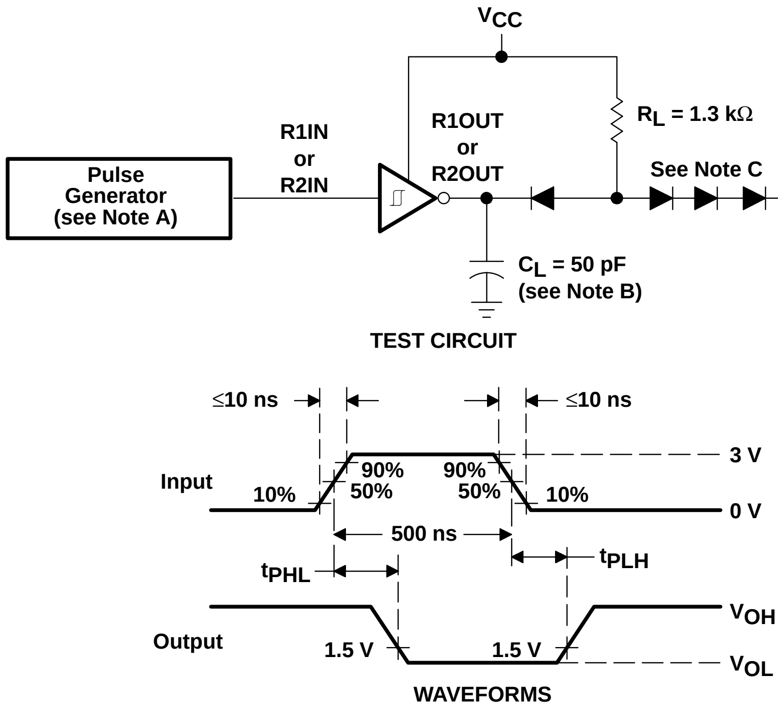
† All typical values are at V_{CC} = 5 V, T_A = 25°C.
‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.
NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 3 and Figure 1)

PARAMETER		TYP	UNIT
$t_{PLH(R)}$	Receiver propagation delay time, low- to high-level output	500	ns
$t_{PHL(R)}$	Receiver propagation delay time, high- to low-level output	500	ns

NOTE 3: Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

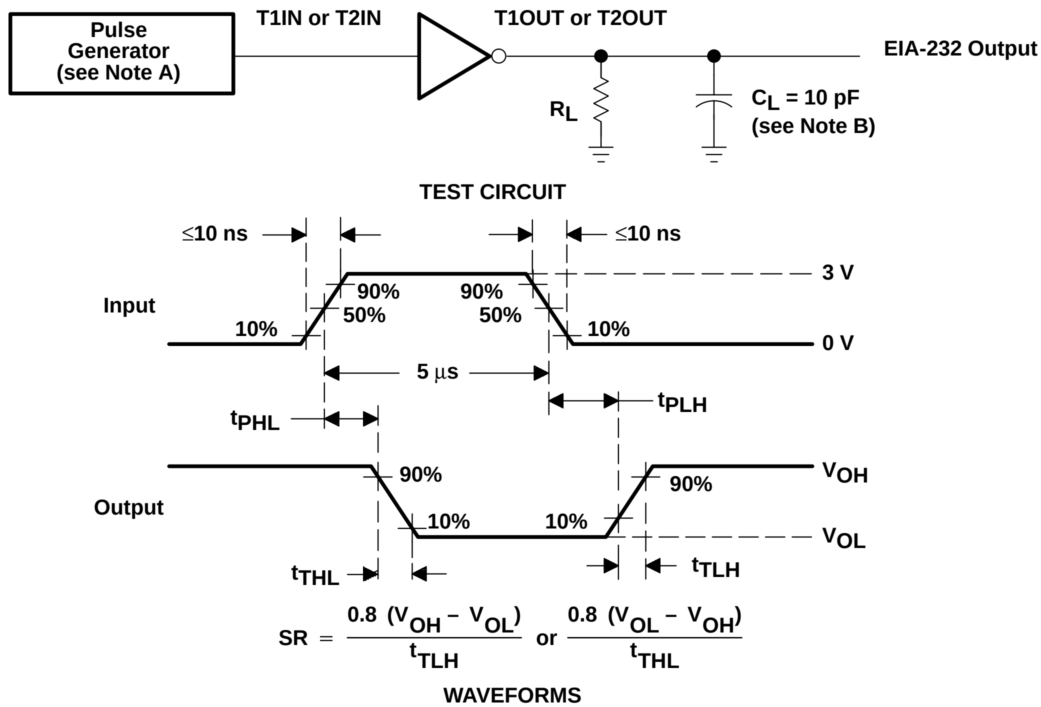
PARAMETER MEASUREMENT INFORMATION



NOTES: A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.
B. C_L includes probe and jig capacitance.
C. All diodes are 1N3064 or equivalent.

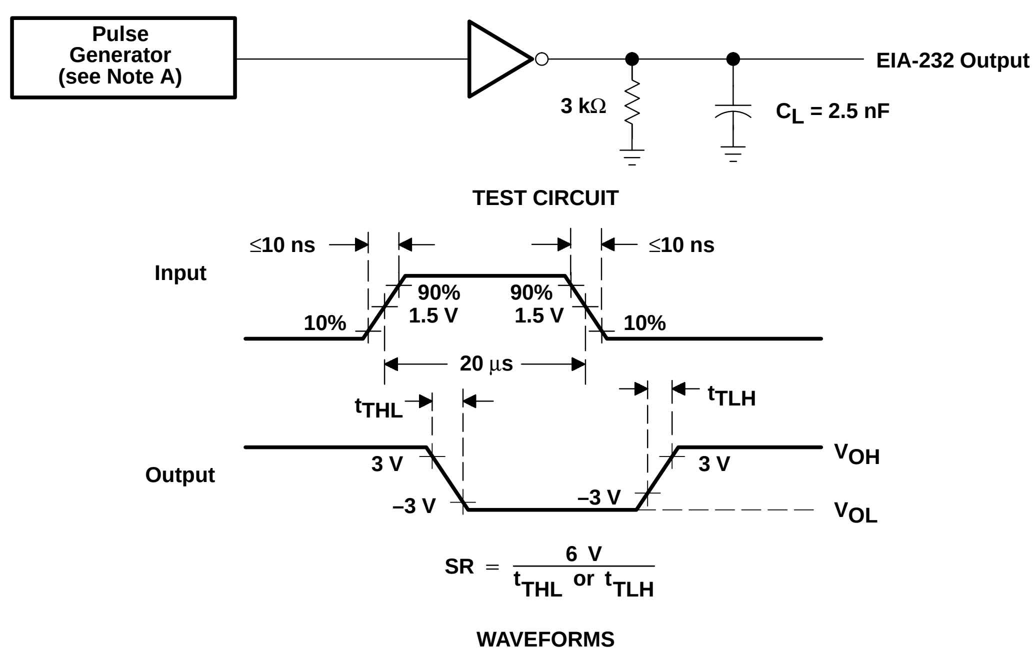
Figure 1. Receiver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements

PARAMETER MEASUREMENT INFORMATION



NOTES: A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.
B. C_L includes probe and jig capacitance.

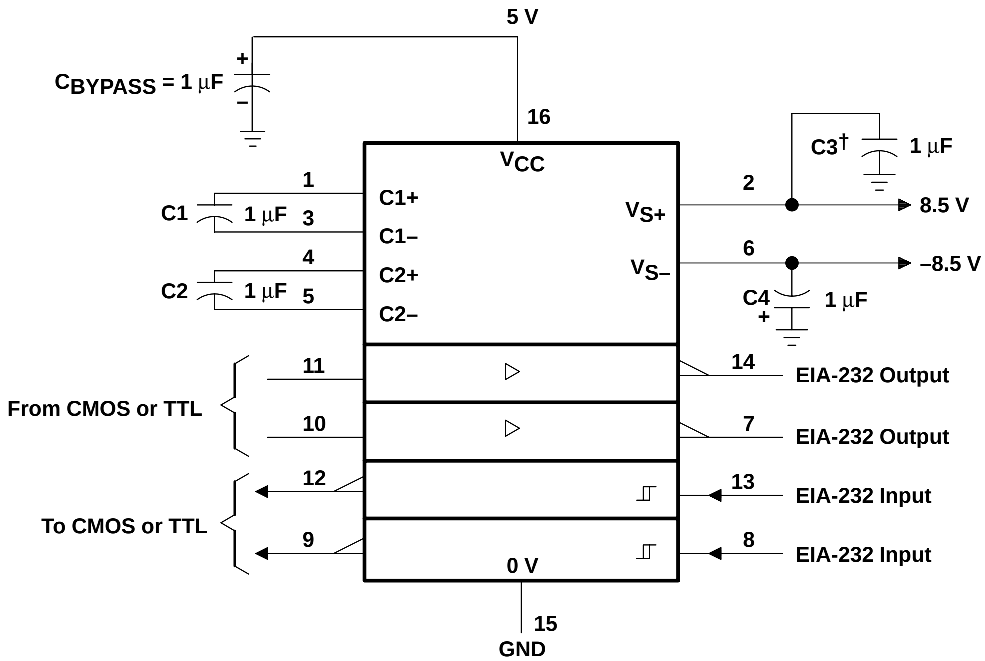
Figure 2. Driver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements (5-µs Input)



NOTE A: The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.

Figure 3. Test Circuit and Waveforms for t_{THL} and t_{TLH} Measurements (20-µs Input)

APPLICATION INFORMATION



† C3 can be connected to V_{CC} or GND.

Figure 4. Typical Operating Circuit

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Power-Supply Monitor with Reset

General Description

The MAX700/701/702 are supervisory circuits used to monitor the power supplies in µP and digital systems. The $\overline{\text{RESET}}$/RESET outputs of the MAX700/701/702 are guaranteed to be in the correct state for V_{CC} voltages down to +1V (Figure 4). They provide excellent circuit reliability and low cost by eliminating external components and adjustments when used with +5V powered circuits.

The MAX702 is the simplest part in the family. When V_{CC} falls to 4.65V, $\overline{\text{RESET}}$ goes low. The MAX702 also provides a debounced manual reset input. The MAX701 performs the same functions but has both $\overline{\text{RESET}}$ and RESET outputs. Their primary function is to provide a system reset. Accordingly, an active reset signal is supplied for low supply voltages and for at least 200ms after the supply voltage reaches its operating value.

In addition to the features of the MAX701 and MAX702, the MAX700 provides preset or adjustable voltage detection so thresholds other than 4.65V can be selected, and adjustable hysteresis. All parts are supplied in 8-pin Plastic DIP and Narrow SO packages in commercial and extended temperature ranges.

Applications

Computers

Controllers

Intelligent Instruments

Automotive Systems

Critical µP Power Monitoring

Features

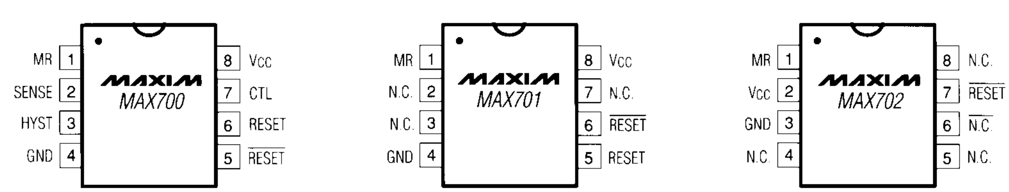
- ♦ **Min 200ms $\overline{\text{RESET}}$ Pulse on Power-Up, Power-Down, and During Low-Voltage Conditions**
- ♦ **Reset Threshold Factory Trimmed for +5V Systems**
- ♦ **No External Components or Adjustments With +5V Powered Circuits**
- ♦ **Debounced Manual Reset Input**
- ♦ **Preset or Adjustable Voltage Detection (MAX700)**
- ♦ **Adjustable Hysteresis (MAX700)**
- ♦ **8-Pin Plastic DIP and Narrow SO Packages**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX700CPA	0°C to +70°C	8 Plastic DIP
MAX700CSA	0°C to +70°C	8 Narrow SO
MAX700C/D	0°C to +70°C	Dice
MAX700EPA	-40°C to +85°C	8 Plastic DIP
MAX700ESA	-40°C to +85°C	8 Narrow SO
MAX701CPA	0°C to +70°C	8 Plastic DIP
MAX701CSA	0°C to +70°C	8 Narrow SO
MAX701C/D	0°C to +70°C	Dice
MAX701EPA	-40°C to +85°C	8 Plastic DIP
MAX701ESA	-40°C to +85°C	8 Narrow SO
MAX702CPA	0°C to +70°C	8 Plastic DIP
MAX702CSA	0°C to +70°C	8 Narrow SO
MAX702C/D	0°C to +70°C	Dice
MAX702EPA	-40°C to +85°C	8 Plastic DIP
MAX702ESA	-40°C to +85°C	8 Narrow SO

Pin Configurations

TOP VIEW



DIP/SO DIP/SO DIP/SO

Power-Supply Monitor with Reset

ABSOLUTE MAXIMUM RATINGS

V_{CC} .... -0.3V to +15.5V
Voltage (with respect to GND) at RESET, $\overline{\text{RESET}}$, HYST, CTL, SENSE .... -0.3V to Vcc
Operating Temperature Range
MAX70_C .... 0°C to +70°C
MAX70_E .... -40°C to +85°C
Rate of Rise, V_{CC} 100V/µs
Power Dissipation, any package 380mW
Storage Temperature Range .... -65°C to +150°C
Lead Temperature (Soldering, 10 sec.) .... 300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect the device reliability.

ELECTRICAL CHARACTERISTICS

(T_A = 25°C, V_{CC} = +5V, CTL = GND on MAX700, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{CC} Monitor Voltage Range MAX700 Only	$T_A = T_{MIN}$ to T_{MAX} CTL = V_{CC}	3		15	V
Min V_{CC} For Valid Reset Output, Declining Supply	$T_A = T_{MIN}$ to T_{MAX} $\overline{\text{RESET}} \le 0.4V$ when sinking 1mA	1.5	1		V
Supply Current			100	200	µA
Reset Threshold Power-up Power-down	$T_A = T_{MIN}$ to T_{MAX}	 4.5 4.5	 4.65 4.62	 4.75 4.75	V
Internal Hysteresis	HYST not connected		30		mV
Reset Output Pulse Width		200	350	500	ms
RESET Fall Time	MAX700/701 Only, C_{LOAD} = 100pF		200		ns
V_{CC} Pulse Duration Guaranteeing No Reset Reset	5V to 4V V_{CC} Pulse	 100	 10 10	 1 	µs
MR Input Threshold			0.7		V
MR Pullup Current			-5	-30	µA
MAX700					
RESET Output Low	I_{SINK} = 3.2mA, V_{CC} = 5V I_{SINK} = 1.6mA, V_{CC} = 3V			0.4 0.4	V
RESET Output High	I_{SOURCE} = 3.2mA, V_{CC} = 4.25V I_{SOURCE} = 1.6mA, V_{CC} = 3V I_{SOURCE} = 0.5mA, V_{CC} = 1.5V	V_{CC}-0.4 V_{CC}-0.4 V_{CC}-0.4			V
$\overline{\text{RESET}}$ Output Low	I_{SINK} = 16mA, V_{CC} = 4.25V I_{SINK} = 1.6mA, V_{CC} = 3V I_{SINK} = 0.4mA, V_{CC} = 1.5V			0.4 0.4 0.4	V
$\overline{\text{RESET}}$ Output High	I_{SOURCE} = 3.2mA, V_{CC} = 5V I_{SOURCE} = 1.6mA, V_{CC} = 3V	V_{CC}-0.4 V_{CC}-0.4			V
MAX701					
RESET Output Low	I_{SINK} = 16mA, V_{CC} = 5V			0.4	V
RESET Output High	I_{SOURCE} = 3.2mA, V_{CC} = 4.25V I_{SOURCE} = 1.6mA, V_{CC} = 3V I_{SOURCE} = 0.5mA, V_{CC} = 1.5V	V_{CC}-0.4 V_{CC}-0.4 V_{CC}-0.4			V
$\overline{\text{RESET}}$ Output Low	I_{SINK} = 3.2mA, V_{CC} = 4.25V I_{SINK} = 1.6mA, V_{CC} = 3V I_{SINK} = 0.4mA, V_{CC} = 1.5V			0.4 0.4 0.4	V
$\overline{\text{RESET}}$ Output High	I_{SOURCE} = 3.2mA, V_{CC} = 5V	V_{CC}-0.4			V

ELECTRICAL CHARACTERISTICS (continued)

(T_A = 25°C, V_{CC} = +5V, CTL = GND on MAX700, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
MAX702					
$\overline{RESET}$ Output Low	I_{SINK} = 3.2mA, V_{CC} = 4.25V I_{SINK} = 1.6mA, V_{CC} = 3V I_{SINK} = 0.4mA, V_{CC} = 1.5V			0.4 0.4 0.4	V
$\overline{RESET}$ Output High	I_{SOURCE} = 3.2mA, V_{CC} = 5V	V_{CC}-0.4			V
MAX700 ONLY (CTL = V_{CC}, unless otherwise noted.)					
SENSE Input Threshold	T_A = T_{MIN} to T_{MAX}	1.25	1.29	1.35	V
SENSE Input Current			0.1		nA
HYST Input On Resistance			0.5		kΩ
CTL Input Threshold			2		V
CTL Pulldown Current			30	100	µA

Pin Description

NAME	FUNCTION
V_{CC}	Chip power and +5V sensing input (when CTL = GND on MAX700).
GND	Ground
$\overline{RESET}$	Goes low when V_{CC} falls below 4.65V, or when CTL = V_{CC} on the MAX700 goes low when SENSE falls below 1.9V.
RESET	MAX700, 701 only – Inverted Version of $\overline{RESET}$.
$\overline{MR}$	Input for manual push button reset. Has internal 5µA pull up. Low input activates the RESET/$\overline{RESET}$ outputs.
CTL	MAX700 only – When CTL = GND, V_{CC} is monitored by the reset circuit. When CTL = V_{CC}, V_{CC} is ignored and SENSE is monitored, allowing the threshold to be set with external resistors.
HYST	MAX700 only – Normally NOT used when voltage is monitored through V_{CC} (CTL = GND). When monitoring through SENSE (CTL = V_{CC}), HYST allows hysteresis to be added, reducing noise and spurious reset activity (Figure 3). HYST turns on 5µs before the RESET/$\overline{RESET}$ outputs are activated, and its on resistance to GND is typically 1kΩ.
SENSE	MAX700 only – The voltage sense input when CTL = V_{CC}. Its threshold is 1.29V. Sense always remains connected to the internal comparator. So, when V_{CC} is being monitored internally (CTL = GND), SENSE should be left open circuit.

Power-Supply Monitor with Reset

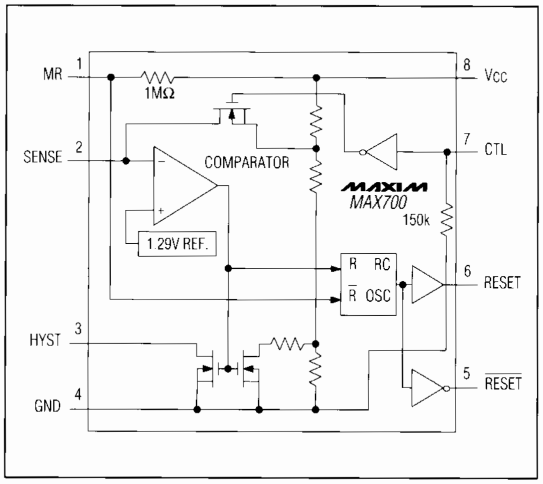


Figure 1. MAX700 Block Diagram

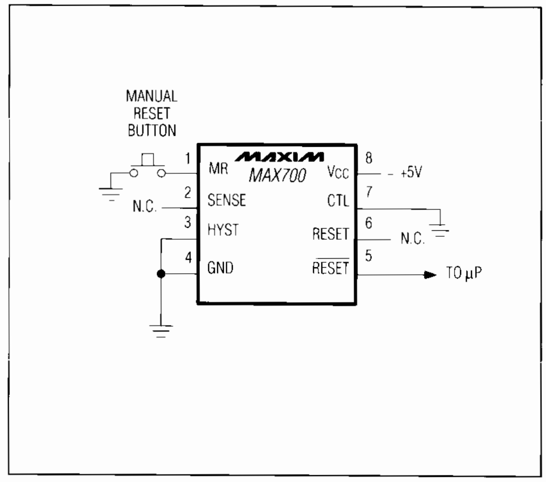


Figure 2. MAX700 Typical Connection Diagram

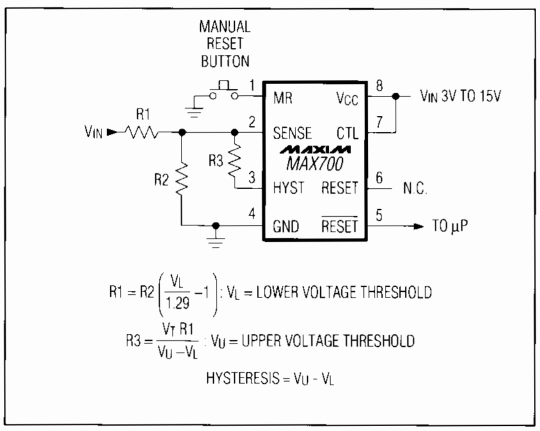


Figure 3. MAX700 Connected for External Sense and Hysteresis

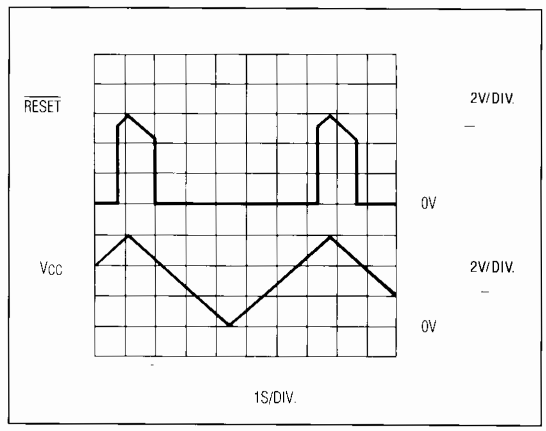


Figure 4. Typical MAX700/701/702 $\overline{RESET}$ Output vs. V_{CC}

Figure 4 shows the $\overline{RESET}$ output of the MAX700/701/702 in the correct state for V_{CC} voltages down to 0V. Note the effect of the built-in hysteresis on the trigger level of $\overline{RESET}$.

19-2551; Rev 0; 6/02

Low-Power, 16-Bit Analog-to-Digital Converters with Parallel Interface

General Description

The MAX1165/MAX1166 16-bit, low-power, successive-approximation analog-to-digital converters (ADCs) feature automatic power-down, factory-trimmed internal clock, and a 16-bit wide (MAX1165) or byte wide (MAX1166) parallel interface. The devices operate from a single +4.75V to +5.25V analog supply and a +2.7V to +5.25V digital supply.

The MAX1165/MAX1166 use an internal 4.096V reference or an external reference. The MAX1165/MAX1166 consume only 1.8mA at a sampling rate of 165ksps with external reference and 2.7mA with internal reference. AutoShutdown™ reduces supply current to 0.1mA at 10ksps.

The MAX1165/MAX1166 are ideal for high-performance, battery-powered, data-acquisition applications. Excellent dynamic performance and low power consumption in a small package make the MAX1165/MAX1166 ideal for circuits with demanding power consumption and space requirements.

The 16-bit wide MAX1165 is available in a 28-pin TSSOP package and the byte wide MAX1166 is available in a 20-pin TSSOP package. Both devices are available in either the 0°C to +70°C commercial, or the -40°C to +85°C extended temperature range.

AutoShutdown is a trademark of Maxim Integrated Products, Inc.

Applications

Temperature Sensor/Monitor
Industrial Process Control
I/O Boards
Data-Acquisition Systems
Cable/Harness Tester
Accelerometer Measurements
Digital Signal Processing

Pin Configurations appear at end of data sheet.
Functional Diagram appears at end of data sheet.

Features

- **16-Bit Wide (MAX1165) and Byte Wide (MAX1166) Parallel Interface**
- **High Speed: 165ksps Sample Rate**
- **Accurate: ±2LSB INL, 16 Bit No Missing Codes**
- **4.096V, 35ppm/°C Internal Reference**
- **External Reference Range: +3.8V to +5.25V**
- **Single +4.75V to +5.25V Analog Supply Voltage**
- **+2.7V to +5.25V Digital Supply Voltage**
- **Low Supply Current**
  - **1.8mA (External Reference)**
  - **2.7mA (Internal Reference)**
  - **0.1µA (10ksps, External Reference)**
- **Small Footprint**
  - **28-Pin TSSOP Package (16-Bit Wide)**
  - **20-Pin TSSOP Package (Byte Wide)**

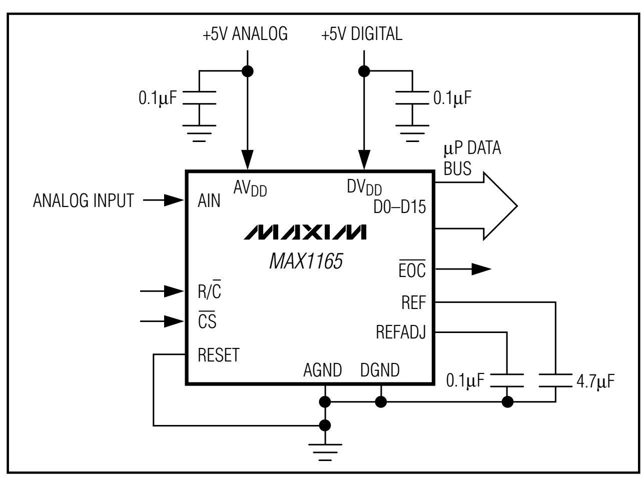
Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	INL
MAX1165ACUI*	0°C to +70°C	28 TSSOP	±2
MAX1165BCUI	0°C to +70°C	28 TSSOP	±2
MAX1165CCUI	0°C to +70°C	28 TSSOP	±4
MAX1165AEUI*	-40°C to +85°C	28 TSSOP	±2
MAX1165BEUI*	-40°C to +85°C	28 TSSOP	±2
MAX1165CEUI*	-40°C to +85°C	28 TSSOP	±4

**Future product—contact factory for availability.*

Ordering Information continued at end of data sheet.

Typical Operating Circuit



ABSOLUTE MAXIMUM RATINGS

AV_{DD} to AGND ....-0.3V to +6V
DV_{DD} to DGND ....-0.3V to (AV_{DD} + 0.3V)
AGND to DGND..-0.3V to +0.3V
AIN, REF, REFADJ to AGND...................-0.3V to (AV_{DD} + 0.3V)
$\overline{CS}$, HBEN, R/$\overline{C}$, RESET to DGND ....-0.3V to +6V
Digital Output (D15–D0, $\overline{EOC}$)
to DGND ....-0.3V to (DV_{DD} + 0.3V)
Maximum Continuous Current Into Any Pin 50mA

Continuous Power Dissipation (T_A = +70°C)
20-Pin TSSOP (derate 10.9mW/°C above+70°C) 879mW
28-Pin TSSOP (derate 12.8mW/°C above +70°C) 1026mW
Operating Temperature Ranges
MAX116_ _CU_ ....0°C to +70°C
MAX116_ _EU_ ....-40°C to +85°C
Storage Temperature Range ....-65°C to +150°C
Junction Temperature ....+150°C
Lead Temperature (soldering, 10s) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(AV_{DD} = DV_{DD} = +5V, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
DC ACCURACY							
Resolution	N			16			Bits
Relative Accuracy (Note 1)	INL	MAX116_A				±2	LSB
		MAX116_B				±2	
		MAX116_C				±4	
Differential Nonlinearity	DNL	No missing codes over temperature	MAX116_A			±1	LSB
			MAX116_B	-1		±1.5	
		MAX116_C				±2	
Transition Noise		RMS noise, external reference, includes quantization noise			0.65		LSB_{RMS}
		Internal reference			0.7		LSB_{RMS}
Offset Error					0.05	1	mV
Gain Error		(Note 2)			±0.002	±0.02	%FSR
Offset Drift					0.6		ppm/°C
Gain Drift					0.2		ppm/°C
DYNAMIC PERFORMANCE ($f_{IN(SINE\text{-}WAVE)}$ = 1kHz, V_{IN} = 4.096$V_{P\text{-}P}$, 165ksps)							
Signal-to-Noise Plus Distortion	SINAD			86	90		dB
Signal-to-Noise Ratio	SNR			87	90		dB
Total Harmonic Distortion	THD				-102	-90	dB
Spurious-Free Dynamic Range	SFDR			92	105		dB
Full-Power Bandwidth		-3dB point			4		MHz
Full-Linear Bandwidth		SINAD > 81dB			33		kHz
CONVERSION RATE							
Sample Rate	f_{SAMPLE}					165	ksps
Aperture Delay					27		ns
Aperture Jitter					<100		ps
ANALOG INPUT							
Input Range	V_{AIN}			0		V_{REF}	V
Input Capacitance	C_{AIN}				40		pF

ELECTRICAL CHARACTERISTICS (continued)

(AV_{DD} = DV_{DD} = +5V, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
INTERNAL REFERENCE							
REF Output Voltage	V_{REF}			4.056	4.096	4.136	V
REF Output Tempco	TC_{REF}				±25		ppm/°C
REF Short-Circuit Current	I_{REFSC}				±10		mA
Capacitive Bypass at REFADJ	C_{REFADJ}			0.1			µF
Capacitive Bypass at REF	C_{REF}			1			µF
REFADJ Input Leakage Current	I_{REFADJ}				20		µA
EXTERNAL REFERENCE							
REFADJ Buffer Disable Threshold		To power down the internal reference		AV_{DD} - 0.4		AV_{DD} - 0.1	V
REF Input Voltage Range		Internal reference disabled		3.8		AV_{DD}	V
REF Input Current	I_{REF}	V_{REF} = +4.096V, f_{SAMPLE} = 165ksps			50	120	µA
		Shutdown mode			±0.1		
DIGITAL INPUTS/OUTPUTS							
Input High Voltage	V_{IH}			0.7 × DV_{DD}			V
Input Low Voltage	V_{IL}					0.3 × DV_{DD}	V
Input Leakage Current	I_{IN}	V_{IH} = 0 or DV_{DD}			±0.1	±1	µA
Input Hysteresis	V_{HYST}				0.1		V
Input Capacitance	C_{IN}				15		pF
Output High Voltage	V_{OH}	I_{SOURCE} = 0.5mA, DV_{DD} = +2.7V to +5.25V, AV_{DD} = +5.25V		DV_{DD} - 0.4			V
Output Low Voltage	V_{OL}	I_{SINK} = 1.6mA, DV_{DD} = +2.7V to +5.25V, AV_{DD} = +5.25V				0.4	V
Three-State Leakage Current	I_{OZ}	D0–D15			±0.1	±10	µA
Three-State Output Capacitance	C_{OZ}				15		pF
POWER REQUIREMENTS							
Analog Supply Voltage	AV_{DD}			4.75		5.25	V
Digital Supply	DV_{DD}			2.7		AV_{DD}	V
Analog Supply Current	I_{AVDD}	Internal reference	165ksps		2.7	3.2	mA
			100ksps		2.0		
			10ksps		1.0		
			1ksps		1.0		
		External reference	165ksps		1.8	2.3	
			100ksps		1.1		
			10ksps		0.1		
			1ksps		0.01		

ELECTRICAL CHARACTERISTICS (continued)

(AV_{DD} = DV_{DD} = +5V, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Digital Supply Current	I_{DVDD}	D0–D15 = all zeros	165ksps		0.5	0.7	mA
			100ksps		0.3		
			10ksps		0.03		
			1ksps		0.003		
Shutdown Supply Current	I_{SHDN}	Full power-down	I_{AVDD}		0.5	5	µA
			I_{DVDD}		0.5	5	
		REF and REF buffer enabled (standby mode)	I_{AVDD}		1.0	1.2	mA
			I_{DVDD} (Note 3)		0.5	5	µA
Power-Supply Rejection Ratio	PSRR	AV_{DD} = +5V ±5%, full-scale input (Note 4)			68		dB

TIMING CHARACTERISTICS (Figures 1 and 2)

(AV_{DD} = +4.75V to +5.25V, DV_{DD} = +2.7V to AV_{DD}, external reference = +4.096V, C_{REF} = 4.7µF, C_{REFADJ} = 0.1µF, C_{LOAD} = 20pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A= +25°C.)

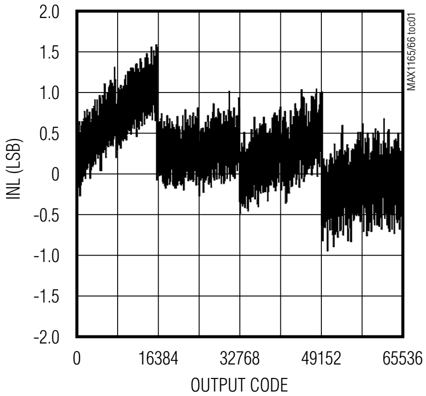
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Acquisition Time	t_{ACQ}		1.1			µs
Conversion Time	t_{CONV}				4.7	
$\overline{CS}$ Pulse Width High	t_{CSH}	(Note 5)	40			ns
$\overline{CS}$ Pulse Width Low (Note 5)	t_{CSL}	V_{DVDD} = 4.75V to 5.25V	40			ns
		V_{DVDD} = 2.7V to 5.25V	60			
R/$\overline{C}$ to $\overline{CS}$ Fall Setup Time	t_{DS}		0			ns
R/$\overline{C}$ to $\overline{CS}$ Fall Hold Time	t_{DH}	V_{DVDD} = 4.75V to 5.25V	40			ns
		V_{DVDD} = 2.7V to 5.25V	60			
$\overline{CS}$ to Output Data Valid	t_{DO}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	
HBEN Transition to Output Data Valid (MAX1166 Only)	t_{DO1}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	
$\overline{EOC}$ Fall to $\overline{CS}$ Fall	t_{DV}		0			ns
$\overline{CS}$ Rise to $\overline{EOC}$ Rise	t_{EOC}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	
Bus Relinquish Time (Note 5)	t_{BR}	V_{DVDD} = 4.75V to 5.25V			40	ns
		V_{DVDD} = 2.7V to 5.25V			80	

Note 1: Relative accuracy is the deviation of the analog value at any code from its theoretical value after offset and gain errors have been removed.
Note 2: Offset nulled.
Note 3: Shutdown supply currents are typically 0.5µA, maximum specification is limited by automated test equipment.
Note 4: Defined as the change in positive full scale caused by a ±5% variation in the nominal supply.
Note 5: To ensure best performance, finish reading the data and wait t_{BR} before starting a new acquisition.

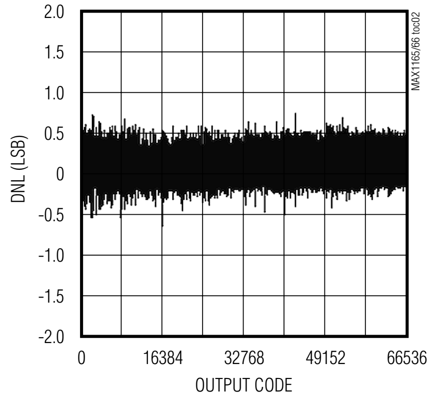
Typical Operating Characteristics

($AV_{DD} = DV_{DD} = +5V$, external reference = +4.096V, $C_{REF} = 4.7\mu F$, $C_{REFADJ} = 0.1\mu F$, $T_A = +25°C$, unless otherwise noted.)

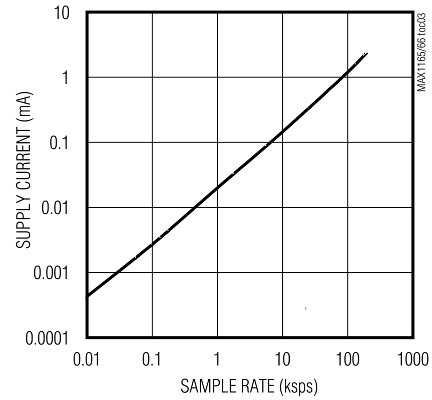
INL vs. OUTPUT CODE



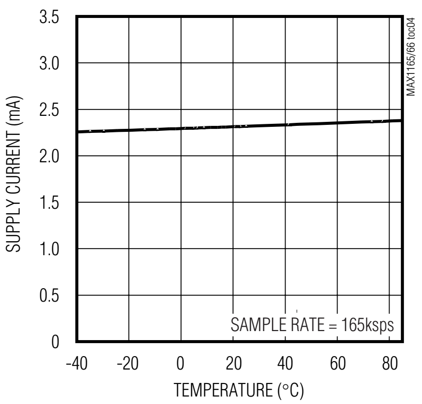
DNL vs. OUTPUT CODE



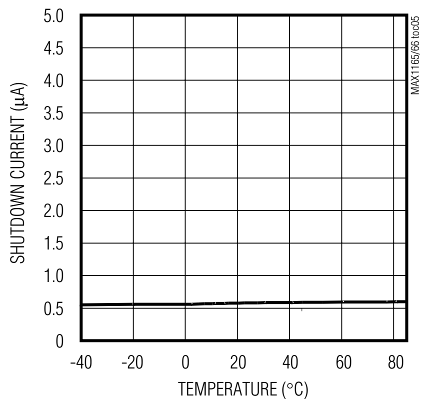
IAV_{DD} + IDV_{DD} SUPPLY CURRENT vs. SAMPLE RATE



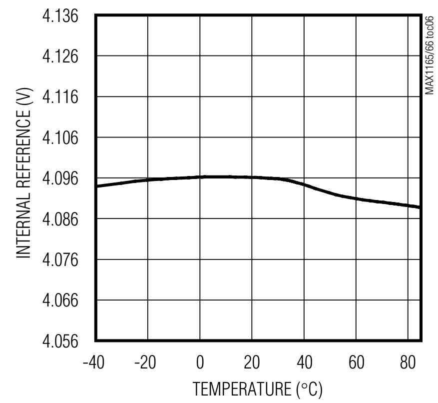
IAV_{DD} + IDV_{DD} SUPPLY CURRENT vs. TEMPERATURE



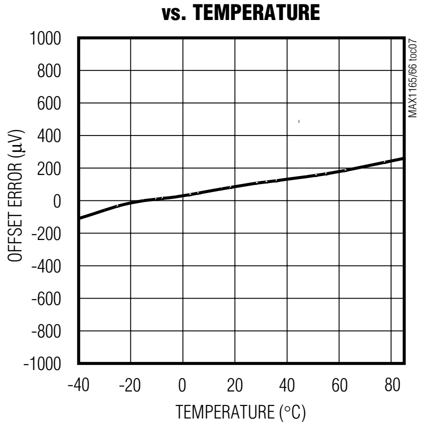
IAV_{DD} + IDV_{DD} SHUTDOWN CURRENT vs. TEMPERATURE



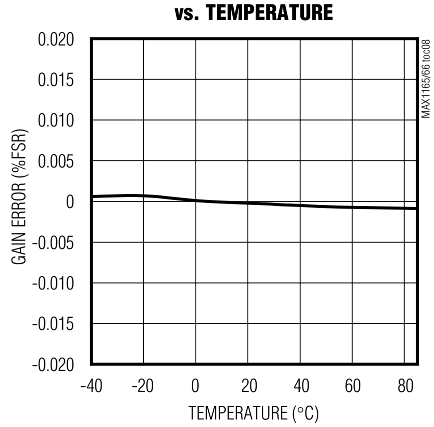
INTERNAL REFERENCE vs. TEMPERATURE



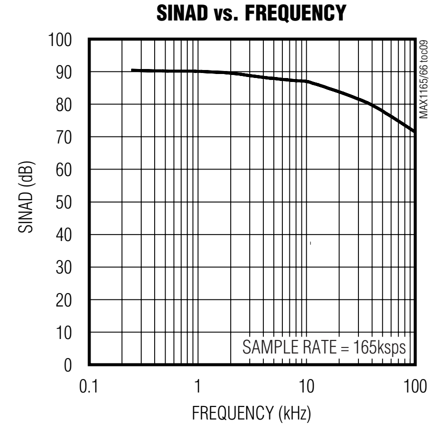
OFFSET ERROR vs. TEMPERATURE



GAIN ERROR vs. TEMPERATURE



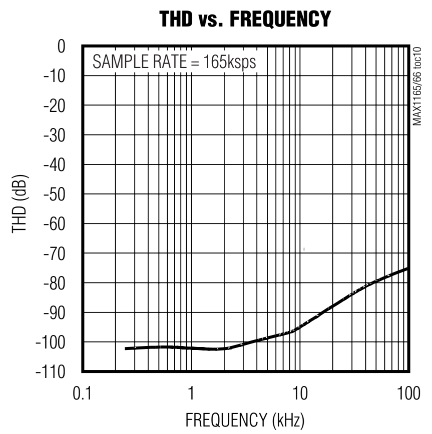
SINAD vs. FREQUENCY

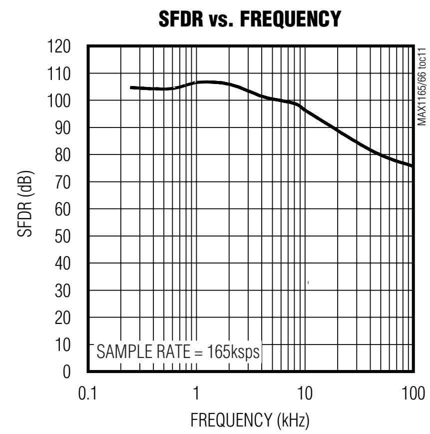


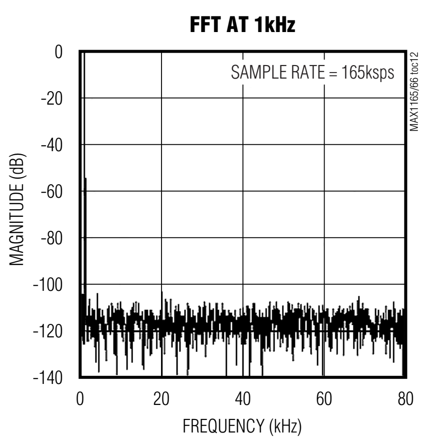
Low-Power, 16-Bit Analog-to-Digital Converter with Parallel Interface

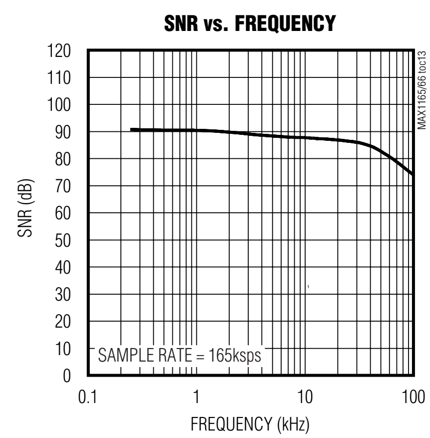
Typical Operating Characteristics (continued)

($AV_{DD} = DV_{DD} = +5V$, external reference = +4.096V, $C_{REF} = 4.7\mu F$, $C_{REFADJ} = 0.1\mu F$, $T_A = +25°C$, unless otherwise noted.)









Pin Description

PIN		NAME		FUNCTION
MAX1165	MAX1166	MAX1165	MAX1166	
1	1	D8	D4/D12	Three-State Digital Data Output
2	2	D9	D5/D13	Three-State Digital Data Output
3	3	D10	D6/D14	Three-State Digital Data Output
4	4	D11	D7/D15	Three-State Digital Data Output. D15 is the MSB.
5	—	D12	—	Three-State Digital Data Output
6	—	D13	—	Three-State Digital Data Output
7	—	D14	—	Three-State Digital Data Output
8	—	D15	—	Three-State Digital Data Output (MSB)
9	5	$R/\overline{C}$		Read/$\overline{\text{Convert}}$ Input. Power up and put the MAX1165/MAX1166 in acquisition mode by holding $R/\overline{C}$ low during the first falling edge of $\overline{CS}$. During the second falling edge of $\overline{CS}$, the level on $R/\overline{C}$ determines whether the reference and reference buffer power down or remain on after conversion. Set $R/\overline{C}$ high during the second falling edge of $\overline{CS}$ to power down the reference and buffer, or set $R/\overline{C}$ low to leave the reference and buffer powered up. Set $R/\overline{C}$ high during the third falling edge of $\overline{CS}$ to put valid data on the bus.
10	6	$\overline{EOC}$		End of Conversion. $\overline{EOC}$ drives low when conversion is complete.
11	7	AV_{DD}		Analog Supply Input. Bypass with a 0.1µF capacitor to AGND.
12	8	AGND		Analog Ground. Primary analog ground (star ground).
13	9	AIN		Analog Input
14	10	AGND		Analog Ground. Connect pin 14 to pin 12 (MAX1165). Connect pin 10 to pin 8 (MAX1166).
15	11	REFADJ		Reference Buffer Output. Bypass REFADJ with a 0.1µF capacitor to AGND for internal reference mode. Connect REFADJ to AV_{DD} to select external reference mode.
16	12	REF		Reference Input/Output. Bypass REF with a 4.7µF capacitor to AGND for internal reference mode. External reference input when in external reference mode.
17	—	RESET		Reset Input. Logic high resets the device.
—	13	HBEN		High-Byte Enable Input. Used to multiplex the 14-bit conversion result: 1: Most significant byte available on the data bus. 0: Least significant byte available on the data bus.
18	14	$\overline{CS}$		Convert Start. The first falling edge of $\overline{CS}$ powers up the device and enables acquire mode when $R/\overline{C}$ is low. The second falling edge of $\overline{CS}$ starts conversion. The third falling edge of $\overline{CS}$ loads the result onto the bus when $R/\overline{C}$ is high.
19	15	DGND		Digital Ground
20	16	DV_{DD}		Digital Supply Voltage. Bypass with a 0.1µF capacitor to DGND.
21	17	D0	D0/D8	Three-State Digital Data Output
22	18	D1	D1/D9	Three-State Digital Data Output
23	19	D2	D2/D10	Three-State Digital Data Output
24	20	D3	D3/D11	Three-State Digital Data Output
25	—	D4	—	Three-State Digital Data Output
26	—	D5	—	Three-State Digital Data Output
27	—	D6	—	Three-State Digital Data Output
28	—	D7	—	Three-State Digital Data Output

Low-Power, 16-Bit Analog-to-Digital Converter with Parallel Interface

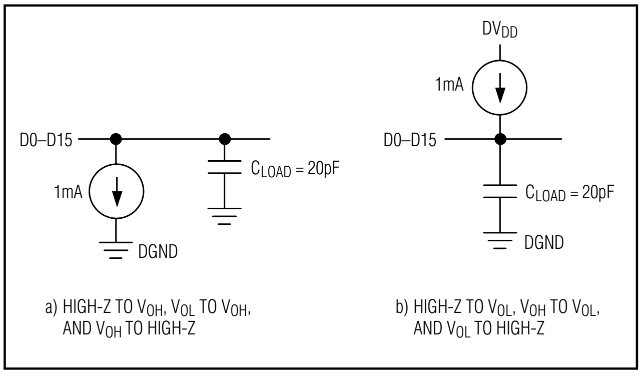


Figure 1. Load Circuits

Detailed Description

Converter Operation

The MAX1165/MAX1166 use a successive-approximation (SAR) conversion technique with an inherent track-and-hold (T/H) stage to convert an analog input into a 16-bit digital output. Parallel outputs provide a high-speed interface to most microprocessors (µPs). The *Functional Diagram* shows a simplified internal architecture of the MAX1165/MAX1166. Figure 3 shows a typical application circuit for the MAX1166.

Analog Input

The equivalent input circuit is shown in Figure 4. A switched capacitor digital-to-analog converter (DAC) provides an inherent T/H function. The single-ended input is connected between AIN and AGND.

Input Bandwidth

The ADC's input-tracking circuitry has a 4MHz small-signal bandwidth, so it is possible to digitize high-speed transient events and measure periodic signals with bandwidths exceeding the ADC's sampling rate by using undersampling techniques. To avoid aliasing of unwanted high-frequency signals into the frequency band of interest, use anti-alias filtering.

Analog Input Protection

Internal protection diodes, which clamp the analog input to AV_{DD} and/or AGND, allow the input to swing from AGND - 0.3V to AV_{DD} + 0.3V, without damaging the device.

If the analog input exceeds 300mV beyond the supplies, limit the input current to 10mA.

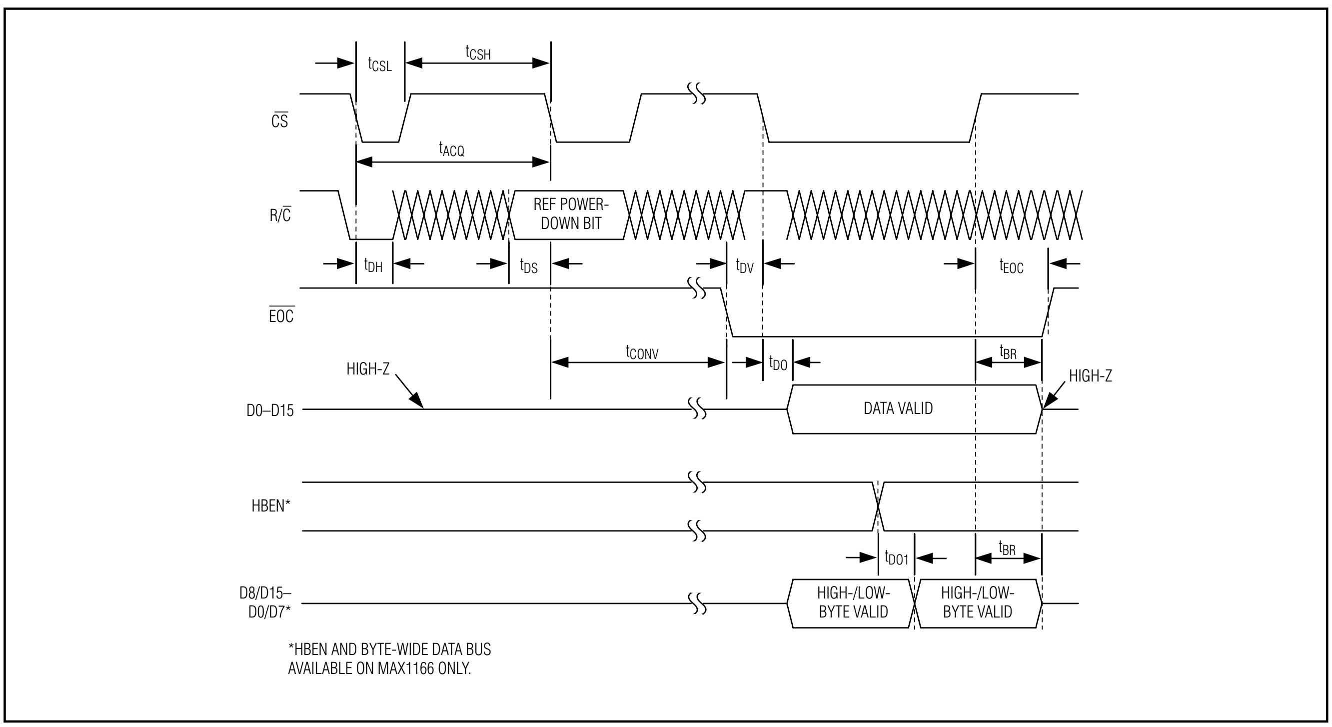


Figure 2. MAX1165/MAX1166 Timing Diagram

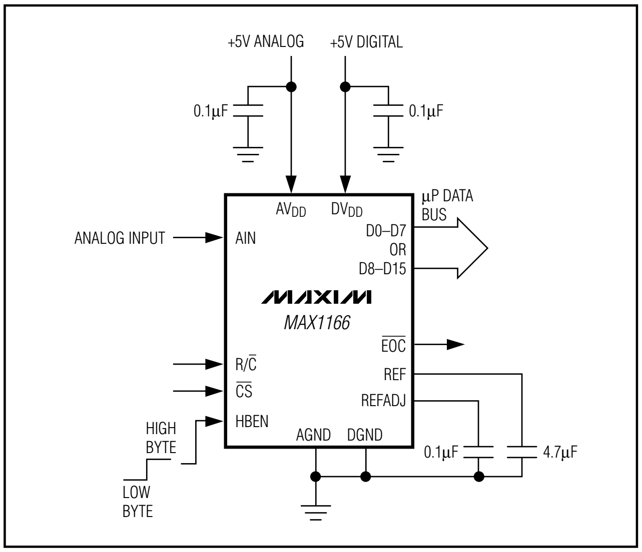


Figure 3. Typical Application Circuit for the MAX1166

Track and Hold (T/H)

In track mode, the analog signal is acquired on the internal hold capacitor. In hold mode, the T/H switches open and the capacitive DAC samples the analog input.

During the acquisition, the analog input (AIN) charges capacitor C_{DAC}. The acquisition ends on the second falling edge of $\overline{CS}$. At this instant, the T/H switches open. The retained charge on C_{DAC} represents a sample of the input.

In hold mode, the capacitive DAC adjusts during the remainder of the conversion time to restore node ZERO to zero within the limits of 16-bit resolution. Force $\overline{CS}$ low to put valid data on the bus at the end of the conversion.

The time required for the T/H to acquire an input signal is a function of how quickly its input capacitance is charged. If the input signal's source impedance is high, the acquisition time lengthens and more time must be allowed between conversions. The acquisition time (t_{ACQ}) is the maximum time the device takes to acquire the signal. Use the following formula to calculate acquisition time:

$$t_{ACQ} = 11\ (R_S + R_{IN}) \times 35pF$$

where R_{IN} = 800Ω, R_S = the input signal's source impedance, and t_{ACQ} is never less than 1.1µs. A source impedance less than 1kΩ does not significantly affect the ADC's performance.

To improve the input signal bandwidth under AC conditions, drive AIN with a wideband buffer (>4MHz) that can drive the ADC's input capacitance and settle quickly.

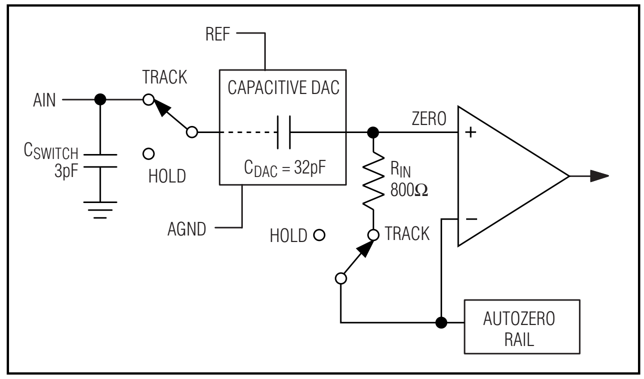


Figure 4. Equivalent Input Circuit

Power-Down Modes

Select standby mode or shutdown mode with the R/$\overline{C}$ bit during the second falling edge of $\overline{CS}$ (see the *Selecting Standby or Shutdown Mode* section). The MAX1165/MAX1166 automatically enter either standby mode (reference and buffer on) or shutdown (reference and buffer off) after each conversion depending on the status of R/$\overline{C}$ during the second falling edge of $\overline{CS}$.

Internal Clock

The MAX1165/MAX1166 generate an internal conversion clock. This frees the microprocessor from the burden of running the SAR conversion clock. Total conversion time after entering hold mode (second falling edge of $\overline{CS}$) to end of conversion ($\overline{EOC}$) falling is 4.7µs (max).

Applications Information

Starting a Conversion

$\overline{CS}$ and R/$\overline{C}$ control acquisition and conversion in the MAX1165/MAX1166 (Figure 2). The first falling edge of $\overline{CS}$ powers up the device and puts it in acquire mode if R/$\overline{C}$ is low. The convert start is ignored if R/$\overline{C}$ is high. The MAX1165/MAX1166 need at least 10ms (C_{REFADJ} = 0.1µF, C_{REF} = 4.7µF) for the internal reference to wake up and settle before starting the conversion if powering up from shutdown. The ADC can wake up, from shutdown, to an unknown state. Put the ADC in a known state by completing one "dummy" conversion. The MAX1165/MAX1166 are in a known state, ready for actual data acquisition, after the completion of the dummy conversion. A dummy conversion consists of one full conversion cycle.

The MAX1165 provides an alternative reset function to reset the device (see the *RESET* section).

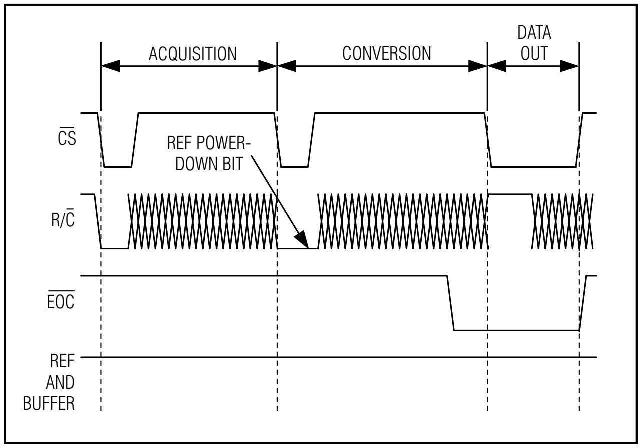


Figure 5. Selecting Standby Mode

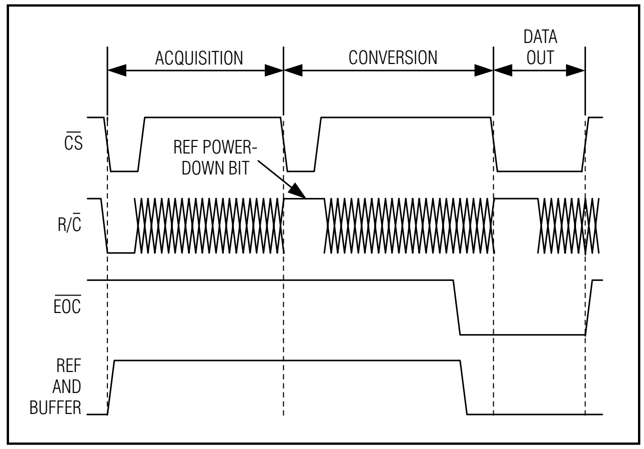


Figure 6. Selecting Shutdown Mode

Selecting Standby or Shutdown Mode

The MAX1165/MAX1166 have a selectable standby or low-power shutdown mode. In standby mode, the ADC's internal reference and reference buffer do not power down between conversions, eliminating the need to wait for the reference to power up before performing the next conversion. Shutdown mode powers down the reference and reference buffer after completing a conversion. The reference and reference buffer require a minimum of 10ms (C_{REFADJ} = 0.1µF, C_{REF} = 4.7µF) to power up and settle from shutdown.

The state of R/$\overline{C}$ at the second falling edge of $\overline{CS}$ selects which power-down mode the MAX1165/MAX1166 enter upon conversion completion. Holding R/$\overline{C}$ low causes the MAX1165/MAX1166 to enter standby mode. The reference and buffer are left on after the conversion completes. R/$\overline{C}$ high causes the MAX1165/MAX1166 to enter shutdown mode and shut down the reference and buffer after conversion (Figures 5 and 6). When using an external reference, set the REF power-down bit high for lowest current operation.

Standby Mode

While in standby mode, the supply current is reduced to less than 1mA (typ). The next falling edge of $\overline{CS}$ with R/$\overline{C}$ low causes the MAX1165/MAX1166 to exit standby mode and begin acquisition. The reference and reference buffer remain active to allow quick turn-on time. Standby mode allows significant power savings while running at the maximum sample rate.

Shutdown Mode

In shutdown mode, the reference and reference buffer are shut down between conversions. Shutdown mode reduces supply current to 0.5µA (typ) immediately after the conversion. The falling edge of $\overline{CS}$ with R/$\overline{C}$ low causes the reference and buffer to wake up and enter acquisition mode. To achieve 16-bit accuracy, allow 10ms (C_{REFADJ} = 0.1µF, C_{REF} = 4.7µF) for the internal reference to wake up.

Internal and External Reference

Internal Reference

The internal reference of the MAX1165/MAX1166 is internally buffered to provide +4.096V output at REF. Bypass REF to AGND and REFADJ to AGND with 4.7µF and 0.1µF, respectively.

Fine adjustments can be made to the internal reference voltage by sinking or sourcing current at REFADJ. The input impedance of REFADJ is nominally 5kΩ. The internal reference voltage is adjustable to ±1.5% with the circuit of Figure 7.

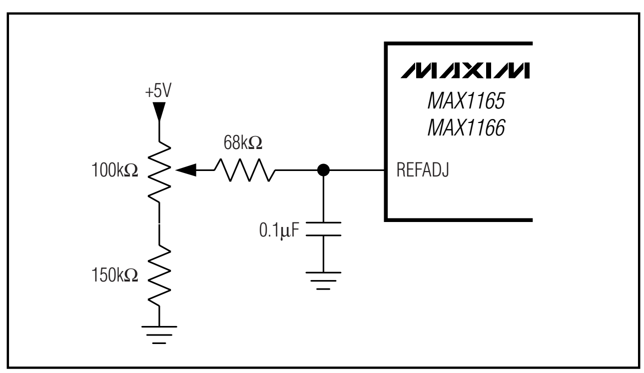


Figure 7. MAX1165/MAX1166 Reference Adjust Circuit

External Reference

An external reference can be placed at either the input (REFADJ) or the output (REF) of the MAX1165/MAX1166s' internal buffer amplifier. When connecting an external reference to REFADJ, the input impedance is typically 5kΩ. Using the buffered REFADJ input makes buffering the external reference unnecessary; however, the internal buffer output must be bypassed at REF with a 1µF capacitor.

Connect REFADJ to AV_{DD} to disable the internal buffer. Directly drive REF using an external reference. During conversion the external reference must be able to drive 100µA of DC load current and have an output impedance of 10Ω or less. REFADJ's impedance is typically 5kΩ. The DC input impedance of REF is a minimum 40kΩ.

For optimal performance, buffer the reference through an op amp and bypass REF with a 1µF capacitor. Consider the MAX1165/MAX1166s' equivalent input noise ($38µV_{RMS}$) when choosing a reference.

Reading a Conversion Result

$\overline{\text{EOC}}$ is provided to flag the microprocessor when a conversion is complete. The falling edge of $\overline{\text{EOC}}$ signals that the data is valid and ready to be output to the bus.

D0–D15 are the parallel outputs of the MAX1165/MAX1166. These three-state outputs allow for direct connection to a microcontroller I/O bus. The outputs remain high-impedance during acquisition and conversion. Data is loaded onto the bus with the third falling edge of $\overline{\text{CS}}$ with R/$\overline{\text{C}}$ high after t_{DO}. Bringing $\overline{\text{CS}}$ high forces the output bus back to high impedance. The MAX1165/MAX1166 then wait for the next falling edge of $\overline{\text{CS}}$ to start the next conversion cycle (Figure 2).

The MAX1165 loads the conversion result onto a 16-bit wide data bus while the MAX1166 has a byte-wide output format. HBEN toggles the output between the most/least significant byte. The least significant byte is loaded onto the output bus when HBEN is low and the most significant byte is on the bus when HBEN is high (Figure 2).

RESET

Toggle RESET with $\overline{\text{CS}}$ high. The next falling edge of $\overline{\text{CS}}$ begins acquisition. This reset is an alternative to the dummy conversion explained in the *Starting a Conversion* section.

Transfer Function

Figure 8 shows the MAX1165/MAX1166 output transfer function. The output is coded in standard binary.

Input Buffer

Most applications require an input buffer amplifier to achieve 16-bit accuracy. If the input signal is multiplexed, the input channel should be switched immediately after acquisition, rather than near the end of or after a conversion. This allows more time for the input buffer amplifier to respond to a large step change in input signal. The input amplifier must have a high enough slew rate to complete the required output voltage change before the beginning of the acquisition time. At the beginning of acquisition, the internal sampling capacitor array connects to AIN (the amplifier output), causing some output disturbance. Ensure that the sampled voltage has settled to within the required limits before the end of the acquisition time. If the frequency of interest is low, AIN can be bypassed with a large enough capacitor to charge the internal sampling capacitor with very little ripple. However, for AC use, AIN must be driven by a wideband buffer (at least 10MHz), which must be stable with the ADC's capacitive load (in parallel with any AIN bypass capacitor used) and also settle quickly. An example of this circuit using the MAX4434 is given in Figure 9.

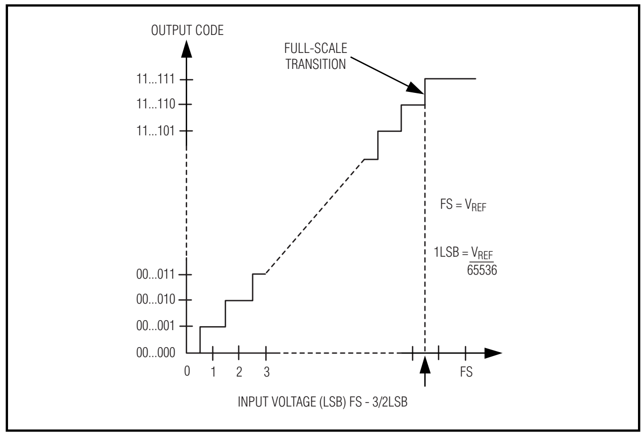


Figure 8. MAX1165/MAX1166 Transfer Function

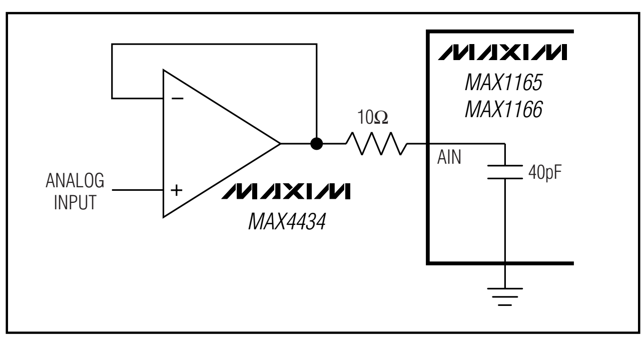


Figure 9. MAX1165/MAX1166 Fast Settling Input Buffer

Layout, Grounding, and Bypassing

For best performance, use printed circuit boards. Do not run analog and digital lines parallel to each other, and do not lay out digital signal paths underneath the ADC package. Use separate analog and digital ground planes with only one point connecting the two ground systems (analog and digital) as close to the device as possible.

Route digital signals far away from sensitive analog and reference inputs. If digital lines must cross analog lines, do so at right angles to minimize coupling digital noise onto the analog lines. If the analog and digital sections share the same supply, then isolate the digital and analog supply by connecting them with a low-value (10Ω) resistor or ferrite bead.

The ADC is sensitive to high-frequency noise on the AV_{DD} supply. Bypass AV_{DD} to AGND with a 0.1µF capacitor in parallel with a 1µF to 10µF low-ESR capacitor with the smallest capacitor closest to the device. Keep capacitor leads short to minimize stray inductance.

Definitions

Integral Nonlinearity

Integral nonlinearity (INL) is the deviation of the values on an actual transfer function from a straight line. This straight line can be either a best-straight-line fit or a line drawn between the end points of the transfer function, once offset and gain errors have been nullified. The static linearity parameters for the MAX1165/MAX1166 are measured using the end-point method.

Differential Nonlinearity

Differential nonlinearity (DNL) is the difference between an actual step width and the ideal value of 1 LSB. A DNL error specification of ±1 LSB guarantees no missing codes and a monotonic transfer function.

Aperture Jitter and Delay

Aperture jitter is the sample-to-sample variation in the time between samples. Aperture delay is the time between the rising edge of the sampling clock and the instant when the actual sample is taken.

Signal-to-Noise Ratio

For a waveform perfectly reconstructed from digital samples, signal-to-noise ratio (SNR) is the ratio of the full-scale analog input (RMS value) to the RMS quantization error (residual error). The ideal, theoretical minimum analog-to-digital noise is caused by quantization noise error only and results directly from the ADC's resolution (N bits):

$$SNR = (6.02 \times N + 1.76)dB$$

where N = 16 bits.

In reality, there are other noise sources besides quantization noise: thermal noise, reference noise, clock jitter, etc. SNR is computed by taking the ratio of the RMS signal to the RMS noise, which includes all spectral components minus the fundamental, the first five harmonics, and the DC offset.

Signal-to-Noise Plus Distortion

Signal-to-noise plus distortion (SINAD) is the ratio of the fundamental input frequency's RMS amplitude to the RMS equivalent of all the other ADC output signals:

$$SINAD\,(dB) = 20 \times \log\left[\frac{Signal_{RMS}}{(Noise + Distortion)_{RMS}}\right]$$

Effective Number of Bits

Effective number of bits (ENOB) indicates the global accuracy of an ADC at a specific input frequency and sampling rate. An ideal ADC's error consists of quantization noise only. With an input range equal to the full-scale range of the ADC, calculate the effective number of bits as follows:

$$ENOB = \frac{SINAD - 1.76}{6.02}$$

Total Harmonic Distortion

Total harmonic distortion (THD) is the ratio of the RMS sum of the first five harmonics of the input signal to the fundamental itself. This is expressed as:

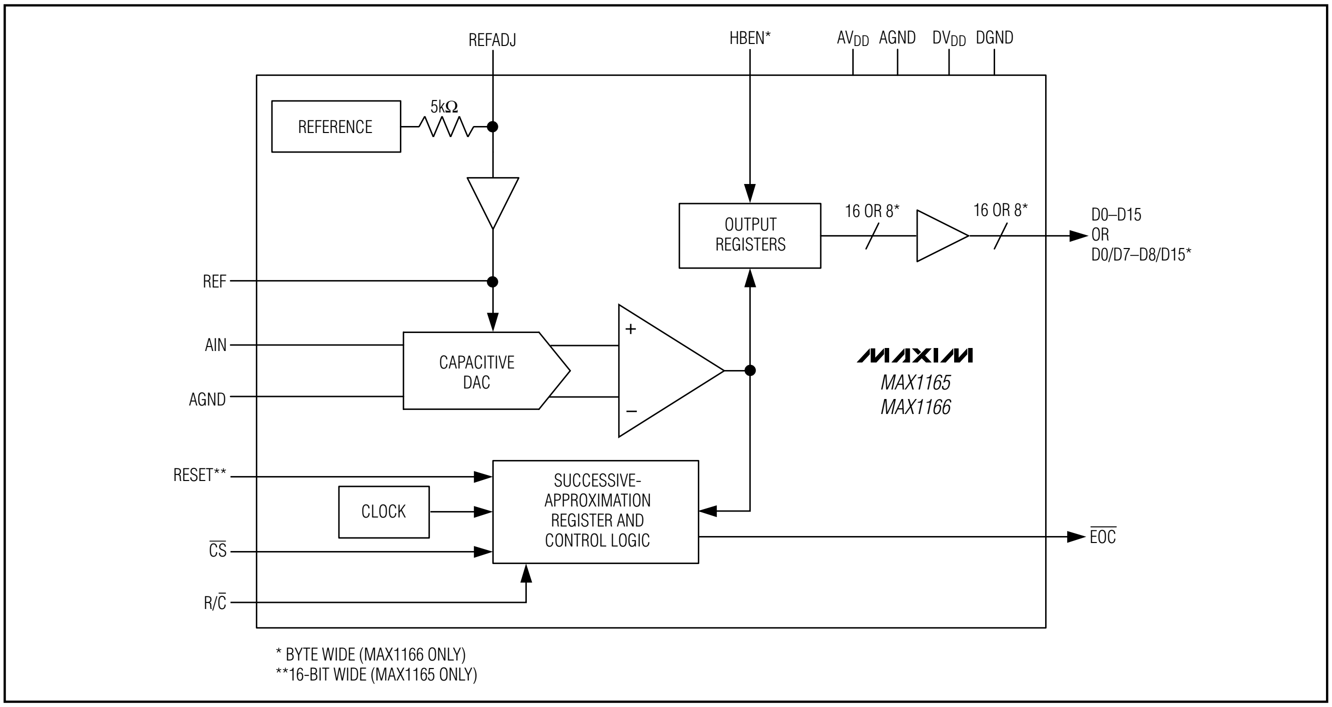
$$THD = 20 \times \log\left[\frac{\left(\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2}\right)}{V_1}\right]$$

where V_1 is the fundamental amplitude and V_2 through V_5 are the 2nd- through 5th-order harmonics.

Spurious-Free Dynamic Range

Spurious-free dynamic range (SFDR) is the ratio of the RMS amplitude of the fundamental (maximum signal component) to the RMS value of the next largest frequency component.

Functional Diagram



Ordering Information (continued)

PART	TEMP RANGE	PIN-PACKAGE	INL
MAX1166ACUP*	0°C to +70°C	20 TSSOP	±2
MAX1166BCUP	0°C to +70°C	20 TSSOP	±2
MAX1166CCUP	0°C to +70°C	20 TSSOP	±4
MAX1166AEUP*	-40°C to +85°C	20 TSSOP	±2
MAX1166BEUP*	-40°C to +85°C	20 TSSOP	±2
MAX1166CEUP*	-40°C to +85°C	20 TSSOP	±4

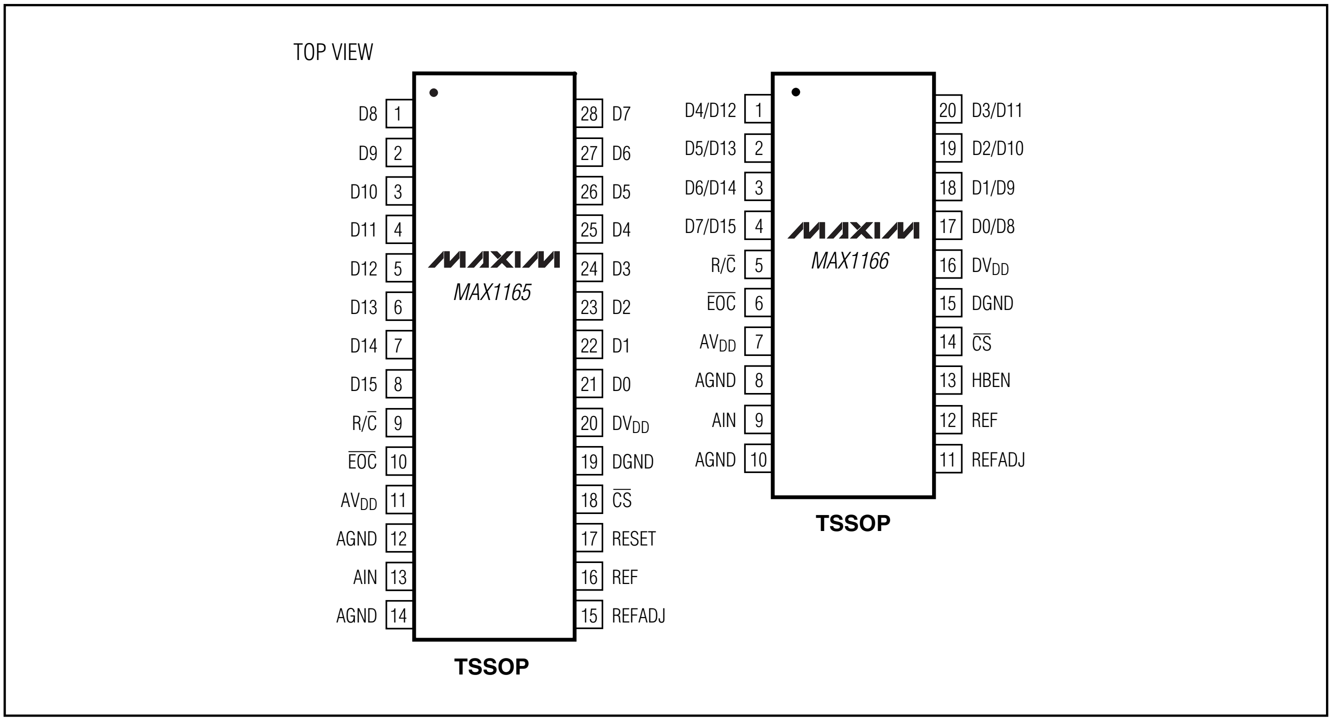
**Future product—contact factory for availability.*

Chip Information

TRANSISTOR COUNT: 15,140

PROCESS: BiCMOS

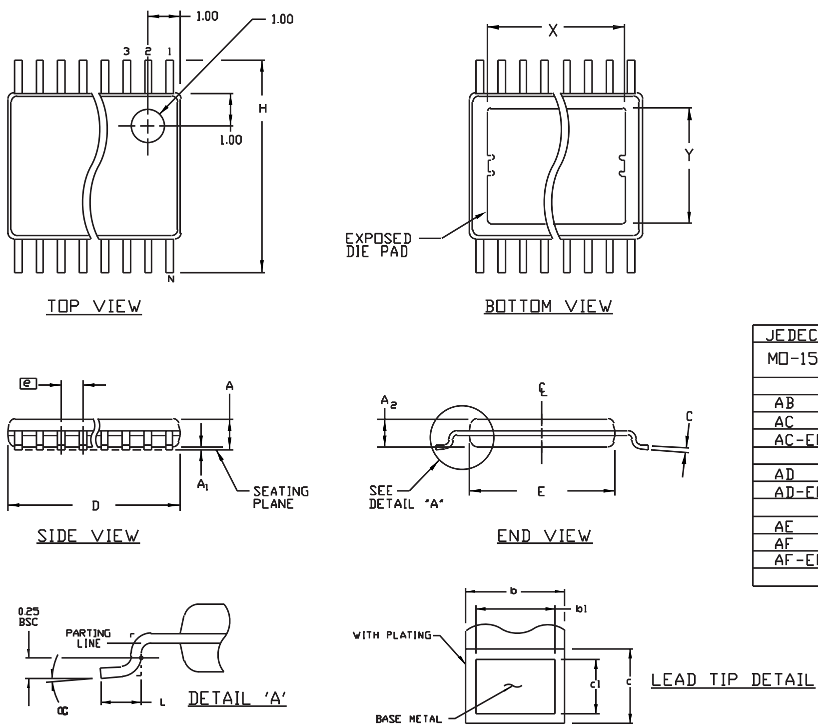
Pin Configurations



Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

TSSOP.EPS



SYMBOL	COMMON DIMENSIONS			
	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	—	1.10		.043
A_1	0.05	0.15	.002	.006
A_2	0.85	0.95	.033	.037
b	0.19	0.30	.007	.012
b1	0.19	0.25	.007	.010
c	0.090	0.20	.0035	.008
c1	0.090	0.135	.0035	.0053
D	SEE VARIATIONS		SEE VARIATIONS	
E	4.30	4.50	.169	.177
e	0.65 BSC		.026 BSC	
H	6.25	6.50	.246	.256
L	0.50	0.70	.020	.028
N	SEE VARIATIONS		SEE VARIATIONS	
Y	2.85	3.15	.112	.124
α	0°	8°	0°	8°

JEDEC			VARIATIONS			
MO-153	N		MILLIMETERS		INCHES	
			MIN.	MAX.	MIN.	MAX.
AB	14	D	4.90	5.10	.193	.201
AC	16	D	4.90	5.10	.193	.201
AC-EP	16	D	4.90	5.10	.193	.201
		X	2.85	3.15	.112	.124
AD	20	D	6.40	6.60	.252	.260
AD-EP	20	D	6.40	6.60	.252	.260
		X	4.00	4.34	.157	.171
AE	24	D	7.70	7.90	.303	.311
AF	28	D	9.60	9.80	.378	.386
AF-EP		D	9.60	9.80	.378	.386
		X	5.35	5.65	.211	.222

NOTES:
1. DIMENSIONS D AND E DO NOT INCLUDE FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15 mm PER SIDE.
3. CONTROLLING DIMENSION: MILLIMETER.
4. MEETS JEDEC OUTLINE MO-153 VARIATIONS AB, AC, AD, AE, AF.
5. DIMENSIONS X AND Y APPLY TO EXPOSED PAD (EP) VERSIONS ONLY.
6. EXPOSED PAD FLUSH WITH BOTTOM OF PACKAGE WITHIN .002".

MAXIM

PROPRIETARY INFORMATION

TITLE:

PACKAGE OUTLINE, TSSOP, 4.40mm BODY, 0.65mm PITCH

APPROVAL	DOCUMENT CONTROL NO.	REV	
	21-0066	C	1/1

Maxim cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in a Maxim product. No circuit patent licenses are implied. Maxim reserves the right to change the circuitry and specifications without notice at any time.

19-1497; Rev 0; 8/99

MAXIM

Dual, 5Ω Analog Switches

General Description

The MAX4621/MAX4622/MAX4623 are precision, dual, high-speed analog switches. The single-pole/single-throw (SPST) MAX4621 and double-pole/single-throw (DPST) MAX4623 dual switches are normally open (NO). The single-pole/double-throw (SPDT) MAX4622 has two normally closed (NC) and two NO poles. All three parts offer low 5Ω on-resistance guaranteed to match to within 0.5Ω between channels and to remain flat over the full analog signal range (Δ0.5Ω max). They also offer low leakage (<500pA at +25°C, <5nA at +85°C) and fast switching times (turn-on time <250ns, turn-off time <200ns).

These analog switches are ideal in low-distortion applications and are the preferred solution over mechanical relays in automatic test equipment or applications where current switching is required. They have low power requirements, use less board space, and are more reliable than mechanical relays.

The MAX4621/MAX4622/MAX4623 are pin-compatible replacements for the DG401/DG403/DG405, respectively, offering improved overall performance. These monolithic switches operate from a single positive supply (+4.5V to +36V) or with bipolar supplies (±4.5V to ±18V) while retaining CMOS-logic input compatibility.

Rail-to-Rail is a registered trademark of Nippon Motorola, Ltd.

Features

- ♦ **Low On-Resistance: 3Ω (typ), 5Ω (max)**
- ♦ **Guaranteed R_{ON} Match Between Channels (0.5Ω max)**
- ♦ **Guaranteed Break-Before-Make Operation (MAX4622)**
- ♦ **Guaranteed Off-Channel Leakage <5nA at +85°C**
- ♦ **Single-Supply Operation (+4.5V to +36V) Bipolar-Supply Operation (±4.5V to ±18V)**
- ♦ **TTL/CMOS-Logic Compatible**
- ♦ **Rail-to-Rail® Analog Signal Handling Capability**
- ♦ **Pin Compatible with DG401/DG403/DG405**

Applications

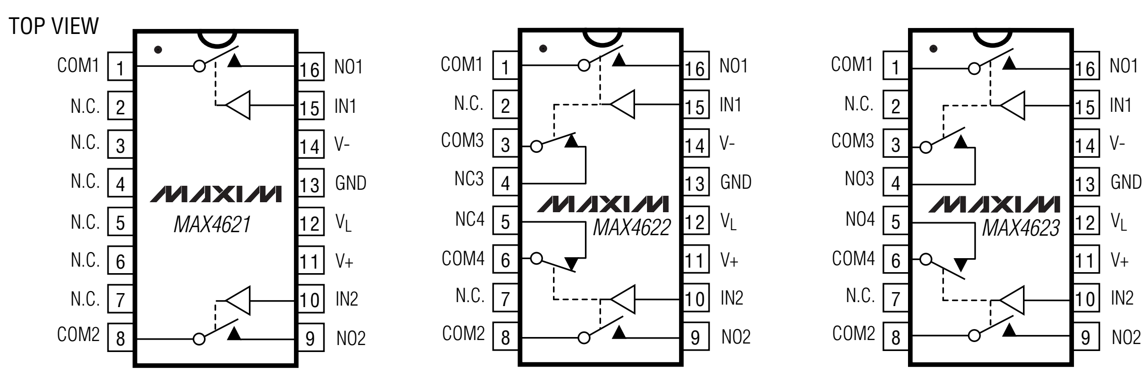
Reed Relay Replacement	Military Radios
Test Equipment	PBX, PABX Systems
Communication Systems	Audio-Signal Routing
Data-Acquisition Systems	Avionics

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX4621CSE	0°C to +70°C	16 Narrow SO
MAX4621CPE	0°C to +70°C	16 Plastic DIP

Ordering Information continued at end of data sheet.

Pin Configurations/Functional Diagrams/Truth Tables



SO/DIP **SO/DIP** **SO/DIP**

MAX4621	
LOGIC	**SWITCH**
0	OFF
1	ON

MAX4622		
LOGIC	**SWITCHES 1, 2**	**SWITCHES 3, 4**
0	OFF	ON
1	ON	OFF

MAX4623	
LOGIC	**SWITCH**
0	OFF
1	ON

SWITCHES SHOWN FOR LOGIC "0" INPUT

Dual, 5Ω Analog Switches

ABSOLUTE MAXIMUM RATINGS

(Voltages Referenced to GND)
V+ to GND ....-0.3V to +44V
V- to GND ....+0.3V to -44V
V+ to V- ....-0.3V to +44V
V_L to GND ....-0.3V to (V+ + 0.3V)
All Other Pins to GND (Note 1) .... (V- - 0.3V) to (V+ + 0.3V)
Continuous Current (COM_, NO_, NC_) ....±100mA
Peak Current (COM_, NO_, NC_)
(pulsed at 1ms, 10% duty cycle) .... ±300mA

Continuous Power Dissipation (T_A = +70°C)
Narrow SO (derate 8.70mW/°C above +70°C) 696mW
Narrow DIP (derate 10.53mW/°C above +70°C) 842mW
Operating Temperature Ranges
MAX462_C_ _ ....0°C to +70°C
MAX462_E_ _ ....-40°C to +85°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10sec) ....+300°C

Note 1: Signals on NO_, NC_, or COM_ exceeding V+ or V- are clamped by internal diodes. Limit forward-diode current to maximum current rating.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—Dual Supplies

(V+ = +15V, V- = -15V, V_L = +5V, GND = 0, V_{INH} = +2.4V, V_{INL} = +0.8V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
ANALOG SWITCH							
Input Voltage Range (Note 3)	$V_{COM\_}$, $V_{NO\_}$, $V_{NC\_}$			V-		V+	V
On-Resistance	R_{ON}	$I_{COM\_}$ = 10mA, $V_{NO\_}$ or $V_{NC\_}$ = ±10V	T_A = +25°C		3	5	Ω
			T_A = T_{MIN} to T_{MAX}			7	
On-Resistance Match Between Channels (Notes 3, 4)	ΔR_{ON}	$I_{COM\_}$ = 10mA, $V_{NO\_}$ or $V_{NC\_}$ = ±10V	T_A = +25°C		0.25	0.5	Ω
			T_A = T_{MIN} to T_{MAX}			0.7	
On-Resistance Flatness (Notes 3, 5)	$R_{FLAT(ON)}$	$I_{COM\_}$ = 10mA; $V_{NO\_}$ or $V_{NC\_}$ = -5V, 0, 5V	T_A = +25°C		0.2	0.5	Ω
			T_A = T_{MIN} to T_{MAX}			0.7	
Off-Leakage Current (NO_ or NC_) (Note 6)	$I_{NO\_}$, $I_{NC\_}$	$V_{NO\_}$ or $V_{NC\_}$ = ±10V, $V_{COM\_}$ = ∓10V	T_A = +25°C	-0.5	0.01	0.5	nA
			T_A = T_{MIN} to T_{MAX}	-5		5	
COM_ Off-Leakage Current (Note 6)	$I_{COM\_(OFF)}$	$V_{COM\_}$ = ±10V, $V_{NO\_}$ or $V_{NC\_}$ = ∓10V	T_A = +25°C	-0.5	0.01	0.5	nA
			T_A = T_{MIN} to T_{MAX}	-5		5	
COM_ On-Leakage Current (Note 6)	$I_{COM\_(ON)}$	$V_{COM\_}$ = ±10V, $V_{NO\_}$ or $V_{NC\_}$ = ∓10V or floating	T_A = +25°C	-1	0.02	1	nA
			T_A = T_{MIN} to T_{MAX}	-10		10	
LOGIC INPUT							
Input Current with Input Voltage High	I_{INH}	$V_{IN\_}$ = 2.4V		-0.5	0.001	0.5	µA
Input Current with Input Voltage Low	I_{INL}	$V_{IN\_}$ = 0.8V		-0.5	0.001	0.5	µA
Logic Input Voltage High	V_{INH}			2.4			V
Logic Input Voltage Low	V_{INL}					0.8	V

ELECTRICAL CHARACTERISTICS—Dual Supplies (continued)

($V+ = +15V$, $V- = -15V$, $V_L = +5V$, GND = 0, $V_{INH} = +2.4V$, $V_{INL} = +0.8V$, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are at $T_A = +25°C$.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
POWER SUPPLY							
Power-Supply Range				±4.5		±20.0	V
Positive Supply Current	I+	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Negative Supply Current	I-	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Logic Supply Current	I_L	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Ground Current	I_{GND}	$V_{IN\_}$ = 0 or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
SWITCH DYNAMIC CHARACTERISTICS							
Turn-On Time	t_{ON}	$V_{COM\_}$ = ±10V, Figure 2	$T_A = +25°C$		120	250	ns
			$T_A = T_{MIN}$ to T_{MAX}			325	
Turn-Off Time	t_{OFF}	$V_{COM\_}$ = ±10V, Figure 2	$T_A = +25°C$		90	200	ns
			$T_A = T_{MIN}$ to T_{MAX}			275	
Break-Before-Make Time Delay (MAX4622 only)	t_D	$V_{COM\_}$ = ±10V, Figure 3, $T_A = +25°C$		5	25		ns
Charge Injection	Q	C_L = 1.0nF, V_{GEN} = 0, R_{GEN} = 0, Figure 4, $T_A = +25°C$			480		pC
Off-Isolation (Note 7)	V_{ISO}	$R_L = 50Ω$, f = 1MHz, Figure 5, $T_A = +25°C$			-62		dB
Crosstalk (Note 8)	V_{CT}	$R_L = 50Ω$, f = 1MHz, Figure 6, $T_A = +25°C$			-60		dB
NC_ or NO_ Capacitance	C_{OFF}	f = 1MHz, Figure 7, $T_A = +25°C$			34		pF
COM_ Off-Capacitance	C_{COM}	f = 1MHz, Figure 7, $T_A = +25°C$			34		pF
On-Capacitance	C_{COM}	f = 1MHz, Figure 8, $T_A = +25°C$			150		pF

ELECTRICAL CHARACTERISTICS—Single Supply

($V+ = +12V$, $V- = 0$, $V_L = +5V$, $GND = 0$, $V_{INH} = +2.4V$, $V_{INL} = +0.8V$, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are $T_A = +25°C$.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
ANALOG SWITCH							
Input Voltage Range (Note 3)	$V_{COM\_}$, $V_{NO\_}$, $V_{NC\_}$			GND		V+	V
On-Resistance	R_{ON}	$I_{COM\_} = 10mA$, $V_{NO\_}$ or $V_{NC\_} = 10V$	$T_A = +25°C$		5.5	8	Ω
			$T_A = T_{MIN}$ to T_{MAX}			10	
On-Resistance Match Between Channels (Notes 3, 4)	ΔR_{ON}	$I_{COM\_} = 10mA$, $V_{NO\_}$ or $V_{NC\_} = 10V$, $T_A = +25°C$			0.2	0.5	Ω
On-Resistance Flatness (Notes 3, 5)	$R_{FLAT(ON)}$	$I_{COM\_} = 10mA$; $V_{NO\_}$ or $V_{NC\_} = 3V, 6V, 9V$; $T_A = +25°C$			0.9	1.3	Ω
NO_ or NC_ Off-Leakage Current (Notes 6, 9)	$I_{NO\_(OFF)}$, $I_{NC\_(OFF)}$	$V_{COM\_} = 1V, 10V$; $V_{NO\_}$ or $V_{NC\_} = 10V, 1V$	$T_A = +25°C$	-0.5	0.01	0.5	nA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
COM_ Off-Leakage Current (Notes 6, 9)	$I_{COM\_(OFF)}$	$V_{COM\_} = 10V, 1V$; $V_{NO\_}$ or $V_{NC\_} = 1V, 10V$	$T_A = +25°C$	-0.5	0.01	0.5	nA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
COM_ On-Leakage Current (Notes 6, 9)	$I_{COM\_(ON)}$	$V_{COM\_} = 10V, 1V$; $V_{NO\_}$ or $V_{NC\_} = 10V$, 1V, or floating	$T_A = +25°C$	-1	0.02	1	nA
			$T_A = T_{MIN}$ to T_{MAX}	-10		10	
LOGIC INPUT							
Input Current with Input Voltage High	I_{INH}	$V_{IN\_} = 2.4V$		-0.5	0.001	0.5	µA
Input Current with Input Voltage Low	I_{INL}	$V_{IN\_} = 0.8V$		-0.5	0.001	0.5	µA
Logic Input Voltage High	V_{INH}			2.4			V
Logic Input Voltage Low	V_{INL}					0.8	V
POWER SUPPLY							
Power-Supply Range				4.5		36.0	V
Positive Supply Current	I+	$V_{IN\_} = 0$ or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Logic Supply Current	I_L	$V_{IN\_} = 0$ or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	
Ground Current	I_{GND}	$V_{IN\_} = 0$ or 5V	$T_A = +25°C$	-0.5	0.001	0.5	µA
			$T_A = T_{MIN}$ to T_{MAX}	-5		5	

ELECTRICAL CHARACTERISTICS—Single Supply (continued)

($V+ = +12V$, $V- = 0$, $V_L = +5V$, $GND = 0$, $V_{INH} = +2.4V$, $V_{INL} = +0.8V$, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are $T_A = +25°C$.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
SWITCH DYNAMIC CHARACTERISTICS							
Turn-On Time (Note 3)	t_{ON}	$V_{COM\_} = 10V$, Figure 2	$T_A = +25°C$		200	350	ns
			$T_A = T_{MIN}$ to T_{MAX}			475	
Turn-Off Time (Note 3)	t_{OFF}	$V_{COM\_} = 10V$, Figure 2	$T_A = +25°C$		100	200	ns
			$T_A = T_{MIN}$ to T_{MAX}			300	
Break-Before-Make Time Delay (MAX4622 only) (Note 3)	t_D	$R_L = 100\Omega$, $C_L = 35pF$, Figure 3, $T_A = +25°C$		10	75		ns
Charge Injection	Q	$C_L = 1.0nF$, $V_{GEN} = 0$, $R_{GEN} = 0$, Figure 4			45		pC
Off-Isolation (Note 7)	V_{ISO}	$R_L = 50\Omega$, f = 1MHz, Figure 5			-62		dB
Crosstalk (Note 8)	V_{CT}	$R_L = 50\Omega$, f = 1MHz, Figure 6			-60		dB

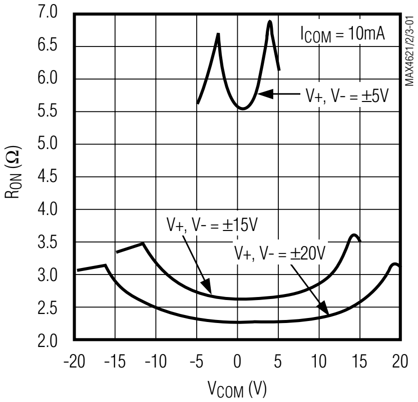
Note 2: The algebraic convention, where the most negative value is a minimum and the most positive value is a maximum, is used in this data sheet.
Note 3: Guaranteed by design.
Note 4: $\Delta R_{ON} = R_{ON\_MAX} - R_{ON\_MIN}$.
Note 5: Flatness is defined as the difference between the maximum and minimum values of on-resistance as measured over the specified analog signal range.
Note 6: Leakage currents are 100% tested at the maximum-rated hot temperature and guaranteed by correlation at +25°C.
Note 7: Off-isolation = $20\log_{10} [V_{COM\_} / (V_{NC\_}$ or $V_{NO\_})]$. $V_{COM\_}$ = output, $V_{NC\_}$ or $V_{NO\_}$ = input to off switch.
Note 8: Between any two switches.
Note 9: Leakage testing for single-supply operation is guaranteed by testing with dual supplies.

Dual, 5Ω Analog Switches

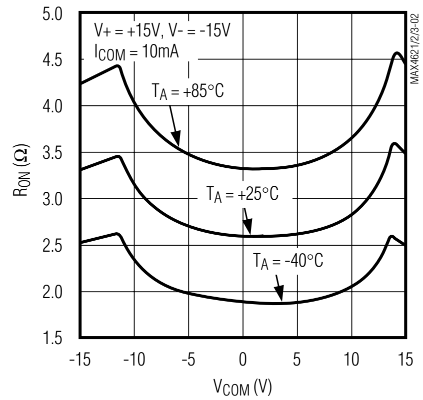
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

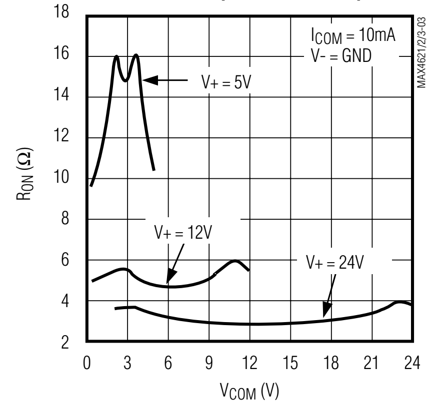
ON-RESISTANCE vs. V_{COM} (DUAL SUPPLIES)



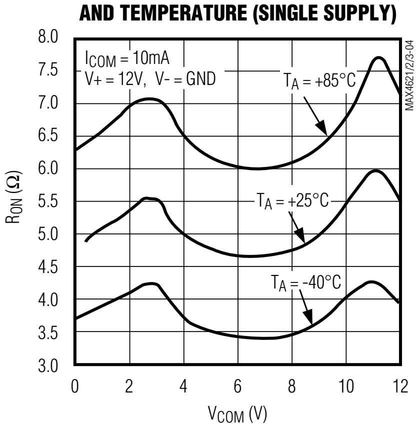
ON-RESISTANCE vs. V_{COM} AND TEMPERATURE (DUAL SUPPLIES)



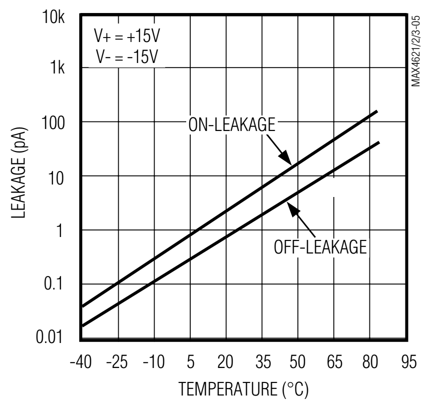
ON-RESISTANCE vs. V_{COM} (SINGLE SUPPLY)



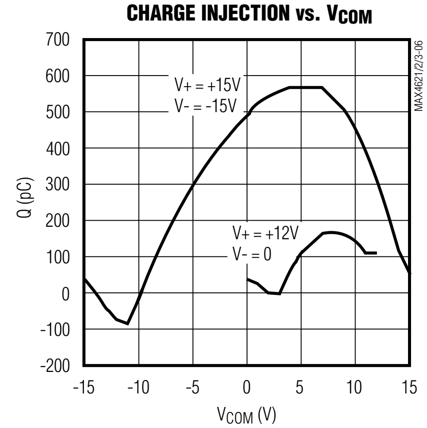
ON-RESISTANCE vs. V_{COM} AND TEMPERATURE (SINGLE SUPPLY)



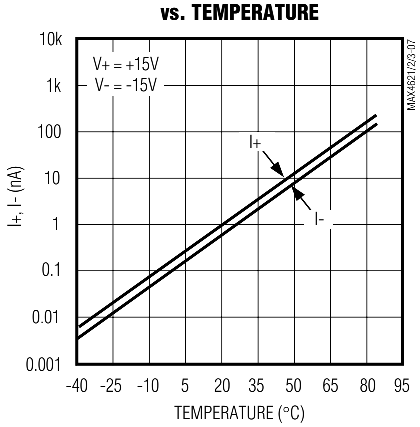
ON/OFF-LEAKAGE CURRENT vs. TEMPERATURE



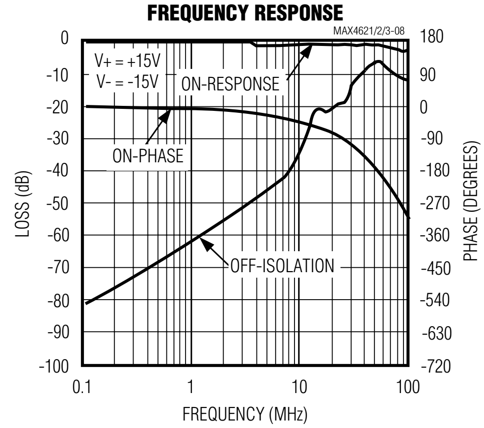
CHARGE INJECTION vs. V_{COM}



SUPPLY CURRENT vs. TEMPERATURE



FREQUENCY RESPONSE



Pin Description

PIN	NAME	FUNCTION
MAX4621		
1, 8	COM1, COM2	Switch Common Terminal
2–7	N.C.	Not internally connected
9, 16	NO2, NO1	Switch Normally Open Terminal
10, 15	IN2, IN1	Digital Logic Inputs
11	V+	Positive Supply-Voltage Input
12	V_L	Logic Supply-Voltage Input
13	GND	Ground
14	V-	Negative Supply Voltage Input
MAX4622		
1, 3, 6, 8	COM_	Switch Common Terminal
2, 7	N.C.	Not internally connected
4, 5, 9, 16	NC_, NO_	Switch Normally Closed/Open Terminal
10, 15	IN2, IN1	Digital Logic Inputs
11	V+	Positive Supply-Voltage Input
12	V_L	Logic Supply-Voltage Input
13	GND	Ground
14	V-	Negative Supply Voltage Input
MAX4623		
1, 3, 6, 8	COM_	Switch Common Terminal
2, 7	N.C.	Not internally connected
4, 5, 9, 16	NO_	Switch Normally Open Terminal
10, 15	IN2, IN1	Digital Logic Inputs
11	V+	Positive Supply-Voltage Input
12	V_L	Logic Supply-Voltage Input
13	GND	Ground
14	V-	Negative Supply Voltage

Applications Information

Operation with Supply Voltages Other than ±15V

The MAX4621/MAX4622/MAX4623 switches operate with ±4.5V to ±18V bipolar supplies and a +4.5V to +36V single supply. In either case, analog signals ranging from V+ to V- can be switched. The *Typical Operating Characteristics* graphs show the typical on-resistance variation with analog signal and supply voltage.

Overvoltage Protection

Proper power-supply sequencing is recommended for all CMOS devices. It is important not to exceed the absolute maximum ratings because stresses beyond the listed ratings may cause permanent damage to the devices. Always sequence V+ on first, followed by V_L, V-, and logic inputs. If power-supply sequencing is not possible, add two small signal diodes in series with the supply pins and a Schottky diode between V+ and V_L (Figure 1). Adding diodes reduces the analog signal range to 1V below V+ and 1V above V-, but low switch resistance and low leakage characteristics are unaffected. The difference between V+ and V- should not exceed +44V.

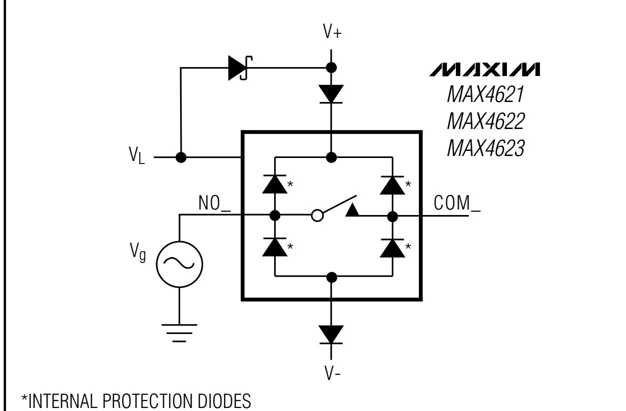


Figure 1. Overvoltage Protection Using Blocking Diodes

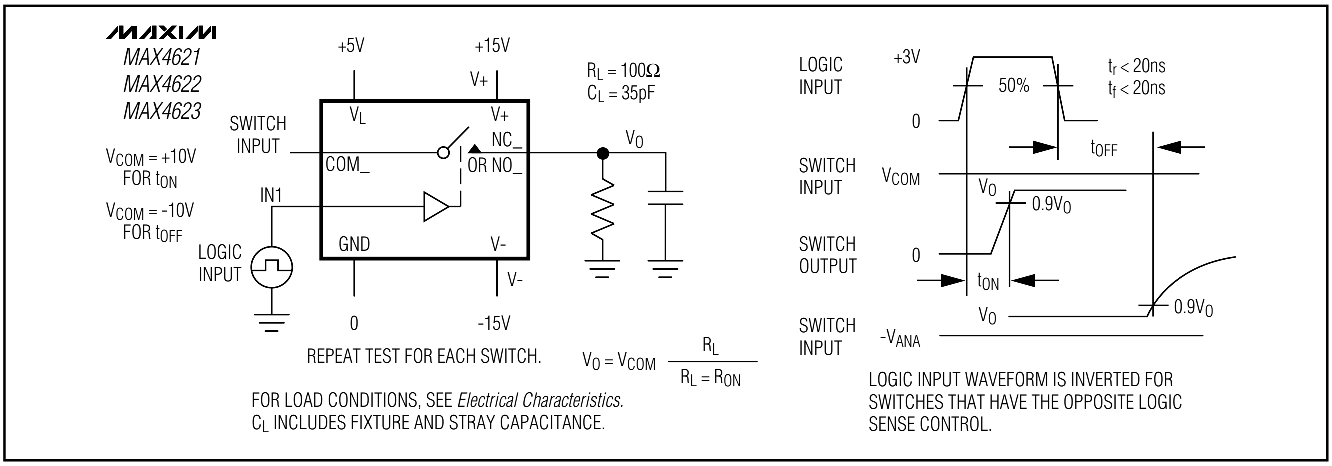


Figure 2. Switching-Time Test Circuit

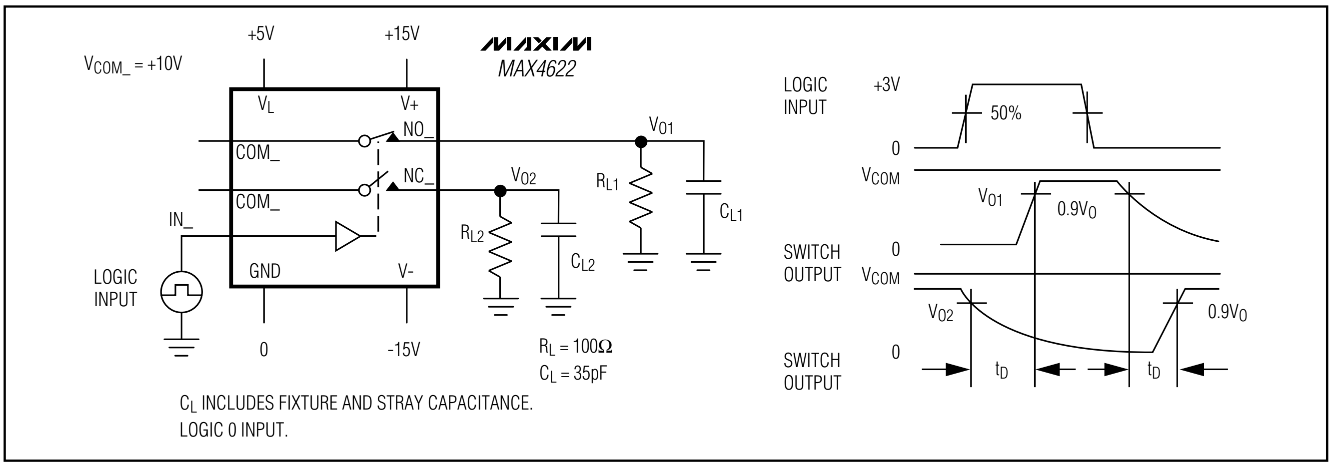


Figure 3. MAX4622 Break-Before-Make Test Circuit

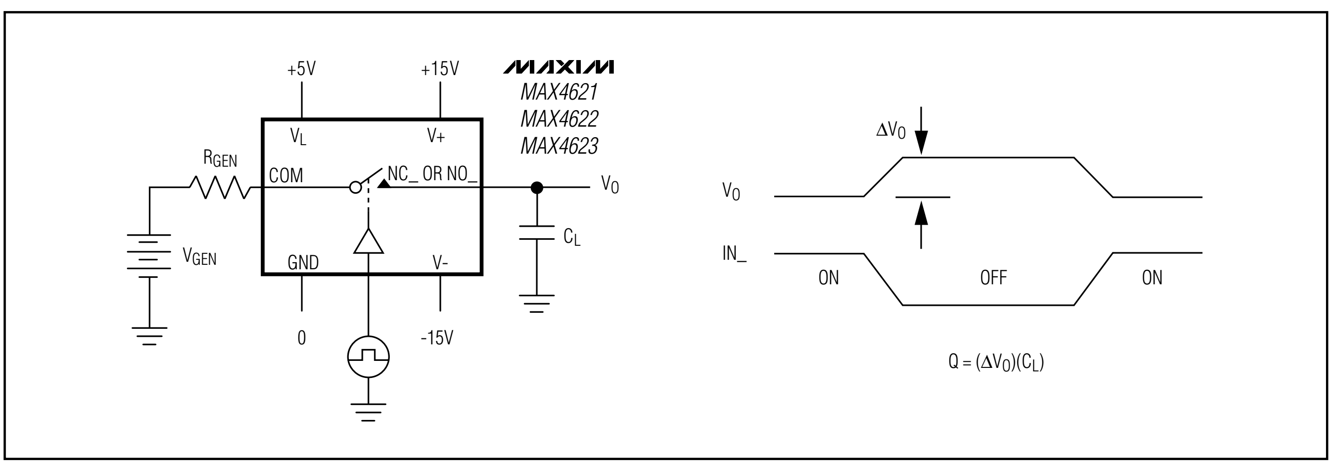
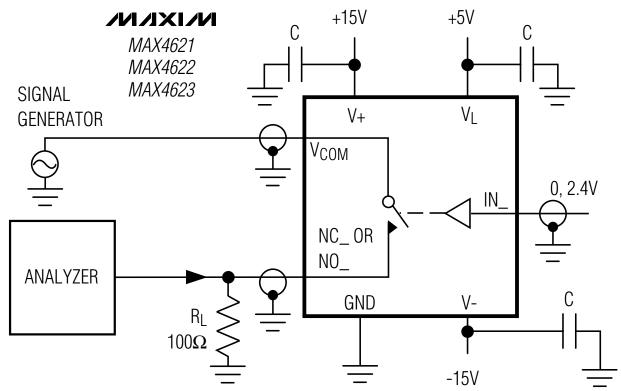


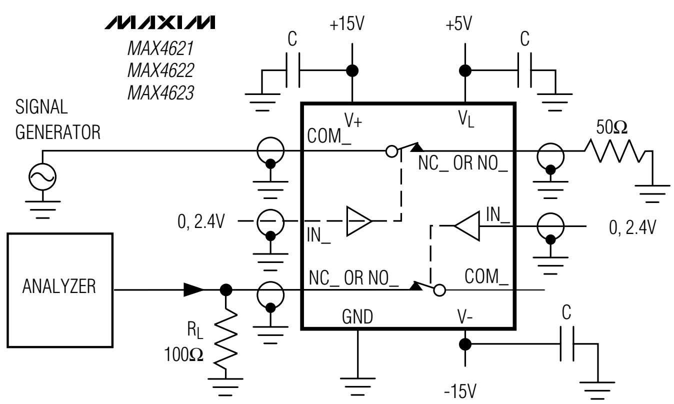
Figure 4. Charge-Injection Test Circuit



FREQUENCY TESTED	SIGNAL GENERATOR	ANALYZER
1MHz	AUTOMATIC SYNTHESIZER	TRACKING SPECTRUM ANALYZER

$$\text{OFF-ISOLATION} = 20\text{LOG}\ \frac{V_{COM}}{V_{NC}\ \text{OR}\ V_{NO}}$$

Figure 5. Off-Isolation



FREQUENCY TESTED	SIGNAL GENERATOR	ANALYZER
1MHz	AUTOMATIC SYNTHESIZER	TRACKING SPECTRUM ANALYZER

Figure 6. Crosstalk Test Circuit

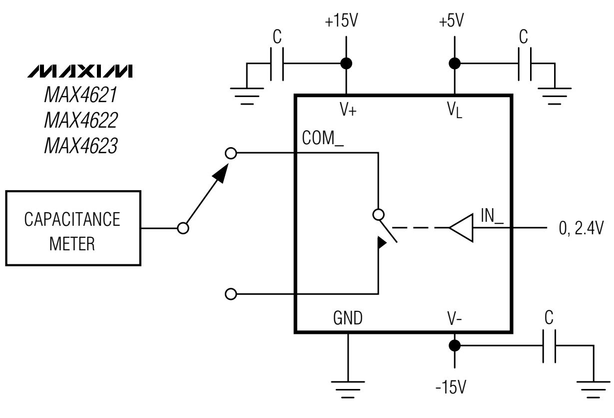


Figure 7. Channel-On Capacitance

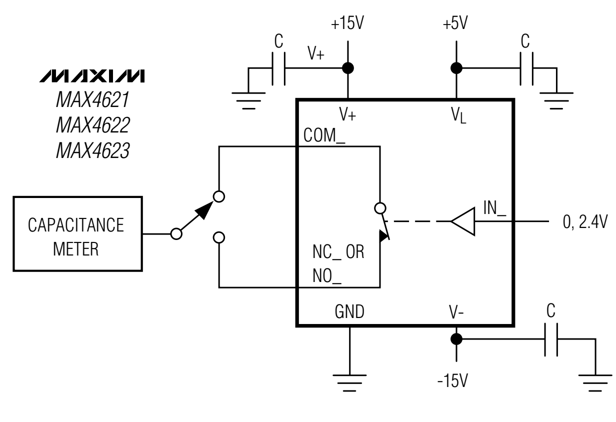


Figure 8. Channel-Off Capacitance

Dual, 5Ω Analog Switches

Ordering Information (continued)

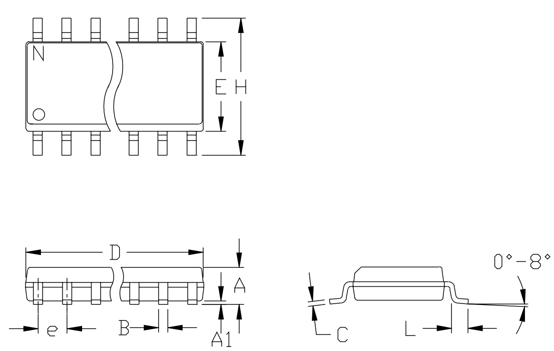
PART	TEMP. RANGE	PIN-PACKAGE
MAX4621ESE	-40°C to +85°C	16 Narrow SO
MAX4621EPE	-40°C to +85°C	16 Plastic DIP
MAX4622CSE	0°C to +70°C	16 Narrow SO
MAX4622CPE	0°C to +70°C	16 Plastic DIP
MAX4622ESE	-40°C to +85°C	16 Narrow SO
MAX4622EPE	-40°C to +85°C	16 Plastic DIP
MAX4623CSE	0°C to +70°C	16 Narrow SO
MAX4623CPE	0°C to +70°C	16 Plastic DIP
MAX4623ESE	-40°C to +85°C	16 Narrow SO
MAX4623EPE	-40°C to +85°C	16 Plastic DIP

Chip Information

TRANSISTOR COUNT: 82

Package Information

SOICN.EPS



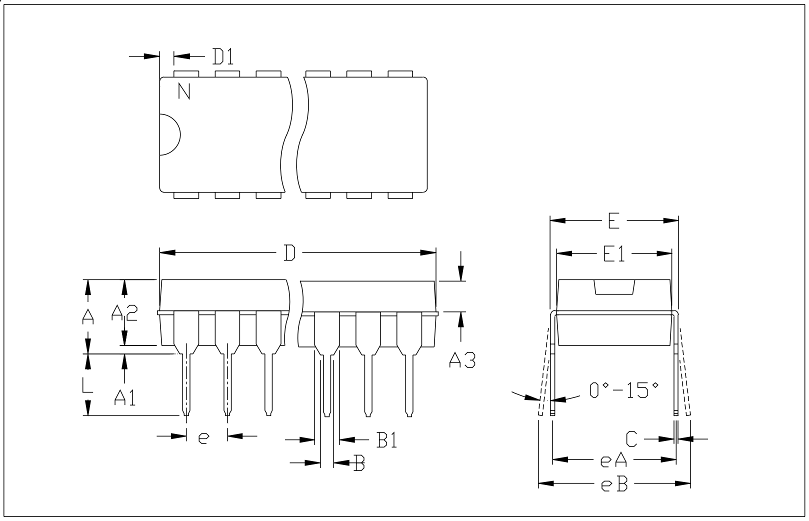
	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.004	0.010	0.10	0.25
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
e	0.050		1.27	
E	0.150	0.157	3.80	4.00
H	0.228	0.244	5.80	6.20
h	0.010	0.020	0.25	0.50
L	0.016	0.050	0.40	1.27

	INCHES		MILLIMETERS			
	MIN	MAX	MIN	MAX	N	MS012
D	0.189	0.197	4.80	5.00	8	A
D	0.337	0.344	8.55	8.75	14	B
D	0.386	0.394	9.80	10.00	16	C

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. LEADS TO BE COPLANAR WITHIN .102mm (.004")
4. CONTROLLING DIMENSION: MILLIMETER
5. MEETS JEDEC MS012-XX AS SHOWN IN ABOVE TABLE
6. N = NUMBER OF PINS

MAXIM 120 SAN GABRIEL DR. SUNNYVALE CA 94086 FAX (408) 737 7194 PROPRIETARY INFORMATION | TITLE: PACKAGE FAMILY OUTLINE: SOIC .150" | 1/1 | 21-0041 A DOCUMENT CONTROL NUMBER REV

Package Information (continued)



	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	---	0.200	---	5.08
A1	0.015	---	0.38	---
A2	0.125	0.175	3.18	4.45
A3	0.055	0.080	1.40	2.03
B	0.016	0.022	0.41	0.56
B1	0.045	0.065	1.14	1.65
C	0.008	0.012	0.20	0.30
D1	0.005	0.080	0.13	2.03
E	0.300	0.325	7.62	8.26
E1	0.240	0.310	6.10	7.87
e	0.100	---	2.54	---
eA	0.300	---	7.62	---
eB	---	0.400	---	10.16
L	0.115	0.150	2.92	3.81

	INCHES		MILLIMETERS			
	MIN	MAX	MIN	MAX	N	MS001
D	0.348	0.390	8.84	9.91	8	AB
D	0.735	0.765	18.67	19.43	14	AC
D	0.745	0.765	18.92	19.43	16	AA
D	0.885	0.915	22.48	23.24	18	AD
D	1.015	1.045	25.78	26.54	20	AE
D	1.14	1.265	28.96	32.13	24	AF
D	1.360	1.380	34.54	35.05	28	*5

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. CONTROLLING DIMENSION: MILLIMETER
4. MEETS JEDEC MS001-XX AS SHOWN IN ABOVE TABLE
5. SIMILIAR TO JEDEC MO-058AB
6. N = NUMBER OF PINS

MAXIM 120 SAN GABRIEL DR. SUNNYVALE CA 94086 FAX (408) 737 7194 PROPRIETARY INFORMATION | TITLE: PACKAGE FAMILY OUTLINE: PDIP .300" | 1/1 | DOCUMENT CONTROL NUMBER 21-0043 | REV A

NOTES

The Design Of An Embedded Controller For An Automated Volt-Drop Test

A Collection Of Screen Captures And Notes

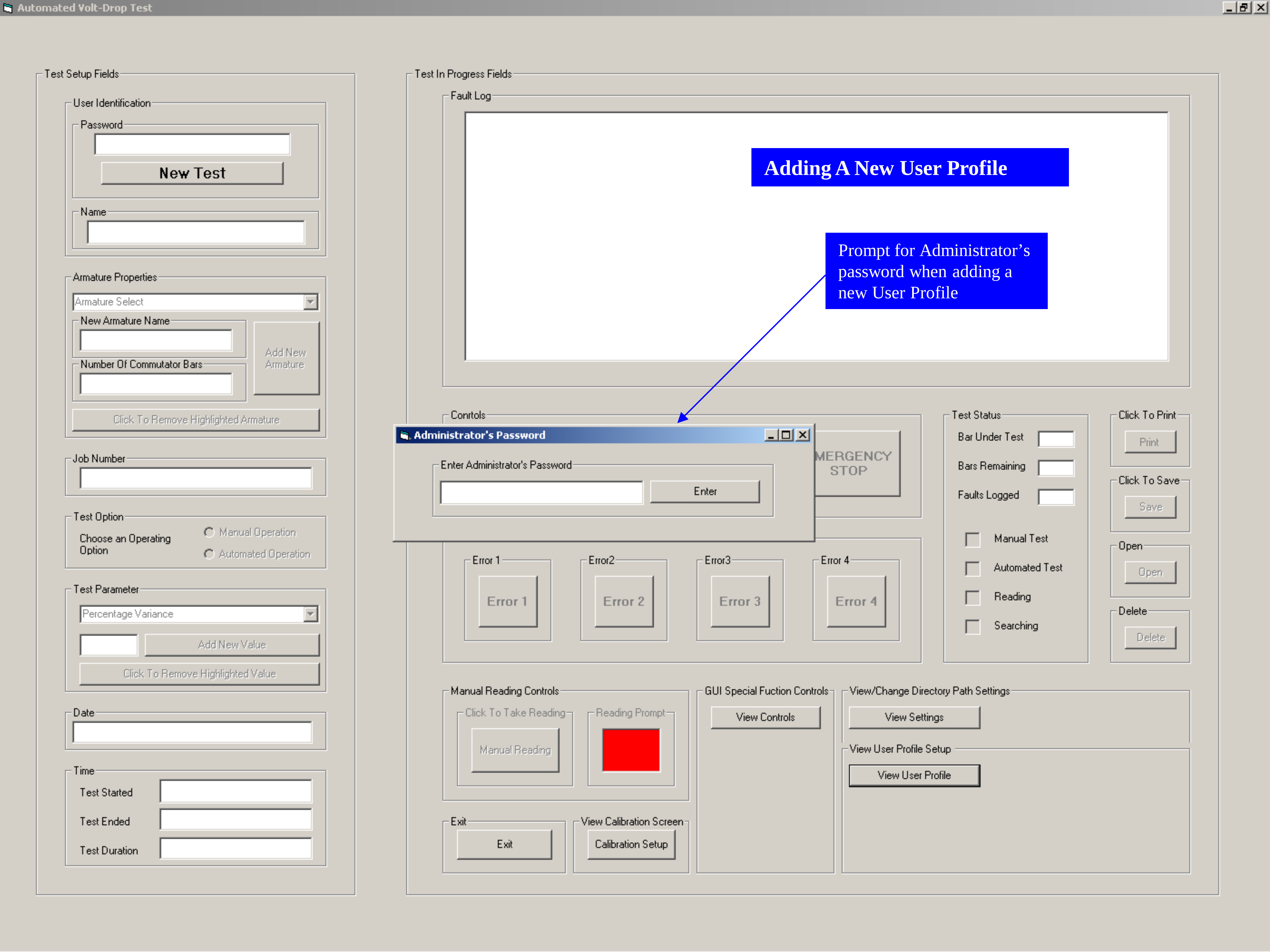
Name: Sunveer Matadin

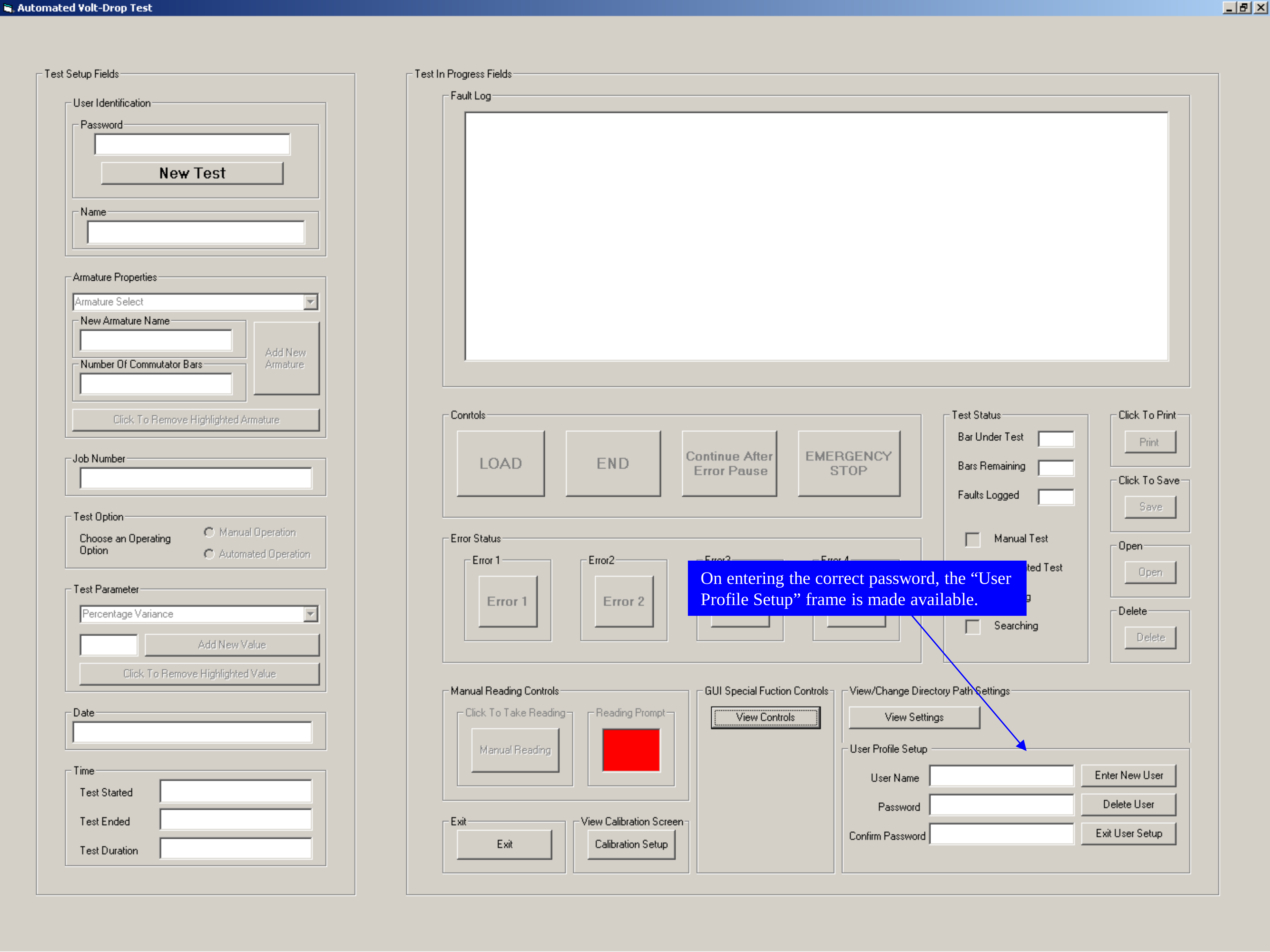
Student Number: 2001 027 41

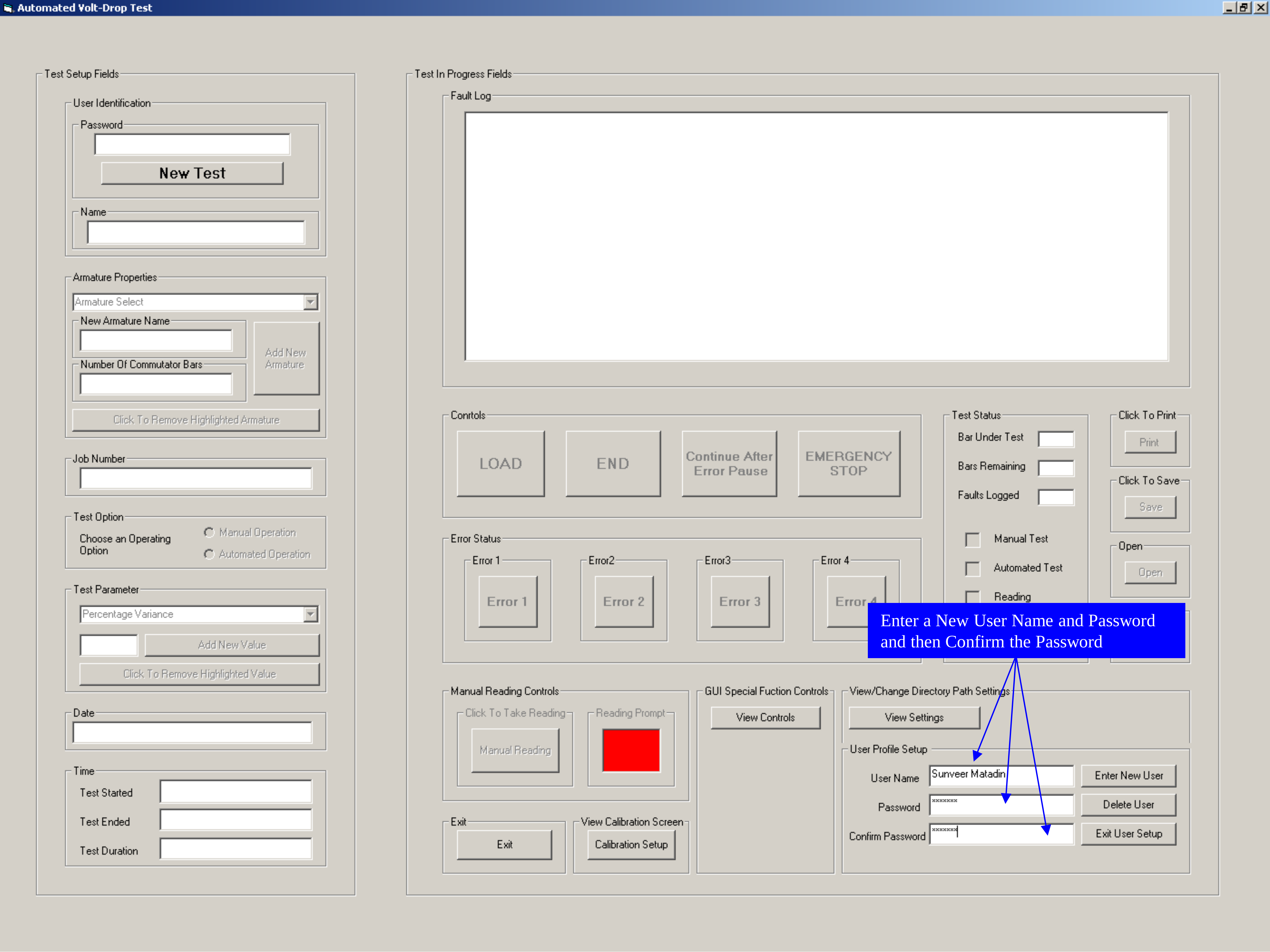
The Design Of An Embedded Controller For An Automated Volt-Drop Test

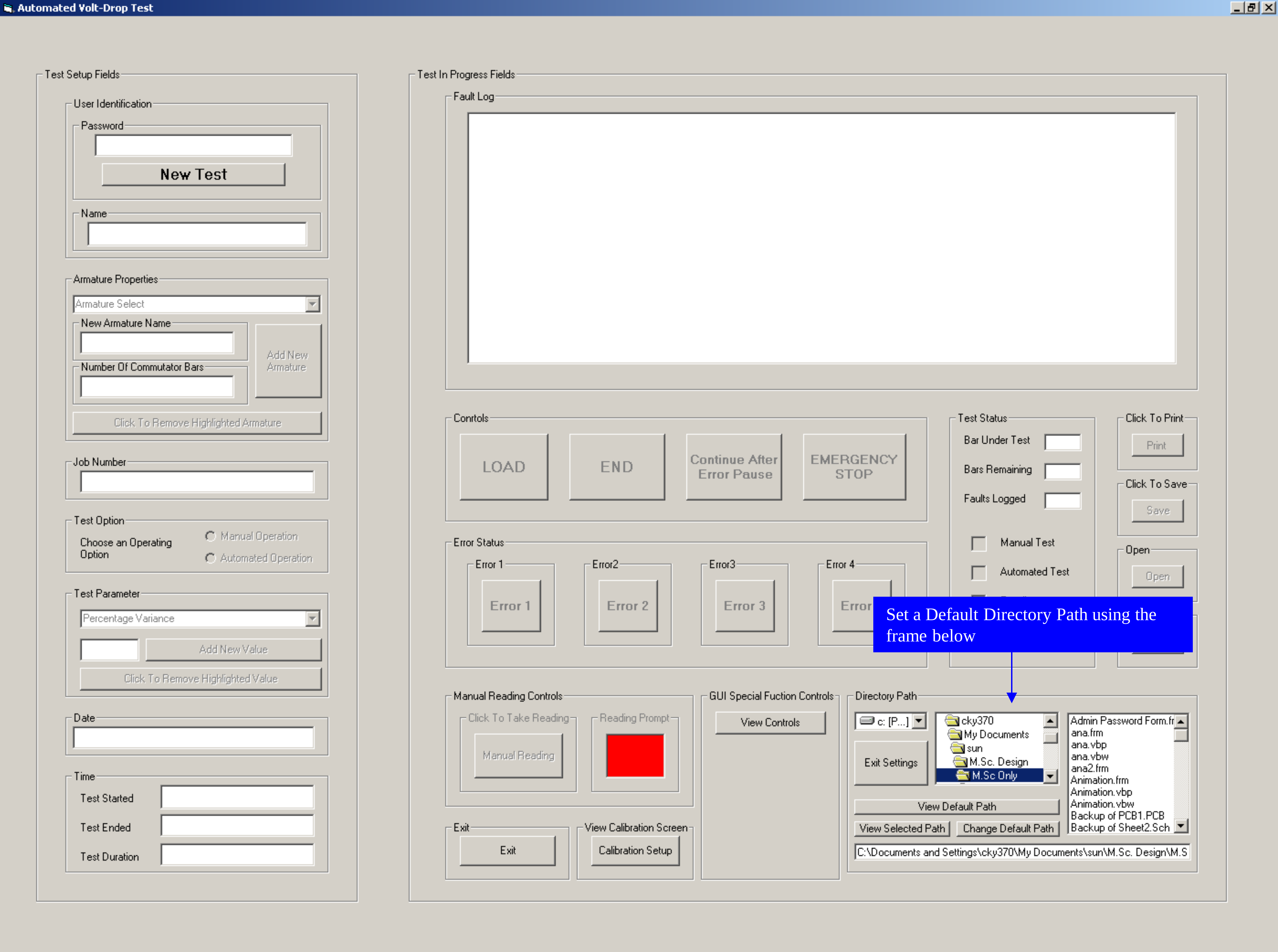
The Graphic User Interface

(GUI)


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Adding A New User Profile
Prompt for Administrator's password when adding a new User Profile
Controls
Administrator's Password
Enter Administrator's Password
Enter
MERGENCY STOP
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
On entering the correct password, the “User Profile Setup” frame is made available.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
User Profile Setup
User Name
Enter New User
Password
Delete User
Confirm Password
Exit User Setup
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Click To Print
Print
Click To Save
Save
Open
Open
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Enter a New User Name and Password and then Confirm the Password
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
User Profile Setup
User Name
Sunveer Matadin
Enter New User
Password
Delete User
Confirm Password
Exit User Setup
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
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User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
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Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
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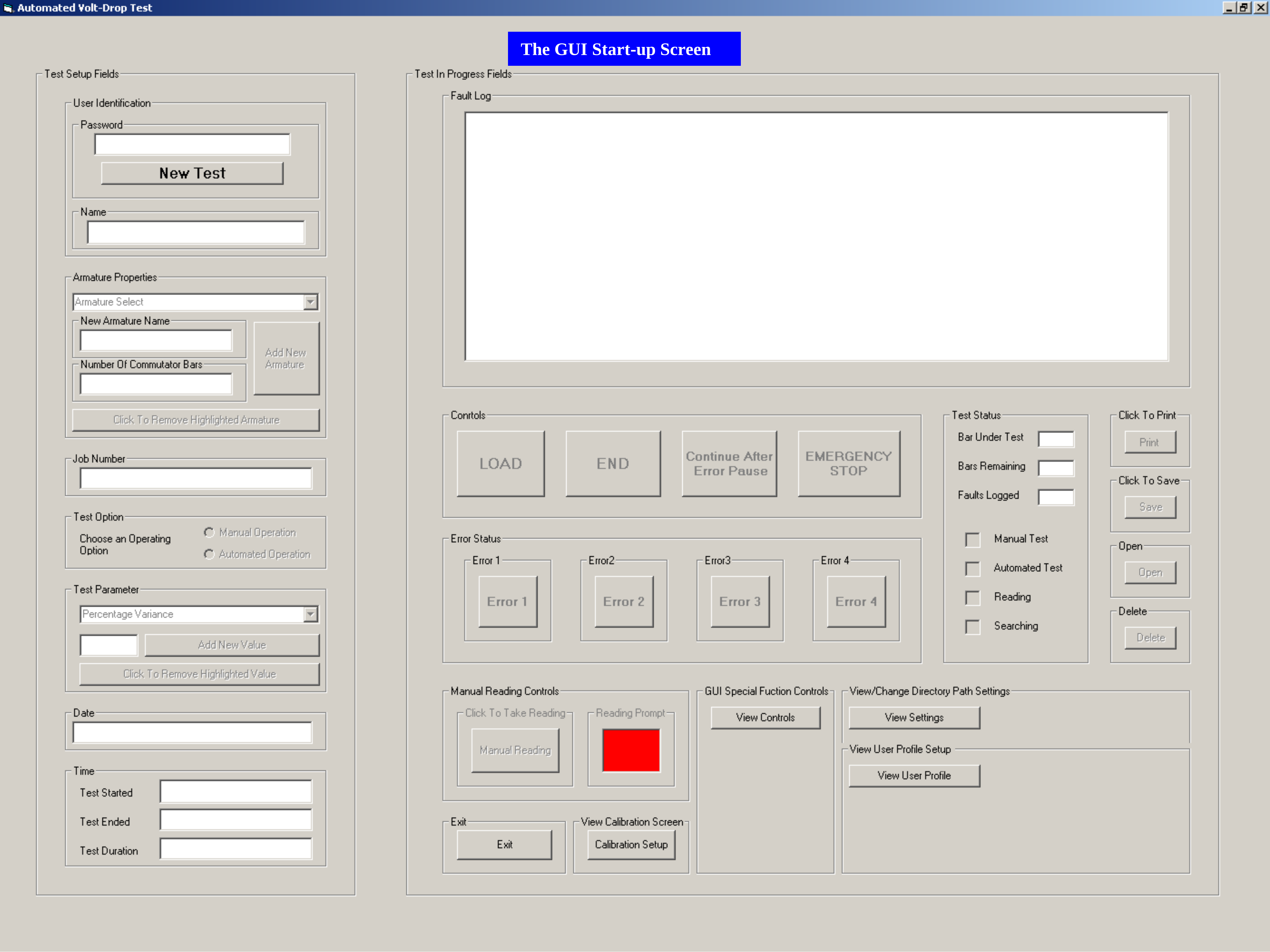
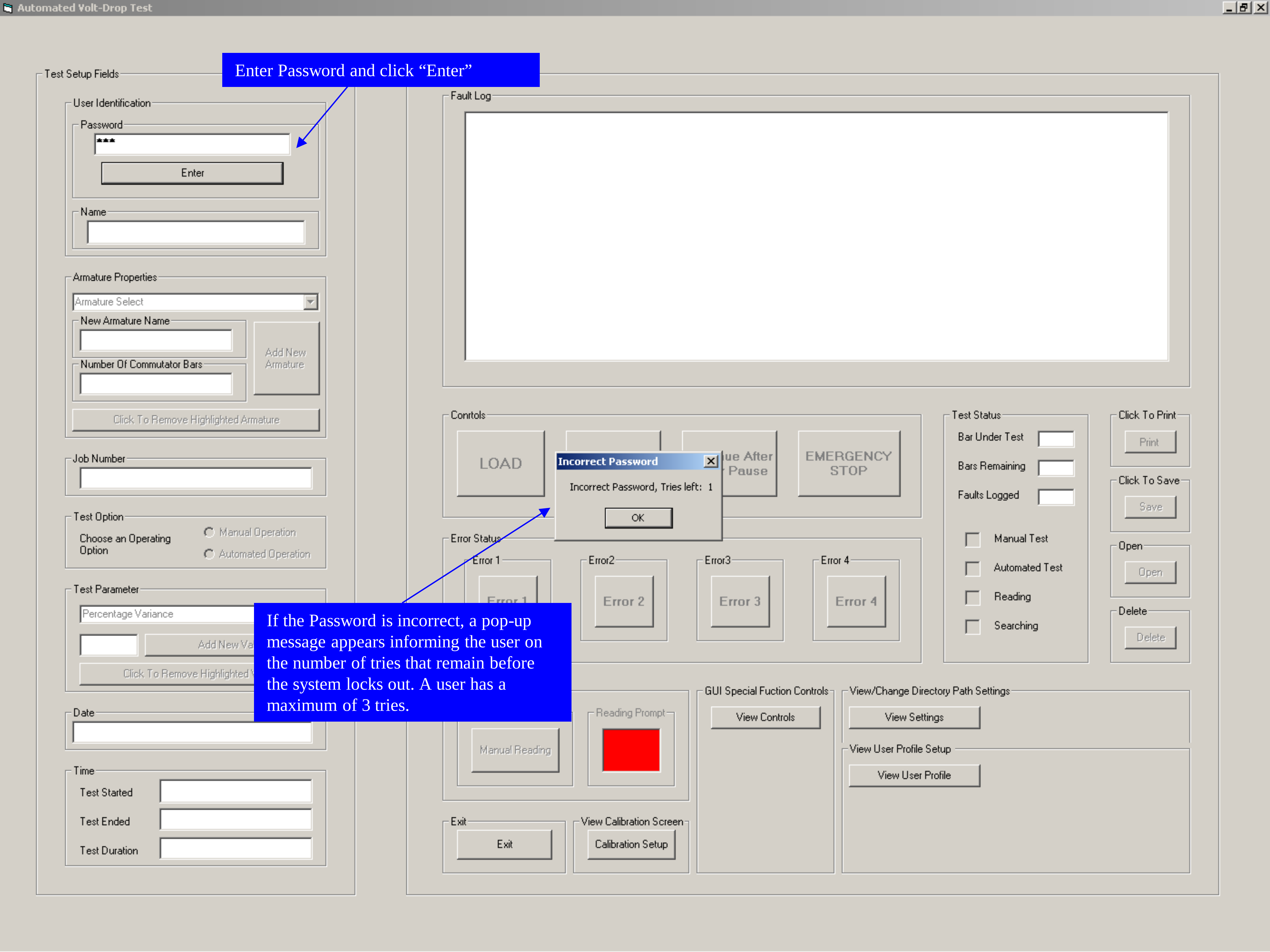
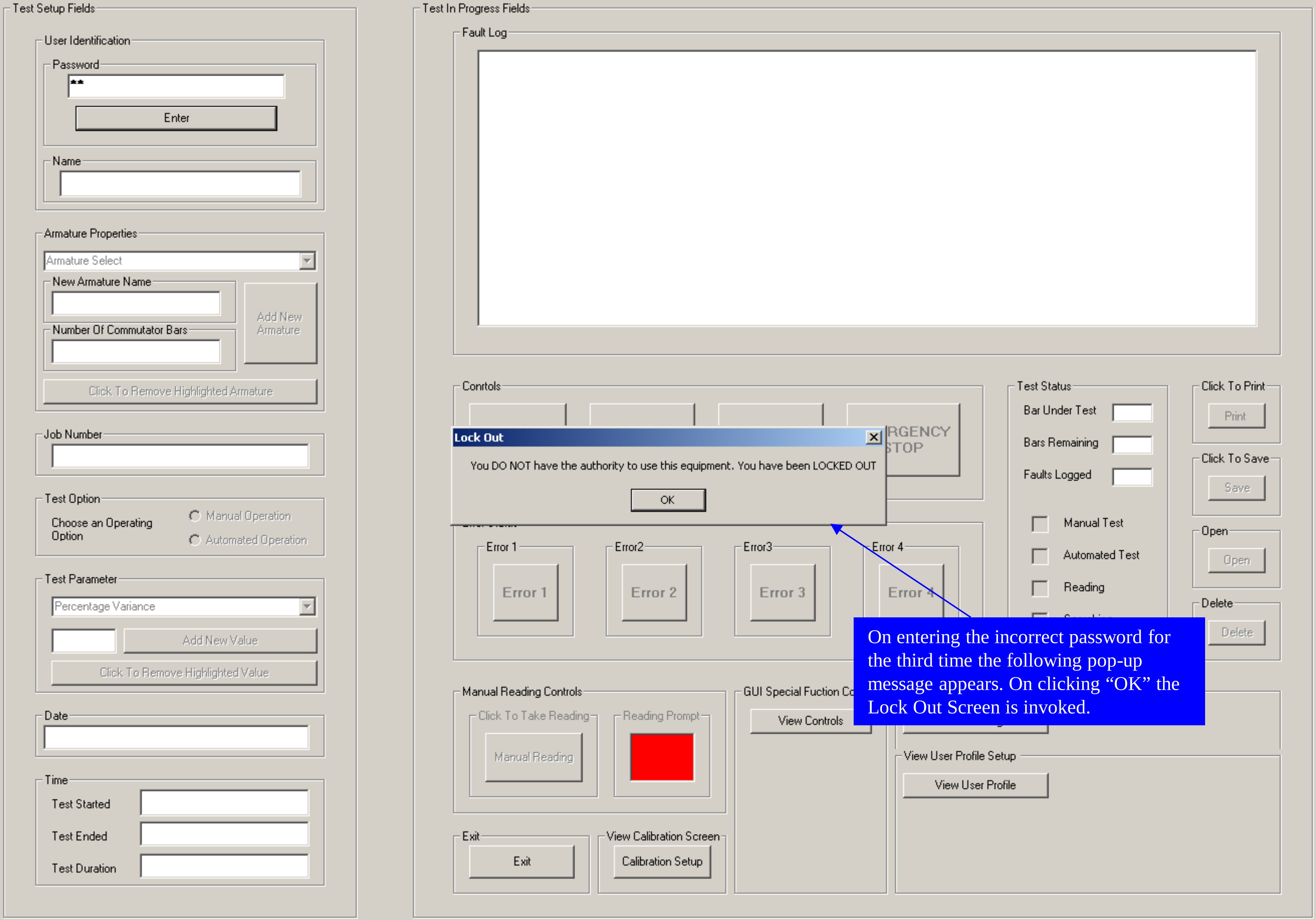
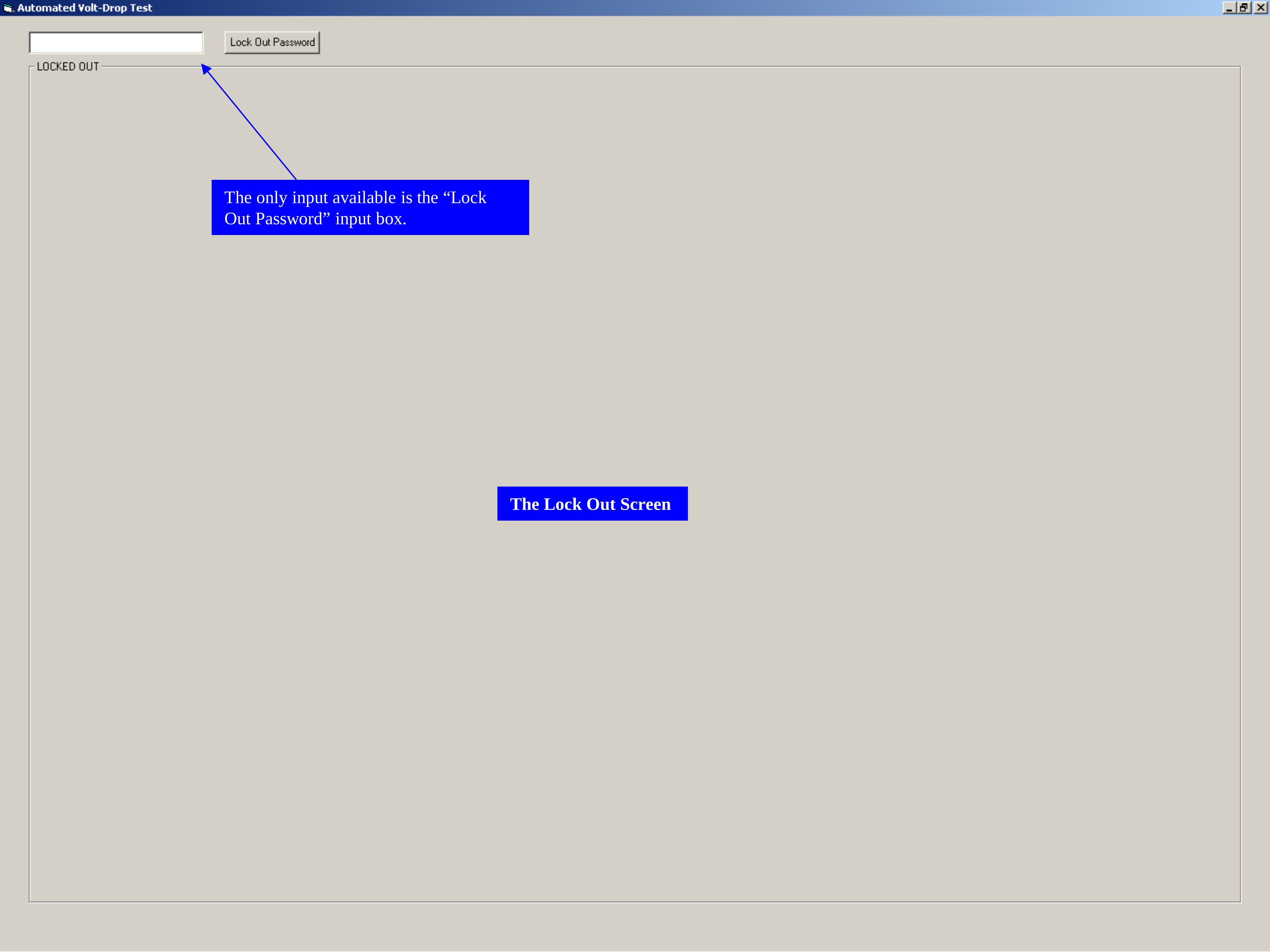
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Click To Print
Print
Click To Save
Save
Open
Open
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error
Set a Default Directory Path using the frame below
Manual Reading Controls
Click To Take Reading
Reading Prompt
Manual Reading
GUI Special Fuction Controls
View Controls
Directory Path
c: [P...]
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
Admin Password Form.fr
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
Exit Settings
View Default Path
View Selected Path
Change Default Path
C:\Documents and Settings\cky370\My Documents\sun\M.Sc. Design\M.S
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
The GUI Start-up Screen
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Enter Password and click "Enter"
Test Setup Fields
User Identification
Password
***
Enter
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Date
Time
Test Started
Test Ended
Test Duration
Fault Log
Controls
LOAD
EMERGENCY STOP
Incorrect Password
Incorrect Password, Tries left: 1
OK
Error Status
Error 1
Error2
Error3
Error 4
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
If the Password is incorrect, a pop-up message appears informing the user on the number of tries that remain before the system locks out. A user has a maximum of 3 tries.
Reading Prompt
Manual Reading
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup



On entering the incorrect password for the third time the following pop-up message appears. On clicking “OK” the Lock Out Screen is invoked.


Automated Volt-Drop Test
Lock Out Password
LOCKED OUT
The only input available is the “Lock Out Password” input box.
The Lock Out Screen

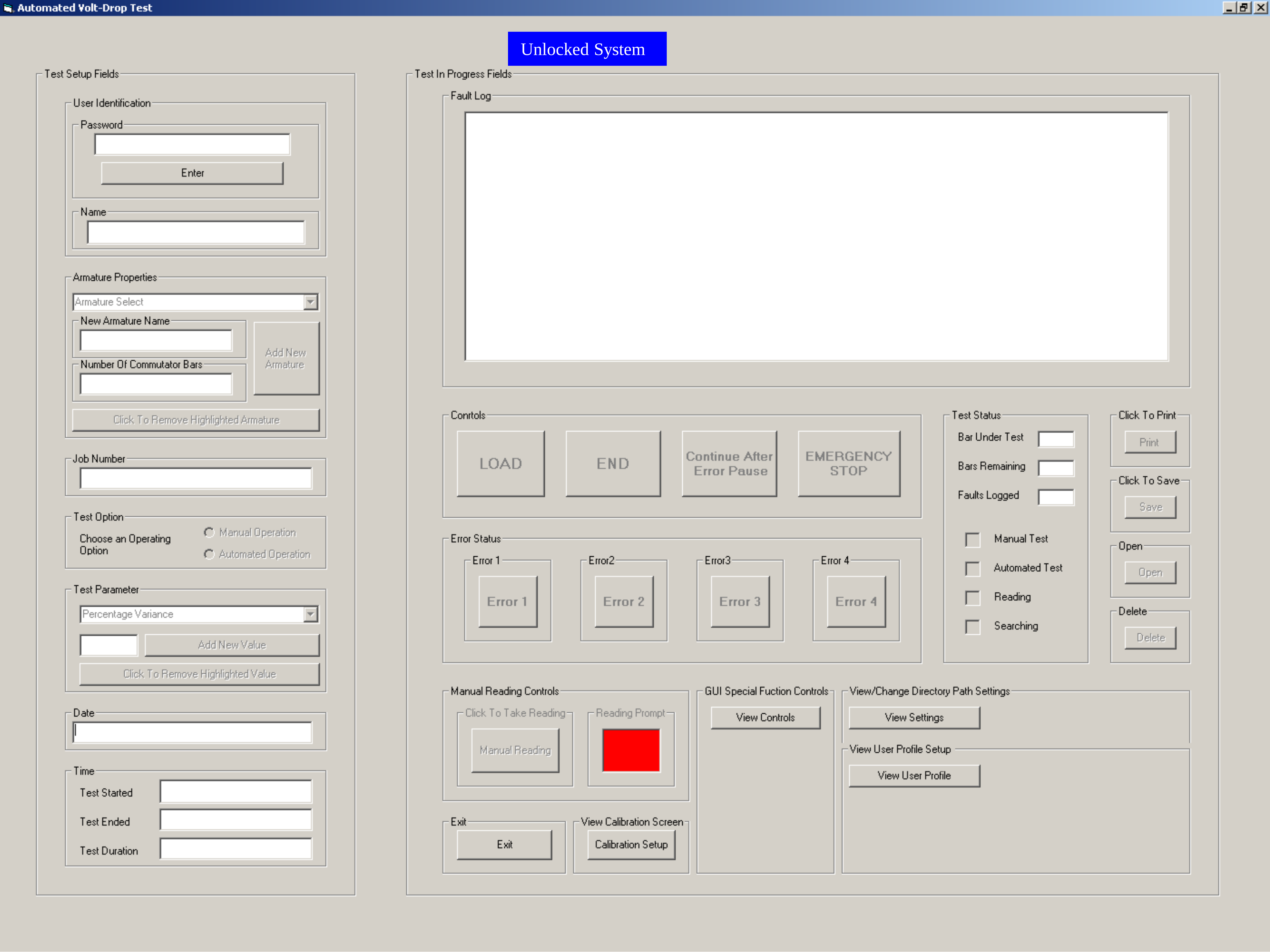
Automated Volt-Drop Test

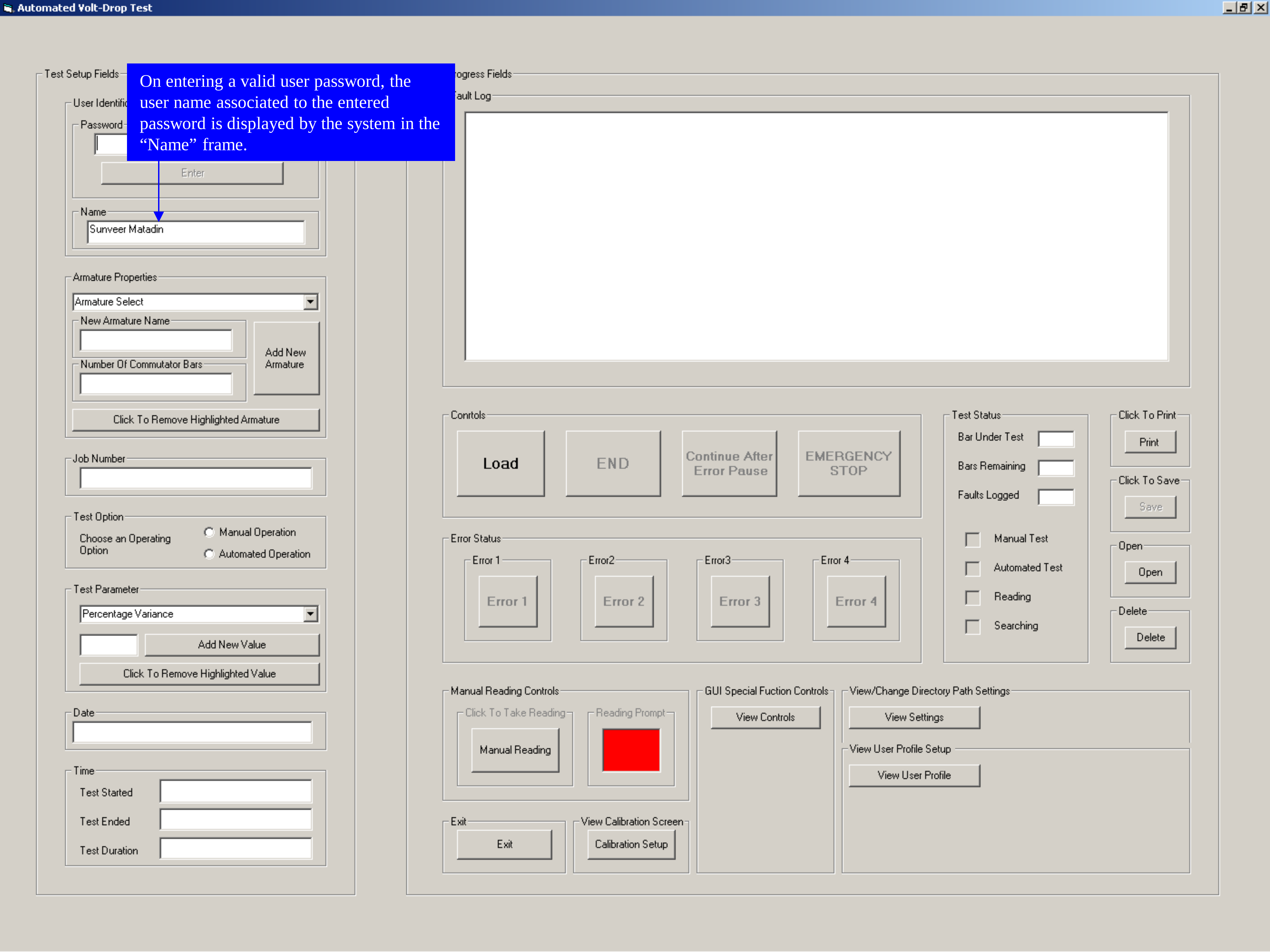
****

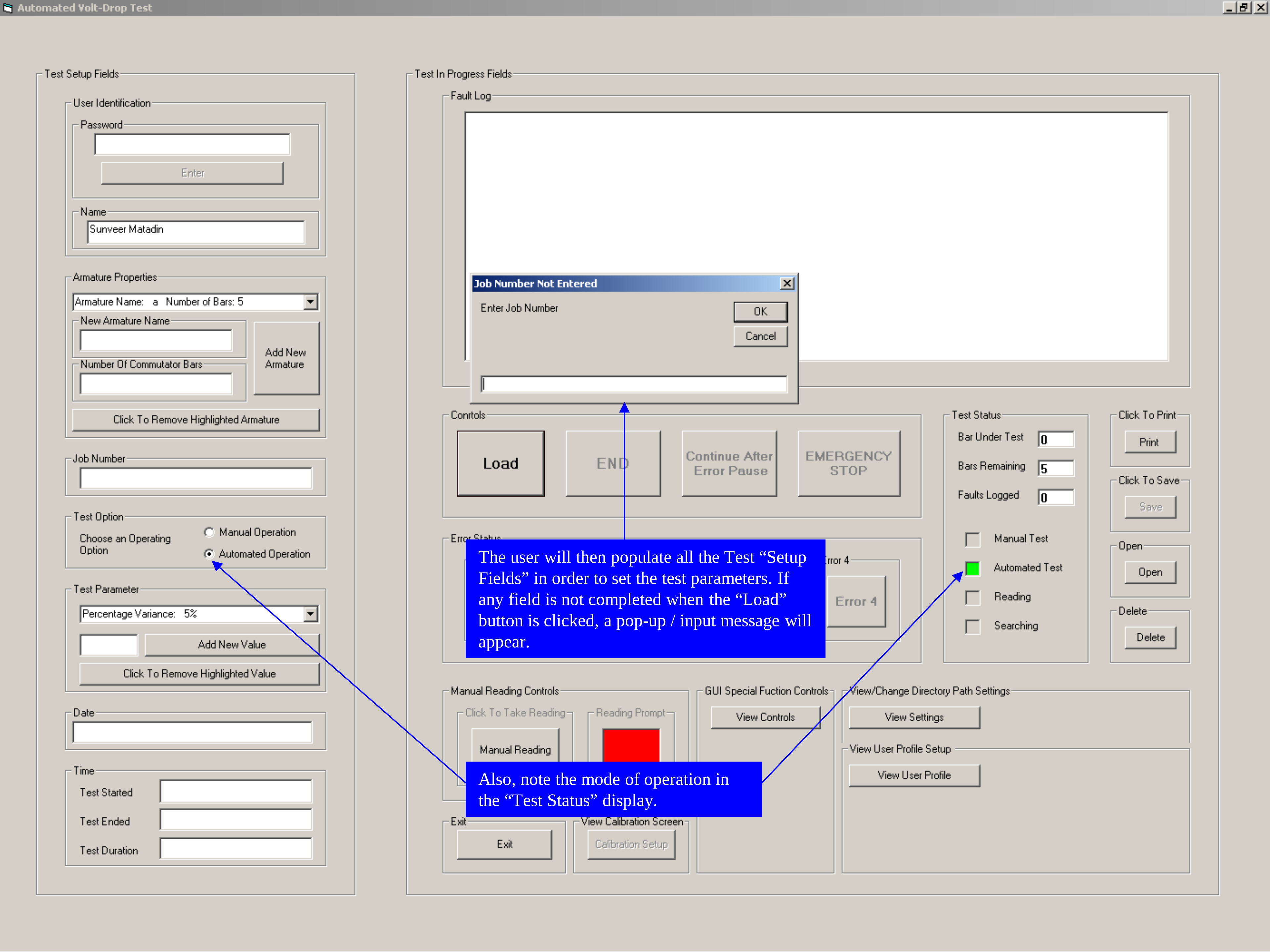
Lock Out Password

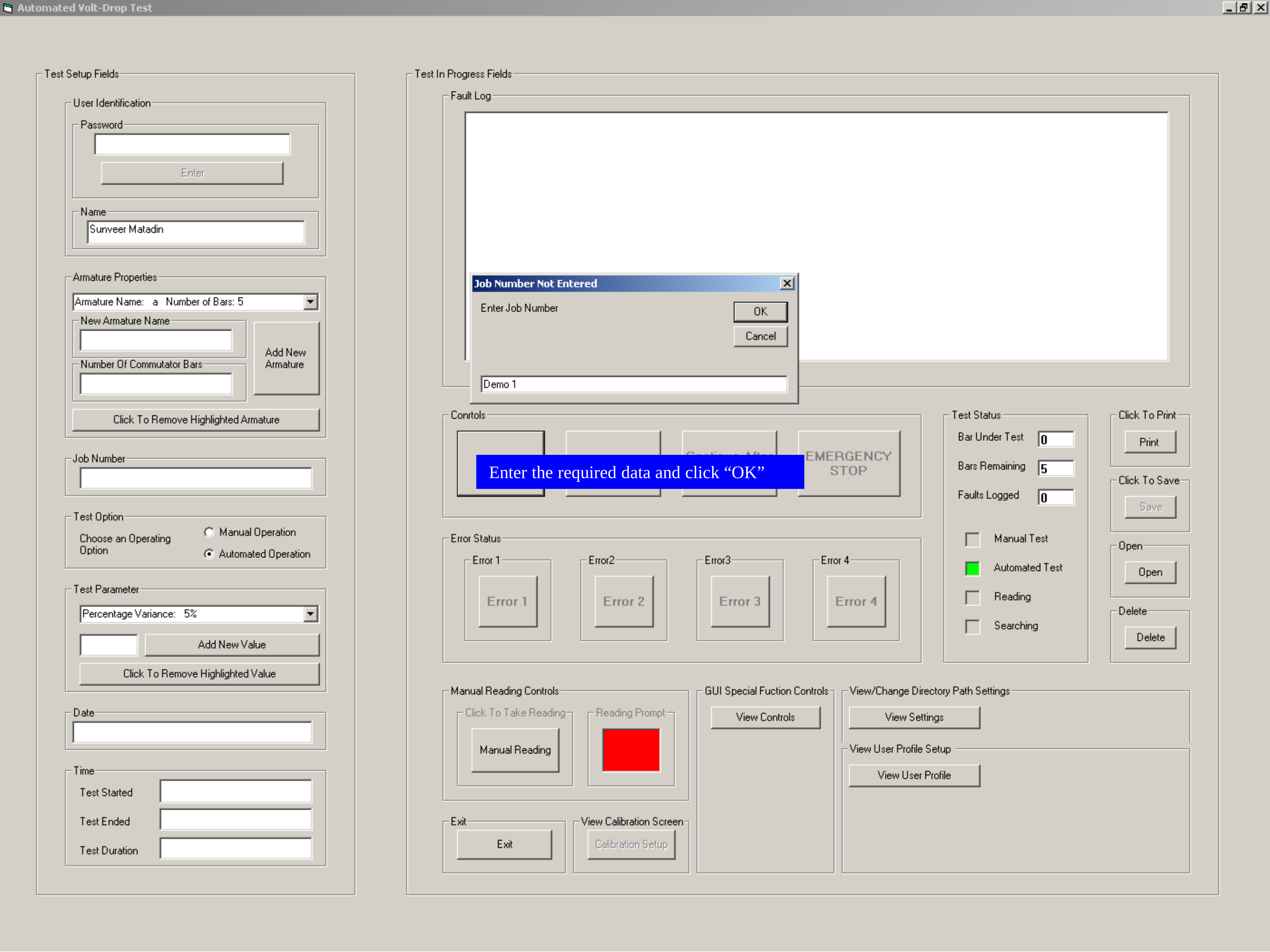
LOCKED OUT

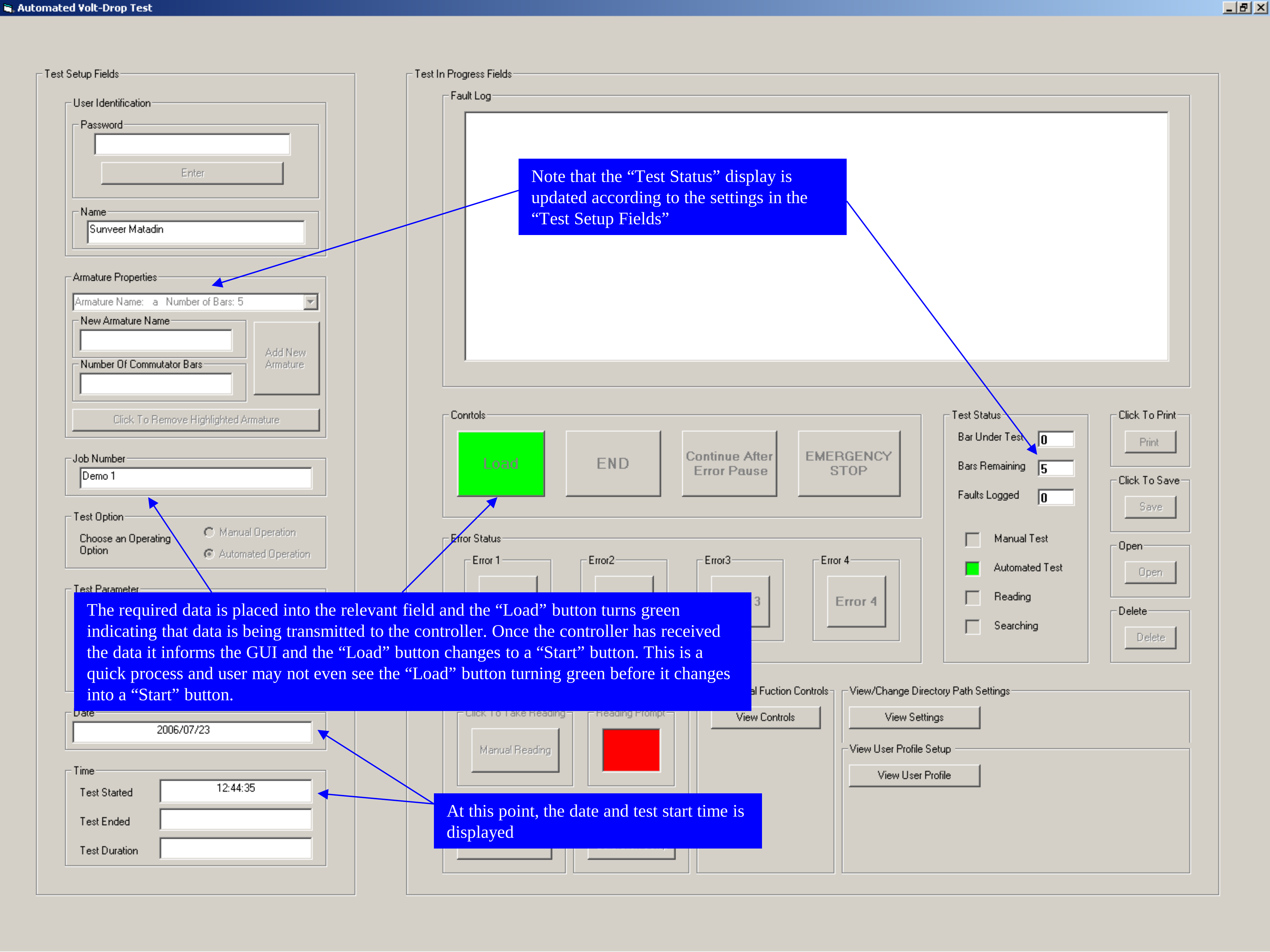
When the correct password is entered by the Administrator, the system is unlocked.


Automated Volt-Drop Test
Unlocked System
Test Setup Fields
User Identification
Password
Enter
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
On entering a valid user password, the user name associated to the entered password is displayed by the system in the "Name" frame.
Test Setup Fields
User Identific
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
ogress Fields
ault Log
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Job Number Not Entered
Enter Job Number
OK
Cancel
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Error Status
Error 4
Test Status
Bar Under Test 0
Bars Remaining 5
Faults Logged 0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup
The user will then populate all the Test “Setup Fields” in order to set the test parameters. If any field is not completed when the “Load” button is clicked, a pop-up / input message will appear.
Also, note the mode of operation in the “Test Status” display.

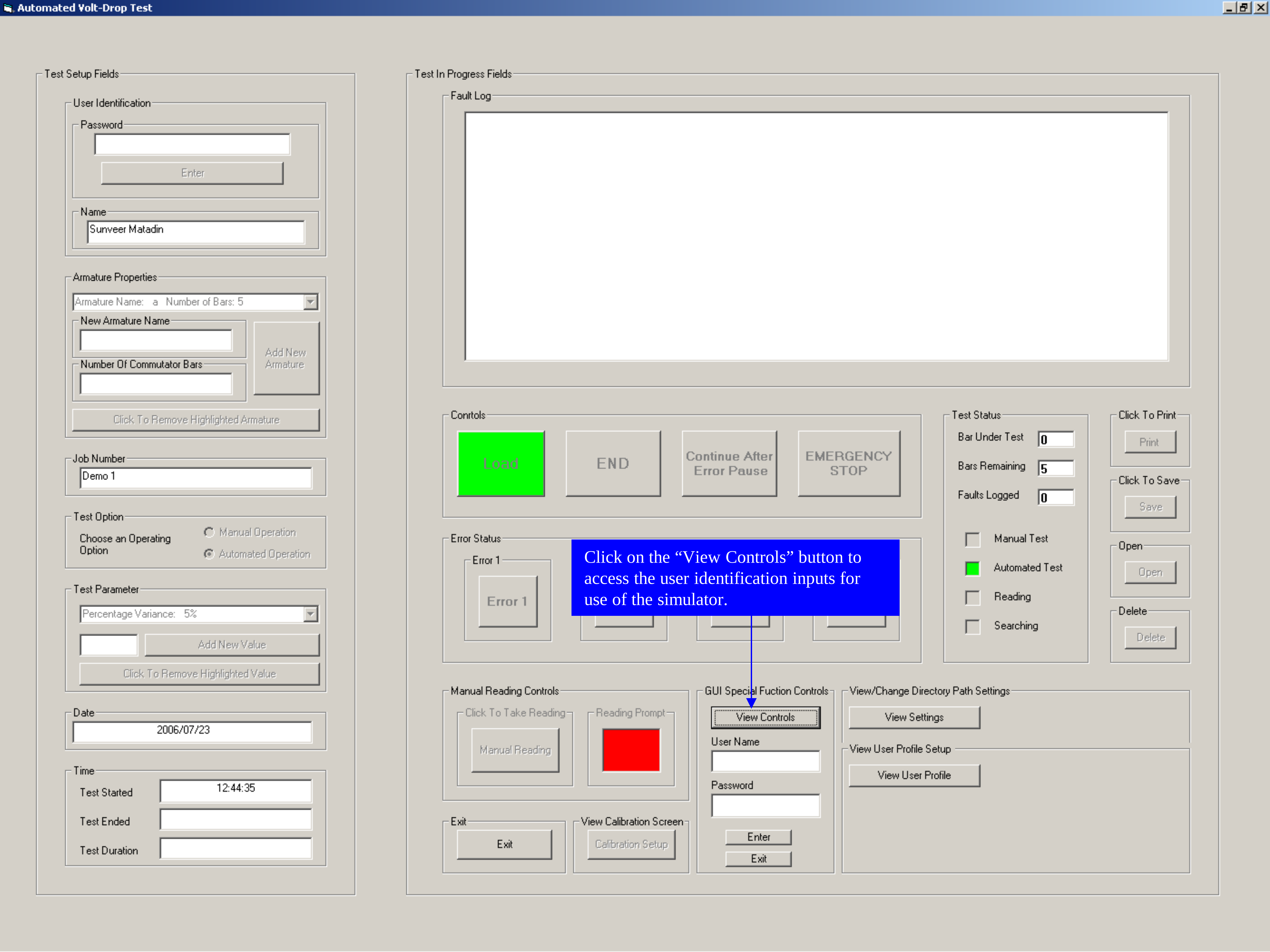

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Job Number Not Entered
Enter Job Number
OK
Cancel
Demo 1
Controls
EMERGENCY STOP
Enter the required data and click “OK”
Test Status
Bar Under Test
0
Bars Remaining
5
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Manual Reading Controls
Click To Take Reading
Reading Prompt
Manual Reading
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

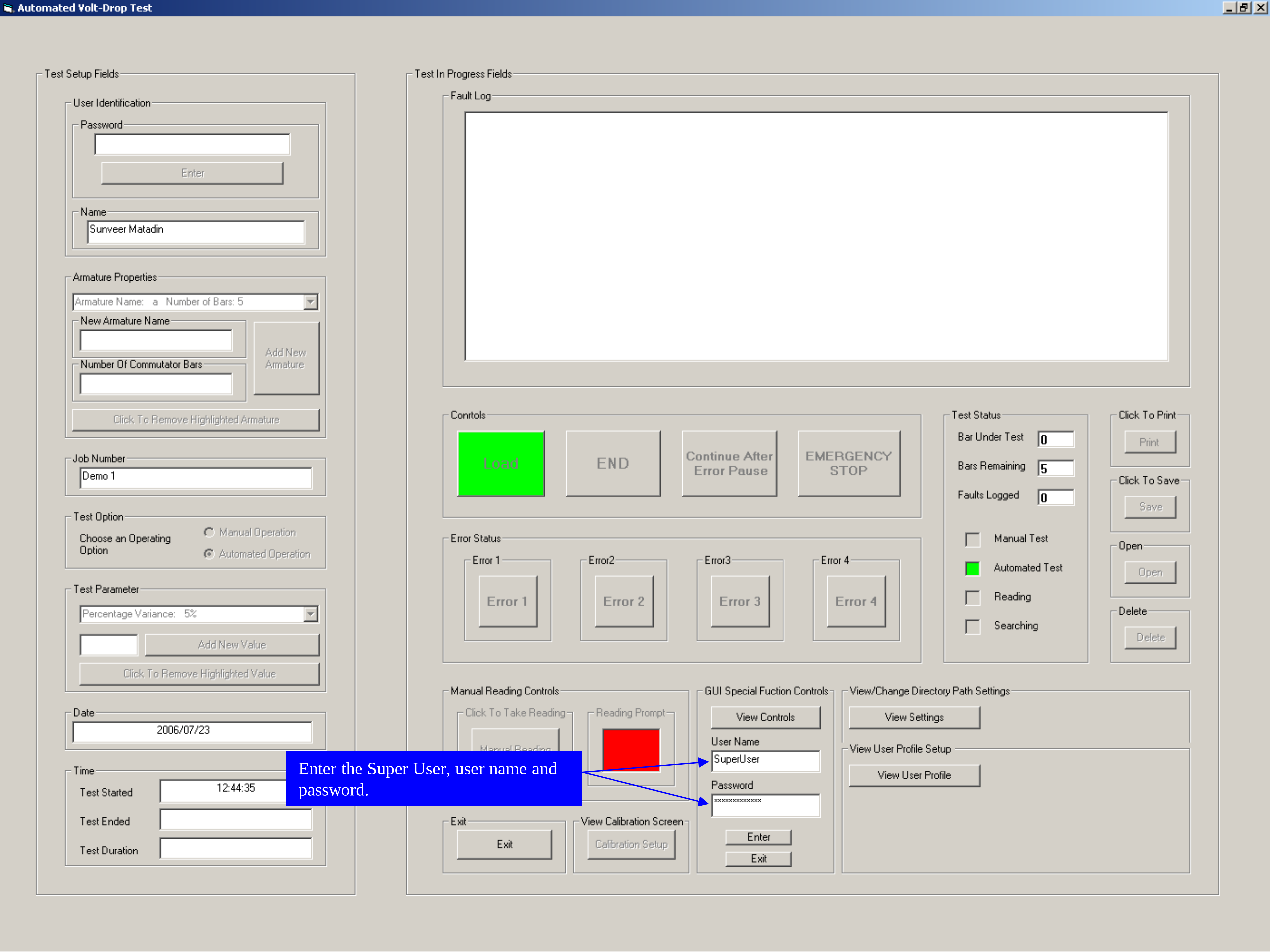


Note that the “Test Status” display is updated according to the settings in the “Test Setup Fields”

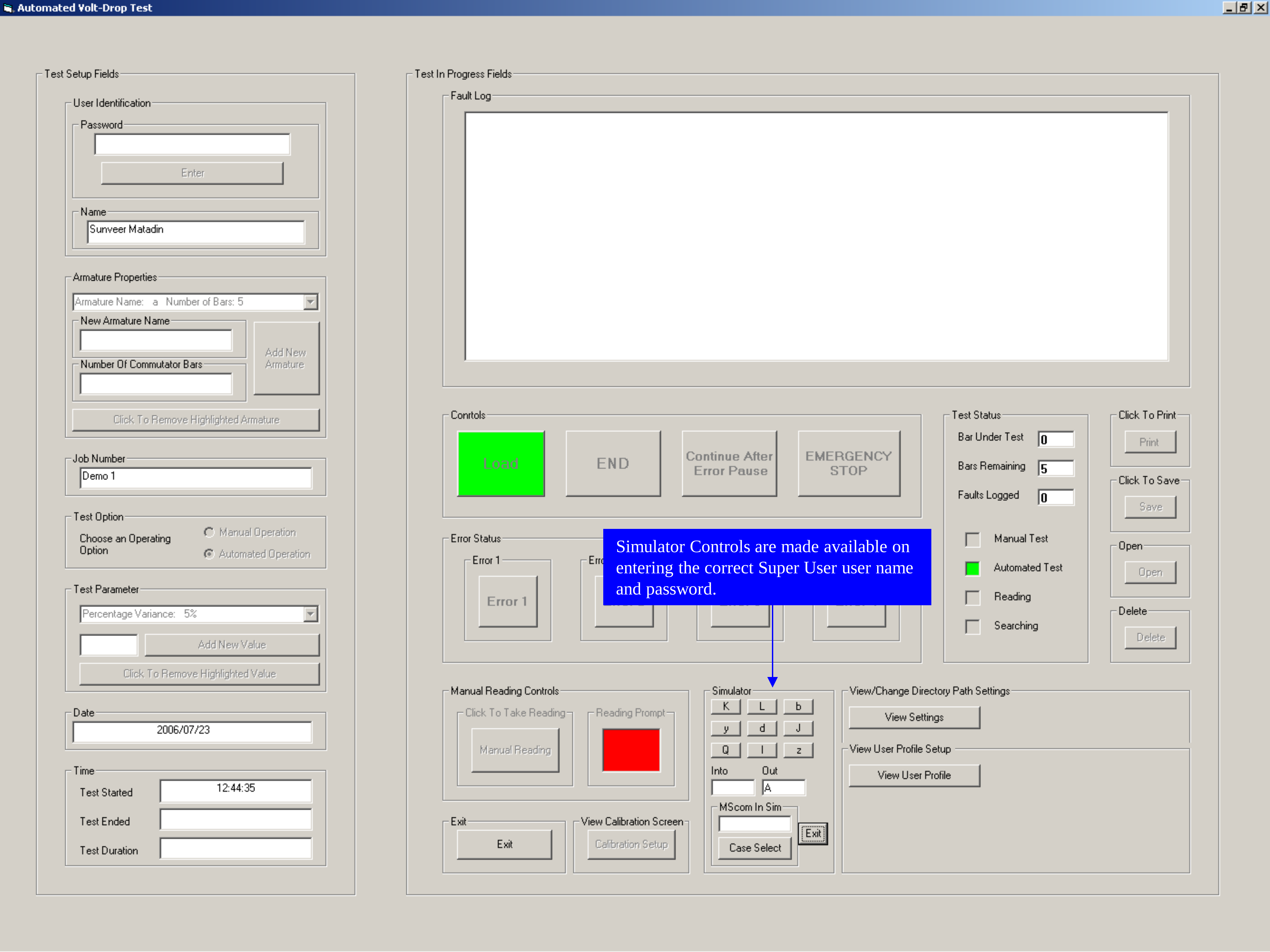
The required data is placed into the relevant field and the “Load” button turns green indicating that data is being transmitted to the controller. Once the controller has received the data it informs the GUI and the “Load” button changes to a “Start” button. This is a quick process and user may not even see the “Load” button turning green before it changes into a “Start” button.

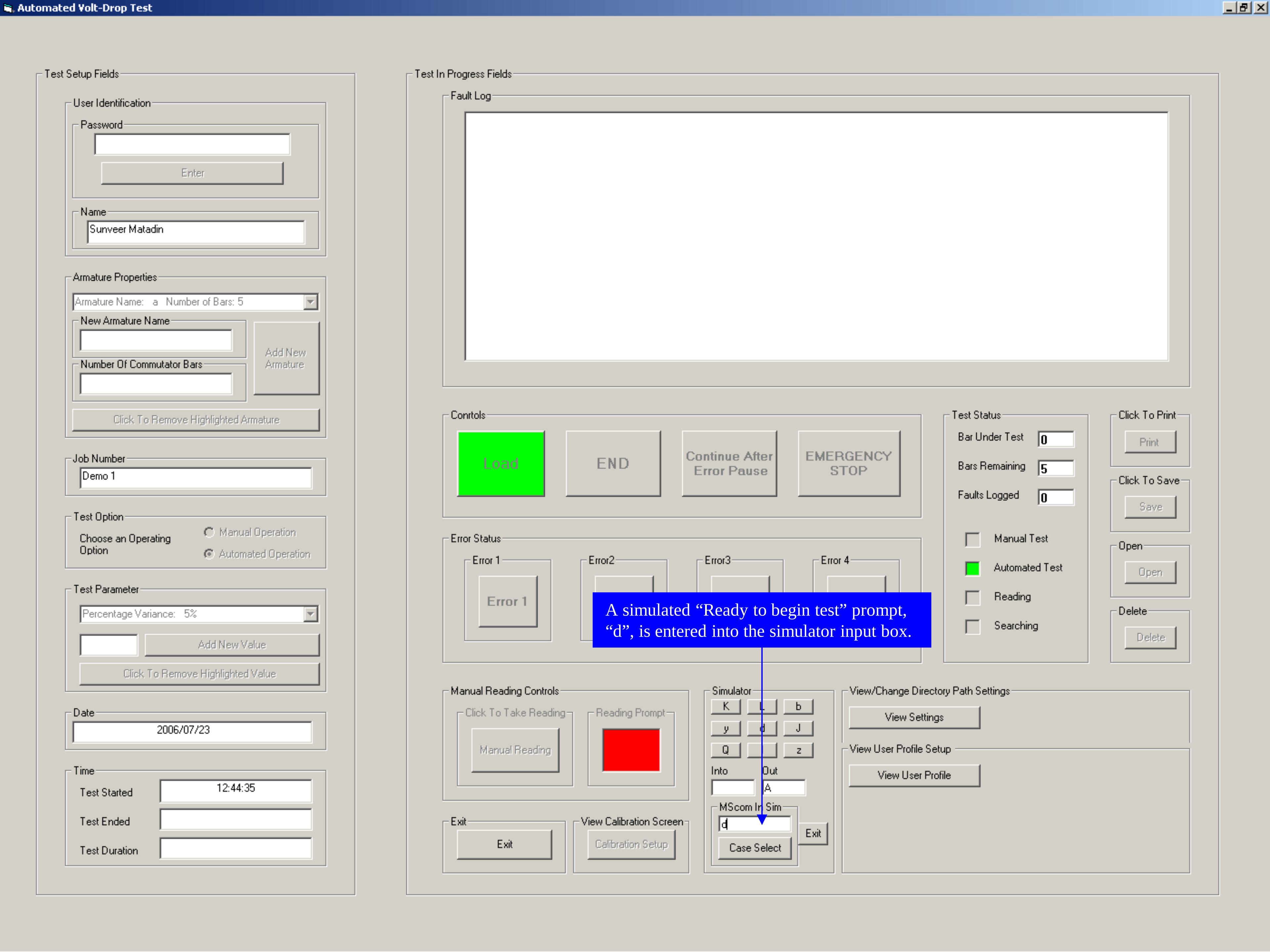
At this point, the date and test start time is displayed

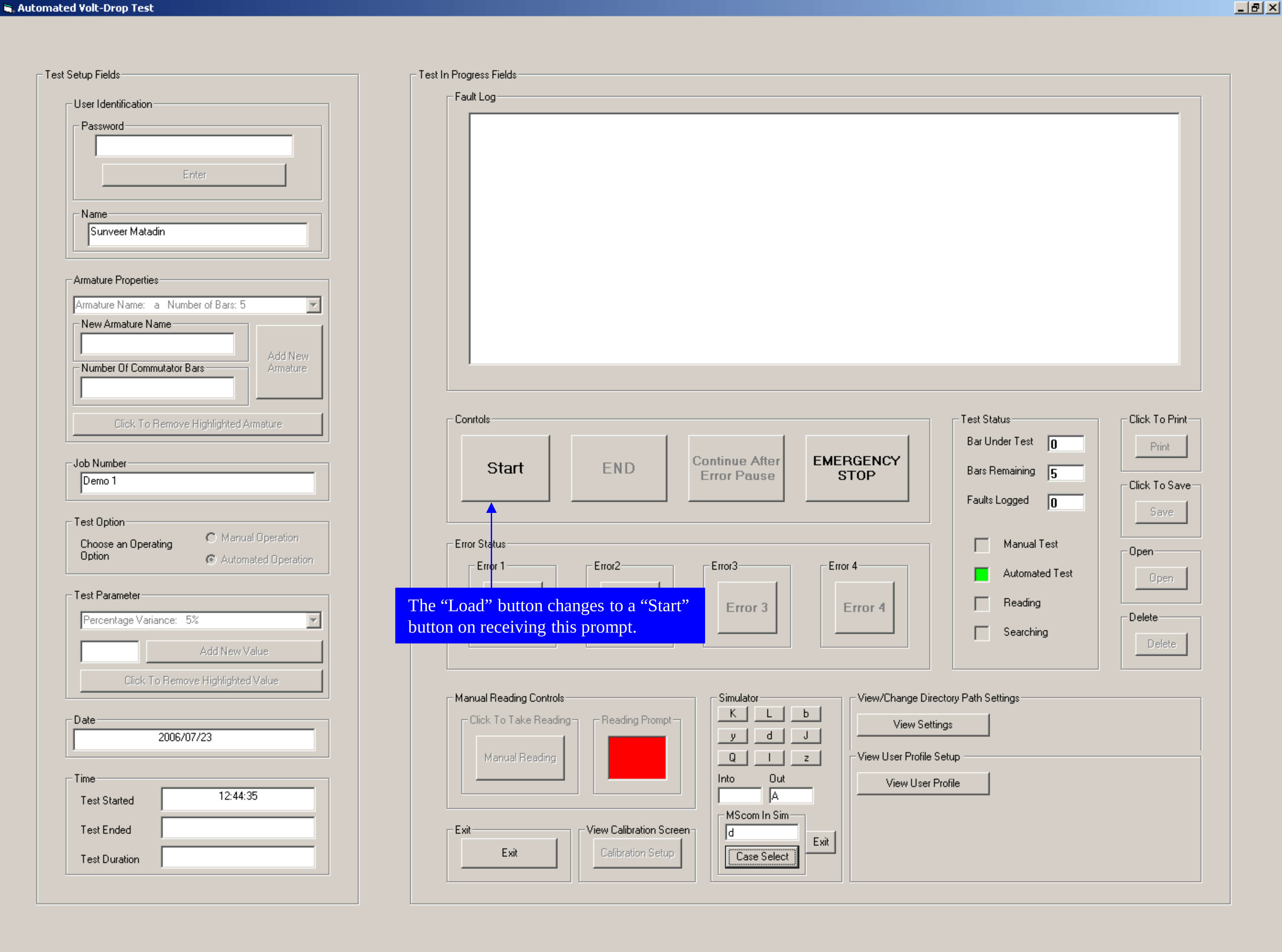

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Demo 1
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/07/23
Time
Test Started
12:44:35
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
5
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Click on the “View Controls” button to access the user identification inputs for use of the simulator.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
User Name
Password
Enter
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

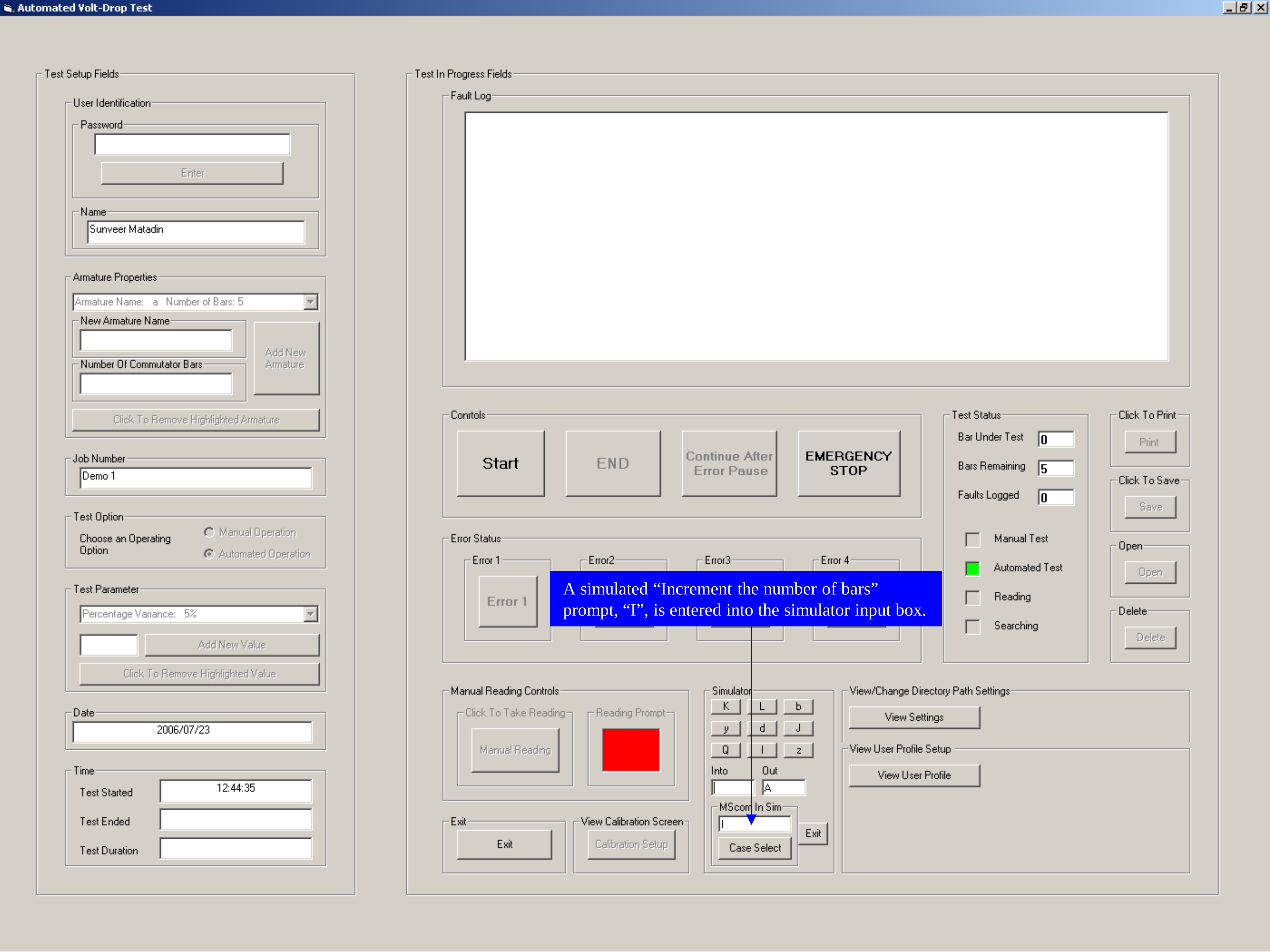


Enter the Super User, user name and password.

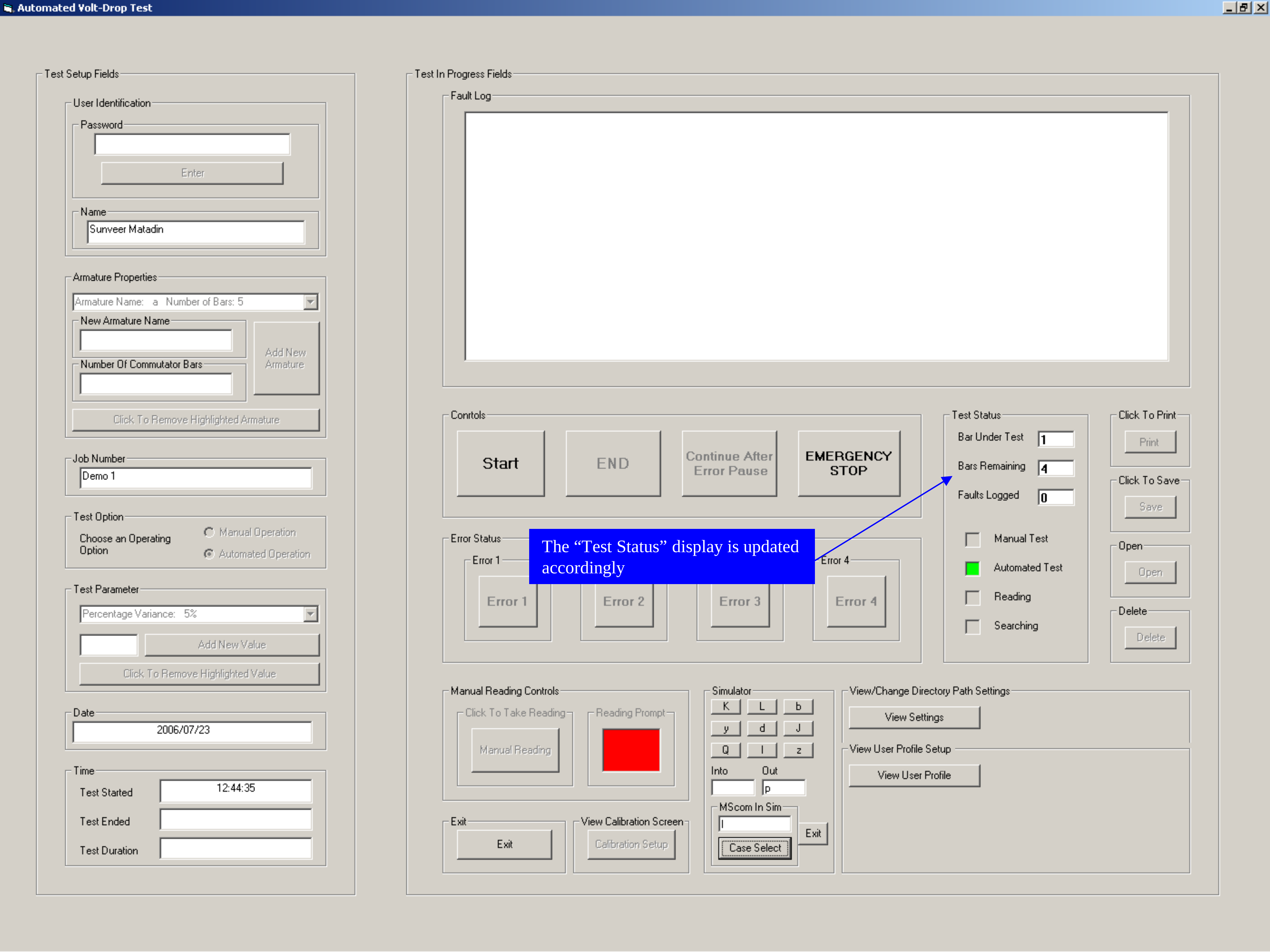

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Demo 1
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/07/23
Time
Test Started
12:44:35
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
5
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Simulator Controls are made available on entering the correct Super User user name and password.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K L b
y d J
Q I z
Into
Out
A
MScom In Sim
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

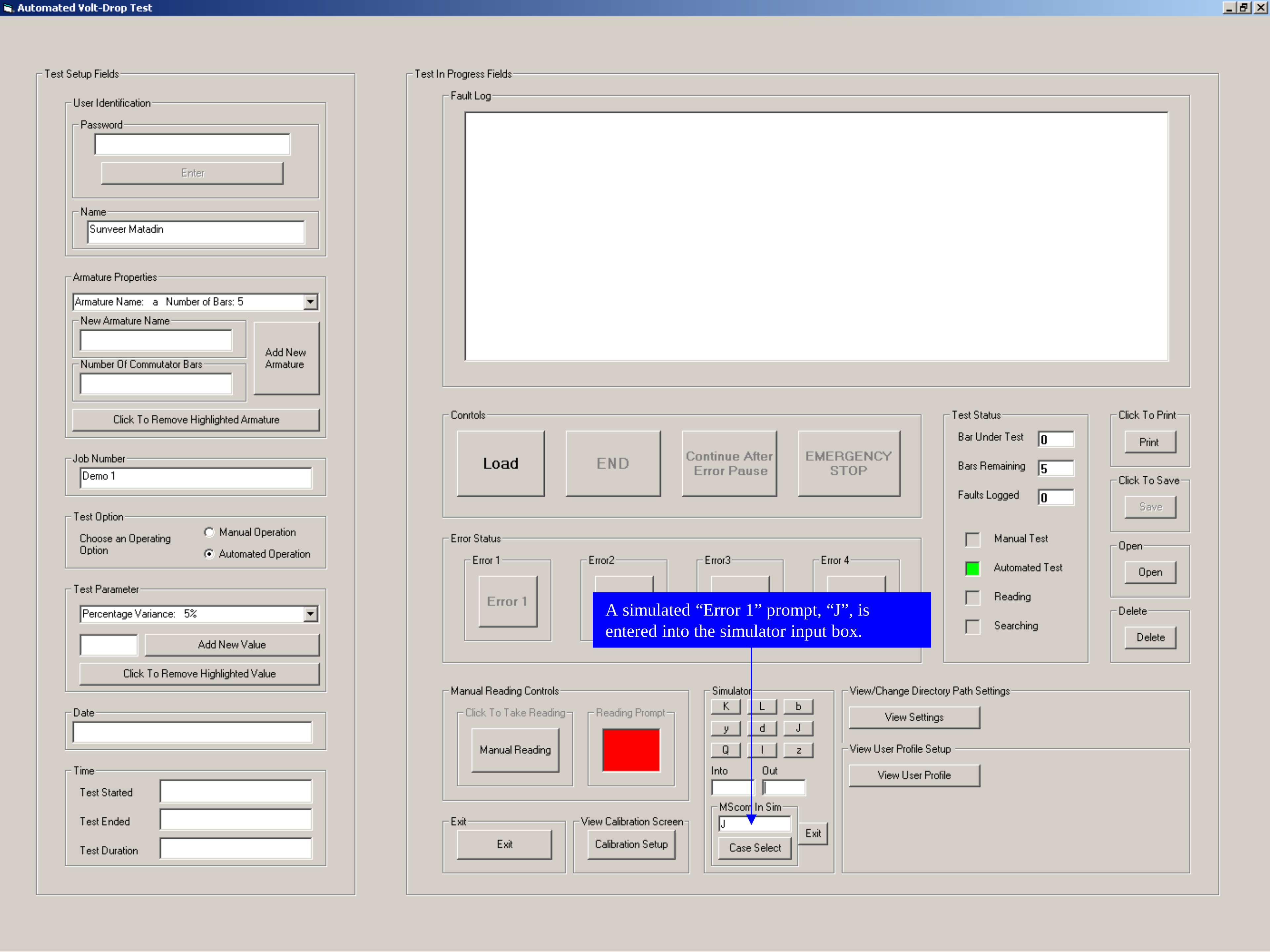

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Demo 1
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/07/23
Time
Test Started
12:44:35
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
5
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 1
A simulated “Ready to begin test” prompt, “d”, is entered into the simulator input box.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
z
Into
Out
A
MScom In Sim
d
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

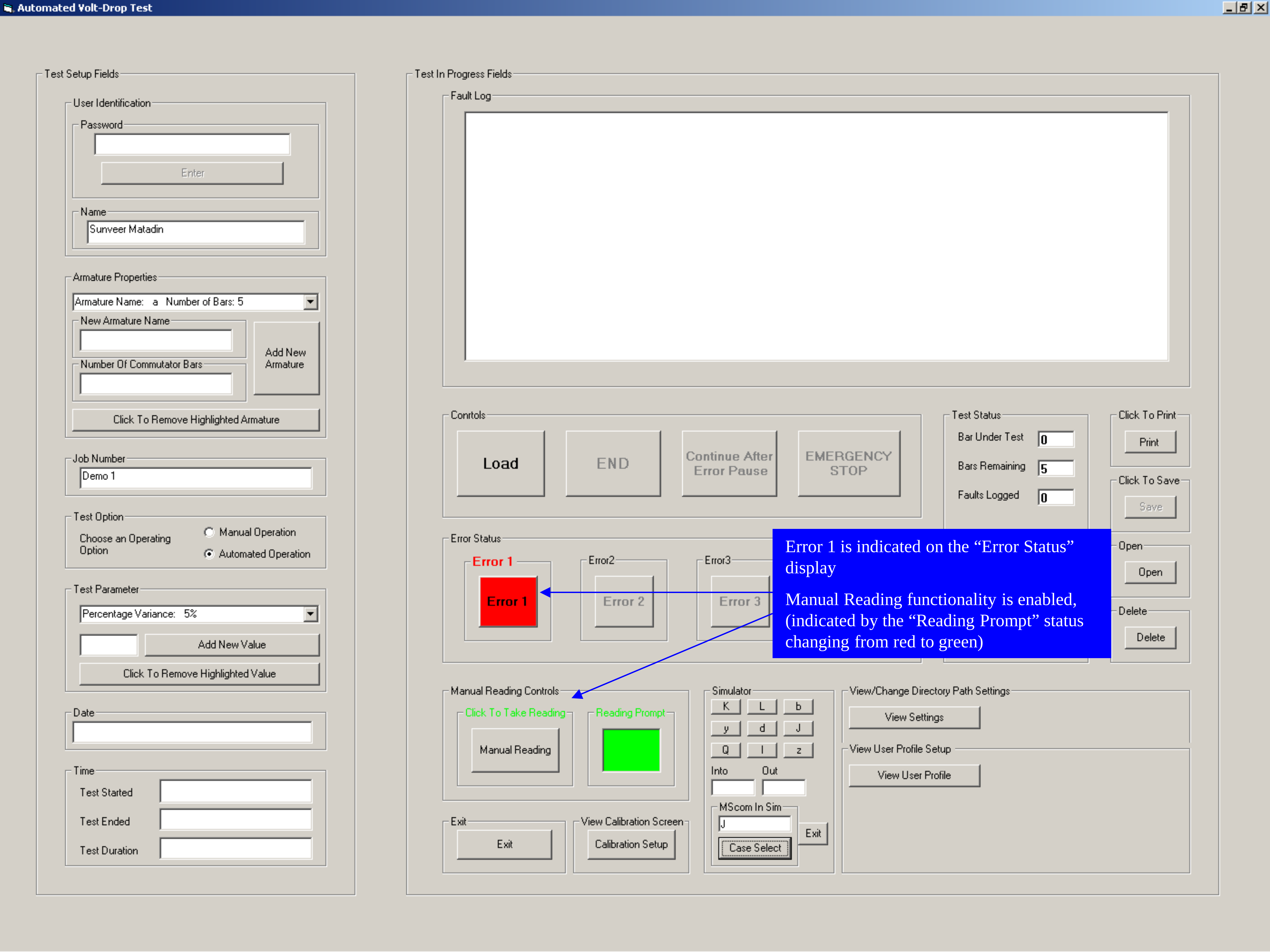

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Demo 1
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/07/23
Time
Test Started
12:44:35
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Start
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
5
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 3
Error 4
The “Load” button changes to a “Start” button on receiving this prompt.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
A
MScom In Sim
d
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup



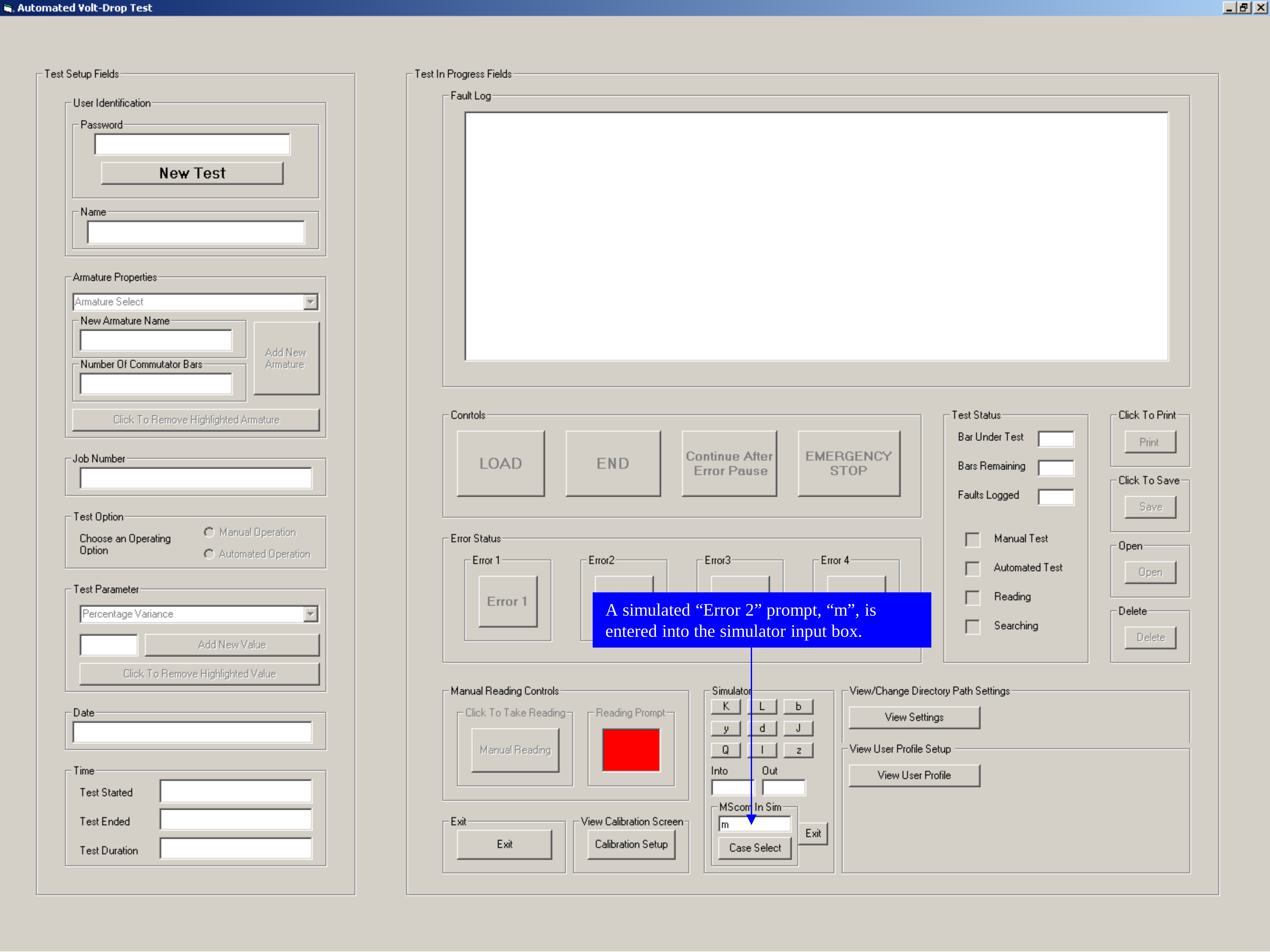
A simulated “Increment the number of bars” prompt, “I”, is entered into the simulator input box.

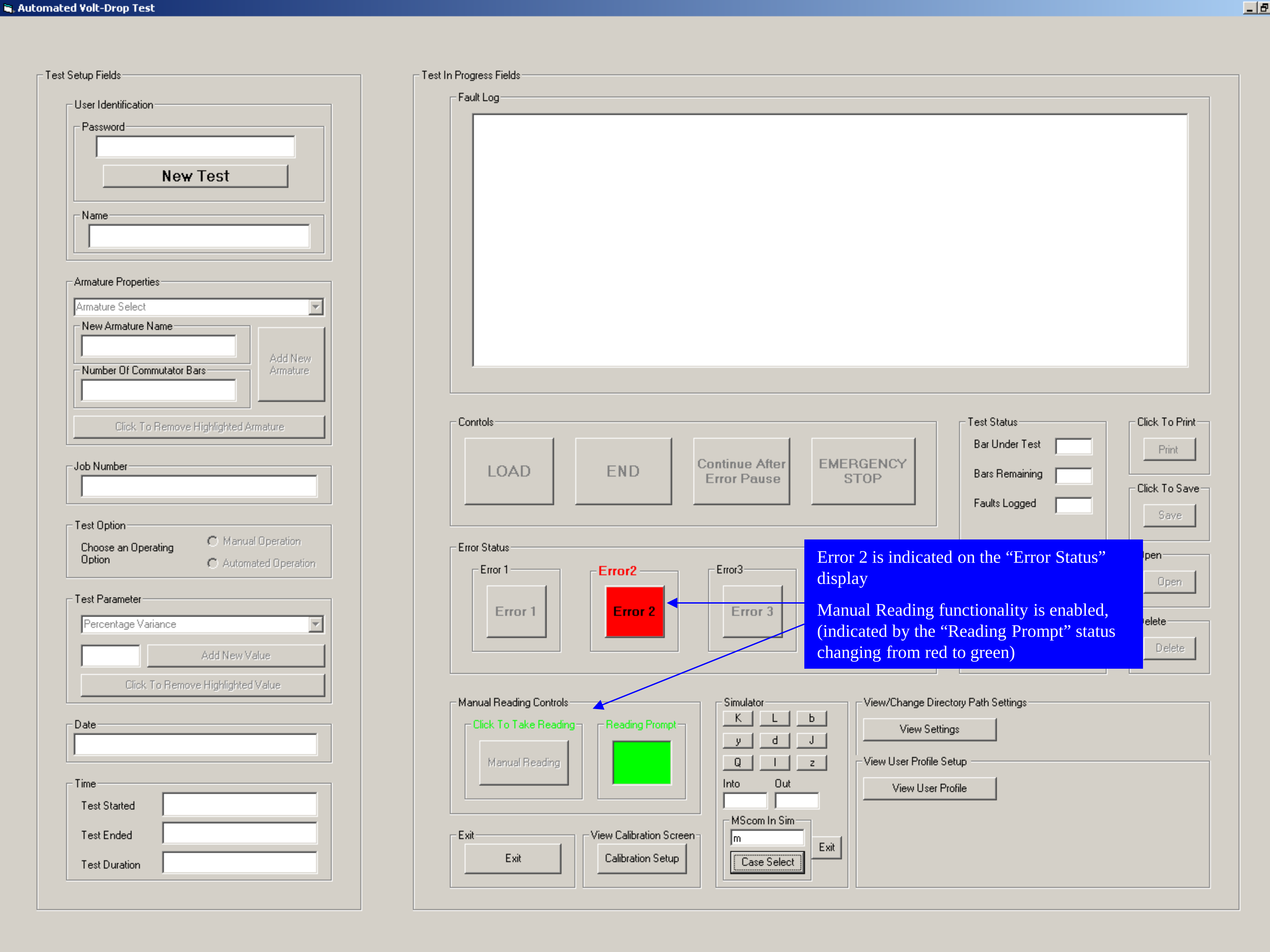

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Demo 1
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/07/23
Time
Test Started
12:44:35
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Contols
Start
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
1
Bars Remaining
4
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 4
Error 1
Error 2
Error 3
Error 4
The “Test Status” display is updated accordingly
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
p
MScom In Sim
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

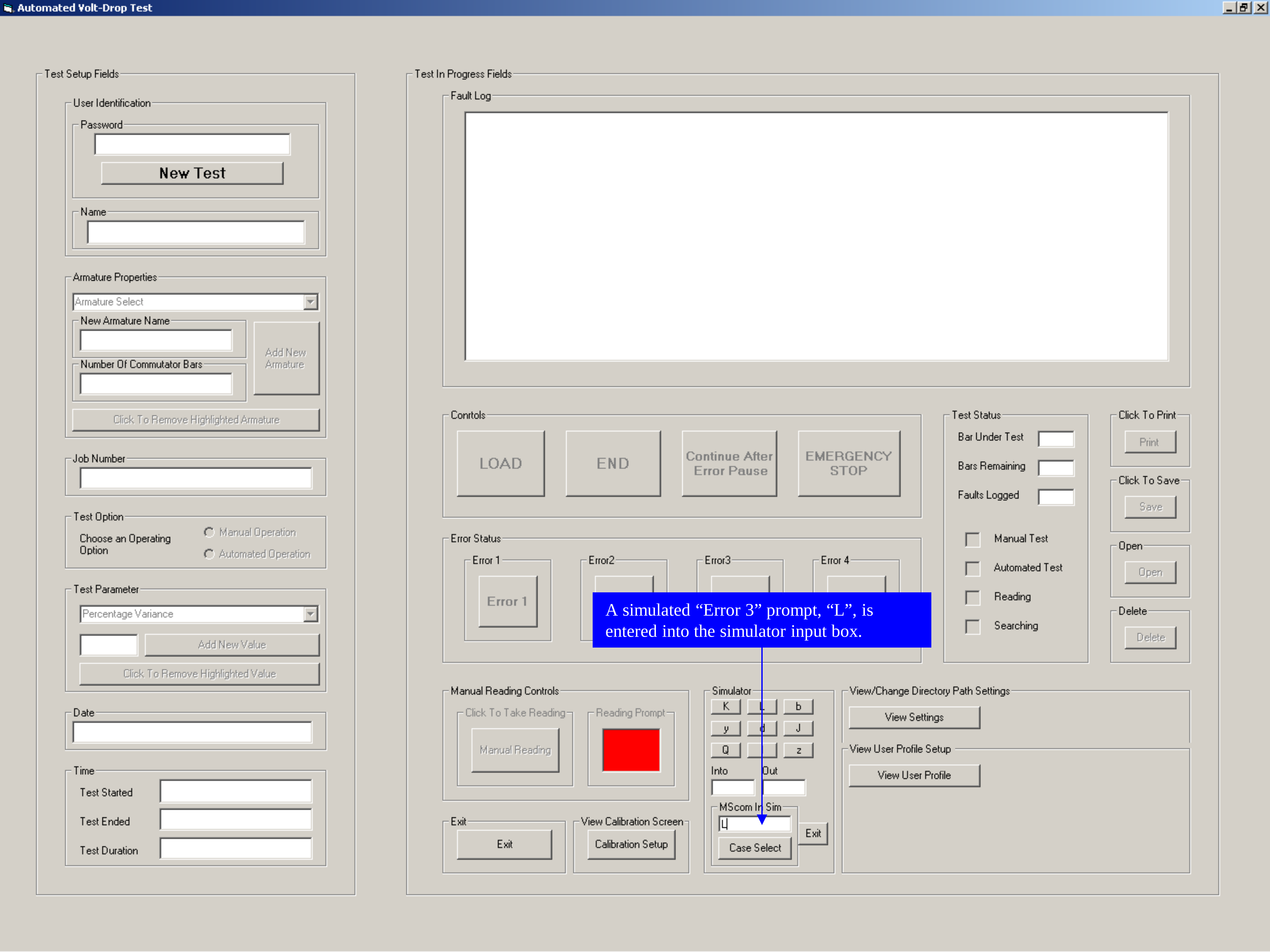

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Demo 1
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
0
Bars Remaining
5
Faults Logged
0
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error3
Error 4
A simulated “Error 1” prompt, “J”, is entered into the simulator input box.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
J
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

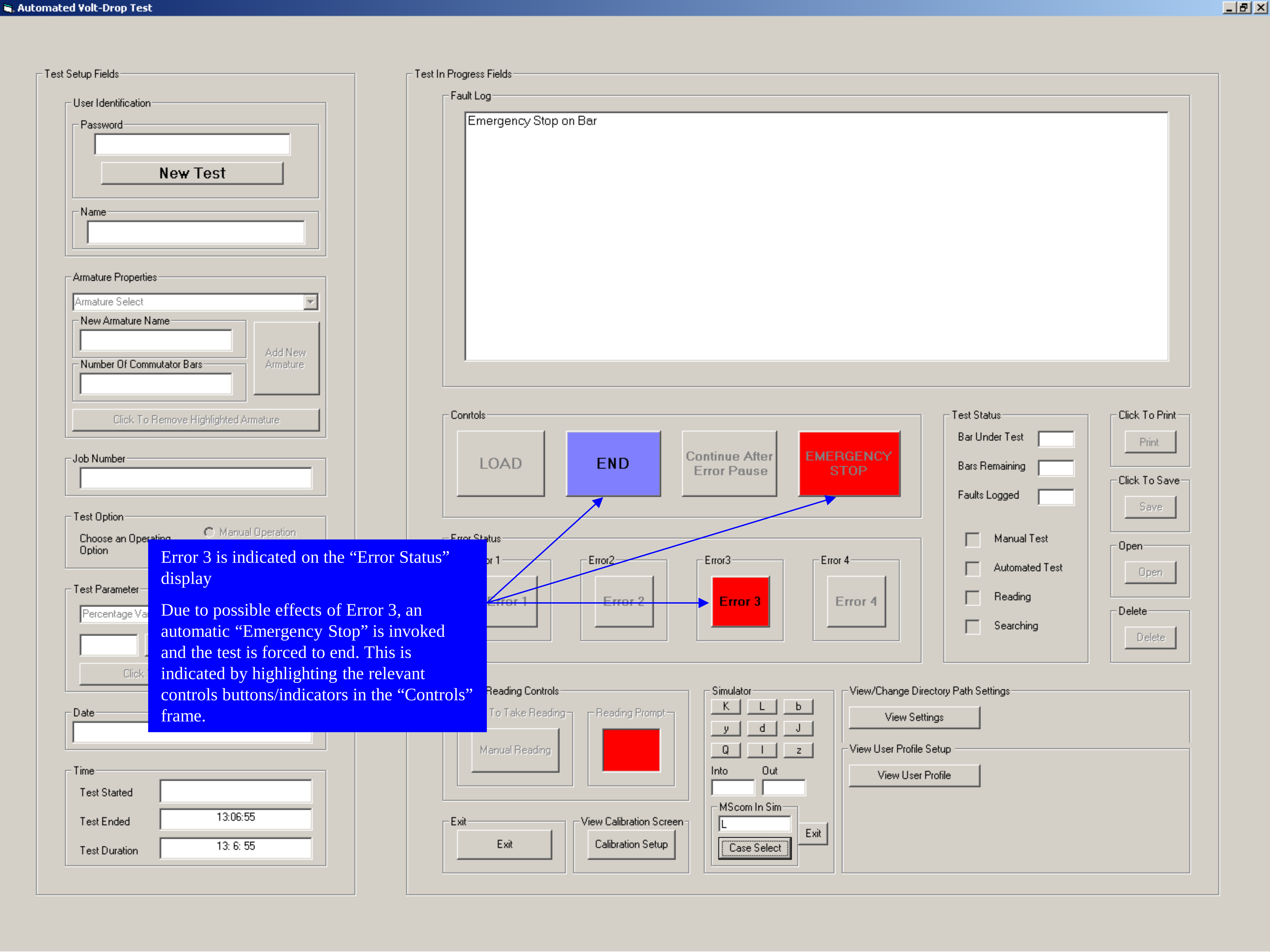


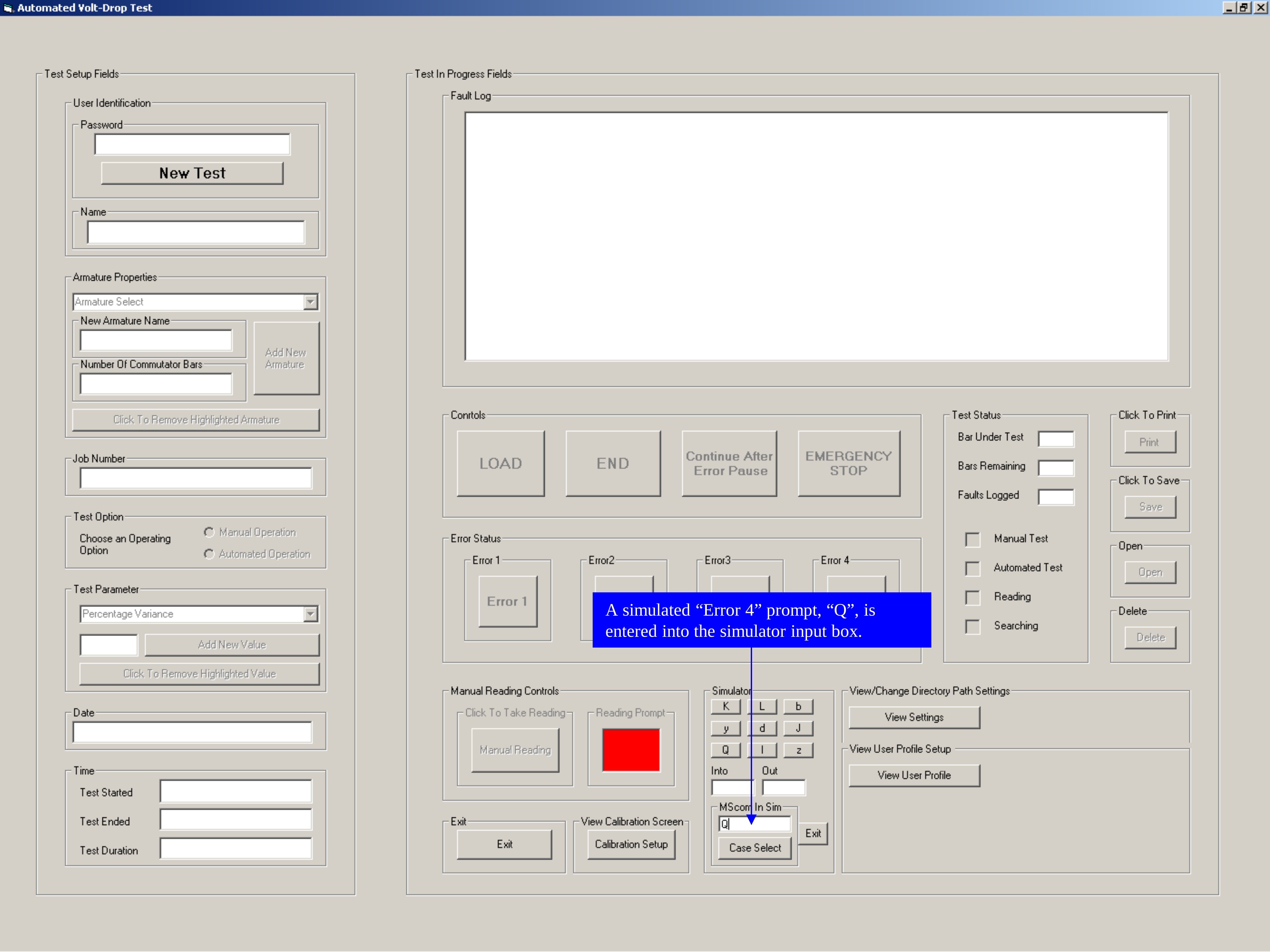
Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Name: a Number of Bars: 5
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Demo 1
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test 0
Bars Remaining 5
Faults Logged 0
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 1 is indicated on the "Error Status" display
Manual Reading functionality is enabled, (indicated by the "Reading Prompt" status changing from red to green)
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K L b
y d J
Q I z
Into
Out
MScom In Sim
J
Case Select
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

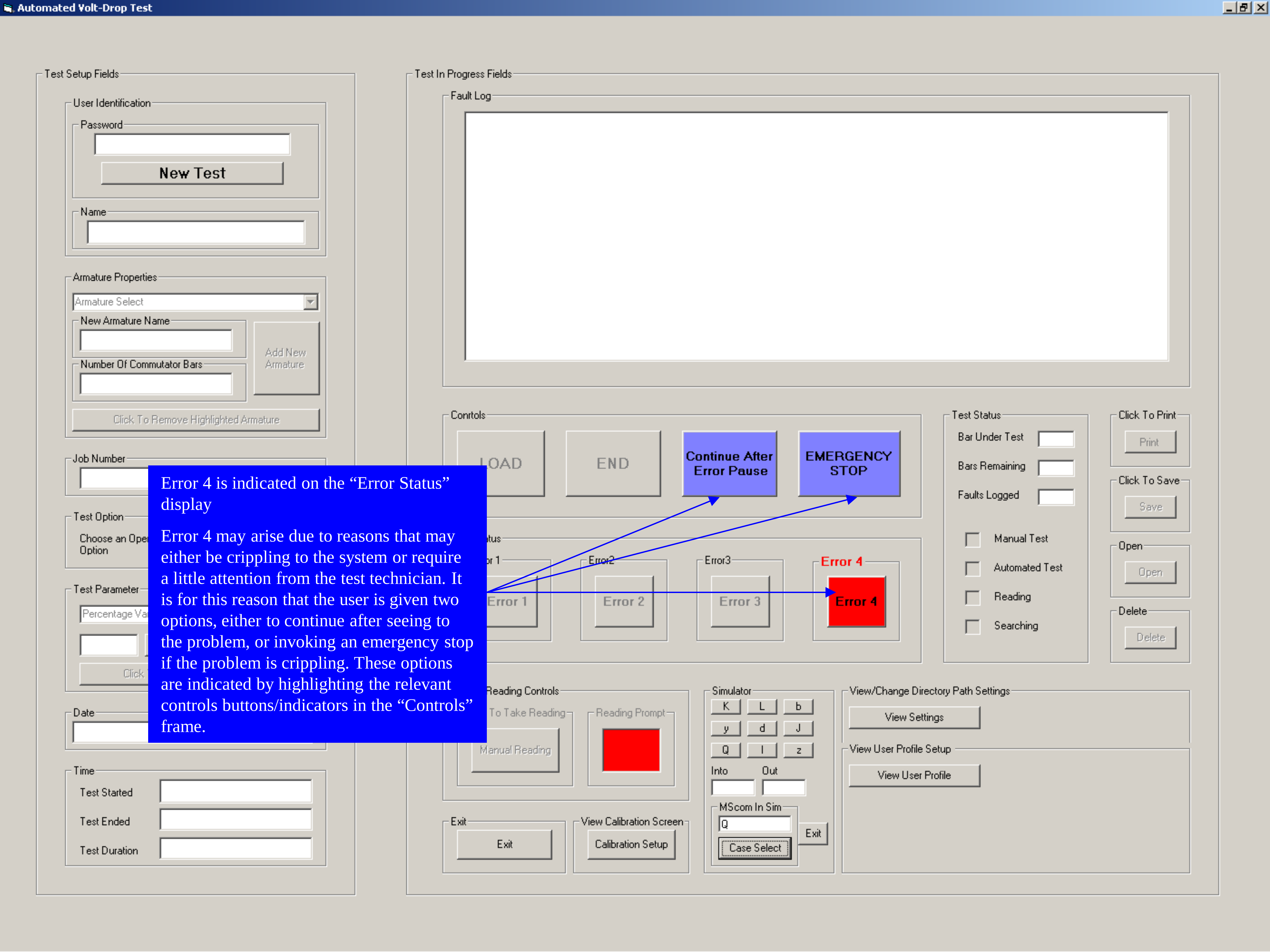

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error2
Error3
Error 4
Error 1
A simulated “Error 2” prompt, “m”, is entered into the simulator input box.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
l
z
Into
Out
MScom In Sim
m
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

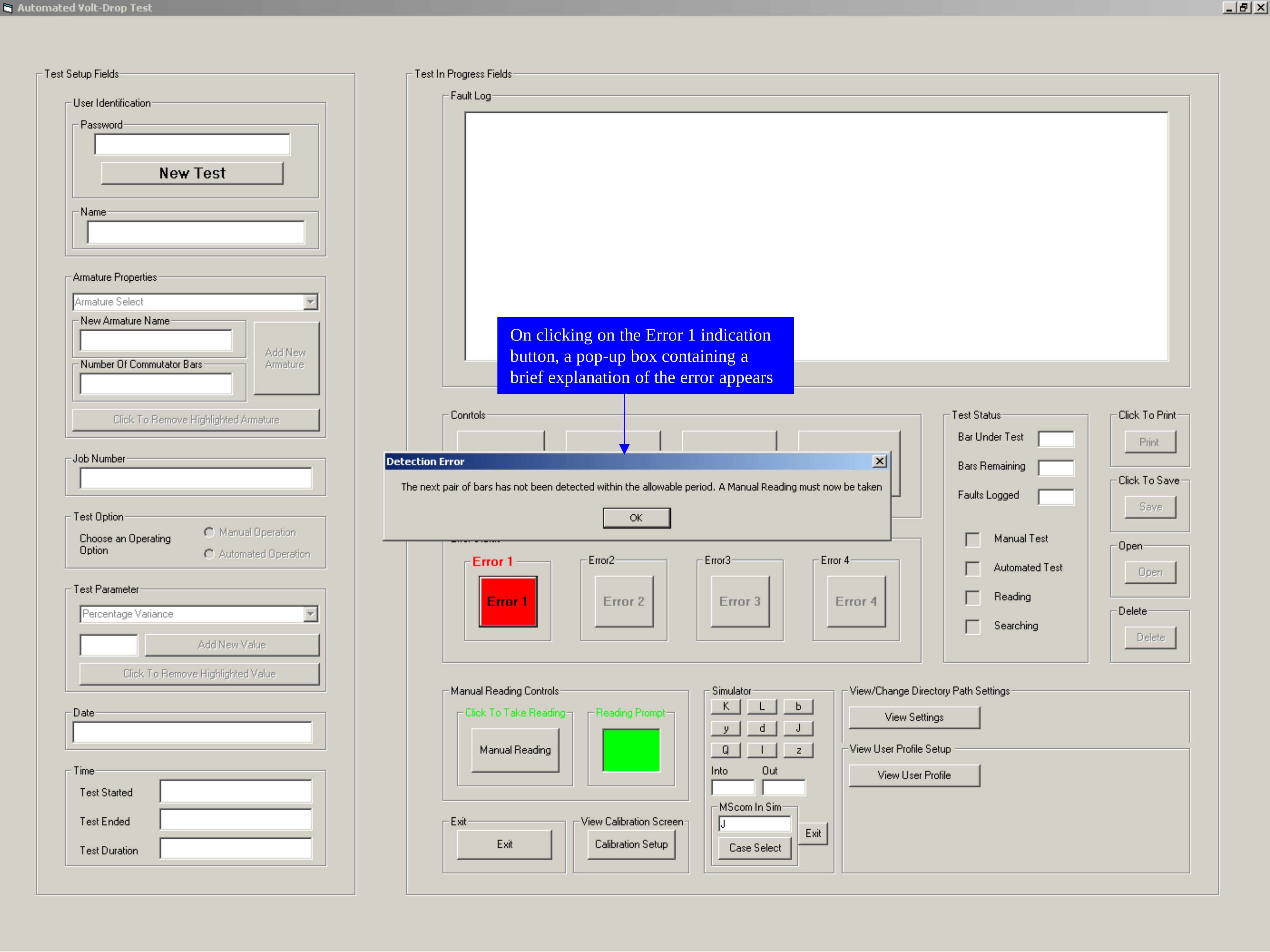

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Click To Print
Print
Click To Save
Save
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 2 is indicated on the “Error Status” display
Manual Reading functionality is enabled, (indicated by the “Reading Prompt” status changing from red to green)
Open
Delete
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
m
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

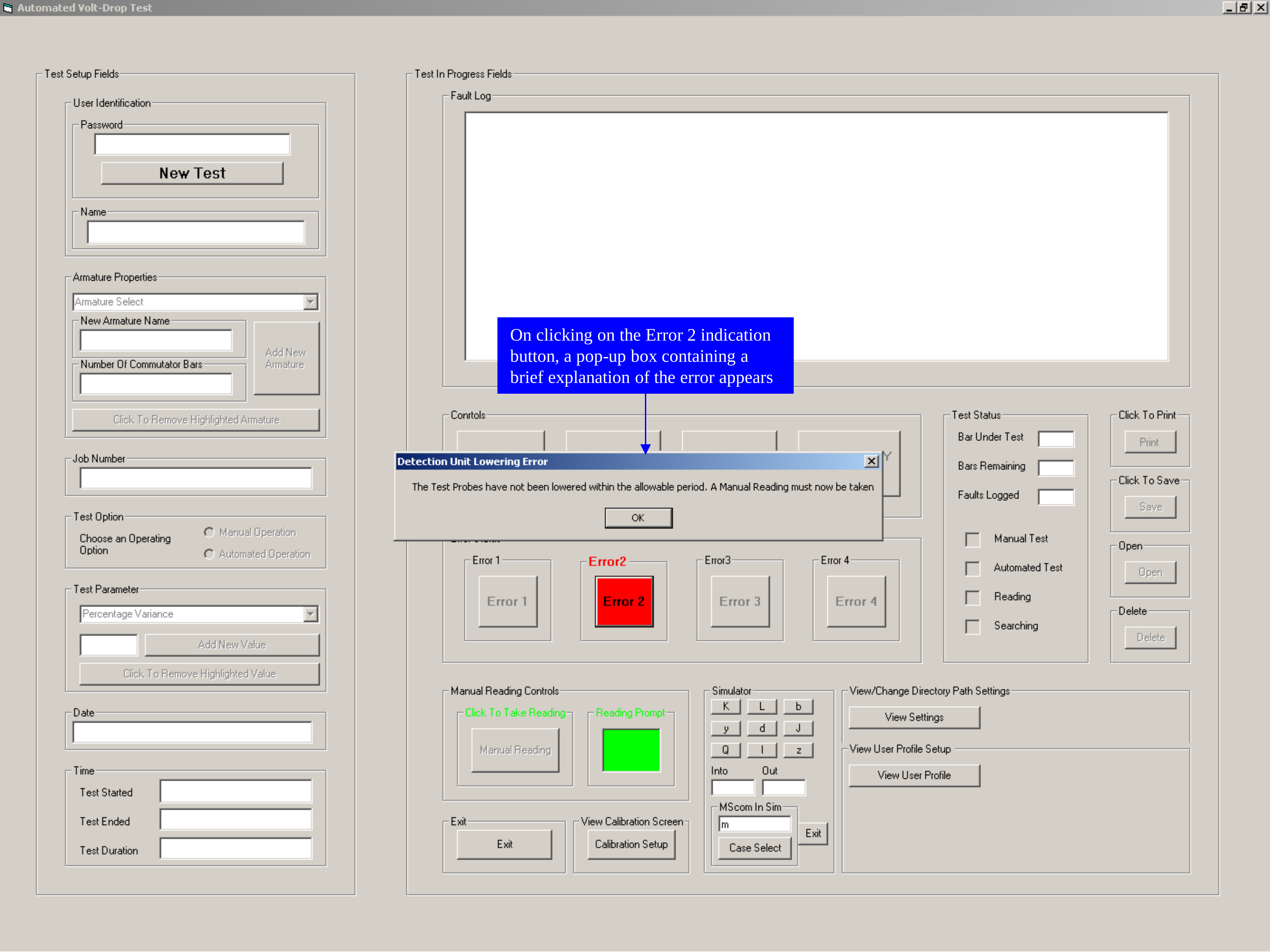

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error3
Error 4
A simulated “Error 3” prompt, “L”, is entered into the simulator input box.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
z
Into
Out
MScom In Sim
L
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

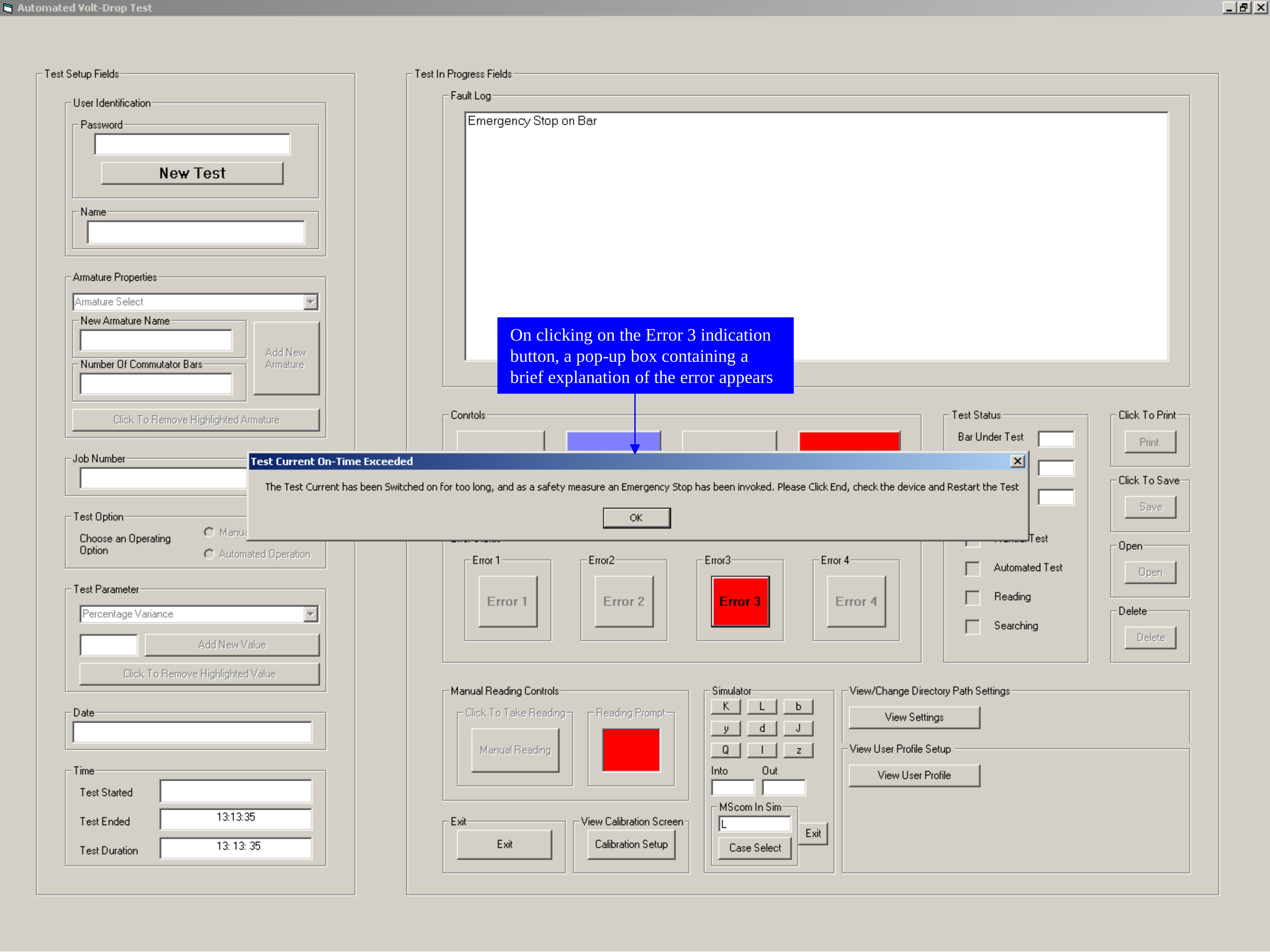

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Test Parameter
Percentage Va
Click
Date
Time
Test Started
Test Ended
13:06:55
Test Duration
13: 6: 55
Test In Progress Fields
Fault Log
Emergency Stop on Bar
Controls
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Error Status
Error2
Error3
Error 4
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Reading Controls
To Take Reading
Reading Prompt
Manual Reading
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
L
Case Select
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup
Error 3 is indicated on the “Error Status” display
Due to possible effects of Error 3, an automatic “Emergency Stop” is invoked and the test is forced to end. This is indicated by highlighting the relevant controls buttons/indicators in the “Controls” frame.

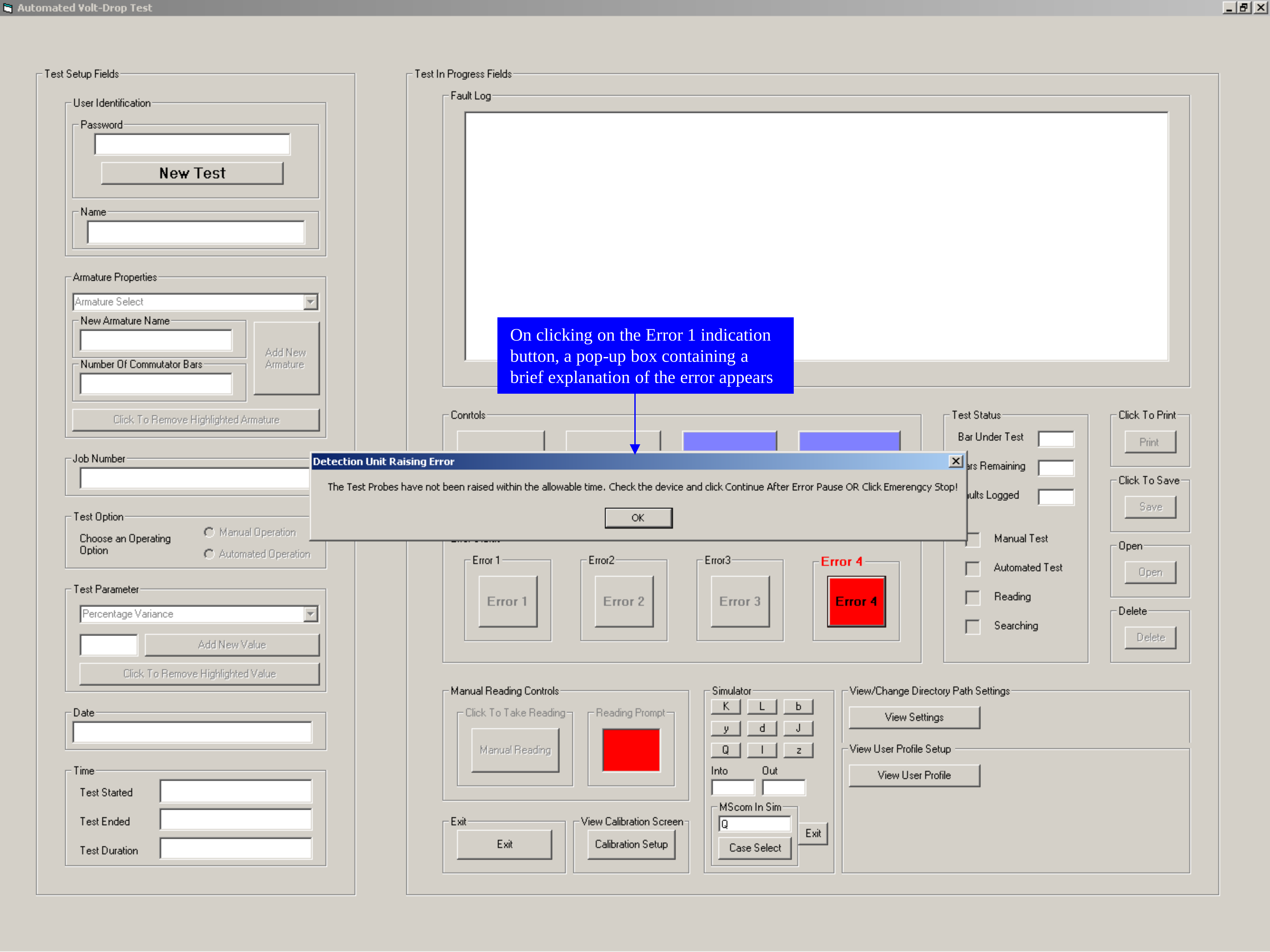

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error3
Error 4
A simulated "Error 4" prompt, "Q", is entered into the simulator input box.
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
Q
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

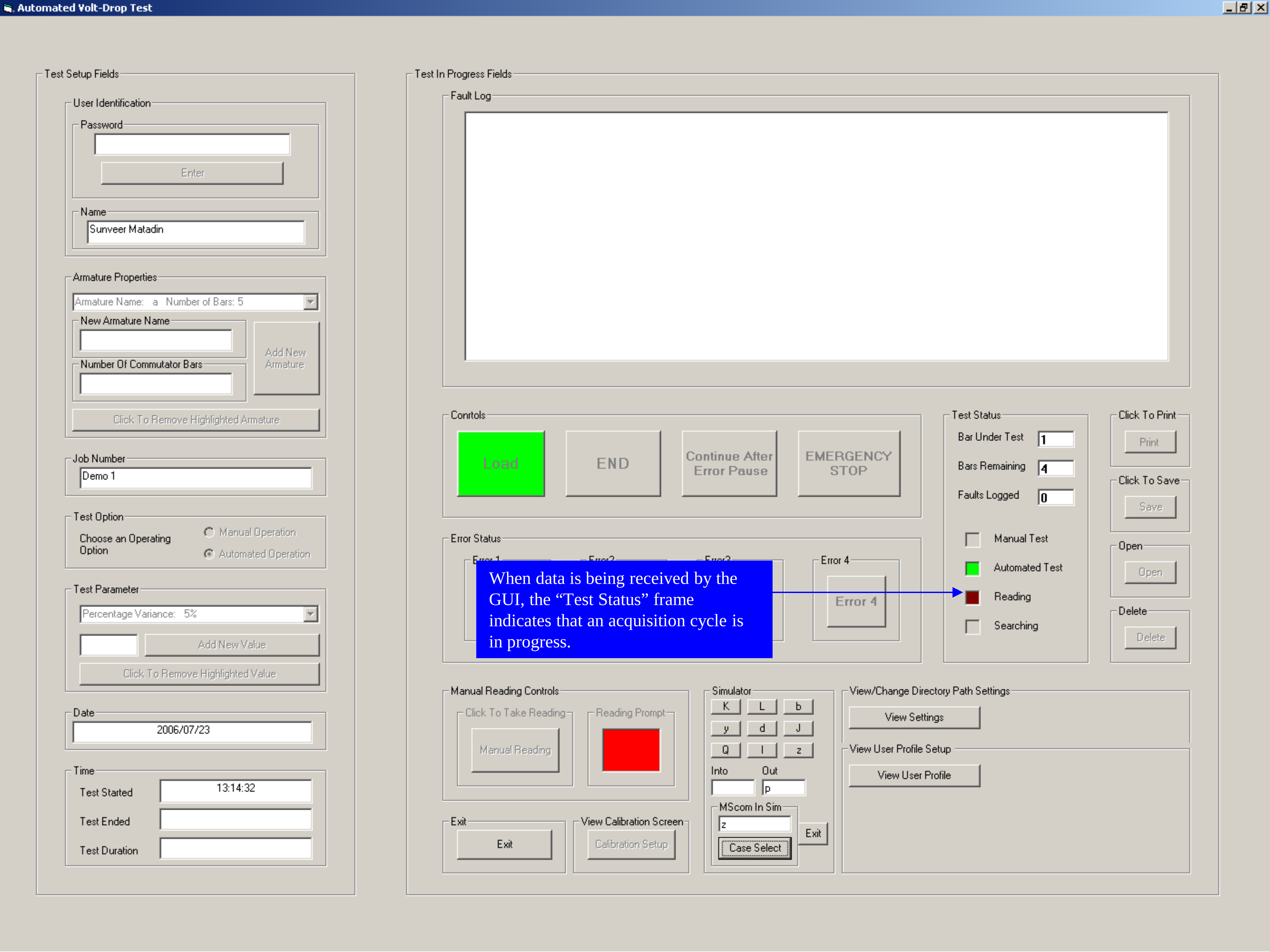

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Test Parameter
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Controls
LOAD
END
Continue After Error Pause
EMERGENCY STOP
Error2
Error3
Error 4
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Reading Controls
Reading Prompt
Manual Reading
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
Q
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup
Error 4 is indicated on the “Error Status” display
Error 4 may arise due to reasons that may either be crippling to the system or require a little attention from the test technician. It is for this reason that the user is given two options, either to continue after seeing to the problem, or invoking an emergency stop if the problem is crippling. These options are indicated by highlighting the relevant controls buttons/indicators in the “Controls” frame.


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
On clicking on the Error 1 indication button, a pop-up box containing a brief explanation of the error appears
Controls
Detection Error
The next pair of bars has not been detected within the allowable period. A Manual Reading must now be taken
OK
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Manual Reading Controls
Click To Take Reading
Reading Prompt
Manual Reading
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
J
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

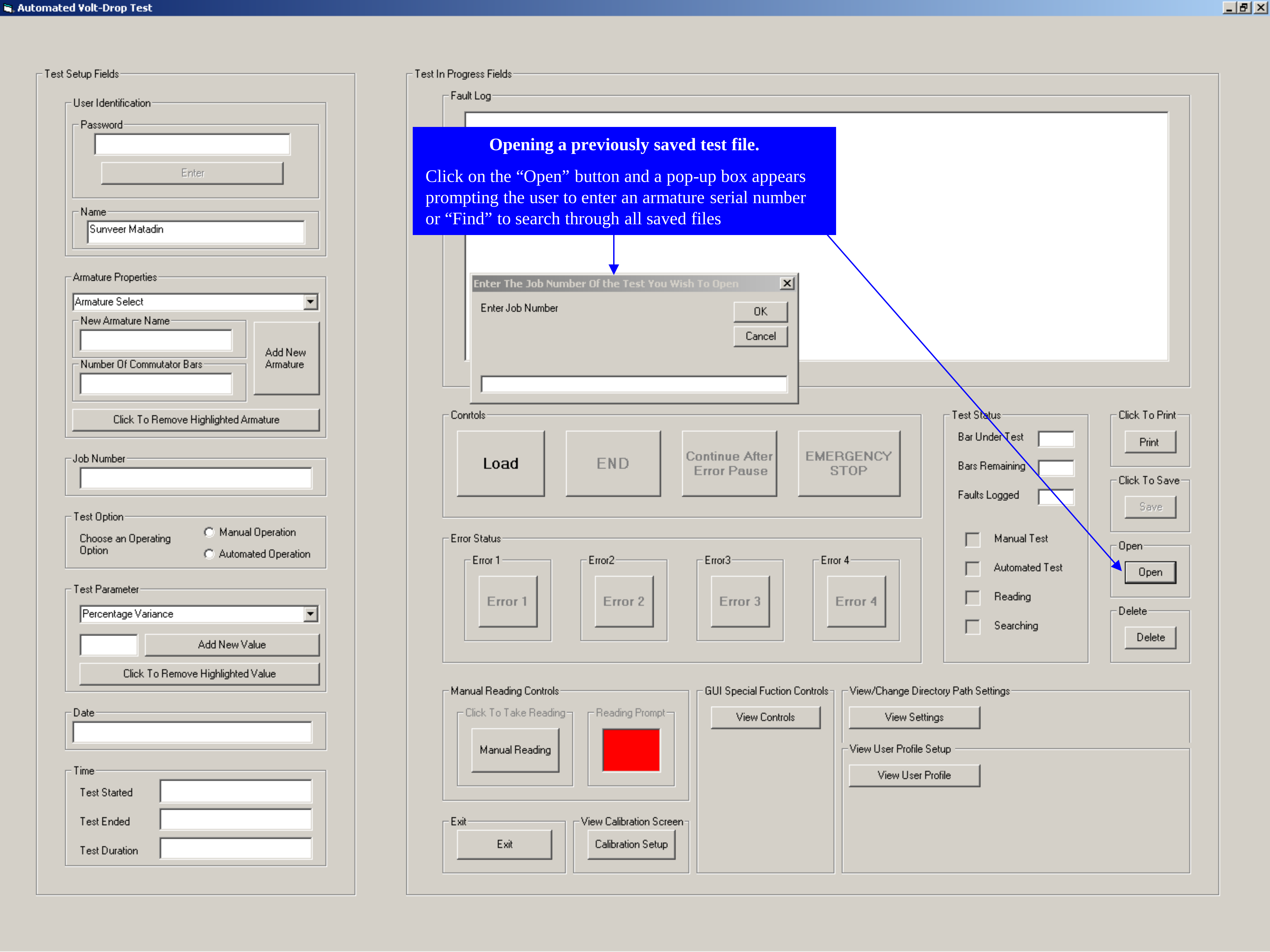

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
On clicking on the Error 2 indication button, a pop-up box containing a brief explanation of the error appears
Controls
Detection Unit Lowering Error
The Test Probes have not been lowered within the allowable period. A Manual Reading must now be taken
OK
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Manual Reading Controls
Click To Take Reading
Reading Prompt
Manual Reading
Simulator
K
L
b
y
d
J
Q
l
z
Into
Out
MScom In Sim
m
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

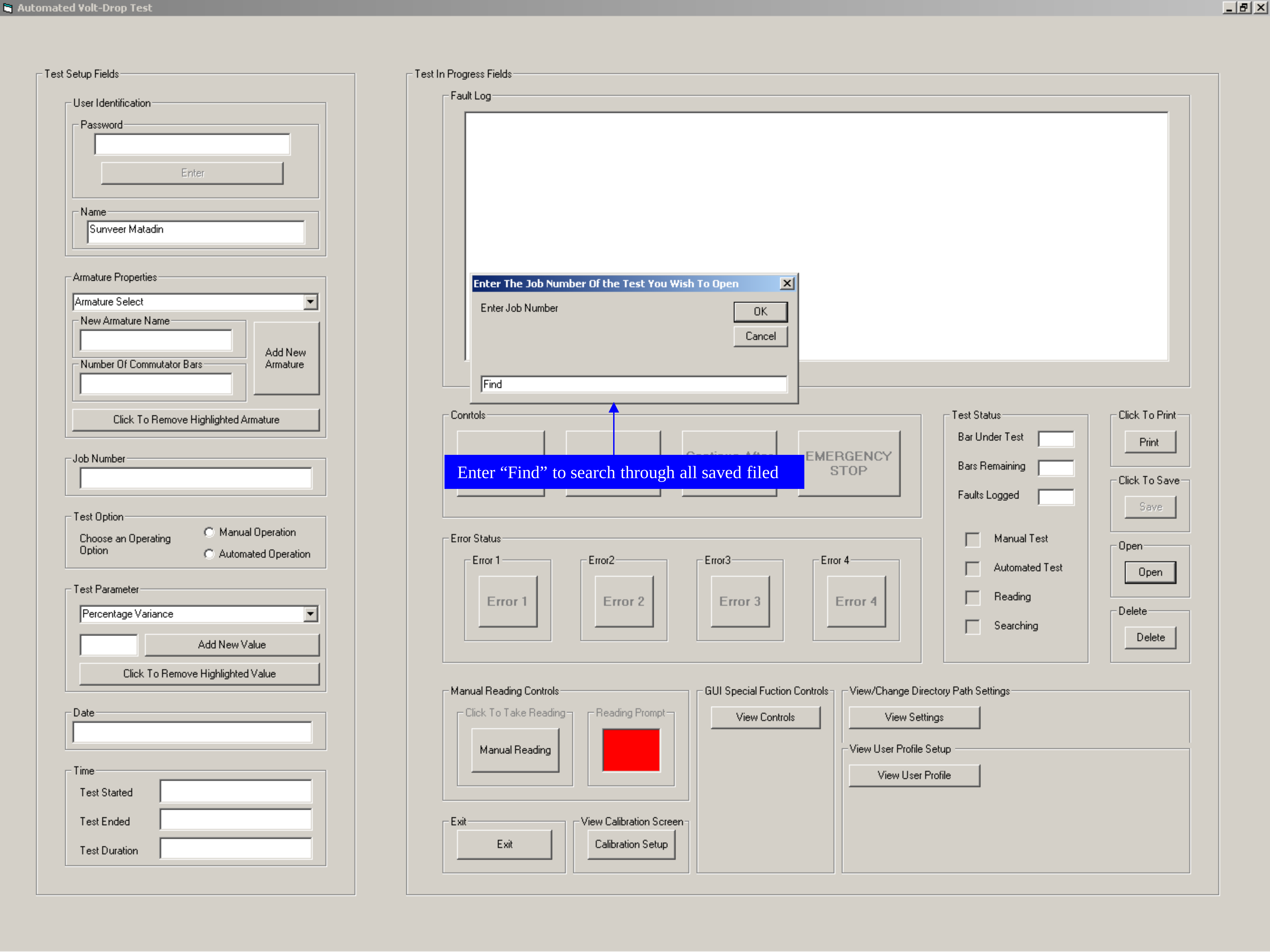

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
13:13:35
Test Duration
13: 13: 35
Test In Progress Fields
Fault Log
Emergency Stop on Bar
On clicking on the Error 3 indication button, a pop-up box containing a brief explanation of the error appears
Controls
Test Current On-Time Exceeded
The Test Current has been Switched on for too long, and as a safety measure an Emergency Stop has been invoked. Please Click End, check the device and Restart the Test
OK
Test Status
Bar Under Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
L
Case Select
Exit
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

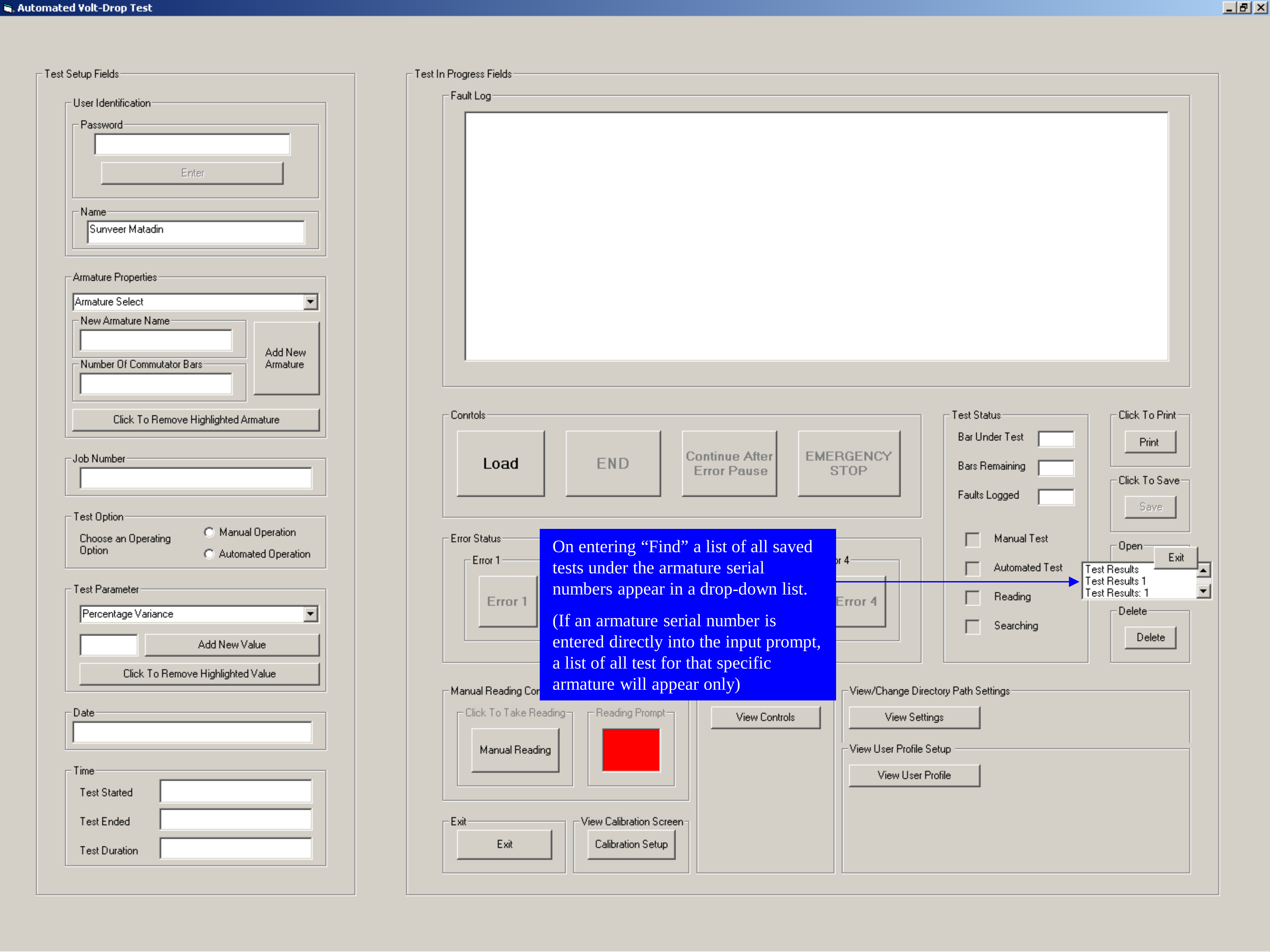

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
On clicking on the Error 1 indication button, a pop-up box containing a brief explanation of the error appears
Controls
Test Status
Bar Under Test
Click To Print
Print
Detection Unit Raising Error
The Test Probes have not been raised within the allowable time. Check the device and click Continue After Error Pause OR Click Emerengcy Stop!
OK
Click To Save
Save
Manual Test
Automated Test
Reading
Searching
Open
Open
Delete
Delete
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
Simulator
K
L
b
y
d
J
Q
I
z
Into
Out
MScom In Sim
Q
Exit
Case Select
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

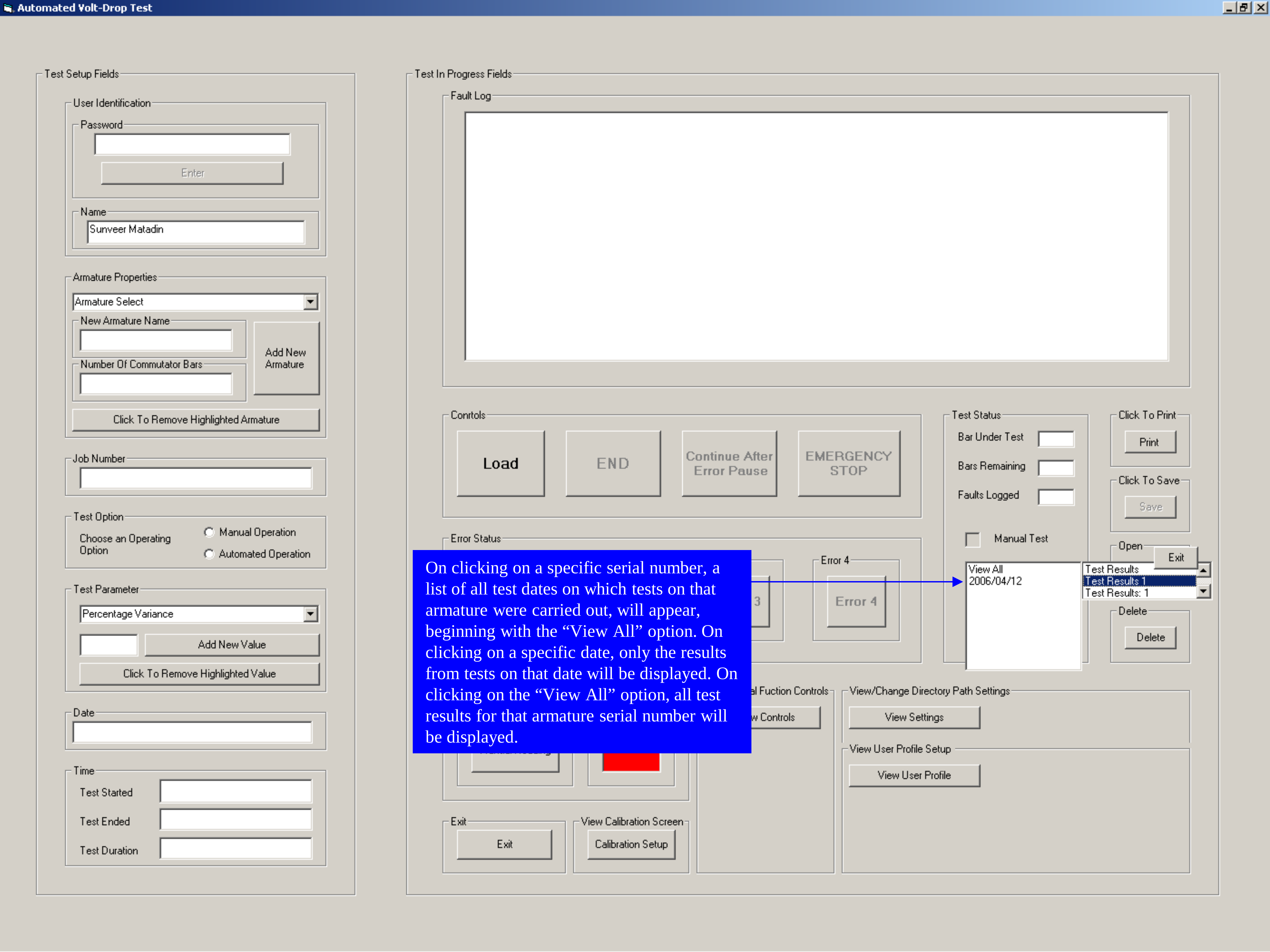


When data is being received by the GUI, the "Test Status" frame indicates that an acquisition cycle is in progress.

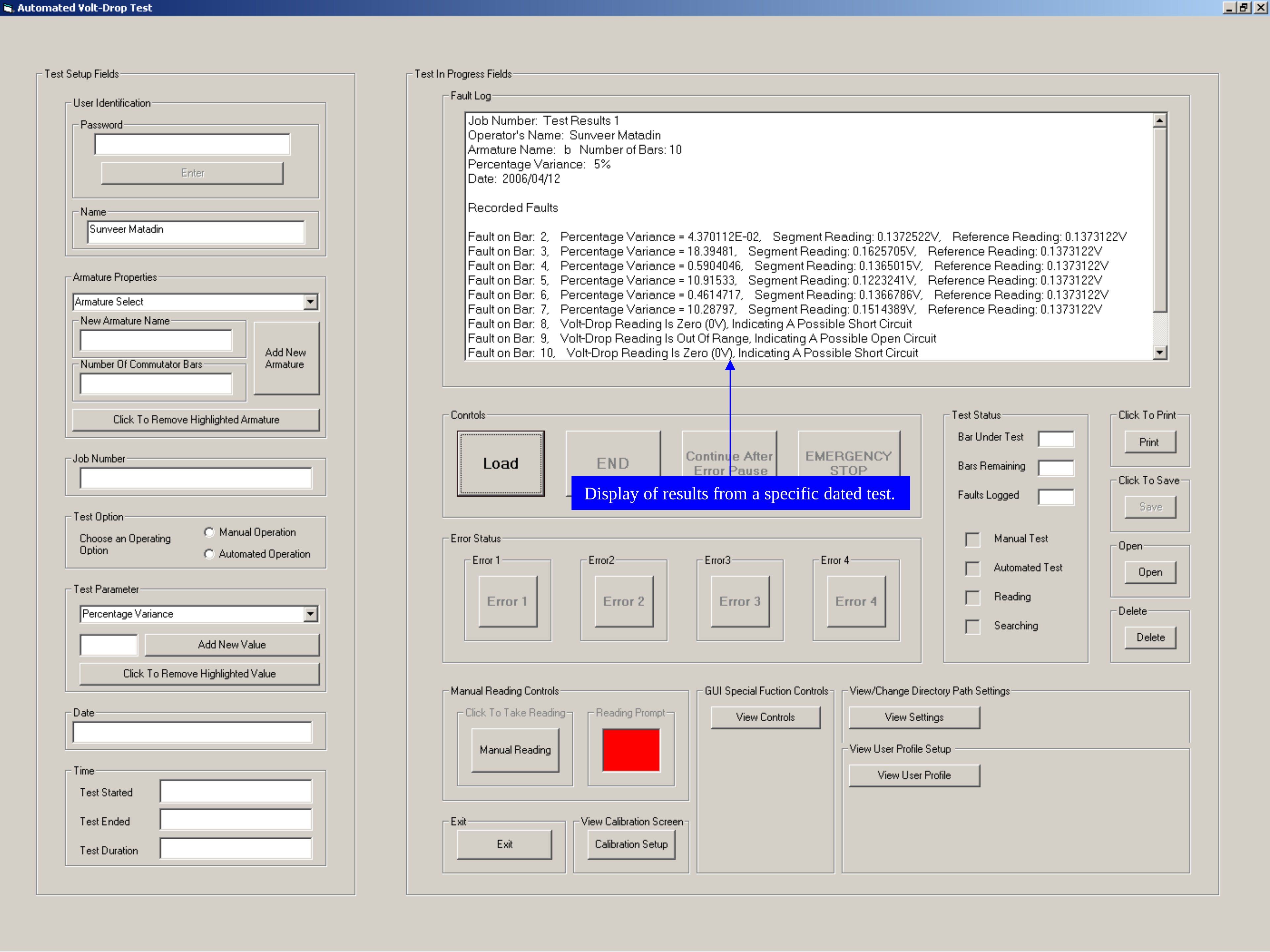

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Select
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Opening a previously saved test file.
Click on the "Open" button and a pop-up box appears prompting the user to enter an armature serial number or "Find" to search through all saved files
Enter The Job Number Of the Test You Wish To Open
Enter Job Number
OK
Cancel
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Error Status
Error 1
Error2
Error3
Error 4
Error 1
Error 2
Error 3
Error 4
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

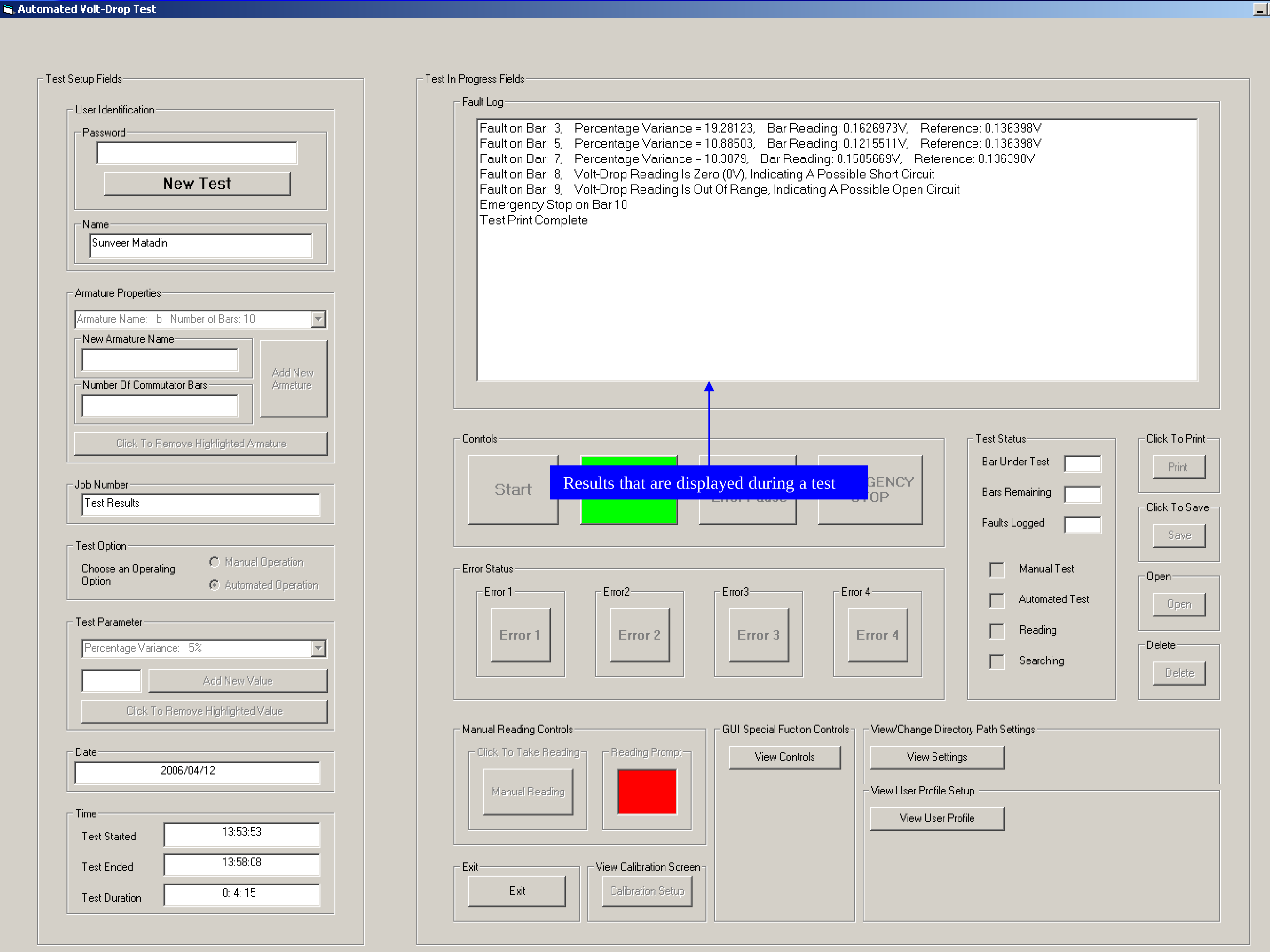

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Enter The Job Number Of the Test You Wish To Open
Enter Job Number
OK
Cancel
Find
Controls
EMERGENCY STOP
Enter “Find” to search through all saved filed
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

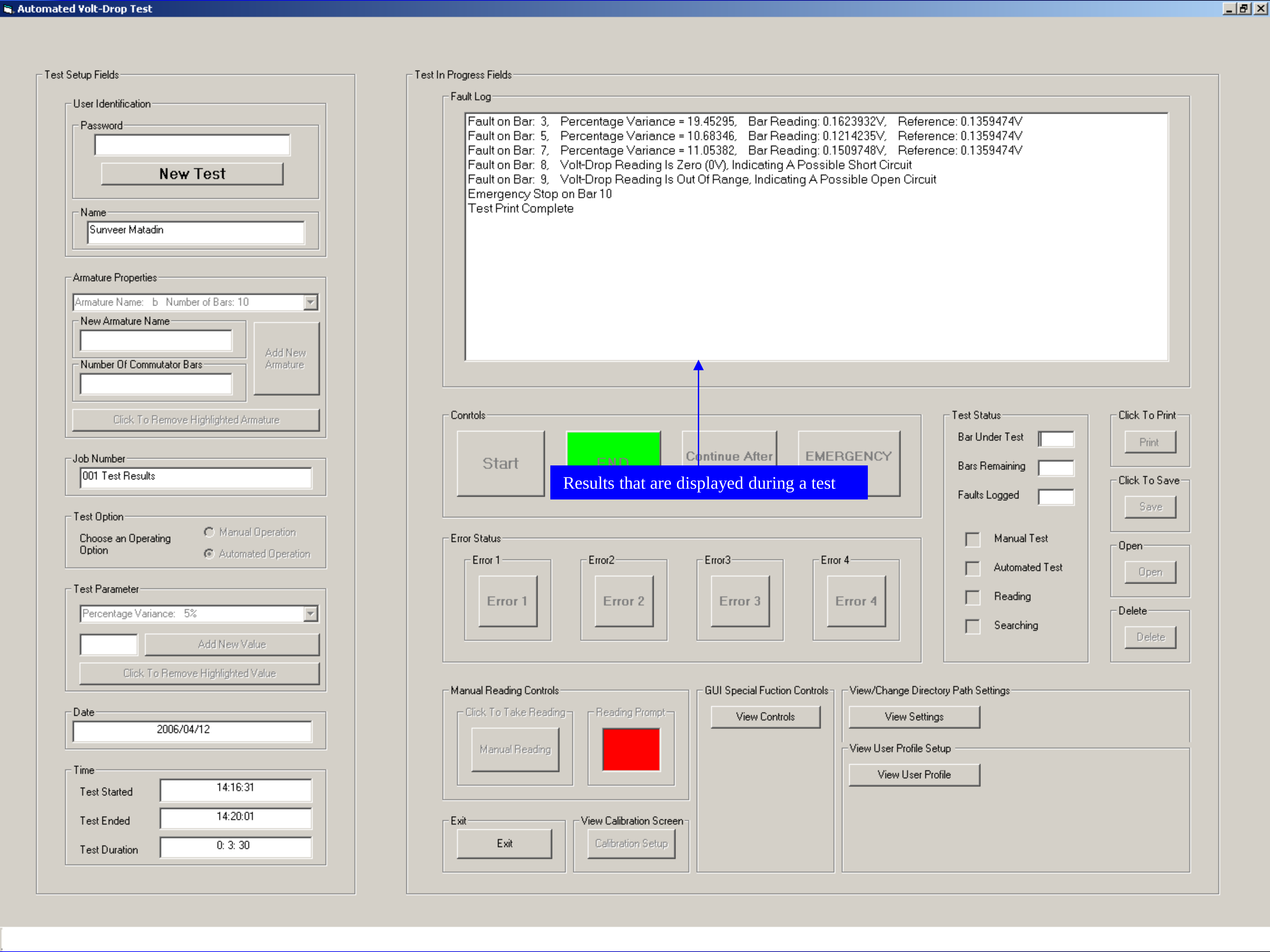

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Conrtols
Load
END
Continue After Error Pause
EMERGENCY STOP
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Exit
Test Results
Test Results 1
Test Results: 1
Delete
Delete
Error Status
Error 1
Error 1
Error 4
On entering “Find” a list of all saved tests under the armature serial numbers appear in a drop-down list.
(If an armature serial number is entered directly into the input prompt, a list of all test for that specific armature will appear only)
Manual Reading Cor
Click To Take Reading
Manual Reading
Reading Prompt
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup



On clicking on a specific serial number, a list of all test dates on which tests on that armature were carried out, will appear, beginning with the "View All" option. On clicking on a specific date, only the results from tests on that date will be displayed. On clicking on the "View All" option, all test results for that armature serial number will be displayed.


Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
Enter
Name
Sunveer Matadin
Armature Properties
Armature Select
New Armature Name
Add New Armature
Number Of Commutator Bars
Click To Remove Highlighted Armature
Job Number
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance
Add New Value
Click To Remove Highlighted Value
Date
Time
Test Started
Test Ended
Test Duration
Test In Progress Fields
Fault Log
Job Number: Test Results 1
Operator's Name: Sunveer Matadin
Armature Name: b Number of Bars: 10
Percentage Variance: 5%
Date: 2006/04/12
Recorded Faults
Fault on Bar: 2, Percentage Variance = 4.370112E-02, Segment Reading: 0.1372522V, Reference Reading: 0.1373122V
Fault on Bar: 3, Percentage Variance = 18.39481, Segment Reading: 0.1625705V, Reference Reading: 0.1373122V
Fault on Bar: 4, Percentage Variance = 0.5904046, Segment Reading: 0.1365015V, Reference Reading: 0.1373122V
Fault on Bar: 5, Percentage Variance = 10.91533, Segment Reading: 0.1223241V, Reference Reading: 0.1373122V
Fault on Bar: 6, Percentage Variance = 0.4614717, Segment Reading: 0.1366786V, Reference Reading: 0.1373122V
Fault on Bar: 7, Percentage Variance = 10.28797, Segment Reading: 0.1514389V, Reference Reading: 0.1373122V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Fault on Bar: 10, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Controls
Load
END
Continue After Error Pause
EMERGENCY STOP
Display of results from a specific dated test.
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

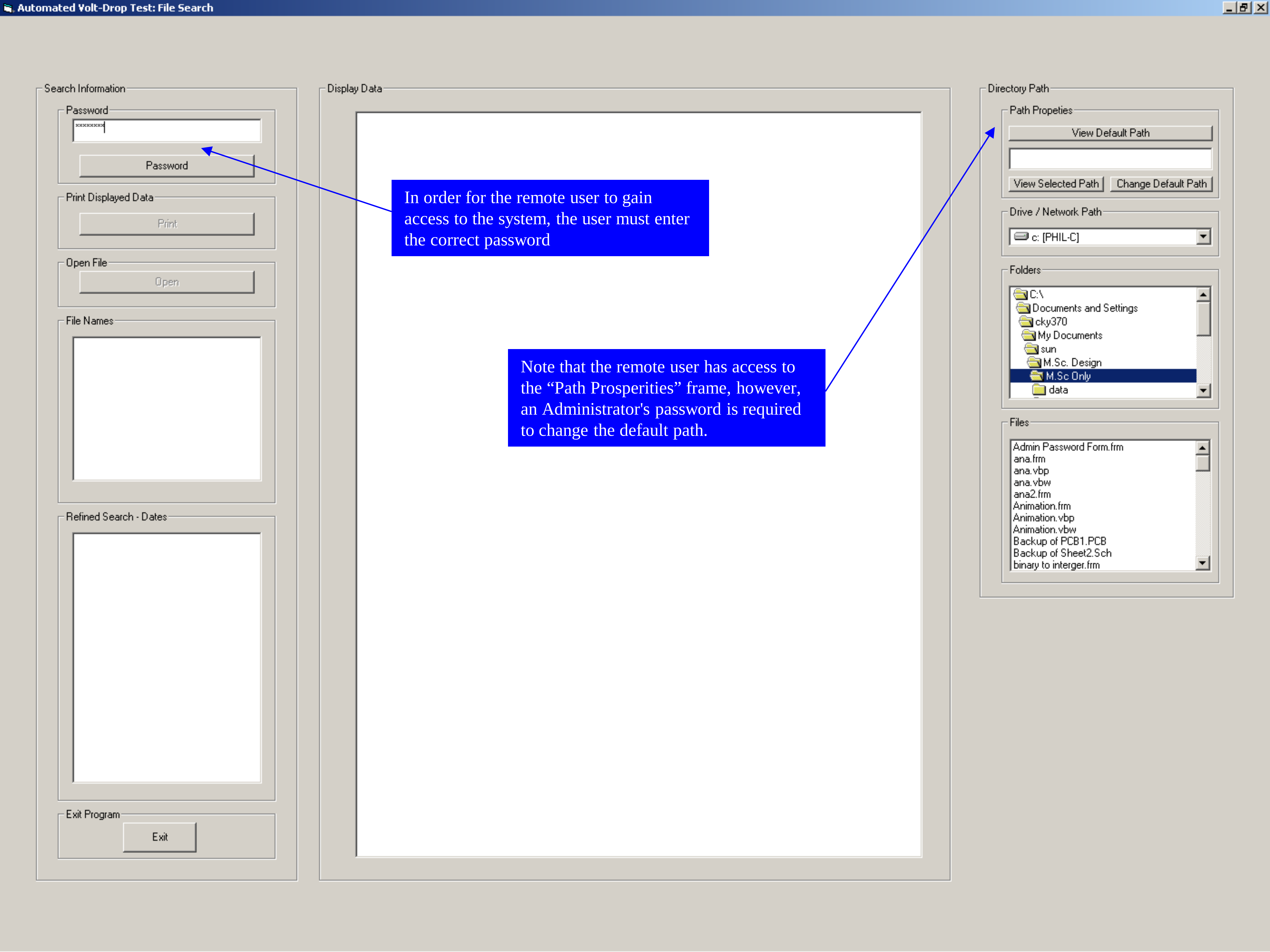

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Sunveer Matadin
Armature Properties
Armature Name: b Number of Bars: 10
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
Test Results
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/04/12
Time
Test Started
13:53:53
Test Ended
13:58:08
Test Duration
0: 4: 15
Test In Progress Fields
Fault Log
Fault on Bar: 3, Percentage Variance = 19.28123, Bar Reading: 0.1626973V, Reference: 0.136398V
Fault on Bar: 5, Percentage Variance = 10.88503, Bar Reading: 0.1215511V, Reference: 0.136398V
Fault on Bar: 7, Percentage Variance = 10.3879, Bar Reading: 0.1505669V, Reference: 0.136398V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Emergency Stop on Bar 10
Test Print Complete
Controls
Start
Results that are displayed during a test
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

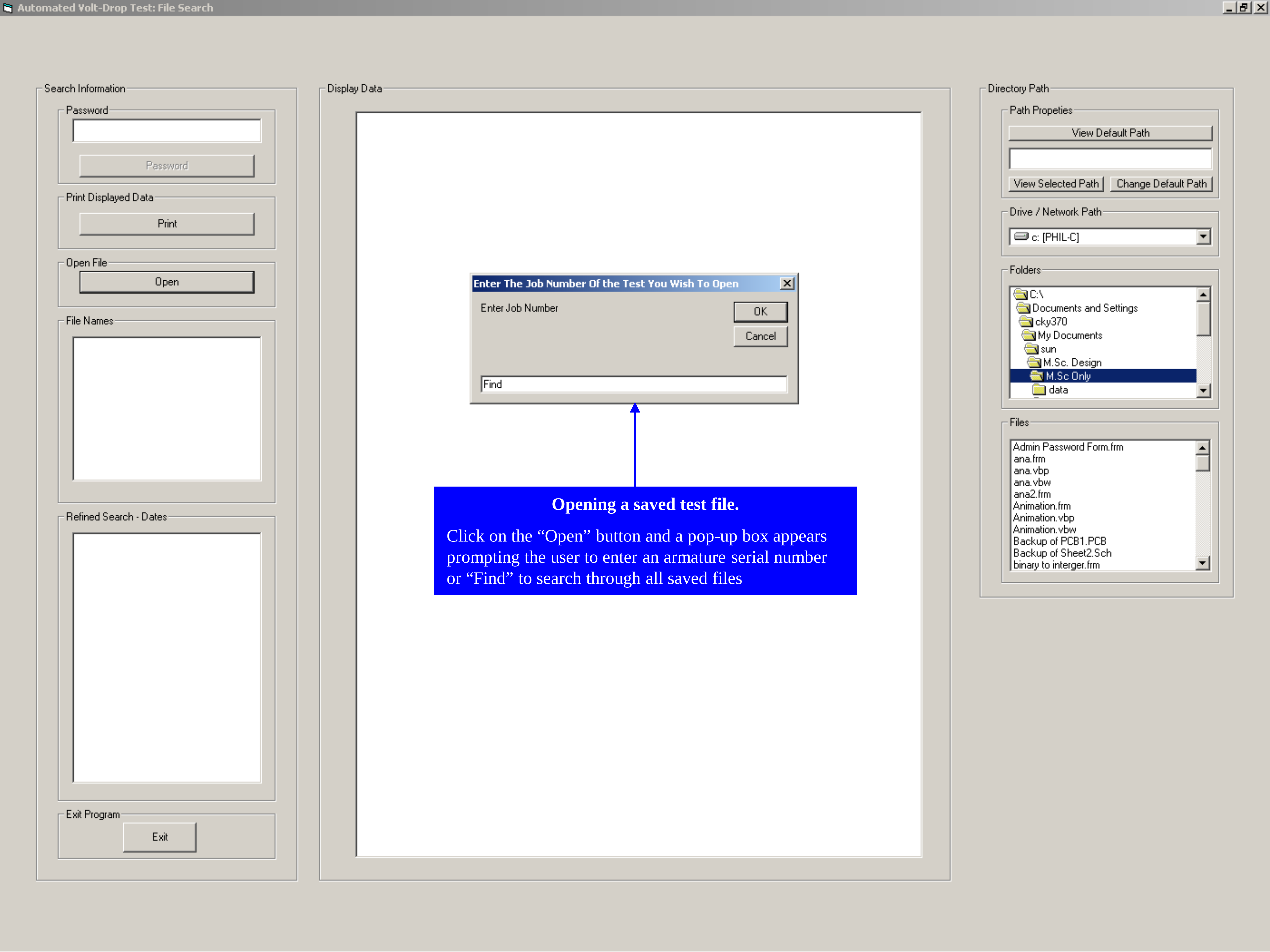

Automated Volt-Drop Test
Test Setup Fields
User Identification
Password
New Test
Name
Sunveer Matadin
Armature Properties
Armature Name: b Number of Bars: 10
New Armature Name
Number Of Commutator Bars
Add New Armature
Click To Remove Highlighted Armature
Job Number
001 Test Results
Test Option
Choose an Operating Option
Manual Operation
Automated Operation
Test Parameter
Percentage Variance: 5%
Add New Value
Click To Remove Highlighted Value
Date
2006/04/12
Time
Test Started
14:16:31
Test Ended
14:20:01
Test Duration
0: 3: 30
Test In Progress Fields
Fault Log
Fault on Bar: 3, Percentage Variance = 19.45295, Bar Reading: 0.1623932V, Reference: 0.1359474V
Fault on Bar: 5, Percentage Variance = 10.68346, Bar Reading: 0.1214235V, Reference: 0.1359474V
Fault on Bar: 7, Percentage Variance = 11.05382, Bar Reading: 0.1509748V, Reference: 0.1359474V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Emergency Stop on Bar 10
Test Print Complete
Conrtols
Start
END
Continue After
EMERGENCY
Results that are displayed during a test
Test Status
Bar Under Test
Bars Remaining
Faults Logged
Manual Test
Automated Test
Reading
Searching
Click To Print
Print
Click To Save
Save
Open
Open
Delete
Delete
Error Status
Error 1
Error 1
Error2
Error 2
Error3
Error 3
Error 4
Error 4
Manual Reading Controls
Click To Take Reading
Manual Reading
Reading Prompt
GUI Special Fuction Controls
View Controls
View/Change Directory Path Settings
View Settings
View User Profile Setup
View User Profile
Exit
Exit
View Calibration Screen
Calibration Setup

The Design Of An Embedded Controller For An Automated Volt-Drop Test

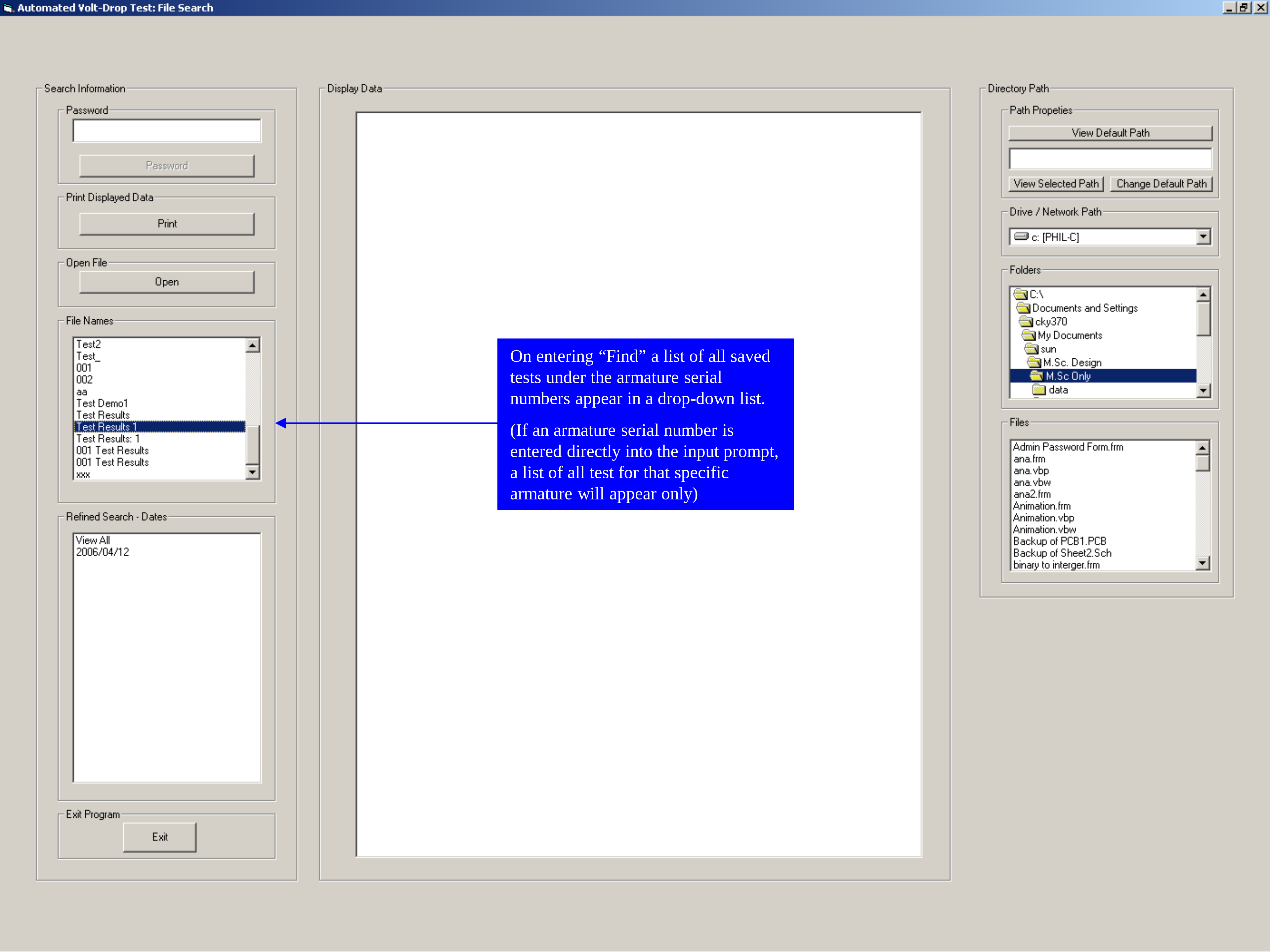
The Remote Graphic User Interface

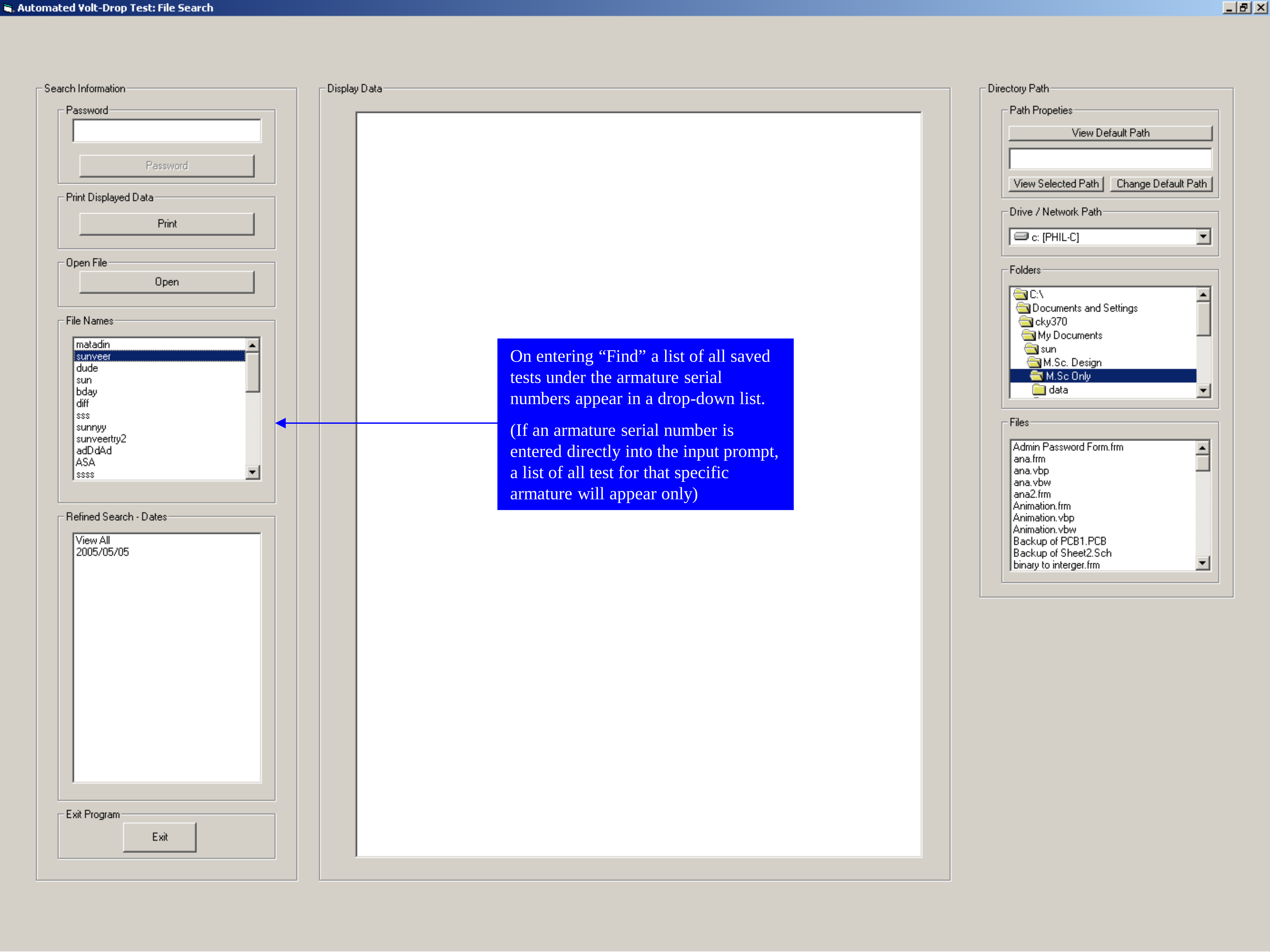
(RGUI)

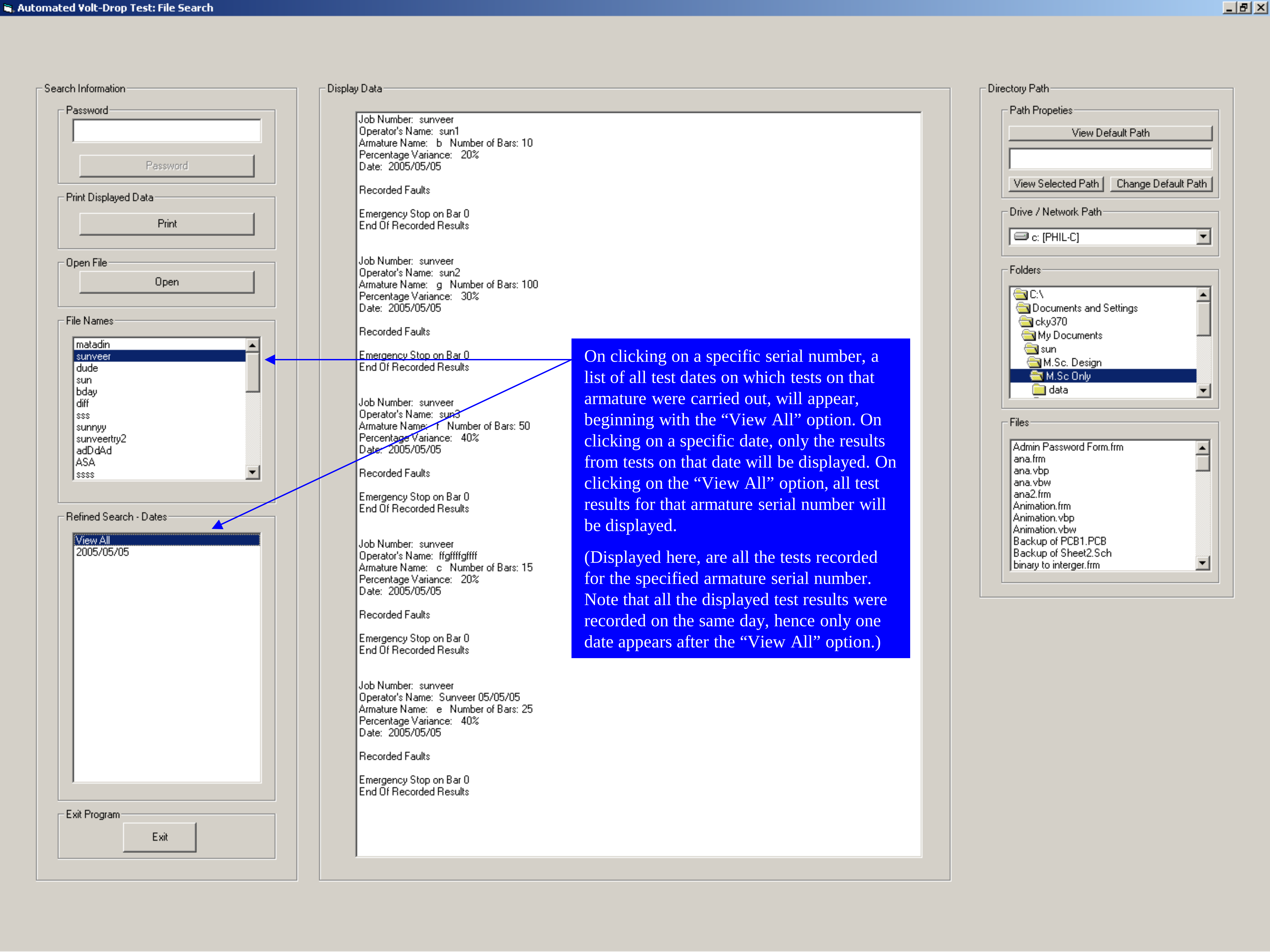

Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
Refined Search - Dates
Exit Program
Exit
Display Data
In order for the remote user to gain access to the system, the user must enter the correct password
Note that the remote user has access to the "Path Prosperities" frame, however, an Administrator's password is required to change the default path.
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
c: [PHIL-C]
Folders
C:\
Documents and Settings
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
data
Files
Admin Password Form.frm
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
binary to interger.frm

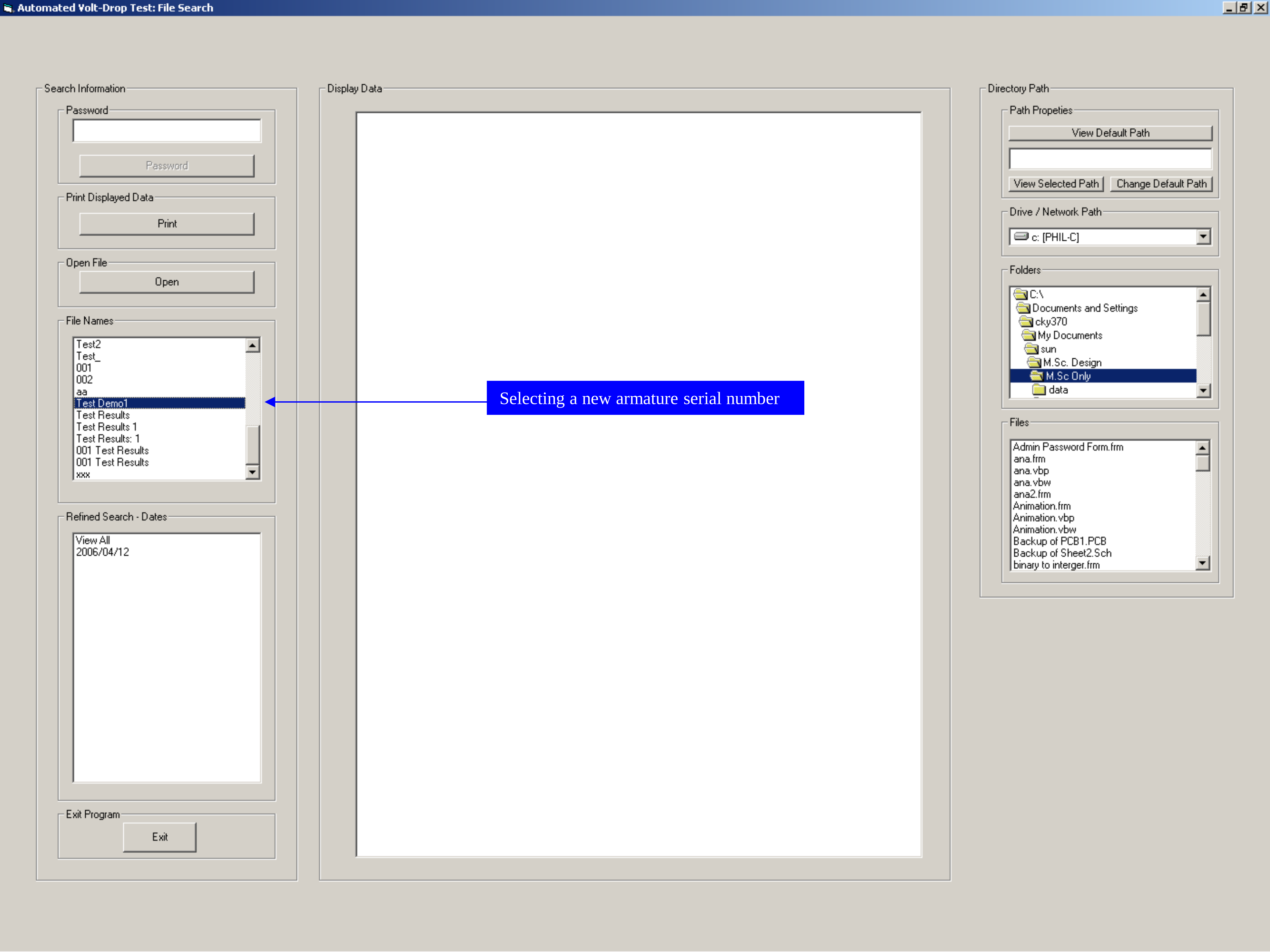


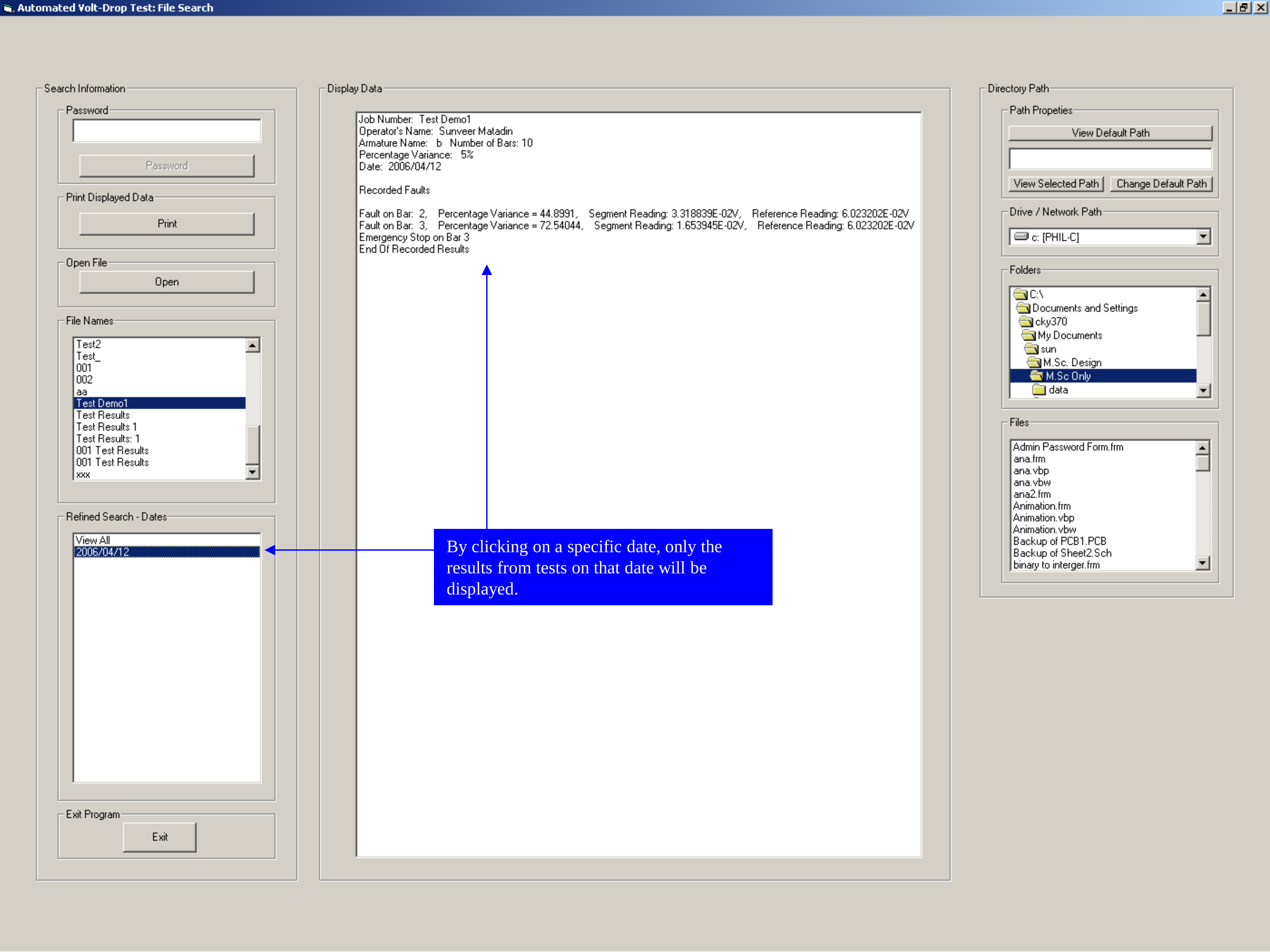
Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
Refined Search - Dates
Exit Program
Exit
Display Data
Enter The Job Number Of the Test You Wish To Open
Enter Job Number
OK
Cancel
Find
Opening a saved test file.
Click on the “Open” button and a pop-up box appears prompting the user to enter an armature serial number or “Find” to search through all saved files
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
c: [PHIL-C]
Folders
C:\
Documents and Settings
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
data
Files
Admin Password Form.frm
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
binary to interger.frm


Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
Test2
Test_
001
002
aa
Test Demo1
Test Results
Test Results 1
Test Results: 1
001 Test Results
001 Test Results
xxx
Refined Search - Dates
View All
2006/04/12
Exit Program
Exit
Display Data
On entering “Find” a list of all saved tests under the armature serial numbers appear in a drop-down list.
(If an armature serial number is entered directly into the input prompt, a list of all test for that specific armature will appear only)
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
c: [PHIL-C]
Folders
C:\
Documents and Settings
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
data
Files
Admin Password Form.frm
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
binary to interger.frm


Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
matadin
sunveer
dude
sun
bday
diff
sss
sunnyy
sunveertry2
adDdAd
ASA
ssss
Refined Search - Dates
View All
2005/05/05
Exit Program
Exit
Display Data
On entering "Find" a list of all saved tests under the armature serial numbers appear in a drop-down list.
(If an armature serial number is entered directly into the input prompt, a list of all test for that specific armature will appear only)
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
c: [PHIL-C]
Folders
C:\
Documents and Settings
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
data
Files
Admin Password Form.frm
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
binary to interger.frm

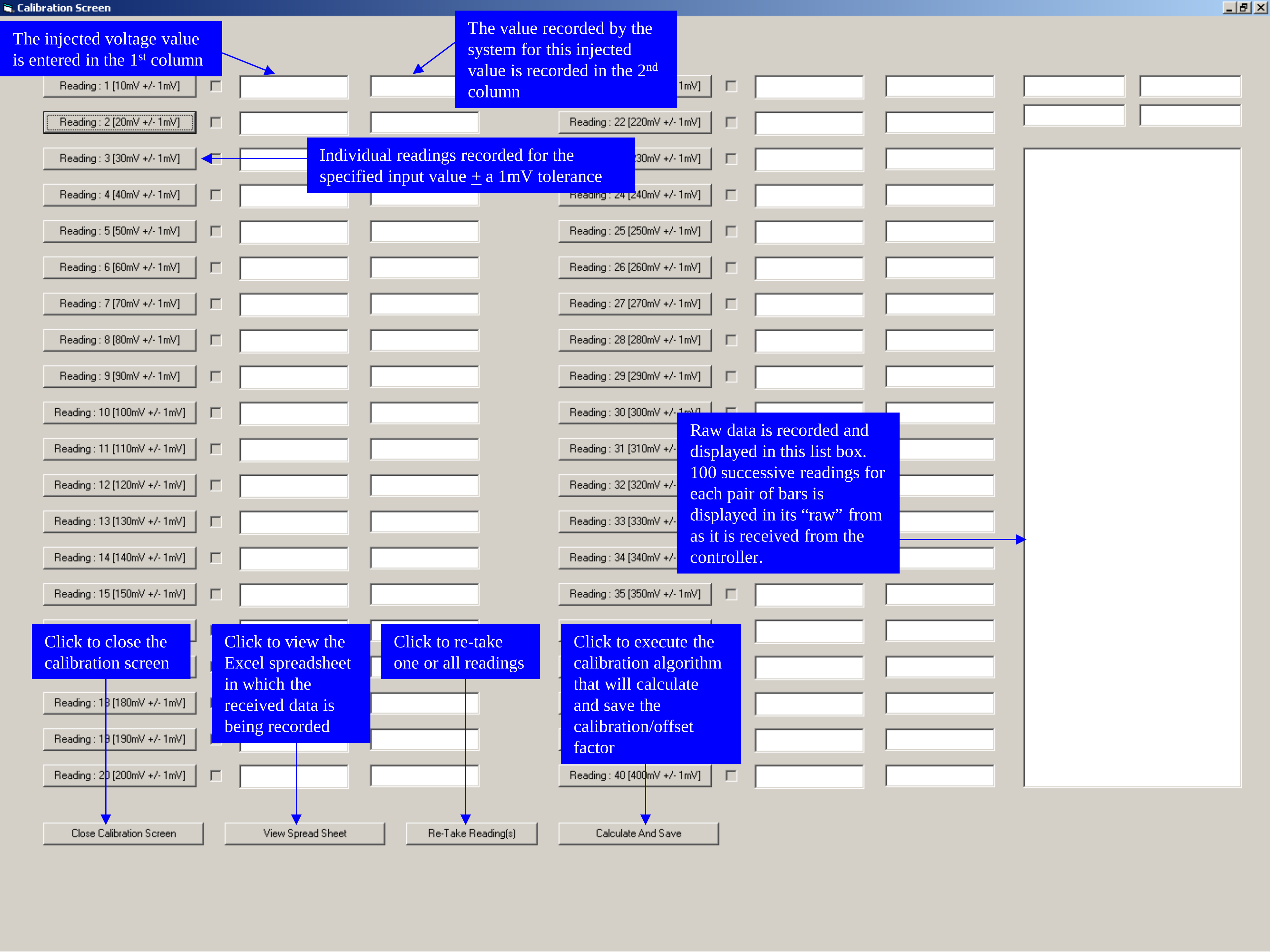

Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
matadin
sunveer
dude
sun
bday
diff
sss
sunnyy
sunveertry2
adDdAd
ASA
ssss
Refined Search - Dates
View All
2005/05/05
Exit Program
Exit
Display Data
Job Number: sunveer
Operator's Name: sun1
Armature Name: b Number of Bars: 10
Percentage Variance: 20%
Date: 2005/05/05
Recorded Faults
Emergency Stop on Bar 0
End Of Recorded Results
Job Number: sunveer
Operator's Name: sun2
Armature Name: g Number of Bars: 100
Percentage Variance: 30%
Date: 2005/05/05
Recorded Faults
Emergency Stop on Bar 0
End Of Recorded Results
Job Number: sunveer
Operator's Name: sun3
Armature Name: f Number of Bars: 50
Percentage Variance: 40%
Date: 2005/05/05
Recorded Faults
Emergency Stop on Bar 0
End Of Recorded Results
Job Number: sunveer
Operator's Name: ffgffffgffff
Armature Name: c Number of Bars: 15
Percentage Variance: 20%
Date: 2005/05/05
Recorded Faults
Emergency Stop on Bar 0
End Of Recorded Results
Job Number: sunveer
Operator's Name: Sunveer 05/05/05
Armature Name: e Number of Bars: 25
Percentage Variance: 40%
Date: 2005/05/05
Recorded Faults
Emergency Stop on Bar 0
End Of Recorded Results
On clicking on a specific serial number, a list of all test dates on which tests on that armature were carried out, will appear, beginning with the “View All” option. On clicking on a specific date, only the results from tests on that date will be displayed. On clicking on the “View All” option, all test results for that armature serial number will be displayed.
(Displayed here, are all the tests recorded for the specified armature serial number. Note that all the displayed test results were recorded on the same day, hence only one date appears after the “View All” option.)
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
c: [PHIL-C]
Folders
C:\
Documents and Settings
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
data
Files
Admin Password Form.frm
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
binary to interger.frm

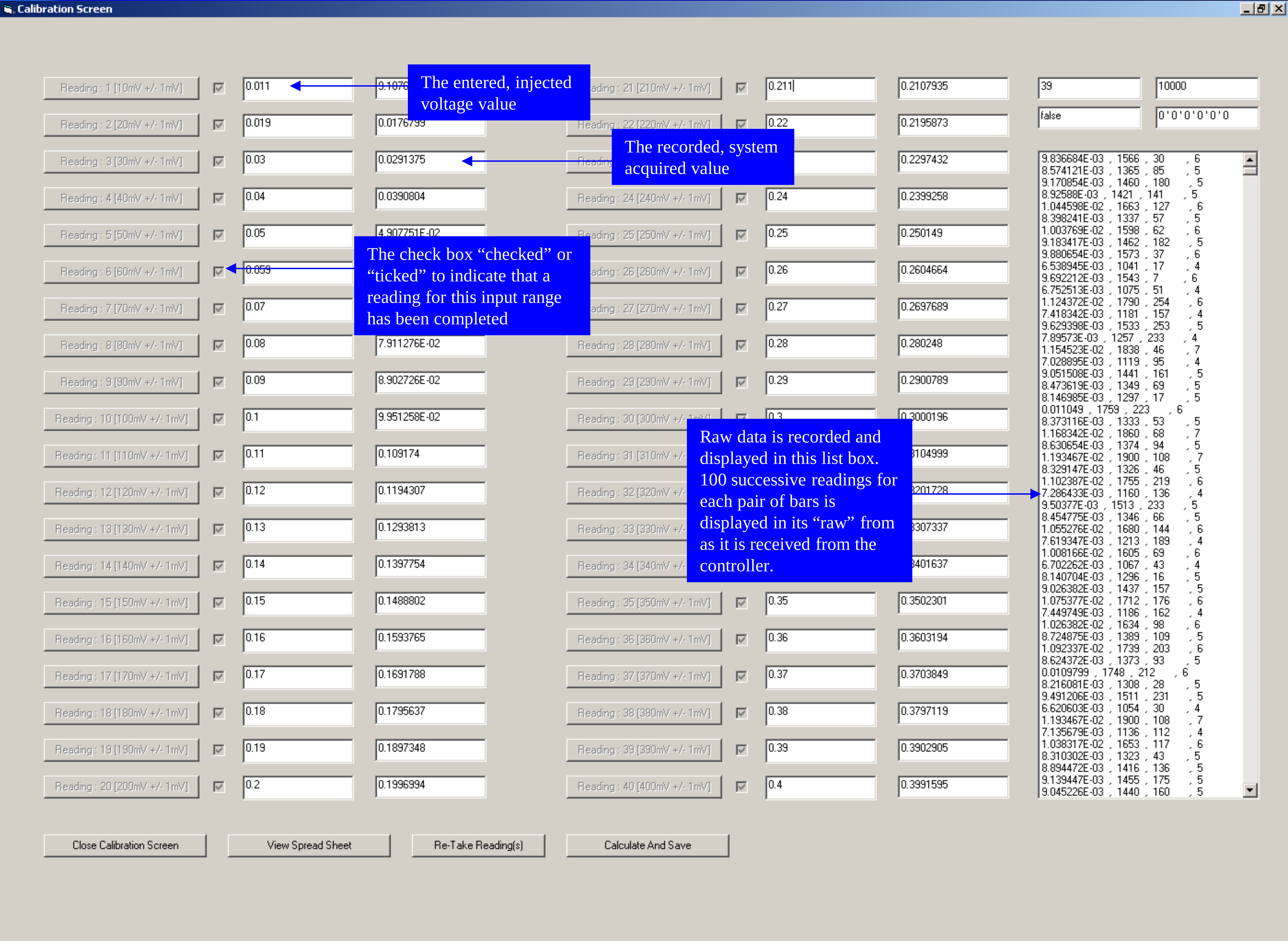

Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
Test2
Test_
001
002
aa
Test Demo1
Test Results
Test Results 1
Test Results: 1
001 Test Results
001 Test Results
xxx
Refined Search - Dates
View All
2006/04/12
Exit Program
Exit
Display Data
Selecting a new armature serial number
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
c: [PHIL-C]
Folders
C:\
Documents and Settings
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
data
Files
Admin Password Form.frm
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
binary to interger.frm


Automated Volt-Drop Test: File Search
Search Information
Password
Password
Print Displayed Data
Print
Open File
Open
File Names
Test2
Test_
001
002
aa
Test Demo1
Test Results
Test Results 1
Test Results: 1
001 Test Results
001 Test Results
xxx
Refined Search - Dates
View All
2006/04/12
Exit Program
Exit
Display Data
Job Number: Test Demo1
Operator's Name: Sunveer Matadin
Armature Name: b Number of Bars: 10
Percentage Variance: 5%
Date: 2006/04/12
Recorded Faults
Fault on Bar: 2, Percentage Variance = 44.8991, Segment Reading: 3.318839E-02V, Reference Reading: 6.023202E-02V
Fault on Bar: 3, Percentage Variance = 72.54044, Segment Reading: 1.653945E-02V, Reference Reading: 6.023202E-02V
Emergency Stop on Bar 3
End Of Recorded Results
By clicking on a specific date, only the results from tests on that date will be displayed.
Directory Path
Path Propeties
View Default Path
View Selected Path
Change Default Path
Drive / Network Path
c: [PHIL-C]
Folders
C:\
Documents and Settings
cky370
My Documents
sun
M.Sc. Design
M.Sc Only
data
Files
Admin Password Form.frm
ana.frm
ana.vbp
ana.vbw
ana2.frm
Animation.frm
Animation.vbp
Animation.vbw
Backup of PCB1.PCB
Backup of Sheet2.Sch
binary to interger.frm

The Design Of An Embedded Controller For An Automated Volt-Drop Test

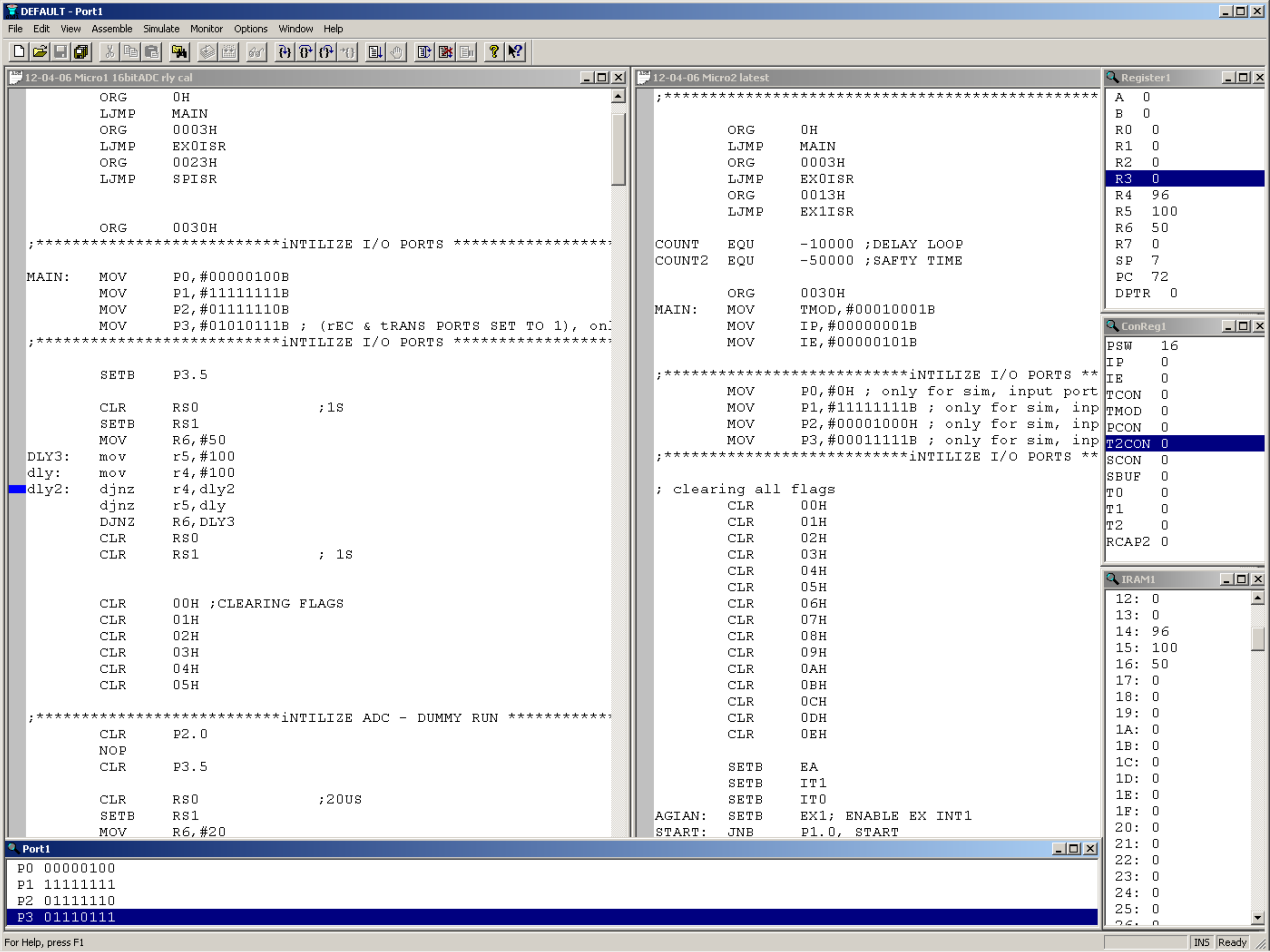
The Calibration Screen

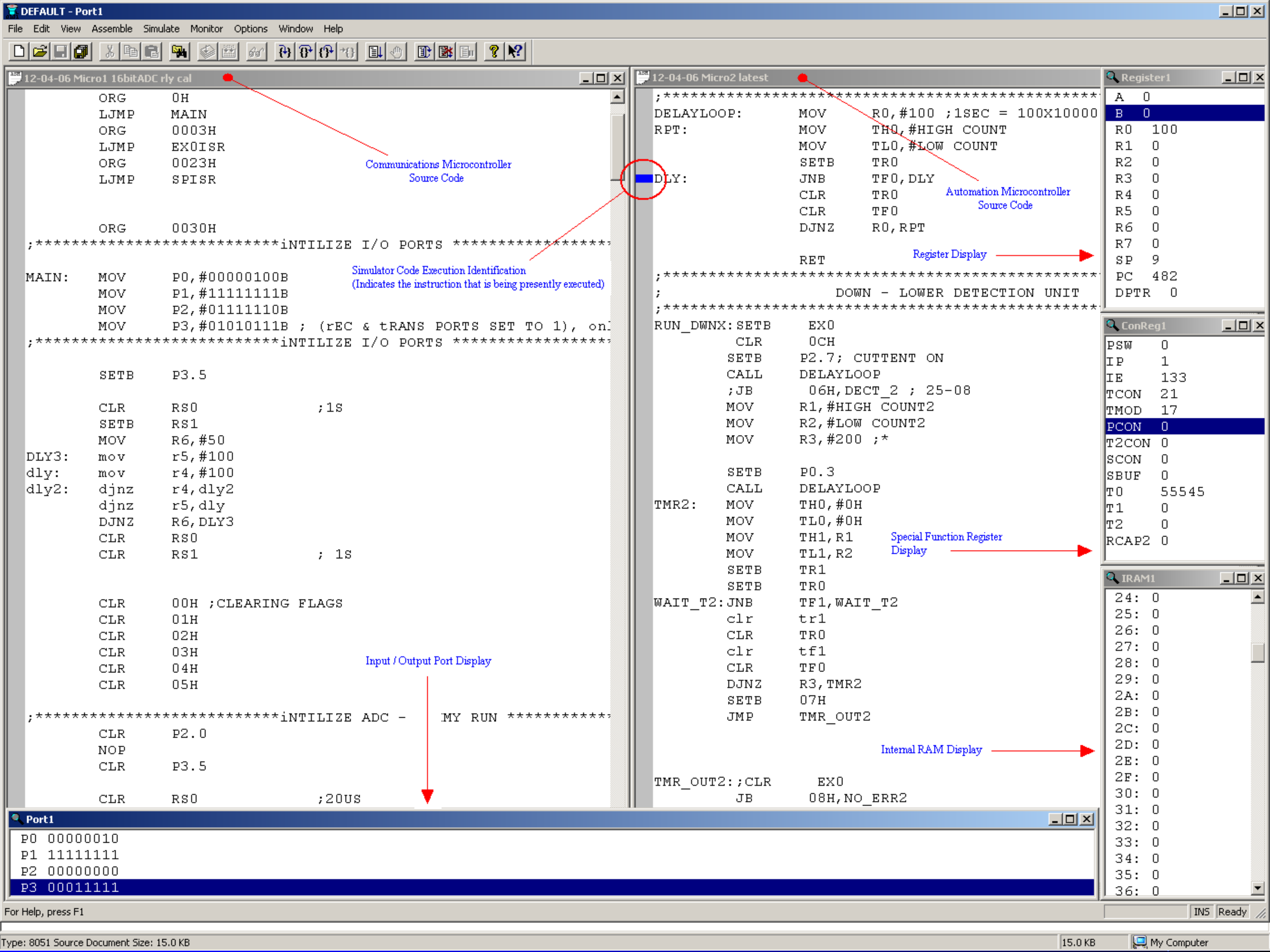

Calibration Screen
The injected voltage value is entered in the 1st column
The value recorded by the system for this injected value is recorded in the 2nd column
Individual readings recorded for the specified input value ± a 1mV tolerance
Raw data is recorded and displayed in this list box. 100 successive readings for each pair of bars is displayed in its “raw” from as it is received from the controller.
Click to close the calibration screen
Click to view the Excel spreadsheet in which the received data is being recorded
Click to re-take one or all readings
Click to execute the calibration algorithm that will calculate and save the calibration/offset factor
Reading : 1 [10mV +/- 1mV]
Reading : 2 [20mV +/- 1mV]
Reading : 3 [30mV +/- 1mV]
Reading : 4 [40mV +/- 1mV]
Reading : 5 [50mV +/- 1mV]
Reading : 6 [60mV +/- 1mV]
Reading : 7 [70mV +/- 1mV]
Reading : 8 [80mV +/- 1mV]
Reading : 9 [90mV +/- 1mV]
Reading : 10 [100mV +/- 1mV]
Reading : 11 [110mV +/- 1mV]
Reading : 12 [120mV +/- 1mV]
Reading : 13 [130mV +/- 1mV]
Reading : 14 [140mV +/- 1mV]
Reading : 15 [150mV +/- 1mV]
Reading : 18 [180mV +/- 1mV]
Reading : 19 [190mV +/- 1mV]
Reading : 20 [200mV +/- 1mV]
Reading : 22 [220mV +/- 1mV]
Reading : 24 [240mV +/- 1mV]
Reading : 25 [250mV +/- 1mV]
Reading : 26 [260mV +/- 1mV]
Reading : 27 [270mV +/- 1mV]
Reading : 28 [280mV +/- 1mV]
Reading : 29 [290mV +/- 1mV]
Reading : 30 [300mV +/- 1mV]
Reading : 35 [350mV +/- 1mV]
Reading : 40 [400mV +/- 1mV]
Close Calibration Screen
View Spread Sheet
Re-Take Reading(s)
Calculate And Save


Calibration Screen
The entered, injected voltage value
The recorded, system acquired value
The check box "checked" or "ticked" to indicate that a reading for this input range has been completed
Raw data is recorded and displayed in this list box. 100 successive readings for each pair of bars is displayed in its "raw" from as it is received from the controller.
Reading : 1 [10mV +/- 1mV] 0.011
Reading : 2 [20mV +/- 1mV] 0.019 0.0176799
Reading : 3 [30mV +/- 1mV] 0.03 0.0291375
Reading : 4 [40mV +/- 1mV] 0.04 0.0390804
Reading : 5 [50mV +/- 1mV] 0.05 4.907751E-02
Reading : 6 [60mV +/- 1mV] 0.059
Reading : 7 [70mV +/- 1mV] 0.07
Reading : 8 [80mV +/- 1mV] 0.08 7.911276E-02
Reading : 9 [90mV +/- 1mV] 0.09 8.902726E-02
Reading : 10 [100mV +/- 1mV] 0.1 9.951258E-02
Reading : 11 [110mV +/- 1mV] 0.11 0.109174
Reading : 12 [120mV +/- 1mV] 0.12 0.1194307
Reading : 13 [130mV +/- 1mV] 0.13 0.1293813
Reading : 14 [140mV +/- 1mV] 0.14 0.1397754
Reading : 15 [150mV +/- 1mV] 0.15 0.1488802
Reading : 16 [160mV +/- 1mV] 0.16 0.1593765
Reading : 17 [170mV +/- 1mV] 0.17 0.1691788
Reading : 18 [180mV +/- 1mV] 0.18 0.1795637
Reading : 19 [190mV +/- 1mV] 0.19 0.1897348
Reading : 20 [200mV +/- 1mV] 0.2 0.1996994
Reading : 21 [210mV +/- 1mV] 0.211 0.2107935
Reading : 22 [220mV +/- 1mV] 0.22 0.2195873
0.2297432
Reading : 24 [240mV +/- 1mV] 0.24 0.2399258
Reading : 25 [250mV +/- 1mV] 0.25 0.250149
Reading : 26 [260mV +/- 1mV] 0.26 0.2604664
Reading : 27 [270mV +/- 1mV] 0.27 0.2697689
Reading : 28 [280mV +/- 1mV] 0.28 0.280248
Reading : 29 [290mV +/- 1mV] 0.29 0.2900789
Reading : 30 [300mV +/- 1mV] 0.3 0.3000196
Reading : 35 [350mV +/- 1mV] 0.35 0.3502301
Reading : 36 [360mV +/- 1mV] 0.36 0.3603194
Reading : 37 [370mV +/- 1mV] 0.37 0.3703849
Reading : 38 [380mV +/- 1mV] 0.38 0.3797119
Reading : 39 [390mV +/- 1mV] 0.39 0.3902905
Reading : 40 [400mV +/- 1mV] 0.4 0.3991595
39
10000
false
0'0'0'0'0'0
9.836684E-03 , 1566 , 30 , 6
8.574121E-03 , 1365 , 85 , 5
9.170854E-03 , 1460 , 180 , 5
8.92588E-03 , 1421 , 141 , 5
1.044598E-02 , 1663 , 127 , 6
8.398241E-03 , 1337 , 57 , 5
1.003769E-02 , 1598 , 62 , 6
9.183417E-03 , 1462 , 182 , 5
9.880654E-03 , 1573 , 37 , 6
6.538945E-03 , 1041 , 17 , 4
9.692212E-03 , 1543 , 7 , 6
6.752513E-03 , 1075 , 51 , 4
1.124372E-02 , 1790 , 254 , 6
7.418342E-03 , 1181 , 157 , 4
9.629398E-03 , 1533 , 253 , 5
7.89573E-03 , 1257 , 233 , 4
1.154523E-02 , 1838 , 46 , 7
7.028895E-03 , 1119 , 95 , 4
9.051508E-03 , 1441 , 161 , 5
8.473619E-03 , 1349 , 69 , 5
8.146985E-03 , 1297 , 17 , 5
0.011049 , 1759 , 223 , 6
8.373116E-03 , 1333 , 53 , 5
1.168342E-02 , 1860 , 68 , 7
8.630654E-03 , 1374 , 94 , 5
1.193467E-02 , 1900 , 108 , 7
8.329147E-03 , 1326 , 46 , 5
1.102387E-02 , 1755 , 219 , 6
7.286433E-03 , 1160 , 136 , 4
9.50377E-03 , 1513 , 233 , 5
8.454775E-03 , 1346 , 66 , 5
1.055276E-02 , 1680 , 144 , 6
7.619347E-03 , 1213 , 189 , 4
1.008166E-02 , 1605 , 69 , 6
6.702262E-03 , 1067 , 43 , 4
8.140704E-03 , 1296 , 16 , 5
9.026382E-03 , 1437 , 157 , 5
1.075377E-02 , 1712 , 176 , 6
7.449749E-03 , 1186 , 162 , 4
1.026382E-02 , 1634 , 98 , 6
8.724875E-03 , 1389 , 109 , 5
1.092337E-02 , 1739 , 203 , 6
8.624372E-03 , 1373 , 93 , 5
0.0109799 , 1748 , 212 , 6
8.216081E-03 , 1308 , 28 , 5
9.491206E-03 , 1511 , 231 , 5
6.620603E-03 , 1054 , 30 , 4
1.193467E-02 , 1900 , 108 , 7
7.135679E-03 , 1136 , 112 , 4
1.038317E-02 , 1653 , 117 , 6
8.310302E-03 , 1323 , 43 , 5
8.894472E-03 , 1416 , 136 , 5
9.139447E-03 , 1455 , 175 , 5
9.045226E-03 , 1440 , 160 , 5
Close Calibration Screen
View Spread Sheet
Re-Take Reading(s)
Calculate And Save

The Design Of An Embedded Controller For An Automated Volt-Drop Test

The Microcontroller Software Development Environment


DEFAULT - Port1
File Edit View Assemble Simulate Monitor Options Window Help
12-04-06 Micro1 16bitADC rly cal
ORG 0H
LJMP MAIN
ORG 0003H
LJMP EX0ISR
ORG 0023H
LJMP SPISR
ORG 0030H
;**************************iNTILIZE I/O PORTS *****************
MAIN: MOV P0,#00000100B
MOV P1,#11111111B
MOV P2,#01111110B
MOV P3,#01010111B ; (rEC & tRANS PORTS SET TO 1), onl
;**************************iNTILIZE I/O PORTS *****************
SETB P3.5
CLR RS0 ;1S
SETB RS1
MOV R6,#50
DLY3: mov r5,#100
dly: mov r4,#100
dly2: djnz r4,dly2
djnz r5,dly
DJNZ R6,DLY3
CLR RS0
CLR RS1 ; 1S
CLR 00H ;CLEARING FLAGS
CLR 01H
CLR 02H
CLR 03H
CLR 04H
CLR 05H
;**************************iNTILIZE ADC - DUMMY RUN ***********
CLR P2.0
NOP
CLR P3.5
CLR RS0 ;20US
SETB RS1
MOV R6,#20
12-04-06 Micro2 latest
;***
ORG 0H
LJMP MAIN
ORG 0003H
LJMP EX0ISR
ORG 0013H
LJMP EX1ISR
COUNT EQU -10000 ;DELAY LOOP
COUNT2 EQU -50000 ;SAFTY TIME
ORG 0030H
MAIN: MOV TMOD,#00010001B
MOV IP,#00000001B
MOV IE,#00000101B
;**************************iNTILIZE I/O PORTS **
MOV P0,#0H ; only for sim, input port
MOV P1,#11111111B ; only for sim, inp
MOV P2,#00001000H ; only for sim, inp
MOV P3,#00011111B ; only for sim, inp
;**************************iNTILIZE I/O PORTS **
; clearing all flags
CLR 00H
CLR 01H
CLR 02H
CLR 03H
CLR 04H
CLR 05H
CLR 06H
CLR 07H
CLR 08H
CLR 09H
CLR 0AH
CLR 0BH
CLR 0CH
CLR 0DH
CLR 0EH
SETB EA
SETB IT1
SETB IT0
AGIAN: SETB EX1; ENABLE EX INT1
START: JNB P1.0, START
Register1
A 0
B 0
R0 0
R1 0
R2 0
R3 0
R4 96
R5 100
R6 50
R7 0
SP 7
PC 72
DPTR 0
ConReg1
PSW 16
IP 0
IE 0
TCON 0
TMOD 0
PCON 0
T2CON 0
SCON 0
SBUF 0
T0 0
T1 0
T2 0
RCAP2 0
IRAM1
12: 0
13: 0
14: 96
15: 100
16: 50
17: 0
18: 0
19: 0
1A: 0
1B: 0
1C: 0
1D: 0
1E: 0
1F: 0
20: 0
21: 0
22: 0
23: 0
24: 0
25: 0
Port1
P0 00000100
P1 11111111
P2 01111110
P3 01110111
For Help, press F1
INS Ready


DEFAULT - Port1
File Edit View Assemble Simulate Monitor Options Window Help
12-04-06 Micro1 16bitADC rly cal
ORG 0H
LJMP MAIN
ORG 0003H
LJMP EX0ISR
ORG 0023H
LJMP SPISR
ORG 0030H
;**************************iNTILIZE I/O PORTS *****************
MAIN: MOV P0,#00000100B
MOV P1,#11111111B
MOV P2,#01111110B
MOV P3,#01010111B ; (rEC & tRANS PORTS SET TO 1), onl
;**************************iNTILIZE I/O PORTS *****************
SETB P3.5
CLR RS0 ;1S
SETB RS1
MOV R6,#50
DLY3: mov r5,#100
dly: mov r4,#100
dly2: djnz r4,dly2
djnz r5,dly
DJNZ R6,DLY3
CLR RS0
CLR RS1 ; 1S
CLR 00H ;CLEARING FLAGS
CLR 01H
CLR 02H
CLR 03H
CLR 04H
CLR 05H
;**************************iNTILIZE ADC - MY RUN ***********
CLR P2.0
NOP
CLR P3.5
CLR RS0 ;20US
Communications Microcontroller Source Code
Simulator Code Execution Identification
(Indicates the instruction that is being presently executed)
Input / Output Port Display
12-04-06 Micro2 latest
;***
DELAYLOOP: MOV R0,#100 ;1SEC = 100X10000
RPT: MOV TH0,#HIGH COUNT
MOV TL0,#LOW COUNT
SETB TR0
DLY: JNB TF0,DLY
CLR TR0
CLR TF0
DJNZ R0,RPT
RET
;***
; DOWN - LOWER DETECTION UNIT
;***
RUN_DWNX:SETB EX0
CLR 0CH
SETB P2.7; CUTTENT ON
CALL DELAYLOOP
;JB 06H,DECT_2 ; 25-08
MOV R1,#HIGH COUNT2
MOV R2,#LOW COUNT2
MOV R3,#200 ;*
SETB P0.3
CALL DELAYLOOP
TMR2: MOV TH0,#0H
MOV TL0,#0H
MOV TH1,R1
MOV TL1,R2
SETB TR1
SETB TR0
WAIT_T2:JNB TF1,WAIT_T2
clr tr1
CLR TR0
clr tf1
CLR TF0
DJNZ R3,TMR2
SETB 07H
JMP TMR_OUT2
TMR_OUT2:;CLR EX0
JB 08H,NO_ERR2
Automation Microcontroller Source Code
Register Display
Special Function Register Display
Internal RAM Display
Register1
A 0
B 0
R0 100
R1 0
R2 0
R3 0
R4 0
R5 0
R6 0
R7 0
SP 9
PC 482
DPTR 0
ConReg1
PSW 0
IP 1
IE 133
TCON 21
TMOD 17
PCON 0
T2CON 0
SCON 0
SBUF 0
T0 55545
T1 0
T2 0
RCAP2 0
IRAM1
24: 0
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27: 0
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29: 0
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2B: 0
2C: 0
2D: 0
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Port1
P0 00000010
P1 11111111
P2 00000000
P3 00011111
For Help, press F1
INS Ready
Type: 8051 Source Document Size: 15.0 KB
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0.199563	0.178944	0.180944	0.200813	0.185363	0.193806	0.177512	0.1995	0.197625	0.174088
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0.1727	0.182819	0.203	0.191444	0.1735	0.181775	0.2056	0.1795	0.175606	0.196194
0.190256	0.171237	0.187006	0.201838	0.179819	0.176413	0.2007	0.1974	0.171981	0.184763
0.1935	0.207006	0.178681	0.174206	0.197219	0.200313	0.172263	0.174019	0.201325	0.1891
0.199513	0.176206	0.178813	0.200181	0.194756	0.170788	0.1867	0.1998	0.180944	0.172713
0.203619	0.182475	0.170231	0.1947	0.201694	0.178106	0.173894	0.201513	0.191006	0.175225
0.1775	0.172544	0.1976	0.198525	0.172263	0.1795	0.204438	0.188894	0.173775	0.191494
0.200838	0.193963	0.172606	0.184244	0.201813	0.190575	0.173212	0.1903	0.206019	0.178325
0.194475	0.202813	0.177938	0.172881	0.199225	0.202394	0.1719	0.1738	0.202838	0.198019
0.194206	0.174044	0.180081	0.199994	0.191181	0.174	0.18115	0.202212	0.191031	0.173788
0.17555	0.197744	0.200606	0.178806	0.176606	0.198588	0.200337	0.174019	0.1811	0.203125
0.175219	0.177638	0.201556	0.1935	0.171831	0.176681	0.202013	0.187931	0.1755	0.195406
0.200506	0.190525	0.172025	0.189006	0.200394	0.179806	0.179619	0.205806	0.189406	0.168825
0.181406	0.2026	0.191563	0.172838	0.184206	0.2022	0.191094	0.1719	0.188594	0.201594
0.202406	0.19715	0.1752	0.178344	0.200075	0.190819	0.169925	0.184325	0.1996	0.183813
0.2024	0.180606	0.173913	0.201206	0.202488	0.174194	0.177188	0.203244	0.1918	0.174206
0.175225	0.185794	0.201406	0.188	0.176606	0.1886	0.200038	0.186331	0.176419	0.1867
0.206369	0.1825	0.172769	0.192206	0.204544	0.181406	0.173406	0.192781	0.20175	0.1764
0.189613	0.202019	0.185394	0.174013	0.191213	0.204088	0.18215	0.168156	0.195019	0.205637
0.20075	0.193875	0.174425	0.183806	0.2019	0.1912	0.1722	0.186006	0.203275	0.187806
0.182144	0.202713	0.1903	0.174219	0.18325	0.198838	0.1835	0.171494	0.196125	0.1991
0.1947	0.2039	0.18155	0.174206	0.195794	0.199831	0.176606	0.175381	0.199913	0.199575
0.200925	0.173913	0.175619	0.201663	0.193206	0.170681	0.1894	0.204406	0.183006	0.172794
0.1699	0.198306	0.200825	0.174494	0.173081	0.201988	0.1899	0.174425	0.186425	0.199413
0.171931	0.185194	0.201212	0.187275	0.175806	0.186475	0.200313	0.185344	0.172888	0.197638
0.19765	0.187913	0.174594	0.189675	0.204619	0.182	0.170806	0.191125	0.205613	0.1815
0.187006	0.202294	0.189613	0.173788	0.188406	0.200606	0.187613	0.169538	0.198388	0.191144
0.188238	0.199906	0.183844	0.168988	0.191888	0.204519	0.183631	0.172975	0.196888	0.201819
0.174006	0.1784	0.20075	0.188706	0.175031	0.1807	0.201663	0.189131	0.173944	0.198206
0.1734	0.197481	0.201188	0.1727	0.172781	0.202212	0.191213	0.172175	0.1855	0.200613
0.201919	0.1895	0.171856	0.194206	0.203406	0.1783	0.171994	0.195419	0.199225	0.175006
0.1928	0.173738	0.179613	0.203144	0.193206	0.174613	0.183969	0.199988	0.184794	0.169888
0.199563	0.178544	0.1751	0.1966	0.2006	0.177794	0.175225	0.197619	0.1999	0.179619
0.194813	0.20175	0.18	0.173613	0.195806	0.2018	0.182	0.172988	0.2024	0.1894
0.199513	0.174488	0.175513	0.202269	0.2006	0.174319	0.184813	0.200075	0.187531	0.1695
0.198213	0.199006	0.173306	0.173625	0.198306	0.2003	0.1715	0.179781	0.202231	0.194425
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0.200306	0.181431	0.172631	0.194906	0.199988	0.1742	0.176594	0.2003	0.197644	0.172181
0.196306	0.1719	0.177556	0.201469	0.194425	0.1734	0.180413	0.199831	0.193781	0.1723
0.199963	0.1819	0.176219	0.202444	0.1979	0.173481	0.184838	0.202306	0.189663	0.174144
0.175806	0.192075	0.200406	0.172994	0.1787	0.2015	0.190788	0.172313	0.186444	0.198594
0.199513	0.200319	0.1687	0.185125	0.198306	0.184813	0.173138	0.193431	0.204644	0.1803
0.1896	0.201669	0.1807	0.174638	0.19995	0.190219	0.175994	0.190319	0.2043	0.179344
0.200794	0.180013	0.172731	0.198838	0.194419	0.173406	0.179581	0.2022	0.188038	0.175006
0.172181	0.19515	0.199488	0.175831	0.1719	0.199488	0.1899	0.173188	0.1914	0.203806
0.172181	0.179206	0.200738	0.1944	0.172075	0.181613	0.202463	0.193406	0.1717	0.1795
0.182869	0.201269	0.191031	0.177219	0.187806	0.2014	0.186438	0.174844	0.188181	0.202438
0.190038	0.173406	0.201406	0.193813	0.1752	0.183988	0.202	0.190844	0.169281	0.1839
0.200813	0.1768	0.181694	0.2007	0.1891	0.169675	0.1864	0.198863	0.182206	0.1723
0.193538	0.199806	0.173675	0.171506	0.202206	0.1915	0.172344	0.180025	0.2008	0.191806
0.17655	0.178281	0.200306	0.193219	0.172306	0.1848	0.204144	0.192413	0.170813	0.183931
0.171581	0.203019	0.1932	0.169094	0.187019	0.2019	0.190806	0.173988	0.184725	0.199663
0.188606	0.202488	0.176694	0.176013	0.200881	0.189788	0.171619	0.19435	0.1995	0.177606
0.198081	0.1867	0.172025	0.193419	0.2059	0.183106	0.172344	0.1939	0.201206	0.1804
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0.177688	0.1768	0.1982	0.200406	0.175362	0.175094	0.199869	0.199413	0.174081	0.176606
0.172606	0.18075	0.200306	0.192806	0.173625	0.191194	0.200763	0.176213	0.1751	0.198788
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0.201406	0.173644	0.19555	0.202613	0.172825	0.184606	0.204013	0.188481	0.172375	0.185594
0.1704	0.1971	0.200044	0.172606	0.182981	0.203006	0.189431	0.1707	0.186319	0.202206
0.1742	0.183869	0.203169	0.191944	0.171344	0.184306	0.2019	0.188775	0.175344	0.187363
0.172881	0.178194	0.205406	0.18795	0.168288	0.193644	0.201212	0.1778	0.178231	0.201344
0.200619	0.1742	0.178744	0.200181	0.196	0.173625	0.175781	0.202806	0.1879	0.1727
0.186713	0.1762	0.187381	0.199388	0.187613	0.172306	0.1894	0.200188	0.183219	0.169
0.185006	0.2011	0.1887	0.170206	0.185506	0.199644	0.185394	0.171506	0.198081	0.202988
0.1921	0.200606	0.1715	0.1831	0.202006	0.187	0.1752	0.194438	0.202219	0.174206
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0.1743	0.189188	0.2027	0.182175	0.173619	0.198806	0.199606	0.1731	0.184406	0.204938
0.191406	0.203394	0.18315	0.171406	0.1915	0.202413	0.180406	0.172438	0.200656	0.203
0.173406	0.178381	0.2003	0.1927	0.172606	0.186006	0.200613	0.181131	0.1731	0.1959
0.179088	0.203006	0.193638	0.1711	0.185594	0.206	0.189594	0.175738	0.186481	0.203606
0.178806	0.174363	0.201269	0.192794	0.172794	0.183913	0.202006	0.182781	0.169025	0.192413
0.1768	0.200975	0.199169	0.172344	0.186013	0.2018	0.192406	0.172013	0.1864	0.202206

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0.178838	0.2028	0.191006	0.1739	0.184375	0.199288	0.187088	0.172038	0.1931	0.20405
0.179806	0.201188	0.199013	0.179806	0.174544	0.195806	0.204488	0.1851	0.173281	0.187644
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0.172719	0.192338	0.203244	0.188194	0.173513	0.1851	0.2035	0.188438	0.175031	0.185794
0.1883	0.200794	0.186481	0.1747	0.186744	0.201588	0.190438	0.175	0.1818	0.20135
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0.200731	0.192838	0.174194	0.173075	0.2008	0.202613	0.175138	0.175213	0.198213	0.2014
0.182088	0.171006	0.189619	0.199806	0.184781	0.175913	0.186425	0.199663	0.1896	0.175
0.2026	0.184581	0.1702	0.191006	0.201981	0.186475	0.174494	0.186413	0.2015	0.189181
0.198069	0.197681	0.178269	0.173888	0.194231	0.202394	0.181206	0.175219	0.194844	0.204606
0.170181	0.182544	0.201912	0.199263	0.174594	0.175806	0.195563	0.203925	0.1832	0.169675
0.200606	0.188194	0.169531	0.1868	0.202406	0.191994	0.172606	0.183019	0.20075	0.190206
0.180413	0.174806	0.202044	0.201219	0.173838	0.1759	0.200888	0.190588	0.173663	0.185513
0.175238	0.194206	0.204394	0.1795	0.172825	0.192644	0.2026	0.1767	0.173663	0.200819
0.174206	0.194425	0.2007	0.180706	0.169469	0.190231	0.1983	0.1899	0.173406	0.182994
0.178806	0.175563	0.196175	0.2038	0.183669	0.169881	0.190894	0.200331	0.187919	0.173906
0.200481	0.197125	0.175019	0.176613	0.197544	0.199525	0.178106	0.1683	0.195106	0.1999
0.1795	0.171031	0.188294	0.2012	0.188275	0.173519	0.185388	0.201737	0.1946	0.173188
0.199806	0.200413	0.1788	0.172038	0.192875	0.2015	0.187594	0.1747	0.1835	0.200881
0.197619	0.1739	0.181581	0.201406	0.1899	0.174319	0.179419	0.2003	0.199288	0.178594
0.174563	0.182088	0.202469	0.194444	0.1748	0.177106	0.200819	0.1989	0.1798	0.170425
0.202813	0.177838	0.170281	0.190006	0.199263	0.190269	0.1695	0.18035	0.202425	0.1991
0.199806	0.190206	0.169081	0.184838	0.200081	0.194788	0.175006	0.175131	0.196331	0.201212
0.1885	0.172219	0.185744	0.200838	0.193219	0.1719	0.1794	0.201163	0.191213	0.174144
0.200825	0.187288	0.17605	0.185675	0.203006	0.190475	0.1748	0.177731	0.202413	0.192338
0.191819	0.174675	0.175056	0.195581	0.202019	0.177581	0.172013	0.191806	0.199606	0.190038
0.1847	0.204094	0.191213	0.1739	0.182206	0.202413	0.199869	0.177144	0.1704	0.1883
0.197431	0.204606	0.183275	0.175175	0.183906	0.204025	0.188356	0.17195	0.185163	0.200838
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0.1772	0.2008	0.195006	0.174356	0.175925	0.199238	0.202019	0.182013	0.1695	0.194944
0.186475	0.175213	0.191725	0.200381	0.183219	0.173181	0.194425	0.202725	0.1864	0.174788
0.190969	0.172788	0.1799	0.202488	0.196794	0.174713	0.176206	0.198444	0.200025	0.178394
0.1731	0.174038	0.195581	0.2046	0.184025	0.176819	0.187006	0.200813	0.190219	0.172694
0.2024	0.177238	0.171881	0.198206	0.200656	0.17995	0.1736	0.190975	0.201781	0.187563
0.182594	0.172144	0.187819	0.201456	0.189406	0.170888	0.181638	0.202019	0.197531	0.1767
0.2019	0.188144	0.175	0.187225	0.200025	0.190219	0.172013	0.1836	0.2036	0.202
0.191	0.175006	0.179831	0.202381	0.200813	0.176356	0.1768	0.1976	0.203906	0.184406

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0.1815	0.167675	0.190788	0.199106	0.188844	0.170775	0.186806	0.2026	0.189625	0.1731
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0.200413	0.180025	0.174194	0.1942	0.201181	0.184231	0.174206	0.188487	0.200413	0.190094
0.175919	0.198775	0.202438	0.170794	0.177625	0.197906	0.200419	0.179406	0.17355	0.201194
0.201244	0.19275	0.1711	0.174525	0.199213	0.200025	0.175581	0.172694	0.1935	0.1986
0.199106	0.189469	0.174806	0.183375	0.202994	0.192825	0.172238	0.17435	0.1972	0.200606
0.194394	0.174538	0.1724	0.196463	0.204525	0.1844	0.171531	0.187581	0.199138	0.188013
0.183087	0.202919	0.1972	0.175606	0.17495	0.2008	0.201419	0.177975	0.170488	0.188381
0.174481	0.172988	0.2024	0.193681	0.174206	0.173688	0.198806	0.204	0.183113	0.172094
0.180419	0.2024	0.202869	0.175944	0.172725	0.1923	0.2055	0.184025	0.176844	0.185531
0.1736	0.178006	0.199563	0.195531	0.1747	0.176413	0.197206	0.204488	0.180381	0.170744
0.185438	0.173406	0.195806	0.203919	0.183606	0.170994	0.190756	0.203387	0.1855	0.1746
0.1934	0.203006	0.186438	0.1766	0.184706	0.204606	0.190819	0.172788	0.175556	0.200075
0.173513	0.1772	0.19995	0.200144	0.178819	0.1742	0.196488	0.206281	0.185206	0.176606
0.200419	0.188744	0.174069	0.1854	0.201406	0.192831	0.175219	0.184038	0.201206	0.1927
0.200413	0.17845	0.174063	0.194006	0.204406	0.183894	0.1732	0.189625	0.200606	0.189006
0.206219	0.187563	0.1726	0.1916	0.2019	0.179381	0.170963	0.192144	0.2031	0.182394
0.186406	0.199131	0.189988	0.1739	0.178475	0.2019	0.194744	0.173294	0.175325	0.1947
0.1755	0.1752	0.202806	0.191606	0.1722	0.1868	0.2038	0.176719	0.174788	0.204413
0.173294	0.197981	0.201394	0.1814	0.1683	0.189075	0.198981	0.189825	0.170706	0.18085
0.1903	0.175638	0.176606	0.199225	0.2003	0.177188	0.1739	0.195106	0.2035	0.1844
0.174231	0.196794	0.199131	0.174806	0.175031	0.1983	0.2012	0.1815	0.167588	0.1867
0.187294	0.199831	0.189181	0.172606	0.182819	0.200337	0.195594	0.174188	0.176619	0.196387
0.176606	0.177219	0.202069	0.197888	0.174269	0.177219	0.1947	0.203956	0.183219	0.173638
0.1787	0.174713	0.199006	0.202994	0.1734	0.174425	0.196094	0.196706	0.1747	0.1747
0.180013	0.199931	0.19555	0.172488	0.175281	0.2003	0.20235	0.177806	0.174206	0.194419
0.172994	0.176281	0.201912	0.200606	0.1794	0.171	0.189081	0.1982	0.186944	0.17355
0.171113	0.185213	0.20075	0.197481	0.174781	0.173581	0.194988	0.2019	0.18355	0.177419
0.196681	0.190206	0.173569	0.181638	0.202969	0.200606	0.179806	0.169294	0.193444	0.202306
0.193	0.172638	0.171906	0.196306	0.198331	0.1784	0.1718	0.1915	0.201806	0.188313
0.175344	0.195913	0.203906	0.1863	0.174306	0.187881	0.199613	0.189625	0.17045	0.181325
0.204	0.1859	0.175806	0.186013	0.2028	0.1899	0.1731	0.1822	0.2024	0.192306
0.184081	0.203981	0.19125	0.1738	0.178344	0.198381	0.201	0.179913	0.171806	0.1912
0.1711	0.190194	0.198775	0.189944	0.172981	0.186419	0.2027	0.1907	0.174425	0.174019
0.186019	0.2056	0.1916	0.174281	0.181406	0.198506	0.202019	0.179619	0.171581	0.1922
0.176044	0.184306	0.204406	0.191613	0.173531	0.177213	0.1991	0.2014	0.180413	0.173212
0.172313	0.193406	0.206256	0.183788	0.174819	0.189663	0.199638	0.189619	0.173675	0.187238
0.176981	0.172675	0.191606	0.1991	0.187931	0.172	0.184994	0.2024	0.195019	0.172494
0.173619	0.187513	0.203113	0.1892	0.173475	0.180981	0.201219	0.186706	0.175	0.195188

0.1896	0.195906	0.191	0.17195	0.185394	0.202406	0.192819	0.173	0.1794	0.2006
0.182344	0.19955	0.198525	0.174269	0.176706	0.2005	0.198269	0.177244	0.175544	0.195981
0.182288	0.172144	0.1918	0.1985	0.187725	0.175806	0.187	0.200381	0.191894	0.173975
0.173738	0.1827	0.2027	0.195019	0.174206	0.1798	0.202006	0.200238	0.1752	0.175281
0.196656	0.171844	0.175794	0.200038	0.199594	0.178219	0.175288	0.196925	0.2008	0.1779
0.184887	0.173625	0.188719	0.2006	0.1871	0.173106	0.1815	0.203806	0.198394	0.176819
0.1794	0.170275	0.1899	0.200363	0.1892	0.172281	0.1851	0.201406	0.192994	0.173469
0.174125	0.185194	0.20075	0.193106	0.1723	0.192138	0.199669	0.189406	0.173244	0.185419
0.202063	0.18325	0.175938	0.185788	0.2019	0.1887	0.172144	0.177944	0.200388	0.201581
0.1863	0.1995	0.1891	0.170231	0.187119	0.201125	0.191006	0.176681	0.186713	0.198331
0.201144	0.190231	0.172525	0.190006	0.197994	0.188694	0.176606	0.186219	0.2027	0.190438
0.187225	0.198813	0.1898	0.1699	0.184838	0.202413	0.1921	0.172788	0.173188	0.195969
0.185175	0.203806	0.192419	0.173194	0.178563	0.2006	0.199194	0.178206	0.175744	0.202013
0.200406	0.175706	0.1729	0.191881	0.2035	0.1811	0.168888	0.190269	0.199238	0.189638
0.186363	0.202256	0.188894	0.171081	0.183606	0.200875	0.19435	0.171194	0.173131	0.197156
0.1752	0.17495	0.2022	0.200606	0.180144	0.174325	0.197113	0.201238	0.181219	0.171019
0.171669	0.185481	0.201638	0.1926	0.173888	0.17995	0.199106	0.203006	0.1755	0.175019
0.173894	0.187619	0.199244	0.190806	0.171006	0.180388	0.199513	0.200306	0.177638	0.172606
0.201613	0.180025	0.1726	0.192144	0.1991	0.190444	0.174438	0.185688	0.201681	0.192631
0.191344	0.173238	0.1735	0.198388	0.197406	0.172606	0.171538	0.196075	0.200075	0.176206
0.202006	0.2014	0.1755	0.174438	0.195038	0.204419	0.186006	0.172544	0.191744	0.203613
0.175613	0.1892	0.200825	0.188744	0.172788	0.1864	0.203806	0.192819	0.175219	0.178081
0.19975	0.1883	0.173613	0.1871	0.1985	0.189625	0.173212	0.183869	0.1995	0.1947
0.202588	0.1787	0.171225	0.1928	0.200706	0.1851	0.174544	0.186013	0.201488	0.188081
0.188606	0.2024	0.1916	0.175031	0.177675	0.202713	0.2024	0.177469	0.172606	0.195106
0.197581	0.199275	0.180025	0.175619	0.197244	0.2011	0.179194	0.170819	0.188744	0.199288
0.202037	0.188606	0.176812	0.1855	0.203613	0.190869	0.171619	0.179394	0.201394	0.192813
0.185144	0.204038	0.189531	0.1723	0.183606	0.1995	0.1974	0.173638	0.175744	0.194738
0.1848	0.202688	0.191588	0.173406	0.178481	0.20075	0.198269	0.175619	0.177406	0.197594
0.1857	0.176819	0.186413	0.2026	0.187906	0.170869	0.1835	0.203344	0.187969	0.170425
0.172181	0.186306	0.199288	0.191006	0.170844	0.1823	0.2015	0.200038	0.172981	0.175225
0.200894	0.2003	0.176406	0.1727	0.197625	0.201406	0.179213	0.170081	0.191619	0.199238
0.173794	0.174356	0.1982	0.201775	0.184419	0.175806	0.1859	0.1987	0.1891	0.169944
0.199806	0.190163	0.168769	0.180094	0.201231	0.201687	0.1743	0.174475	0.196825	0.200731
0.198206	0.2026	0.181194	0.171813	0.1883	0.201319	0.190219	0.173094	0.181625	0.201406
0.201219	0.1855	0.174425	0.186544	0.203806	0.191406	0.174806	0.179806	0.202013	0.201125
0.190812	0.1999	0.1875	0.173294	0.184025	0.201037	0.195931	0.1752	0.173013	0.197988
0.202019	0.1918	0.172038	0.176888	0.199619	0.200713	0.178425	0.173613	0.191881	0.200731
0.177244	0.201344	0.201319	0.178325	0.1695	0.1871	0.201806	0.1896	0.174369	0.179606
0.205613	0.187225	0.174813	0.18395	0.202037	0.195169	0.174088	0.1747	0.198675	0.201406

0.196413	0.1736	0.1882	0.201381	0.180294	0.174438	0.194806	0.200894	0.182725	0.175444
0.203088	0.181625	0.169406	0.18795	0.201406	0.1887	0.173381	0.182606	0.202231	0.196013
0.175581	0.202406	0.199794	0.173625	0.175344	0.196013	0.201663	0.1783	0.1704	0.191688
0.197819	0.203006	0.1807	0.172069	0.19115	0.198144	0.189688	0.171806	0.183288	0.201544
0.169463	0.192394	0.196825	0.172538	0.1766	0.200813	0.198394	0.1806	0.175406	0.192069
0.174869	0.195806	0.201538	0.182131	0.1719	0.192419	0.199994	0.18405	0.176825	0.192194
0.171288	0.197806	0.203806	0.180769	0.171806	0.1912	0.199131	0.189613	0.1734	0.186406
0.2015	0.190594	0.169944	0.183794	0.201438	0.193	0.172025	0.1742	0.200419	0.201469
0.176619	0.173738	0.1942	0.2054	0.183006	0.172794	0.193294	0.202706	0.1831	0.1762
0.18675	0.169544	0.183106	0.200781	0.191038	0.173562	0.175944	0.199475	0.200444	0.1748
0.171956	0.178594	0.200938	0.203294	0.177288	0.171	0.191638	0.201912	0.1787	0.170813
0.200419	0.180219	0.171606	0.194412	0.203	0.185456	0.175588	0.188013	0.200144	0.187238
0.1963	0.174006	0.175213	0.200419	0.199806	0.1768	0.175819	0.198219	0.198594	0.179944
0.171494	0.184413	0.2023	0.191094	0.172881	0.183213	0.201325	0.200038	0.177244	0.175006
0.200944	0.179288	0.172181	0.194806	0.201394	0.18155	0.1671	0.194994	0.200581	0.182206
0.189606	0.199325	0.189625	0.1706	0.182588	0.202438	0.196406	0.1719	0.175206	0.1983
0.196025	0.203606	0.177906	0.173481	0.191744	0.204438	0.183194	0.168025	0.1879	0.199813
0.195806	0.204531	0.183644	0.1751	0.1843	0.2044	0.19045	0.171838	0.17615	0.201206
0.175263	0.175875	0.201406	0.200038	0.1768	0.173288	0.200144	0.200406	0.175	0.1751
0.173913	0.197406	0.206819	0.181406	0.170469	0.193406	0.2035	0.185488	0.176825	0.187006
0.179038	0.173138	0.1911	0.2026	0.187194	0.175744	0.1847	0.203844	0.191206	0.172606
0.201763	0.198206	0.175513	0.1743	0.194769	0.204175	0.185156	0.172981	0.184181	0.203806
0.173506	0.176731	0.1947	0.204406	0.1832	0.172981	0.1863	0.204544	0.1912	0.174319
0.172694	0.1848	0.202806	0.196875	0.173481	0.1742	0.198006	0.204013	0.183006	0.174806
0.203325	0.1848	0.176669	0.188606	0.1983	0.189644	0.1719	0.185588	0.2028	0.192819
0.1889	0.1747	0.182606	0.203006	0.196081	0.1727	0.174544	0.197419	0.205738	0.183806
0.1707	0.184938	0.203806	0.190425	0.173888	0.1802	0.201181	0.199506	0.176888	0.1758
0.200306	0.1844	0.174019	0.188469	0.1963	0.1912	0.170763	0.183006	0.201737	0.197406
0.2006	0.180013	0.173288	0.192787	0.206	0.1848	0.176844	0.187006	0.204144	0.183238
0.181675	0.200381	0.2003	0.178488	0.173625	0.192288	0.202844	0.188669	0.176338	0.196669
0.194425	0.202481	0.187225	0.174206	0.183513	0.1994	0.193538	0.172875	0.174044	0.197613
0.189913	0.1704	0.18275	0.200825	0.193238	0.174206	0.1727	0.199806	0.2019	0.1783
0.182325	0.201394	0.196406	0.174819	0.175744	0.1987	0.199375	0.178425	0.1736	0.1928
0.183006	0.172363	0.192706	0.200606	0.18965	0.170588	0.1831	0.202819	0.200838	0.176213
0.199606	0.178206	0.176013	0.196	0.205744	0.185581	0.1752	0.184081	0.203131	0.190544
0.178419	0.171963	0.191575	0.205494	0.1846	0.1766	0.185406	0.202881	0.191969	0.172325
0.201206	0.181925	0.169181	0.188406	0.2014	0.19115	0.1723	0.1787	0.1982	0.202413
0.189206	0.173381	0.186413	0.202813	0.196719	0.1768	0.1731	0.195	0.204025	0.183994
0.201387	0.201163	0.174425	0.1732	0.194856	0.204363	0.1846	0.175588	0.186819	0.203325
0.182069	0.168994	0.187225	0.200025	0.19	0.171856	0.1843	0.203006	0.192706	0.174044

0.188238	0.199225	0.190206	0.1726	0.182475	0.201113	0.18715	0.178	0.186181	0.1974
0.174819	0.176825	0.200631	0.199819	0.180094	0.175606	0.195388	0.206306	0.181581	0.172206
0.202006	0.186475	0.173581	0.186306	0.2043	0.191031	0.174206	0.184406	0.200331	0.192838
0.19035	0.174588	0.181975	0.202519	0.194475	0.173406	0.1768	0.1992	0.199588	0.179513
0.202281	0.186306	0.173994	0.186425	0.203606	0.190613	0.1715	0.1799	0.2014	0.200856
0.202294	0.185494	0.174713	0.186819	0.200706	0.191194	0.175213	0.172194	0.2054	0.196138
0.205006	0.190819	0.169538	0.179906	0.201488	0.197644	0.176219	0.1758	0.196594	0.205469
0.17625	0.1734	0.1926	0.202819	0.188325	0.174806	0.184388	0.2018	0.1935	0.172181
0.185744	0.202231	0.191	0.173206	0.182144	0.200038	0.201006	0.174819	0.174606	0.197406
0.1752	0.196825	0.203606	0.179906	0.170013	0.1899	0.202475	0.186381	0.176419	0.186294
0.191	0.201094	0.188	0.173306	0.1848	0.200825	0.191006	0.171813	0.181406	0.2024
0.175819	0.186013	0.2015	0.191206	0.1715	0.177688	0.203619	0.1963	0.1729	0.173625
0.168194	0.193406	0.1999	0.187806	0.175994	0.1864	0.204706	0.189688	0.172006	0.184031
0.1956	0.206	0.185237	0.1742	0.1908	0.199031	0.190206	0.172881	0.185113	0.200606
0.168094	0.19115	0.199238	0.189163	0.172325	0.182731	0.202731	0.191006	0.174613	0.1771
0.202413	0.176681	0.1723	0.1959	0.203069	0.183769	0.170231	0.1894	0.200781	0.182394
0.190213	0.175213	0.186463	0.202806	0.188344	0.171294	0.184406	0.201375	0.193188	0.1752
0.199844	0.171981	0.1736	0.198019	0.202638	0.1826	0.174831	0.176875	0.184781	0.201269
0.194781	0.2015	0.1848	0.173988	0.18515	0.203069	0.1891	0.16915	0.182281	0.202413
0.206013	0.189206	0.175606	0.181794	0.1995	0.196619	0.173744	0.173181	0.1958	0.205406
0.1787	0.202206	0.200813	0.173506	0.1751	0.202206	0.1998	0.173381	0.175806	0.197519
0.191806	0.174206	0.175006	0.199163	0.200806	0.180619	0.168325	0.190675	0.1987	0.188088
0.178538	0.2018	0.200825	0.1772	0.1731	0.196	0.2015	0.180875	0.171069	0.190206
0.187225	0.202413	0.1898	0.172013	0.18	0.202944	0.203019	0.177538	0.171994	0.195663
0.172706	0.174069	0.197688	0.2023	0.178425	0.172412	0.1921	0.202606	0.186475	0.1739
0.173994	0.1894	0.202413	0.188331	0.169131	0.188	0.202481	0.191219	0.174019	0.177744
0.1979	0.1986	0.173625	0.174869	0.2014	0.196631	0.171188	0.177213	0.1963	0.1999
0.173675	0.174788	0.197606	0.198331	0.178813	0.176606	0.194581	0.2024	0.183619	0.166981
0.171681	0.187144	0.2044	0.190794	0.173744	0.177219	0.1983	0.196413	0.1719	0.175819
0.206144	0.183225	0.174144	0.187806	0.1992	0.188944	0.173675	0.186206	0.202006	0.192437
0.203006	0.181988	0.174438	0.187919	0.201544	0.189406	0.170806	0.181494	0.201488	0.201588
0.171994	0.193444	0.2005	0.187338	0.175606	0.185806	0.20315	0.191219	0.1752	0.179894
0.202031	0.197675	0.1854	0.173881	0.1878	0.202206	0.191006	0.171013	0.1794	0.2022
0.17445	0.197913	0.200594	0.183794	0.175375	0.186488	0.206013	0.191488	0.172894	0.186206
0.174294	0.178781	0.199581	0.200075	0.178463	0.174206	0.191663	0.202019	0.183913	0.175225
0.178206	0.199525	0.202425	0.1763	0.171381	0.197013	0.206813	0.186206	0.176406	0.185088
0.178419	0.173206	0.192838	0.202781	0.185444	0.175906	0.18545	0.204544	0.192756	0.174425
0.175006	0.185913	0.204025	0.191538	0.174369	0.173925	0.201975	0.194425	0.174863	0.1719
0.190425	0.172	0.179213	0.200331	0.201238	0.177231	0.171237	0.192038	0.199225	0.189113
0.177206	0.1974	0.201281	0.18235	0.172756	0.186006	0.2038	0.191869	0.174188	0.177456

0.186363	0.176781	0.187619	0.196925	0.189213	0.170819	0.183338	0.200337	0.194587	0.175225
0.187281	0.201231	0.1902	0.175006	0.183019	0.199531	0.1975	0.175269	0.17995	0.2024
0.172731	0.1807	0.201806	0.198488	0.173431	0.175806	0.198537	0.2012	0.178306	0.171813
0.175406	0.1966	0.2028	0.1819	0.167194	0.187331	0.201513	0.190812	0.172675	0.183644
0.177625	0.1679	0.192756	0.200413	0.185237	0.174813	0.1902	0.1987	0.1867	0.175012
0.172419	0.178206	0.199238	0.1979	0.174475	0.173688	0.196825	0.204025	0.182219	0.171694
0.177506	0.1738	0.1923	0.204388	0.181	0.169525	0.190894	0.204138	0.185206	0.175938
0.179013	0.201963	0.194844	0.174438	0.1723	0.196731	0.200769	0.183538	0.171594	0.188419
0.201138	0.183819	0.175606	0.188631	0.1979	0.190369	0.173212	0.185406	0.2027	0.195113
0.203806	0.191031	0.175	0.1767	0.201806	0.201406	0.178413	0.173606	0.199806	0.202006
0.196606	0.1748	0.176206	0.197625	0.201206	0.178325	0.172013	0.1915	0.199556	0.188669
0.196306	0.204488	0.1815	0.173188	0.1892	0.201013	0.1912	0.168506	0.1848	0.200606
0.2031	0.191213	0.172894	0.177213	0.201006	0.188375	0.170575	0.183213	0.199694	0.194819
0.193038	0.174806	0.174894	0.201644	0.1995	0.173406	0.1791	0.2022	0.194463	0.173506
0.2011	0.200075	0.1775	0.175269	0.194481	0.206038	0.183981	0.175238	0.187606	0.2018
0.172444	0.189406	0.199588	0.187563	0.175344	0.184606	0.201581	0.193	0.1727	0.1747
0.1735	0.198544	0.202219	0.1794	0.173581	0.1951	0.193338	0.1752	0.1743	0.200331
0.190819	0.169381	0.18085	0.201806	0.200606	0.176863	0.1735	0.192813	0.203238	0.184956
0.1964	0.174013	0.175513	0.197813	0.20055	0.180013	0.172406	0.192219	0.199794	0.187113
0.176981	0.1739	0.193444	0.205744	0.184419	0.174013	0.1871	0.196756	0.183956	0.174581
0.199594	0.17515	0.175244	0.195288	0.204406	0.184388	0.173988	0.188538	0.200825	0.189725
0.168975	0.184794	0.2007	0.194806	0.175606	0.1731	0.201244	0.198738	0.176881	0.1752
0.1979	0.1894	0.1707	0.183606	0.201538	0.197638	0.17355	0.176781	0.1951	0.203806
0.206819	0.185806	0.176206	0.184731	0.203425	0.191619	0.171675	0.183931	0.202825	0.18915
0.1843	0.2007	0.192619	0.172656	0.175219	0.198537	0.199225	0.180375	0.169406	0.191288
0.200044	0.201206	0.177406	0.174675	0.194844	0.205613	0.184419	0.176419	0.184794	0.205619
0.179038	0.170206	0.194206	0.20115	0.187806	0.172025	0.185444	0.2028	0.19115	0.172756
0.187481	0.199788	0.190294	0.173663	0.180469	0.2007	0.197694	0.180144	0.170788	0.190775
0.196063	0.203963	0.184825	0.1772	0.186019	0.200719	0.1907	0.173106	0.175781	0.199056
0.173819	0.175738	0.197613	0.206038	0.184419	0.175213	0.1843	0.200125	0.191619	0.174306
0.177125	0.1695	0.1926	0.197106	0.188125	0.173212	0.182737	0.201488	0.197431	0.175381
0.202013	0.202856	0.176369	0.172075	0.1912	0.200125	0.188569	0.175869	0.185531	0.204138
0.202469	0.178019	0.175181	0.194206	0.203344	0.1846	0.169206	0.188487	0.199394	0.190369
0.201544	0.1878	0.175806	0.185431	0.2007	0.1895	0.173219	0.1803	0.1992	0.200794
0.186331	0.201519	0.190806	0.172694	0.1797	0.199538	0.202488	0.177694	0.173638	0.1928
0.204544	0.191681	0.172381	0.175138	0.200838	0.2006	0.173944	0.171106	0.1922	0.20075
0.175638	0.201269	0.20075	0.176994	0.174206	0.192744	0.205613	0.186838	0.175263	0.185113
0.197	0.202425	0.179819	0.1719	0.189938	0.2028	0.185681	0.174494	0.185688	0.202675
0.174425	0.18475	0.2017	0.196619	0.175806	0.174006	0.197494	0.205406	0.1827	0.176606
0.1999	0.1999	0.180025	0.168556	0.191338	0.200744	0.188038	0.171156	0.185269	0.203006

0.177638	0.199994	0.1975	0.173688	0.176063	0.199619	0.199831	0.180544	0.169806	0.1926
0.198206	0.172381	0.176838	0.195875	0.199538	0.1807	0.1675	0.1891	0.201269	0.185581
0.193206	0.200813	0.188606	0.171894	0.183288	0.202544	0.192206	0.172694	0.180019	0.200888
0.200825	0.199806	0.1715	0.1743	0.195538	0.201206	0.180038	0.168344	0.188881	0.199856
0.187119	0.2035	0.191225	0.1715	0.181213	0.202406	0.195138	0.173513	0.171875	0.199225
0.1894	0.198806	0.189406	0.1687	0.1851	0.203275	0.189625	0.174844	0.179494	0.2028
0.187856	0.197906	0.1912	0.171906	0.184275	0.202425	0.191013	0.1715	0.17435	0.1975
0.201244	0.189613	0.17275	0.1814	0.202463	0.194463	0.1754	0.1731	0.197625	0.20195
0.1731	0.175006	0.198019	0.201881	0.181088	0.170938	0.1912	0.202494	0.185906	0.171894
0.178206	0.173994	0.195044	0.203006	0.1815	0.172794	0.188475	0.199238	0.189619	0.174806
0.174713	0.184194	0.204669	0.189081	0.173006	0.1807	0.203006	0.197419	0.171594	0.174469
0.190444	0.168706	0.183806	0.203169	0.192831	0.1732	0.1771	0.200013	0.201125	0.177206
0.173506	0.1766	0.1992	0.200656	0.176075	0.173506	0.198194	0.2019	0.18155	0.171144
0.179137	0.202413	0.203	0.177625	0.171525	0.191994	0.202438	0.188406	0.173975	0.1835
0.191606	0.174044	0.1806	0.199544	0.200606	0.176825	0.174606	0.193694	0.201906	0.183606
0.1975	0.200025	0.1816	0.1697	0.19075	0.2015	0.186619	0.173406	0.184975	0.205469
0.2038	0.1727	0.184606	0.202256	0.193775	0.174081	0.1739	0.199113	0.202988	0.1752
0.176606	0.185188	0.201638	0.190438	0.171781	0.176825	0.200038	0.200619	0.178481	0.172381
0.1718	0.184144	0.201188	0.195969	0.1717	0.174019	0.198806	0.200025	0.182269	0.170006
0.1866	0.204569	0.189294	0.173738	0.17775	0.200281	0.201219	0.17755	0.169556	0.190888
0.172094	0.184025	0.199594	0.1907	0.173506	0.181206	0.202206	0.198763	0.178744	0.174444
0.193238	0.205431	0.187194	0.1747	0.186813	0.202387	0.191006	0.173913	0.183531	0.198781
0.183788	0.171806	0.188038	0.199906	0.190344	0.171031	0.184825	0.200494	0.1943	0.173913
0.175606	0.181294	0.200881	0.197563	0.173581	0.180825	0.2024	0.197625	0.175919	0.1755
0.202544	0.187606	0.175806	0.183556	0.204644	0.191213	0.174013	0.175806	0.199613	0.202613
0.190713	0.175606	0.179137	0.202006	0.201	0.179413	0.1694	0.191606	0.199894	0.190206
0.182019	0.201525	0.19755	0.17125	0.1747	0.197638	0.201344	0.178756	0.170437	0.1898
0.199006	0.1885	0.173806	0.182788	0.201113	0.197613	0.173788	0.174481	0.196181	0.201288
0.201088	0.177944	0.167238	0.189613	0.1987	0.189888	0.172713	0.186031	0.172075	0.2038
0.17765	0.200988	0.2024	0.177519	0.1729	0.194419	0.200875	0.1775	0.174006	0.195013
0.1747	0.196038	0.204488	0.1838	0.168825	0.188888	0.197281	0.188381	0.173613	0.181613
0.1893	0.174406	0.1729	0.1978	0.199806	0.179969	0.171406	0.188181	0.199113	0.190206
0.170544	0.183344	0.202256	0.196	0.1736	0.173206	0.197744	0.199344	0.181638	0.170425
0.177406	0.173494	0.190188	0.200944	0.188138	0.175031	0.185369	0.2015	0.1943	0.174663
0.1991	0.1791	0.170806	0.189206	0.200963	0.189475	0.171044	0.184138	0.202806	0.193294
0.18825	0.171531	0.1847	0.202438	0.194438	0.171281	0.1796	0.200606	0.201744	0.173581
0.205419	0.191056	0.171094	0.182681	0.2028	0.1943	0.173125	0.1727	0.199913	0.2014
0.190413	0.172706	0.177788	0.202206	0.200825	0.178606	0.173806	0.1912	0.201394	0.187606
0.186806	0.203562	0.193219	0.173688	0.174144	0.198219	0.2015	0.180694	0.168494	0.191744
0.193194	0.17255	0.177406	0.200419	0.1995	0.1783	0.16935	0.188544	0.200606	0.189531

0.203631	0.199619	0.1816	0.168038	0.189625	0.1979	0.186581	0.1753	0.185194	0.199744
0.173206	0.186438	0.202044	0.192813	0.173613	0.180025	0.202219	0.197631	0.1743	0.175763
0.199094	0.173638	0.175	0.196613	0.206206	0.182481	0.172025	0.187613	0.201394	0.189638
0.189213	0.175338	0.186438	0.200825	0.1883	0.172769	0.184388	0.2003	0.191006	0.174606
0.1992	0.179244	0.170838	0.195006	0.2023	0.1835	0.1743	0.187581	0.199794	0.190206
0.2019	0.176794	0.170594	0.195606	0.204025	0.178706	0.171225	0.194475	0.204606	0.182269
0.200075	0.1806	0.1716	0.194412	0.203475	0.187831	0.175944	0.185538	0.204588	0.188881
0.1781	0.172188	0.1906	0.201238	0.188763	0.174206	0.183125	0.201294	0.192606	0.173638
0.186219	0.202731	0.189794	0.171194	0.17555	0.199381	0.2028	0.1727	0.174806	0.196831
0.186819	0.203194	0.1891	0.17275	0.181	0.200713	0.200744	0.170475	0.173206	0.1967
0.197638	0.203413	0.183213	0.174538	0.1866	0.199606	0.1859	0.175044	0.191606	0.202488
0.175225	0.196737	0.204606	0.181981	0.17355	0.189613	0.199225	0.190606	0.172606	0.184356
0.18635	0.200844	0.190806	0.173794	0.1822	0.2005	0.197494	0.1742	0.1755	0.195806
0.204025	0.18995	0.175006	0.181625	0.200825	0.1979	0.177394	0.174613	0.196406	0.202356
0.173206	0.188744	0.200025	0.190806	0.172888	0.184363	0.1999	0.194256	0.173925	0.177406
0.18955	0.1742	0.182206	0.201406	0.196963	0.172381	0.174231	0.199	0.201594	0.181688
0.174881	0.201513	0.201594	0.178819	0.174038	0.194213	0.204781	0.181681	0.168894	0.19115
0.196731	0.200025	0.1783	0.172544	0.193463	0.203806	0.183288	0.1699	0.187575	0.203288
0.189906	0.198594	0.18635	0.174881	0.187238	0.202006	0.187681	0.176606	0.190006	0.200188
0.199538	0.186413	0.1766	0.189006	0.201269	0.189094	0.1723	0.180606	0.203613	0.2011
0.194969	0.205613	0.185669	0.175744	0.185538	0.2015	0.192838	0.172269	0.193394	0.203244
0.198525	0.1755	0.1758	0.1995	0.199919	0.1771	0.170788	0.191106	0.1996	0.1887
0.177419	0.201206	0.199806	0.1796	0.173613	0.19075	0.199588	0.189206	0.1732	0.1848
0.195806	0.204025	0.184125	0.176388	0.187006	0.204069	0.191794	0.174813	0.180013	0.202331
0.182388	0.170456	0.188944	0.2003	0.186738	0.174719	0.185138	0.201113	0.1928	0.171394
0.1707	0.1847	0.2008	0.19075	0.1715	0.176606	0.2014	0.204	0.176731	0.176206
0.199056	0.191006	0.171406	0.1837	0.200763	0.191006	0.1731	0.1768	0.19635	0.202763
0.181494	0.169544	0.188013	0.200825	0.191619	0.172281	0.183	0.200681	0.200631	0.177688
0.190688	0.1739	0.176419	0.198381	0.202425	0.183262	0.172694	0.1854	0.202819	0.18995
0.205406	0.182081	0.176987	0.1859	0.201181	0.190425	0.173	0.176075	0.198231	0.202806
0.203006	0.1918	0.172388	0.178069	0.2015	0.203056	0.178713	0.169538	0.191494	0.203106
0.171225	0.185913	0.204038	0.191544	0.174369	0.172519	0.1951	0.2008	0.1828	0.169294
0.1891	0.199856	0.188775	0.172769	0.185406	0.203363	0.191619	0.173212	0.182019	0.1997
0.174581	0.196138	0.203006	0.1842	0.172019	0.186344	0.200206	0.191213	0.173794	0.177162
0.172981	0.172306	0.197444	0.203606	0.181181	0.172494	0.187275	0.200694	0.187994	0.174738
0.174194	0.192206	0.204044	0.1867	0.16885	0.189744	0.2014	0.190013	0.172388	0.184406
0.181625	0.1711	0.188069	0.200606	0.190169	0.170294	0.184988	0.202819	0.195425	0.17515
0.175619	0.186413	0.205644	0.1902	0.1735	0.180038	0.200075	0.203606	0.178606	0.174344
0.199869	0.190281	0.170806	0.182813	0.202013	0.203019	0.172706	0.175069	0.1964	0.2015
0.173594	0.180888	0.202006	0.199119	0.174425	0.175819	0.195588	0.205625	0.1823	0.175744

0.187461	0.187412
0.187057	0.187412
0.18747	0.187412
0.187408	
0.187291	
0.187247	
0.187497	
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0.18765	
0.187708	

0.199563	0.178944	0.180944	0.200813	0.185363	0.193806	0.177512	0.1995	0.197625	0.174088
0.171538	0.183744	0.200181	0.190025	0.171563	0.185588	0.1987	0.186706	0.176869	0.1883
0.1727	0.182819	0.203	0.191444	0.1735	0.181775	0.2056	0.1795	0.175606	0.196194
0.190256	0.171237	0.187006	0.201838	0.179819	0.176413	0.2007	0.1974	0.171981	0.184763
0.1935	0.207006	0.178681	0.174206	0.197219	0.200313	0.172263	0.174019	0.201325	0.1891
0.199513	0.176206	0.178813	0.200181	0.194756	0.170788	0.1867	0.1998	0.180944	0.172713
0.203619	0.182475	0.170231	0.1947	0.201694	0.178106	0.173894	0.201513	0.191006	0.175225
0.1775	0.172544	0.1976	0.198525	0.172263	0.1795	0.204438	0.188894	0.173775	0.191494
0.200838	0.193963	0.172606	0.184244	0.201813	0.190575	0.173212	0.1903	0.206019	0.178325
0.194475	0.202813	0.177938	0.172881	0.199225	0.202394	0.1719	0.1738	0.202838	0.198019
0.194206	0.174044	0.180081	0.199994	0.191181	0.174	0.18115	0.202212	0.191031	0.173788
0.17555	0.197744	0.200606	0.178806	0.176606	0.198588	0.200337	0.174019	0.1811	0.203125
0.175219	0.177638	0.201556	0.1935	0.171831	0.176681	0.202013	0.187931	0.1755	0.195406
0.200506	0.190525	0.172025	0.189006	0.200394	0.179806	0.179619	0.205806	0.189406	0.168825
0.181406	0.2026	0.191563	0.172838	0.184206	0.2022	0.191094	0.1719	0.188594	0.201594
0.202406	0.19715	0.1752	0.178344	0.200075	0.190819	0.169925	0.184325	0.1996	0.183813
0.2024	0.180606	0.173913	0.201206	0.202488	0.174194	0.177188	0.203244	0.1918	0.174206
0.175225	0.185794	0.201406	0.188	0.176606	0.1886	0.200038	0.186331	0.176419	0.1867
0.206369	0.1825	0.172769	0.192206	0.204544	0.181406	0.173406	0.192781	0.20175	0.1764
0.189613	0.202019	0.185394	0.174013	0.191213	0.204088	0.18215	0.168156	0.195019	0.205637
0.20075	0.193875	0.174425	0.183806	0.2019	0.1912	0.1722	0.186006	0.203275	0.187806
0.182144	0.202713	0.1903	0.174219	0.18325	0.198838	0.1835	0.171494	0.196125	0.1991
0.1947	0.2039	0.18155	0.174206	0.195794	0.199831	0.176606	0.175381	0.199913	0.199575
0.200925	0.173913	0.175619	0.201663	0.193206	0.170681	0.1894	0.204406	0.183006	0.172794
0.1699	0.198306	0.200825	0.174494	0.173081	0.201988	0.1899	0.174425	0.186425	0.199413
0.171931	0.185194	0.201212	0.187275	0.175806	0.186475	0.200313	0.185344	0.172888	0.197638
0.19765	0.187913	0.174594	0.189675	0.204619	0.182	0.170806	0.191125	0.205613	0.1815
0.187006	0.202294	0.189613	0.173788	0.188406	0.200606	0.187613	0.169538	0.198388	0.191144
0.188238	0.199906	0.183844	0.168988	0.191888	0.204519	0.183631	0.172975	0.196888	0.201819
0.174006	0.1784	0.20075	0.188706	0.175031	0.1807	0.201663	0.189131	0.173944	0.198206
0.1734	0.197481	0.201188	0.1727	0.172781	0.202212	0.191213	0.172175	0.1855	0.200613
0.201919	0.1895	0.171856	0.194206	0.203406	0.1783	0.171994	0.195419	0.199225	0.175006
0.1928	0.173738	0.179613	0.203144	0.193206	0.174613	0.183969	0.199988	0.184794	0.169888
0.199563	0.178544	0.1751	0.1966	0.2006	0.177794	0.175225	0.197619	0.1999	0.179619
0.194813	0.20175	0.18	0.173613	0.195806	0.2018	0.182	0.172988	0.2024	0.1894
0.199513	0.174488	0.175513	0.202269	0.2006	0.174319	0.184813	0.200075	0.187531	0.1695
0.198213	0.199006	0.173306	0.173625	0.198306	0.2003	0.1715	0.179781	0.202231	0.194425
0.200813	0.188669	0.17445	0.188	0.201456	0.181744	0.1734	0.2011	0.195606	0.17275
0.1855	0.203006	0.189	0.175619	0.184738	0.1998	0.183588	0.170413	0.1923	0.203938
0.204	0.183738	0.173294	0.197006	0.200862	0.1779	0.175669	0.197269	0.200363	0.177806
1	2	3	4	5	6	7	8	9	10

0.174681	0.200888	0.1939	0.1752	0.179606	0.201206	0.197531	0.174144	0.176806	0.201406
0.200306	0.181431	0.172631	0.194906	0.199988	0.1742	0.176594	0.2003	0.197644	0.172181
0.196306	0.1719	0.177556	0.201469	0.194425	0.1734	0.180413	0.199831	0.193781	0.1723
0.199963	0.1819	0.176219	0.202444	0.1979	0.173481	0.184838	0.202306	0.189663	0.174144
0.175806	0.192075	0.200406	0.172994	0.1787	0.2015	0.190788	0.172313	0.186444	0.198594
0.199513	0.200319	0.1687	0.185125	0.198306	0.184813	0.173138	0.193431	0.204644	0.1803
0.1896	0.201669	0.1807	0.174638	0.19995	0.190219	0.175994	0.190319	0.2043	0.179344
0.200794	0.180013	0.172731	0.198838	0.194419	0.173406	0.179581	0.2022	0.188038	0.175006
0.172181	0.19515	0.199488	0.175831	0.1719	0.199488	0.1899	0.173188	0.1914	0.203806
0.172181	0.179206	0.200738	0.1944	0.172075	0.181613	0.202463	0.193406	0.1717	0.1795
0.182869	0.201269	0.191031	0.177219	0.187806	0.2014	0.186438	0.174844	0.188181	0.202438
0.190038	0.173406	0.201406	0.193813	0.1752	0.183988	0.202	0.190844	0.169281	0.1839
0.200813	0.1768	0.181694	0.2007	0.1891	0.169675	0.1864	0.198863	0.182206	0.1723
0.193538	0.199806	0.173675	0.171506	0.202206	0.1915	0.172344	0.180025	0.2008	0.191806
0.17655	0.178281	0.200306	0.193219	0.172306	0.1848	0.204144	0.192413	0.170813	0.183931
0.171581	0.203019	0.1932	0.169094	0.187019	0.2019	0.190806	0.173988	0.184725	0.199663
0.188606	0.202488	0.176694	0.176013	0.200881	0.189788	0.171619	0.19435	0.1995	0.177606
0.198081	0.1867	0.172025	0.193419	0.2059	0.183106	0.172344	0.1939	0.201206	0.1804
0.180619	0.202356	0.183019	0.172944	0.196825	0.1999	0.176381	0.175006	0.198206	0.198438
0.182206	0.172044	0.196088	0.200813	0.177406	0.173925	0.198381	0.202281	0.172794	0.174694
0.1791	0.201894	0.1889	0.176406	0.186475	0.199894	0.189406	0.170544	0.192888	0.200875
0.177688	0.1768	0.1982	0.200406	0.175362	0.175094	0.199869	0.199413	0.174081	0.176606
0.172606	0.18075	0.200306	0.192806	0.173625	0.191194	0.200763	0.176213	0.1751	0.198788
0.196875	0.201212	0.179219	0.1751	0.198263	0.197681	0.175888	0.177206	0.202019	0.199913
0.1819	0.170206	0.194394	0.2024	0.173613	0.179819	0.203713	0.1887	0.173138	0.188606
0.201406	0.173644	0.19555	0.202613	0.172825	0.184606	0.204013	0.188481	0.172375	0.185594
0.1704	0.1971	0.200044	0.172606	0.182981	0.203006	0.189431	0.1707	0.186319	0.202206
0.1742	0.183869	0.203169	0.191944	0.171344	0.184306	0.2019	0.188775	0.175344	0.187363
0.172881	0.178194	0.205406	0.18795	0.168288	0.193644	0.201212	0.1778	0.178231	0.201344
0.200619	0.1742	0.178744	0.200181	0.196	0.173625	0.175781	0.202806	0.1879	0.1727
0.186713	0.1762	0.187381	0.199388	0.187613	0.172306	0.1894	0.200188	0.183219	0.169
0.185006	0.2011	0.1887	0.170206	0.185506	0.199644	0.185394	0.171506	0.198081	0.202988
0.1921	0.200606	0.1715	0.1831	0.202006	0.187	0.1752	0.194438	0.202219	0.174206
0.172075	0.201219	0.191631	0.173638	0.183994	0.201125	0.191006	0.173625	0.1843	0.2028
0.1743	0.189188	0.2027	0.182175	0.173619	0.198806	0.199606	0.1731	0.184406	0.204938
0.191406	0.203394	0.18315	0.171406	0.1915	0.202413	0.180406	0.172438	0.200656	0.203
0.173406	0.178381	0.2003	0.1927	0.172606	0.186006	0.200613	0.181131	0.1731	0.1959
0.179088	0.203006	0.193638	0.1711	0.185594	0.206	0.189594	0.175738	0.186481	0.203606
0.178806	0.174363	0.201269	0.192794	0.172794	0.183913	0.202006	0.182781	0.169025	0.192413
0.1768	0.200975	0.199169	0.172344	0.186013	0.2018	0.192406	0.172013	0.1864	0.202206

11	12	13	14	15	16	17	18	19	20

0.1994	0.174206	0.174675	0.196606	0.203163	0.181619	0.171806	0.188894	0.2024	0.191213
0.178838	0.2028	0.191006	0.1739	0.184375	0.199288	0.187088	0.172038	0.1931	0.20405
0.179806	0.201188	0.199013	0.179806	0.174544	0.195806	0.204488	0.1851	0.173281	0.187644
0.185563	0.204138	0.191006	0.173013	0.182606	0.201438	0.194412	0.1729	0.178206	0.1999
0.1847	0.1743	0.185144	0.203106	0.1899	0.1717	0.177013	0.200356	0.1991	0.175394
0.1687	0.1901	0.2008	0.188413	0.173681	0.186819	0.200925	0.188794	0.1703	0.185406
0.172719	0.192338	0.203244	0.188194	0.173513	0.1851	0.2035	0.188438	0.175031	0.185794
0.1883	0.200794	0.186481	0.1747	0.186744	0.201588	0.190438	0.175	0.1818	0.20135
0.181888	0.171619	0.189675	0.199338	0.1883	0.171706	0.185294	0.202181	0.189738	0.172794
0.200731	0.192838	0.174194	0.173075	0.2008	0.202613	0.175138	0.175213	0.198213	0.2014
0.182088	0.171006	0.189619	0.199806	0.184781	0.175913	0.186425	0.199663	0.1896	0.175
0.2026	0.184581	0.1702	0.191006	0.201981	0.186475	0.174494	0.186413	0.2015	0.189181
0.198069	0.197681	0.178269	0.173888	0.194231	0.202394	0.181206	0.175219	0.194844	0.204606
0.170181	0.182544	0.201912	0.199263	0.174594	0.175806	0.195563	0.203925	0.1832	0.169675
0.200606	0.188194	0.169531	0.1868	0.202406	0.191994	0.172606	0.183019	0.20075	0.190206
0.180413	0.174806	0.202044	0.201219	0.173838	0.1759	0.200888	0.190588	0.173663	0.185513
0.175238	0.194206	0.204394	0.1795	0.172825	0.192644	0.2026	0.1767	0.173663	0.200819
0.174206	0.194425	0.2007	0.180706	0.169469	0.190231	0.1983	0.1899	0.173406	0.182994
0.178806	0.175563	0.196175	0.2038	0.183669	0.169881	0.190894	0.200331	0.187919	0.173906
0.200481	0.197125	0.175019	0.176613	0.197544	0.199525	0.178106	0.1683	0.195106	0.1999
0.1795	0.171031	0.188294	0.2012	0.188275	0.173519	0.185388	0.201737	0.1946	0.173188
0.199806	0.200413	0.1788	0.172038	0.192875	0.2015	0.187594	0.1747	0.1835	0.200881
0.197619	0.1739	0.181581	0.201406	0.1899	0.174319	0.179419	0.2003	0.199288	0.178594
0.174563	0.182088	0.202469	0.194444	0.1748	0.177106	0.200819	0.1989	0.1798	0.170425
0.202813	0.177838	0.170281	0.190006	0.199263	0.190269	0.1695	0.18035	0.202425	0.1991
0.199806	0.190206	0.169081	0.184838	0.200081	0.194788	0.175006	0.175131	0.196331	0.201212
0.1885	0.172219	0.185744	0.200838	0.193219	0.1719	0.1794	0.201163	0.191213	0.174144
0.200825	0.187288	0.17605	0.185675	0.203006	0.190475	0.1748	0.177731	0.202413	0.192338
0.191819	0.174675	0.175056	0.195581	0.202019	0.177581	0.172013	0.191806	0.199606	0.190038
0.1847	0.204094	0.191213	0.1739	0.182206	0.202413	0.199869	0.177144	0.1704	0.1883
0.197431	0.204606	0.183275	0.175175	0.183906	0.204025	0.188356	0.17195	0.185163	0.200838
0.172825	0.1768	0.196	0.204075	0.185381	0.1749	0.1868	0.200825	0.192975	0.172144
0.1772	0.2008	0.195006	0.174356	0.175925	0.199238	0.202019	0.182013	0.1695	0.194944
0.186475	0.175213	0.191725	0.200381	0.183219	0.173181	0.194425	0.202725	0.1864	0.174788
0.190969	0.172788	0.1799	0.202488	0.196794	0.174713	0.176206	0.198444	0.200025	0.178394
0.1731	0.174038	0.195581	0.2046	0.184025	0.176819	0.187006	0.200813	0.190219	0.172694
0.2024	0.177238	0.171881	0.198206	0.200656	0.17995	0.1736	0.190975	0.201781	0.187563
0.182594	0.172144	0.187819	0.201456	0.189406	0.170888	0.181638	0.202019	0.197531	0.1767
0.2019	0.188144	0.175	0.187225	0.200025	0.190219	0.172013	0.1836	0.2036	0.202
0.191	0.175006	0.179831	0.202381	0.200813	0.176356	0.1768	0.1976	0.203906	0.184406
21	22	23	24	25	26	27	28	29	30

0.172025	0.1836	0.201838	0.194713	0.175794	0.176888	0.1991	0.198325	0.178744	0.169
0.1815	0.167675	0.190788	0.199106	0.188844	0.170775	0.186806	0.2026	0.189625	0.1731
0.203	0.189106	0.175019	0.181994	0.200838	0.200406	0.173688	0.1743	0.195906	0.204038
0.200413	0.180025	0.174194	0.1942	0.201181	0.184231	0.174206	0.188487	0.200413	0.190094
0.175919	0.198775	0.202438	0.170794	0.177625	0.197906	0.200419	0.179406	0.17355	0.201194
0.201244	0.19275	0.1711	0.174525	0.199213	0.200025	0.175581	0.172694	0.1935	0.1986
0.199106	0.189469	0.174806	0.183375	0.202994	0.192825	0.172238	0.17435	0.1972	0.200606
0.194394	0.174538	0.1724	0.196463	0.204525	0.1844	0.171531	0.187581	0.199138	0.188013
0.183087	0.202919	0.1972	0.175606	0.17495	0.2008	0.201419	0.177975	0.170488	0.188381
0.174481	0.172988	0.2024	0.193681	0.174206	0.173688	0.198806	0.204	0.183113	0.172094
0.180419	0.2024	0.202869	0.175944	0.172725	0.1923	0.2055	0.184025	0.176844	0.185531
0.1736	0.178006	0.199563	0.195531	0.1747	0.176413	0.197206	0.204488	0.180381	0.170744
0.185438	0.173406	0.195806	0.203919	0.183606	0.170994	0.190756	0.203387	0.1855	0.1746
0.1934	0.203006	0.186438	0.1766	0.184706	0.204606	0.190819	0.172788	0.175556	0.200075
0.173513	0.1772	0.19995	0.200144	0.178819	0.1742	0.196488	0.206281	0.185206	0.176606
0.200419	0.188744	0.174069	0.1854	0.201406	0.192831	0.175219	0.184038	0.201206	0.1927
0.200413	0.17845	0.174063	0.194006	0.204406	0.183894	0.1732	0.189625	0.200606	0.189006
0.206219	0.187563	0.1726	0.1916	0.2019	0.179381	0.170963	0.192144	0.2031	0.182394
0.186406	0.199131	0.189988	0.1739	0.178475	0.2019	0.194744	0.173294	0.175325	0.1947
0.1755	0.1752	0.202806	0.191606	0.1722	0.1868	0.2038	0.176719	0.174788	0.204413
0.173294	0.197981	0.201394	0.1814	0.1683	0.189075	0.198981	0.189825	0.170706	0.18085
0.1903	0.175638	0.176606	0.199225	0.2003	0.177188	0.1739	0.195106	0.2035	0.1844
0.174231	0.196794	0.199131	0.174806	0.175031	0.1983	0.2012	0.1815	0.167588	0.1867
0.187294	0.199831	0.189181	0.172606	0.182819	0.200337	0.195594	0.174188	0.176619	0.196387
0.176606	0.177219	0.202069	0.197888	0.174269	0.177219	0.1947	0.203956	0.183219	0.173638
0.1787	0.174713	0.199006	0.202994	0.1734	0.174425	0.196094	0.196706	0.1747	0.1747
0.180013	0.199931	0.19555	0.172488	0.175281	0.2003	0.20235	0.177806	0.174206	0.194419
0.172994	0.176281	0.201912	0.200606	0.1794	0.171	0.189081	0.1982	0.186944	0.17355
0.171113	0.185213	0.20075	0.197481	0.174781	0.173581	0.194988	0.2019	0.18355	0.177419
0.196681	0.190206	0.173569	0.181638	0.202969	0.200606	0.179806	0.169294	0.193444	0.202306
0.193	0.172638	0.171906	0.196306	0.198331	0.1784	0.1718	0.1915	0.201806	0.188313
0.175344	0.195913	0.203906	0.1863	0.174306	0.187881	0.199613	0.189625	0.17045	0.181325
0.204	0.1859	0.175806	0.186013	0.2028	0.1899	0.1731	0.1822	0.2024	0.192306
0.184081	0.203981	0.19125	0.1738	0.178344	0.198381	0.201	0.179913	0.171806	0.1912
0.1711	0.190194	0.198775	0.189944	0.172981	0.186419	0.2027	0.1907	0.174425	0.174019
0.186019	0.2056	0.1916	0.174281	0.181406	0.198506	0.202019	0.179619	0.171581	0.1922
0.176044	0.184306	0.204406	0.191613	0.173531	0.177213	0.1991	0.2014	0.180413	0.173212
0.172313	0.193406	0.206256	0.183788	0.174819	0.189663	0.199638	0.189619	0.173675	0.187238
0.176981	0.172675	0.191606	0.1991	0.187931	0.172	0.184994	0.2024	0.195019	0.172494
0.173619	0.187513	0.203113	0.1892	0.173475	0.180981	0.201219	0.186706	0.175	0.195188
31	32	33	34	35	36	37	38	39	40

0.1896	0.195906	0.191	0.17195	0.185394	0.202406	0.192819	0.173	0.1794	0.2006
0.182344	0.19955	0.198525	0.174269	0.176706	0.2005	0.198269	0.177244	0.175544	0.195981
0.182288	0.172144	0.1918	0.1985	0.187725	0.175806	0.187	0.200381	0.191894	0.173975
0.173738	0.1827	0.2027	0.195019	0.174206	0.1798	0.202006	0.200238	0.1752	0.175281
0.196656	0.171844	0.175794	0.200038	0.199594	0.178219	0.175288	0.196925	0.2008	0.1779
0.184887	0.173625	0.188719	0.2006	0.1871	0.173106	0.1815	0.203806	0.198394	0.176819
0.1794	0.170275	0.1899	0.200363	0.1892	0.172281	0.1851	0.201406	0.192994	0.173469
0.174125	0.185194	0.20075	0.193106	0.1723	0.192138	0.199669	0.189406	0.173244	0.185419
0.202063	0.18325	0.175938	0.185788	0.2019	0.1887	0.172144	0.177944	0.200388	0.201581
0.1863	0.1995	0.1891	0.170231	0.187119	0.201125	0.191006	0.176681	0.186713	0.198331
0.201144	0.190231	0.172525	0.190006	0.197994	0.188694	0.176606	0.186219	0.2027	0.190438
0.187225	0.198813	0.1898	0.1699	0.184838	0.202413	0.1921	0.172788	0.173188	0.195969
0.185175	0.203806	0.192419	0.173194	0.178563	0.2006	0.199194	0.178206	0.175744	0.202013
0.200406	0.175706	0.1729	0.191881	0.2035	0.1811	0.168888	0.190269	0.199238	0.189638
0.186363	0.202256	0.188894	0.171081	0.183606	0.200875	0.19435	0.171194	0.173131	0.197156
0.1752	0.17495	0.2022	0.200606	0.180144	0.174325	0.197113	0.201238	0.181219	0.171019
0.171669	0.185481	0.201638	0.1926	0.173888	0.17995	0.199106	0.203006	0.1755	0.175019
0.173894	0.187619	0.199244	0.190806	0.171006	0.180388	0.199513	0.200306	0.177638	0.172606
0.201613	0.180025	0.1726	0.192144	0.1991	0.190444	0.174438	0.185688	0.201681	0.192631
0.191344	0.173238	0.1735	0.198388	0.197406	0.172606	0.171538	0.196075	0.200075	0.176206
0.202006	0.2014	0.1755	0.174438	0.195038	0.204419	0.186006	0.172544	0.191744	0.203613
0.175613	0.1892	0.200825	0.188744	0.172788	0.1864	0.203806	0.192819	0.175219	0.178081
0.19975	0.1883	0.173613	0.1871	0.1985	0.189625	0.173212	0.183869	0.1995	0.1947
0.202588	0.1787	0.171225	0.1928	0.200706	0.1851	0.174544	0.186013	0.201488	0.188081
0.188606	0.2024	0.1916	0.175031	0.177675	0.202713	0.2024	0.177469	0.172606	0.195106
0.197581	0.199275	0.180025	0.175619	0.197244	0.2011	0.179194	0.170819	0.188744	0.199288
0.202037	0.188606	0.176812	0.1855	0.203613	0.190869	0.171619	0.179394	0.201394	0.192813
0.185144	0.204038	0.189531	0.1723	0.183606	0.1995	0.1974	0.173638	0.175744	0.194738
0.1848	0.202688	0.191588	0.173406	0.178481	0.20075	0.198269	0.175619	0.177406	0.197594
0.1857	0.176819	0.186413	0.2026	0.187906	0.170869	0.1835	0.203344	0.187969	0.170425
0.172181	0.186306	0.199288	0.191006	0.170844	0.1823	0.2015	0.200038	0.172981	0.175225
0.200894	0.2003	0.176406	0.1727	0.197625	0.201406	0.179213	0.170081	0.191619	0.199238
0.173794	0.174356	0.1982	0.201775	0.184419	0.175806	0.1859	0.1987	0.1891	0.169944
0.199806	0.190163	0.168769	0.180094	0.201231	0.201687	0.1743	0.174475	0.196825	0.200731
0.198206	0.2026	0.181194	0.171813	0.1883	0.201319	0.190219	0.173094	0.181625	0.201406
0.201219	0.1855	0.174425	0.186544	0.203806	0.191406	0.174806	0.179806	0.202013	0.201125
0.190812	0.1999	0.1875	0.173294	0.184025	0.201037	0.195931	0.1752	0.173013	0.197988
0.202019	0.1918	0.172038	0.176888	0.199619	0.200713	0.178425	0.173613	0.191881	0.200731
0.177244	0.201344	0.201319	0.178325	0.1695	0.1871	0.201806	0.1896	0.174369	0.179606
0.205613	0.187225	0.174813	0.18395	0.202037	0.195169	0.174088	0.1747	0.198675	0.201406
41	42	43	44	45	46	47	48	49	50

0.196413	0.1736	0.1882	0.201381	0.180294	0.174438	0.194806	0.200894	0.182725	0.175444
0.203088	0.181625	0.169406	0.18795	0.201406	0.1887	0.173381	0.182606	0.202231	0.196013
0.175581	0.202406	0.199794	0.173625	0.175344	0.196013	0.201663	0.1783	0.1704	0.191688
0.197819	0.203006	0.1807	0.172069	0.19115	0.198144	0.189688	0.171806	0.183288	0.201544
0.169463	0.192394	0.196825	0.172538	0.1766	0.200813	0.198394	0.1806	0.175406	0.192069
0.174869	0.195806	0.201538	0.182131	0.1719	0.192419	0.199994	0.18405	0.176825	0.192194
0.171288	0.197806	0.203806	0.180769	0.171806	0.1912	0.199131	0.189613	0.1734	0.186406
0.2015	0.190594	0.169944	0.183794	0.201438	0.193	0.172025	0.1742	0.200419	0.201469
0.176619	0.173738	0.1942	0.2054	0.183006	0.172794	0.193294	0.202706	0.1831	0.1762
0.18675	0.169544	0.183106	0.200781	0.191038	0.173562	0.175944	0.199475	0.200444	0.1748
0.171956	0.178594	0.200938	0.203294	0.177288	0.171	0.191638	0.201912	0.1787	0.170813
0.200419	0.180219	0.171606	0.194412	0.203	0.185456	0.175588	0.188013	0.200144	0.187238
0.1963	0.174006	0.175213	0.200419	0.199806	0.1768	0.175819	0.198219	0.198594	0.179944
0.171494	0.184413	0.2023	0.191094	0.172881	0.183213	0.201325	0.200038	0.177244	0.175006
0.200944	0.179288	0.172181	0.194806	0.201394	0.18155	0.1671	0.194994	0.200581	0.182206
0.189606	0.199325	0.189625	0.1706	0.182588	0.202438	0.196406	0.1719	0.175206	0.1983
0.196025	0.203606	0.177906	0.173481	0.191744	0.204438	0.183194	0.168025	0.1879	0.199813
0.195806	0.204531	0.183644	0.1751	0.1843	0.2044	0.19045	0.171838	0.17615	0.201206
0.175263	0.175875	0.201406	0.200038	0.1768	0.173288	0.200144	0.200406	0.175	0.1751
0.173913	0.197406	0.206819	0.181406	0.170469	0.193406	0.2035	0.185488	0.176825	0.187006
0.179038	0.173138	0.1911	0.2026	0.187194	0.175744	0.1847	0.203844	0.191206	0.172606
0.201763	0.198206	0.175513	0.1743	0.194769	0.204175	0.185156	0.172981	0.184181	0.203806
0.173506	0.176731	0.1947	0.204406	0.1832	0.172981	0.1863	0.204544	0.1912	0.174319
0.172694	0.1848	0.202806	0.196875	0.173481	0.1742	0.198006	0.204013	0.183006	0.174806
0.203325	0.1848	0.176669	0.188606	0.1983	0.189644	0.1719	0.185588	0.2028	0.192819
0.1889	0.1747	0.182606	0.203006	0.196081	0.1727	0.174544	0.197419	0.205738	0.183806
0.1707	0.184938	0.203806	0.190425	0.173888	0.1802	0.201181	0.199506	0.176888	0.1758
0.200306	0.1844	0.174019	0.188469	0.1963	0.1912	0.170763	0.183006	0.201737	0.197406
0.2006	0.180013	0.173288	0.192787	0.206	0.1848	0.176844	0.187006	0.204144	0.183238
0.181675	0.200381	0.2003	0.178488	0.173625	0.192288	0.202844	0.188669	0.176338	0.196669
0.194425	0.202481	0.187225	0.174206	0.183513	0.1994	0.193538	0.172875	0.174044	0.197613
0.189913	0.1704	0.18275	0.200825	0.193238	0.174206	0.1727	0.199806	0.2019	0.1783
0.182325	0.201394	0.196406	0.174819	0.175744	0.1987	0.199375	0.178425	0.1736	0.1928
0.183006	0.172363	0.192706	0.200606	0.18965	0.170588	0.1831	0.202819	0.200838	0.176213
0.199606	0.178206	0.176013	0.196	0.205744	0.185581	0.1752	0.184081	0.203131	0.190544
0.178419	0.171963	0.191575	0.205494	0.1846	0.1766	0.185406	0.202881	0.191969	0.172325
0.201206	0.181925	0.169181	0.188406	0.2014	0.19115	0.1723	0.1787	0.1982	0.202413
0.189206	0.173381	0.186413	0.202813	0.196719	0.1768	0.1731	0.195	0.204025	0.183994
0.201387	0.201163	0.174425	0.1732	0.194856	0.204363	0.1846	0.175588	0.186819	0.203325
0.182069	0.168994	0.187225	0.200025	0.19	0.171856	0.1843	0.203006	0.192706	0.174044
51	52	53	54	55	56	57	58	59	60

0.188238	0.199225	0.190206	0.1726	0.182475	0.201113	0.18715	0.178	0.186181	0.1974
0.174819	0.176825	0.200631	0.199819	0.180094	0.175606	0.195388	0.206306	0.181581	0.172206
0.202006	0.186475	0.173581	0.186306	0.2043	0.191031	0.174206	0.184406	0.200331	0.192838
0.19035	0.174588	0.181975	0.202519	0.194475	0.173406	0.1768	0.1992	0.199588	0.179513
0.202281	0.186306	0.173994	0.186425	0.203606	0.190613	0.1715	0.1799	0.2014	0.200856
0.202294	0.185494	0.174713	0.186819	0.200706	0.191194	0.175213	0.172194	0.2054	0.196138
0.205006	0.190819	0.169538	0.179906	0.201488	0.197644	0.176219	0.1758	0.196594	0.205469
0.17625	0.1734	0.1926	0.202819	0.188325	0.174806	0.184388	0.2018	0.1935	0.172181
0.185744	0.202231	0.191	0.173206	0.182144	0.200038	0.201006	0.174819	0.174606	0.197406
0.1752	0.196825	0.203606	0.179906	0.170013	0.1899	0.202475	0.186381	0.176419	0.186294
0.191	0.201094	0.188	0.173306	0.1848	0.200825	0.191006	0.171813	0.181406	0.2024
0.175819	0.186013	0.2015	0.191206	0.1715	0.177688	0.203619	0.1963	0.1729	0.173625
0.168194	0.193406	0.1999	0.187806	0.175994	0.1864	0.204706	0.189688	0.172006	0.184031
0.1956	0.206	0.185237	0.1742	0.1908	0.199031	0.190206	0.172881	0.185113	0.200606
0.168094	0.19115	0.199238	0.189163	0.172325	0.182731	0.202731	0.191006	0.174613	0.1771
0.202413	0.176681	0.1723	0.1959	0.203069	0.183769	0.170231	0.1894	0.200781	0.182394
0.190213	0.175213	0.186463	0.202806	0.188344	0.171294	0.184406	0.201375	0.193188	0.1752
0.199844	0.171981	0.1736	0.198019	0.202638	0.1826	0.174831	0.176875	0.184781	0.201269
0.194781	0.2015	0.1848	0.173988	0.18515	0.203069	0.1891	0.16915	0.182281	0.202413
0.206013	0.189206	0.175606	0.181794	0.1995	0.196619	0.173744	0.173181	0.1958	0.205406
0.1787	0.202206	0.200813	0.173506	0.1751	0.202206	0.1998	0.173381	0.175806	0.197519
0.191806	0.174206	0.175006	0.199163	0.200806	0.180619	0.168325	0.190675	0.1987	0.188088
0.178538	0.2018	0.200825	0.1772	0.1731	0.196	0.2015	0.180875	0.171069	0.190206
0.187225	0.202413	0.1898	0.172013	0.18	0.202944	0.203019	0.177538	0.171994	0.195663
0.172706	0.174069	0.197688	0.2023	0.178425	0.172412	0.1921	0.202606	0.186475	0.1739
0.173994	0.1894	0.202413	0.188331	0.169131	0.188	0.202481	0.191219	0.174019	0.177744
0.1979	0.1986	0.173625	0.174869	0.2014	0.196631	0.171188	0.177213	0.1963	0.1999
0.173675	0.174788	0.197606	0.198331	0.178813	0.176606	0.194581	0.2024	0.183619	0.166981
0.171681	0.187144	0.2044	0.190794	0.173744	0.177219	0.1983	0.196413	0.1719	0.175819
0.206144	0.183225	0.174144	0.187806	0.1992	0.188944	0.173675	0.186206	0.202006	0.192437
0.203006	0.181988	0.174438	0.187919	0.201544	0.189406	0.170806	0.181494	0.201488	0.201588
0.171994	0.193444	0.2005	0.187338	0.175606	0.185806	0.20315	0.191219	0.1752	0.179894
0.202031	0.197675	0.1854	0.173881	0.1878	0.202206	0.191006	0.171013	0.1794	0.2022
0.17445	0.197913	0.200594	0.183794	0.175375	0.186488	0.206013	0.191488	0.172894	0.186206
0.174294	0.178781	0.199581	0.200075	0.178463	0.174206	0.191663	0.202019	0.183913	0.175225
0.178206	0.199525	0.202425	0.1763	0.171381	0.197013	0.206813	0.186206	0.176406	0.185088
0.178419	0.173206	0.192838	0.202781	0.185444	0.175906	0.18545	0.204544	0.192756	0.174425
0.175006	0.185913	0.204025	0.191538	0.174369	0.173925	0.201975	0.194425	0.174863	0.1719
0.190425	0.172	0.179213	0.200331	0.201238	0.177231	0.171237	0.192038	0.199225	0.189113
0.177206	0.1974	0.201281	0.18235	0.172756	0.186006	0.2038	0.191869	0.174188	0.177456

61	62	63	64	65	66	67	68	69	70

0.186363	0.176781	0.187619	0.196925	0.189213	0.170819	0.183338	0.200337	0.194587	0.175225
0.187281	0.201231	0.1902	0.175006	0.183019	0.199531	0.1975	0.175269	0.17995	0.2024
0.172731	0.1807	0.201806	0.198488	0.173431	0.175806	0.198537	0.2012	0.178306	0.171813
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0.177625	0.1679	0.192756	0.200413	0.185237	0.174813	0.1902	0.1987	0.1867	0.175012
0.172419	0.178206	0.199238	0.1979	0.174475	0.173688	0.196825	0.204025	0.182219	0.171694
0.177506	0.1738	0.1923	0.204388	0.181	0.169525	0.190894	0.204138	0.185206	0.175938
0.179013	0.201963	0.194844	0.174438	0.1723	0.196731	0.20			
0.201138	0.183819	0.175606	0.188631	0.1979	0.190369	0.17			
0.203806	0.191031	0.175	0.1767	0.201806	0.201406	0.17			
0.196606	0.1748	0.176206	0.197625	0.201206	0.178325	0.17			
0.196306	0.204488	0.1815	0.173188	0.1892	0.201013	0.			
0.2031	0.191213	0.172894	0.177213	0.201006	0.188375	0.17			
0.193038	0.174806	0.174894	0.201644	0.1995	0.173406	0.			
0.2011	0.200075	0.1775	0.175269	0.194481	0.206038	0.18			
0.172444	0.189406	0.199588	0.187563	0.175344	0.184606	0.20			
0.1735	0.198544	0.202219	0.1794	0.173581	0.1951	0.19			
0.190819	0.169381	0.18085	0.201806	0.200606	0.176863	0.			
0.1964	0.174013	0.175513	0.197813	0.20055	0.180013	0.17			
0.176981	0.1739	0.193444	0.205744	0.184419	0.174013	0.			
0.199594	0.17515	0.175244	0.195288	0.204406	0.184388	0.17			
0.168975	0.184794	0.2007	0.194806	0.175606	0.1731	0.20			
0.1979	0.1894	0.1707	0.183606	0.201538	0.197638	0.1			
0.206819	0.185806	0.176206	0.184731	0.203425	0.191619	0.17			
0.1843	0.2007	0.192619	0.172656	0.175219	0.198537	0.19			
0.200044	0.201206	0.177406	0.174675	0.194844	0.205613	0.18			
0.179038	0.170206	0.194206	0.20115	0.187806	0.172025	0.18			
0.187481	0.199788	0.190294	0.173663	0.180469	0.2007	0.19			
0.196063	0.203963	0.184825	0.1772	0.186019	0.200719	0.			
0.173819	0.175738	0.197613	0.206038	0.184419	0.175213	0.			
0.177125	0.1695	0.1926	0.197106	0.188125	0.173212	0.18			
0.202013	0.202856	0.176369	0.172075	0.1912	0.200125	0.18			
0.202469	0.178019	0.175181	0.194206	0.203344	0.1846	0.169206	0.188487	0.199394	0.190369
0.201544	0.1878	0.175806	0.185431	0.2007	0.1895	0.173219	0.1803	0.1992	0.200794
0.186331	0.201519	0.190806	0.172694	0.1797	0.199538	0.202488	0.177694	0.173638	0.1928
0.204544	0.191681	0.172381	0.175138	0.200838	0.2006	0.173944	0.171106	0.1922	0.20075
0.175638	0.201269	0.20075	0.176994	0.174206	0.192744	0.205613	0.186838	0.175263	0.185113
0.197	0.202425	0.179819	0.1719	0.189938	0.2028	0.185681	0.174494	0.185688	0.202675
0.174425	0.18475	0.2017	0.196619	0.175806	0.174006	0.197494	0.205406	0.1827	0.176606
0.1999	0.1999	0.180025	0.168556	0.191338	0.200744	0.188038	0.171156	0.185269	0.203006
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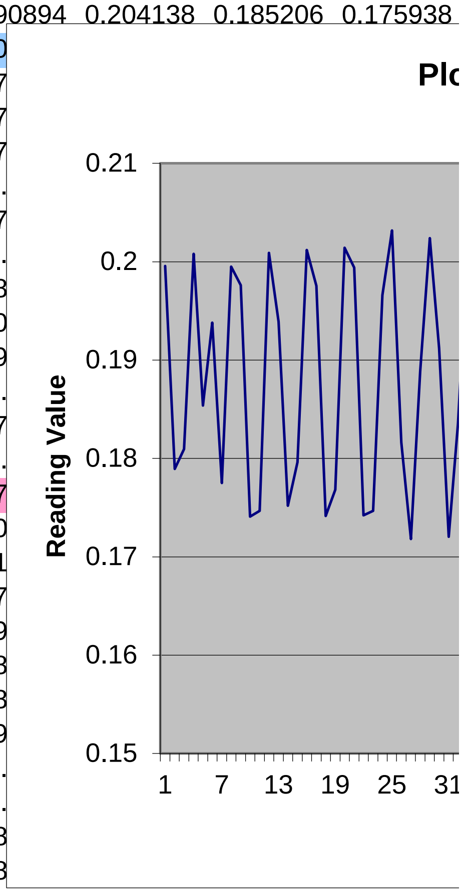

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0.193206	0.200813	0.188606	0.171894	0.183288	0.202544	0.192206	0.172694	0.180019	0.200888
0.200825	0.199806	0.1715	0.1743	0.195538	0.201206	0.180038	0.168344	0.188881	0.199856
0.187119	0.2035	0.191225	0.1715	0.181213	0.202406	0.195138	0.173513	0.171875	0.199225
0.1894	0.198806	0.189406	0.1687	0.1851	0.203275	0.189625	0.174844	0.179494	0.2028
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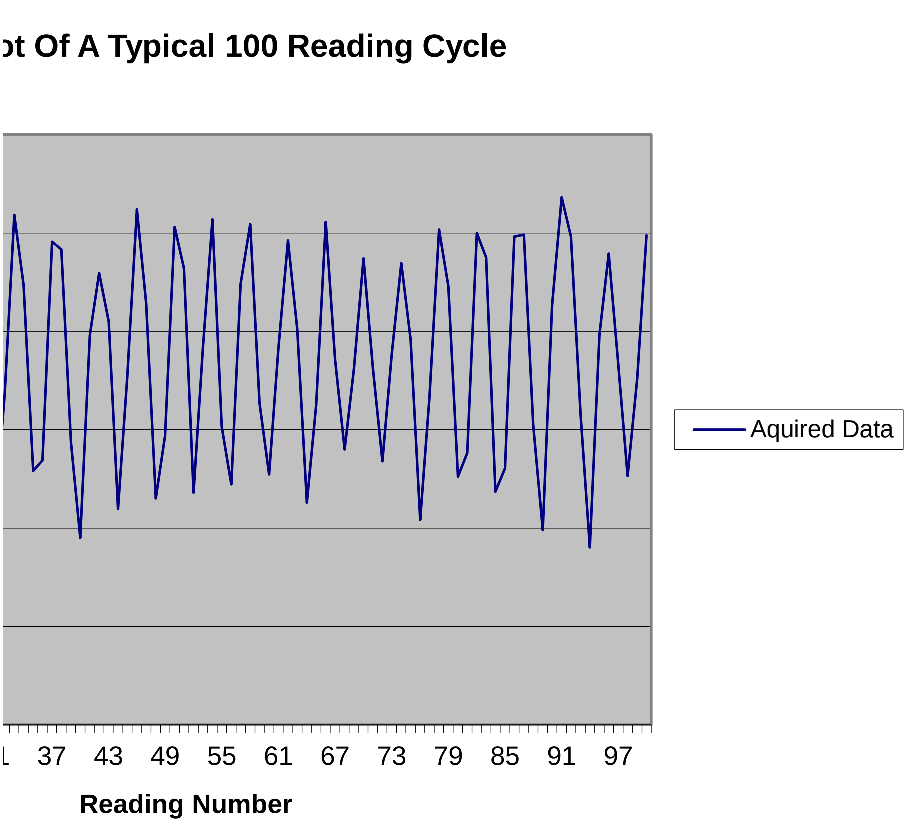

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0.2019	0
0.188406	0.1
0.193694	0.2
0.173406	0.1
0.199113	0.2
0.200619	0.1
0.200025	0.1
0.17755	0.1
0.198763	0.1
0.173913	0.1
0.200494	
0.197625	0.1
0.175806	0.1
0.191606	0.1
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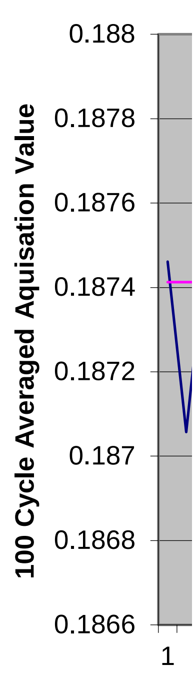

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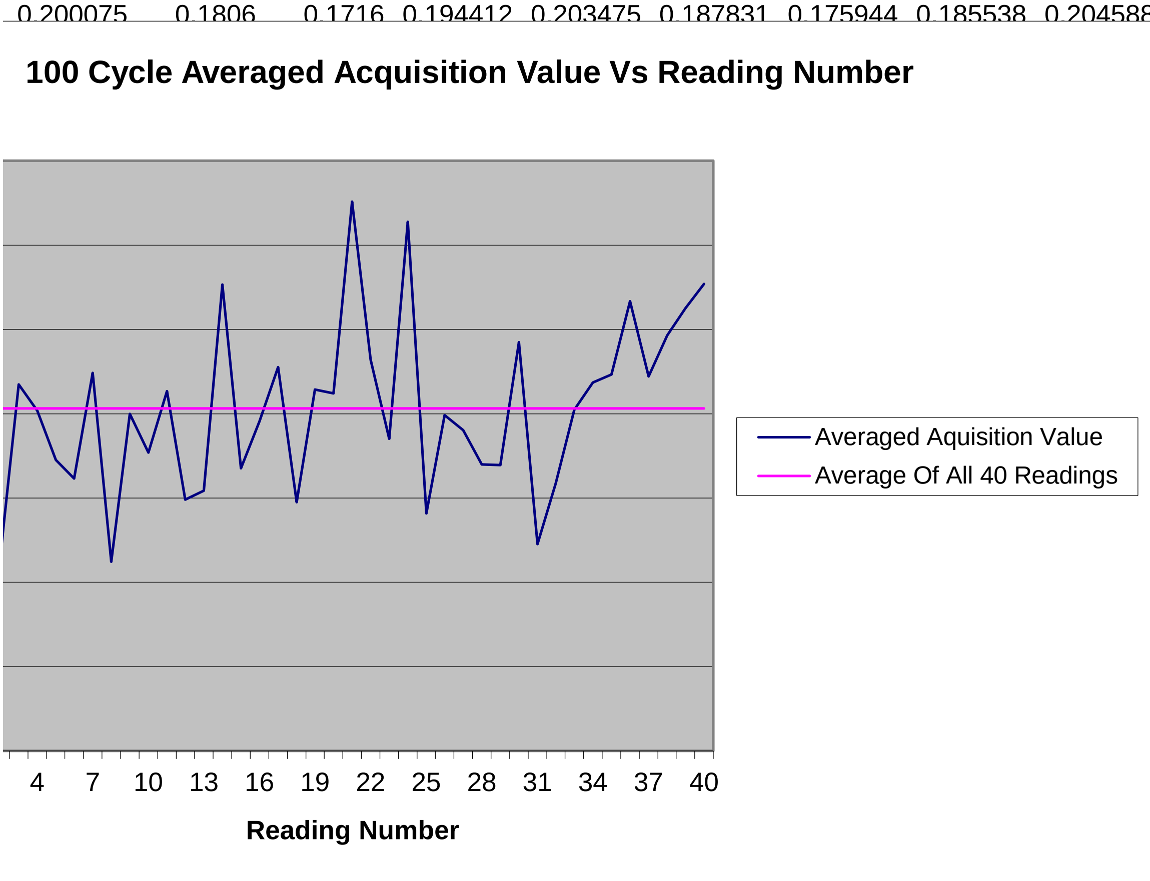
0.1991	0.1791	0.170806	0.189206	0.200963	0.189475	0.171044	0.184138	0.202806	0.193294
0.18825	0.171531	0.1847	0.202438	0.194438	0.171281	0.1796	0.200606	0.201744	0.173581
0.205419	0.191056	0.171094	0.182681	0.2028	0.1943	0.173125	0.1727	0.199913	0.2014
0.190413	0.172706	0.177788	0.202206	0.200825	0.178606	0.173806	0.1912	0.201394	0.187606
0.186806	0.203562	0.193219	0.173688	0.174144	0.198219	0.2015	0.180694	0.168494	0.191744
0.193194	0.17255	0.177406	0.200419	0.1995	0.1783	0.16935	0.188544	0.200606	0.189531

81	82	83	84	85	86	87	88	89	90

0.203631	0.199619	0.1816	0.168038	0.189625	0.1979	0.186581	0.1753	0.185194	0.199744
0.173206	0.186438	0.202044	0.192813	0.173613	0.180025	0.202219	0.197631	0.1743	0.175763
0.199094	0.173638	0.175	0.196613	0.206206	0.182481	0.172025	0.187613	0.201394	0.189638
0.189213	0.175338	0.186438	0.200825	0.1883	0.172769	0.184388	0.2003	0.191006	0.174606
0.1992	0.179244	0.170838	0.195006	0.2023	0.1835	0.1743	0.187581	0.199794	0.190206
0.2019	0.176794	0.170594	0.195606	0.204025	0.178706	0.171225	0.194475	0.204606	0.182269
0.200075	0.1806	0.1716	0.194412	0.203475	0.187831	0.175944	0.185538	0.204588	0.188881
									0.173638
									0.196831
									0.1967
									0.202488
									0.184356
									0.195806
									0.202356
									0.177406
									0.181688
									0.19115
									0.203288
									0.200188
									0.2011
									0.203244
									0.1887
									0.1848
									0.202331
									0.171394
									0.176206
									0.202763
									0.177688
									0.18995
									0.202806
									0.203106
									0.169294
0.1891	0.199856	0.188775	0.172769	0.185406	0.203363	0.191619	0.173212	0.182019	0.1997
0.174581	0.196138	0.203006	0.1842	0.172019	0.186344	0.200206	0.191213	0.173794	0.177162
0.172981	0.172306	0.197444	0.203606	0.181181	0.172494	0.187275	0.200694	0.187994	0.174738
0.174194	0.192206	0.204044	0.1867	0.16885	0.189744	0.2014	0.190013	0.172388	0.184406
0.181625	0.1711	0.188069	0.200606	0.190169	0.170294	0.184988	0.202819	0.195425	0.17515
0.175619	0.186413	0.205644	0.1902	0.1735	0.180038	0.200075	0.203606	0.178606	0.174344
0.199869	0.190281	0.170806	0.182813	0.202013	0.203019	0.172706	0.175069	0.1964	0.2015
0.173594	0.180888	0.202006	0.199119	0.174425	0.175819	0.195588	0.205625	0.1823	0.175744
91	92	93	94	95	96	97	98	99	100



Forty Poin

Difference Between The Averaged Maximum And Minimum Acqui

	0.187461	0.187412
	0.187057	0.187412
	0.18747	0.187412
	0.187408	0.187412
	0.187291	0.187412
	0.187247	0.187412
	0.187497	0.187412
	0.187049	0.187412
	0.1874	0.187412
	0.187308	0.187412
	0.187454	0.187412
	0.187196	0.187412
	0.187217	0.187412
	0.187707	0.187412
	0.18727	0.187412
	0.187382	0.187412
	0.18751	0.187412
	0.18719	0.187412
	0.187458	0.187412
	0.187448	0.187412
	0.187903	0.187412
	0.187528	0.187412
	0.18734	0.187412
	0.187855	0.187412
	0.187163	0.187412
	0.187396	0.187412
	0.187361	0.187412
	0.187279	0.187412
	0.187278	0.187412
	0.18757	0.187412
	0.187091	0.187412
	0.187235	0.187412
	0.187409	0.187412
	0.187474	0.187412
	0.187493	0.187412
	0.187667	0.187412
	0.187488	0.187412
	0.187586	0.187412
	0.18765	0.187412
	0.187708	0.187412
t Average	0.187412	
ed Values	0.000854	

0.009837	0.008574	0.009171	0.008926	0.010446	0.008398	0.010038	0.009183	0.009881	0.006539
0.017268	0.016394	0.018555	0.016796	0.018405	0.018103	0.016225	0.019541	0.016281	0.020465
0.025126	0.029648	0.02755	0.02848	0.029353	0.0238	0.033888	0.02642	0.031545	0.029083
0.044856	0.034962	0.041074	0.038788	0.04103	0.039585	0.038273	0.043078	0.034177	0.043618
0.056564	0.044114	0.055327	0.039095	0.055854	0.04294	0.054975	0.045258	0.053241	0.046357
0.061438	0.051859	0.063448	0.050138	0.065823	0.050459	0.062839	0.05348	0.058222	0.06157
0.077198	0.059303	0.07566	0.065295	0.067431	0.074001	0.061011	0.075119	0.06191	0.076225
0.073373	0.08255	0.075082	0.081099	0.078197	0.071187	0.082839	0.085766	0.086514	0.075779
0.089579	0.084114	0.096709	0.081476	0.095704	0.08059	0.097594	0.079127	0.096533	0.078191
0.108279	0.090986	0.109786	0.090785	0.102117	0.097494	0.102123	0.098216	0.099296	0.103298
0.103078	0.118926	0.100239	0.123844	0.097312	0.11941	0.096118	0.119824	0.100031	0.12059
0.109755	0.130948	0.107374	0.128147	0.109535	0.135013	0.107946	0.13108	0.108681	0.128976
0.113976	0.140898	0.118756	0.142921	0.121552	0.130584	0.126866	0.132676	0.128668	0.129058
0.154579	0.136778	0.135207	0.146771	0.130276	0.150974	0.123857	0.153172	0.129083	0.153687
0.136363	0.160603	0.134177	0.156778	0.14554	0.152104	0.154397	0.135905	0.160697	0.133335
0.150352	0.171382	0.147136	0.174064	0.146225	0.172814	0.144523	0.17331	0.148003	0.167946
0.149943	0.183731	0.157494	0.176124	0.166872	0.17179	0.169454	0.165415	0.176288	0.161621
0.169454	0.190666	0.167443	0.192845	0.163562	0.192626	0.173474	0.181495	0.165132	0.166526
0.191476	0.192205	0.185345	0.197619	0.176388	0.202487	0.174366	0.205308	0.176646	0.203323
0.184315	0.210314	0.193913	0.215358	0.184133	0.214673	0.185547	0.210415	0.194611	0.201313
0.200245	0.227538	0.196595	0.223913	0.194623	0.225521	0.195923	0.22593	0.200195	0.21522
0.215264	0.23358	0.20483	0.239209	0.20348	0.22956	0.21657	0.213273	0.225459	0.210101
0.242023	0.232412	0.226526	0.237211	0.2174	0.241545	0.213116	0.245226	0.216319	0.246784
0.248285	0.224334	0.254466	0.22593	0.258116	0.223769	0.256627	0.224987	0.251683	0.229139
0.261652	0.244724	0.252607	0.252877	0.243229	0.257494	0.240232	0.264937	0.23642	0.263662
0.245647	0.2776	0.247236	0.275804	0.252073	0.266432	0.252054	0.265741	0.257582	0.257896
0.250446	0.283229	0.253266	0.286438	0.256093	0.272908	0.266445	0.272173	0.268857	0.265936
0.266696	0.298241	0.26299	0.295967	0.263549	0.291903	0.280917	0.273976	0.287827	0.271784
0.309573	0.275804	0.304384	0.273976	0.298587	0.283361	0.295101	0.291903	0.284133	0.296225
0.284121	0.314768	0.288248	0.304127	0.298317	0.300597	0.300044	0.296998	0.305942	0.290992
0.324416	0.299391	0.317984	0.304761	0.316005	0.307889	0.314183	0.307933	0.308486	0.316382
0.308951	0.337029	0.305188	0.338938	0.306357	0.336043	0.306878	0.335691	0.304529	0.335842
0.327381	0.335691	0.328907	0.332085	0.334673	0.319001	0.34495	0.315961	0.346979	0.314617
0.338028	0.332607	0.349824	0.329259	0.352475	0.323423	0.358455	0.326897	0.357814	0.324435
0.354717	0.349774	0.350151	0.354378	0.341514	0.362117	0.334774	0.365974	0.331457	0.362952
0.36559	0.349579	0.370195	0.349774	0.378354	0.343712	0.375892	0.344535	0.379234	0.345057
0.354573	0.383518	0.361602	0.373675	0.367852	0.373869	0.36951	0.368543	0.375553	0.365873
0.364152	0.394579	0.36907	0.386715	0.37348	0.383109	0.377682	0.380936	0.381922	0.374699
0.373367	0.403423	0.377632	0.397563	0.388788	0.392663	0.391583	0.388003	0.395471	0.383518
0.411652	0.391438	0.404422	0.396583	0.403361	0.401753	0.396809	0.408248	0.387852	0.411652

0.009692	0.006753	0.011244	0.007418	0.009629	0.007896	0.011545	0.007029	0.009052	0.008474
0.015283	0.019541	0.014717	0.019548	0.016244	0.021784	0.014818	0.020842	0.015188	0.021043
0.029347	0.030402	0.026884	0.032456	0.026457	0.032513	0.025936	0.034604	0.026024	0.03299
0.033379	0.043046	0.03402	0.045779	0.031966	0.042443	0.033335	0.03934	0.036891	0.037858
0.050691	0.046577	0.049943	0.050176	0.047852	0.04968	0.04603	0.05392	0.042487	0.053423
0.052896	0.063417	0.051357	0.065628	0.051796	0.067544	0.051338	0.067136	0.050484	0.062594
0.060704	0.078222	0.058907	0.075961	0.06115	0.076093	0.063229	0.073191	0.073178	0.064246
0.071671	0.082456	0.08809	0.077531	0.069108	0.080094	0.088913	0.078888	0.072688	0.07517
0.096715	0.081602	0.097519	0.083863	0.09407	0.086237	0.087871	0.093411	0.082845	0.09468
0.095484	0.105534	0.091351	0.109768	0.088788	0.110163	0.088467	0.108938	0.084221	0.112557
0.098474	0.112795	0.10544	0.113103	0.108153	0.108348	0.107984	0.105955	0.118524	0.099824
0.113693	0.124152	0.116175	0.121357	0.118486	0.115509	0.12365	0.111451	0.130144	0.108838
0.136671	0.122205	0.140704	0.116112	0.142312	0.113662	0.140905	0.112092	0.143957	0.126256
0.127224	0.153461	0.132079	0.143775	0.138832	0.137569	0.143945	0.13032	0.148976	0.125823
0.16005	0.134271	0.164629	0.138499	0.159805	0.14652	0.150791	0.153706	0.140798	0.156784
0.154303	0.16228	0.16321	0.152525	0.171256	0.14559	0.174516	0.147136	0.174611	0.143411
0.181734	0.154579	0.182808	0.15397	0.184114	0.155126	0.184328	0.155201	0.179541	0.15559
0.19478	0.166457	0.193719	0.172199	0.189089	0.168053	0.195013	0.165157	0.194309	0.184466
0.172111	0.204227	0.175327	0.203756	0.183731	0.194975	0.18691	0.187946	0.195038	0.185923
0.198593	0.199837	0.206244	0.189981	0.207783	0.186539	0.212959	0.18441	0.214793	0.184793
0.208807	0.212192	0.211407	0.208134	0.219447	0.201382	0.222858	0.19652	0.226024	0.196388
0.233982	0.205025	0.237852	0.203455	0.234567	0.211464	0.221715	0.216451	0.219479	0.222224
0.211853	0.246036	0.212563	0.247249	0.217211	0.238807	0.224347	0.234516	0.226181	0.231489
0.248587	0.237199	0.239234	0.243794	0.232374	0.25059	0.226665	0.252004	0.222305	0.255704
0.233568	0.267148	0.236244	0.261237	0.229843	0.268486	0.234686	0.264548	0.258505	0.241583
0.266156	0.25652	0.269372	0.250465	0.2713	0.247249	0.27478	0.241545	0.27566	0.244887
0.273668	0.260044	0.28365	0.256677	0.285477	0.254064	0.28544	0.253951	0.282261	0.25897
0.291884	0.266445	0.295025	0.264014	0.294152	0.262406	0.294152	0.263379	0.298317	0.265377
0.280509	0.297016	0.277569	0.303097	0.277412	0.305063	0.274196	0.304749	0.277437	0.308386
0.311181	0.288989	0.314937	0.283624	0.319234	0.28483	0.31184	0.283844	0.316112	0.293536
0.30353	0.319001	0.29951	0.32402	0.298241	0.325459	0.290999	0.325842	0.296822	0.325773
0.30549	0.336884	0.307048	0.328838	0.309893	0.326771	0.31598	0.324334	0.314366	0.325653
0.348907	0.314422	0.342908	0.315521	0.347946	0.318807	0.345063	0.317199	0.340515	0.325653
0.355	0.325773	0.353379	0.330452	0.342852	0.338568	0.340126	0.345471	0.331558	0.349554
0.334014	0.36804	0.335302	0.365873	0.333863	0.363009	0.340132	0.356514	0.348166	0.354573
0.375515	0.34559	0.368851	0.354573	0.363411	0.36103	0.357971	0.370678	0.349749	0.376489
0.379466	0.362657	0.383411	0.352362	0.388342	0.354083	0.386344	0.358989	0.379039	0.363229
0.386244	0.367462	0.396796	0.362607	0.396407	0.363832	0.396778	0.363222	0.393379	0.365157
0.402858	0.379108	0.40608	0.376696	0.403499	0.369391	0.405528	0.377173	0.406445	0.380716
0.384931	0.411652	0.385377	0.411652	0.383982	0.411652	0.385138	0.411652	0.388342	0.411652

0.008147	0.011049	0.008373	0.011683	0.008631	0.011935	0.008329	0.011024	0.007286	0.009504
0.01434	0.020634	0.015905	0.021671	0.014008	0.020747	0.016501	0.020867	0.01576	0.020358
0.0238	0.033618	0.02456	0.033373	0.024221	0.034843	0.024994	0.034183	0.024724	0.03299
0.039755	0.039893	0.038769	0.039642	0.038631	0.040917	0.036972	0.041828	0.036074	0.041307
0.044171	0.054479	0.042041	0.05233	0.048254	0.049893	0.048844	0.047977	0.053009	0.043405
0.050364	0.063423	0.04897	0.065999	0.050446	0.065666	0.052802	0.066011	0.051193	0.063109
0.075188	0.06554	0.072067	0.067676	0.069711	0.068851	0.06816	0.071281	0.064215	0.075565
0.086162	0.08483	0.075603	0.079466	0.080201	0.078178	0.080892	0.075823	0.080333	0.070785
0.079793	0.096646	0.080678	0.095879	0.084422	0.095314	0.082714	0.093681	0.084529	0.094083
0.087437	0.108134	0.092462	0.112173	0.085421	0.111558	0.085427	0.108568	0.089579	0.111288
0.116482	0.09853	0.11941	0.098436	0.116552	0.104447	0.108876	0.103926	0.113832	0.110697
0.129378	0.10934	0.129742	0.109428	0.126256	0.114077	0.119598	0.121432	0.118982	0.121533
0.132067	0.126822	0.13272	0.127864	0.130861	0.127839	0.136294	0.119824	0.140207	0.118097
0.15517	0.12706	0.150741	0.129441	0.150364	0.131602	0.144359	0.137356	0.139943	0.14044
0.13809	0.15625	0.143555	0.154579	0.148744	0.149158	0.152412	0.146539	0.153876	0.141922
0.17267	0.146771	0.175402	0.142117	0.17468	0.146382	0.174937	0.144121	0.173474	0.144391
0.18071	0.156991	0.183926	0.158405	0.185113	0.153568	0.18093	0.154384	0.186432	0.157431
0.176872	0.184535	0.172864	0.185804	0.173461	0.187732	0.167035	0.190559	0.166834	0.19919
0.199008	0.184121	0.19218	0.192161	0.191093	0.19076	0.186935	0.197167	0.180006	0.201677
0.21429	0.180308	0.216941	0.182318	0.212129	0.18897	0.209874	0.18934	0.207173	0.196036
0.226526	0.196325	0.230094	0.191658	0.229573	0.194378	0.198128	0.224127	0.19478	0.22495
0.213116	0.223813	0.220396	0.217293	0.224322	0.216891	0.220986	0.216482	0.224384	0.207827
0.229083	0.230961	0.22544	0.232167	0.222374	0.240848	0.21718	0.246495	0.212092	0.245773
0.223832	0.257751	0.222249	0.255804	0.22794	0.251489	0.229812	0.250126	0.228907	0.247952
0.260779	0.237871	0.258505	0.245226	0.252255	0.252638	0.248053	0.254856	0.2374	0.264523
0.276175	0.244629	0.276979	0.245226	0.277205	0.245264	0.274491	0.245641	0.277701	0.244014
0.275873	0.260364	0.283844	0.254372	0.28483	0.256093	0.287889	0.256495	0.28456	0.253266
0.295622	0.265396	0.294479	0.26294	0.298342	0.267764	0.296709	0.264667	0.297098	0.267764
0.271822	0.302242	0.274837	0.304673	0.274234	0.306947	0.27527	0.303097	0.276175	0.306357
0.305138	0.291935	0.314786	0.283411	0.313373	0.285477	0.319812	0.283229	0.312356	0.283222
0.292173	0.327173	0.296683	0.327186	0.290641	0.324755	0.295371	0.322726	0.296225	0.321539
0.318731	0.317902	0.318807	0.325666	0.313982	0.335226	0.305	0.337475	0.304868	0.333612
0.333474	0.319001	0.343951	0.314686	0.348166	0.31598	0.348555	0.317601	0.345339	0.313373
0.328882	0.351394	0.333694	0.345339	0.343731	0.337299	0.342023	0.340302	0.343763	0.338907
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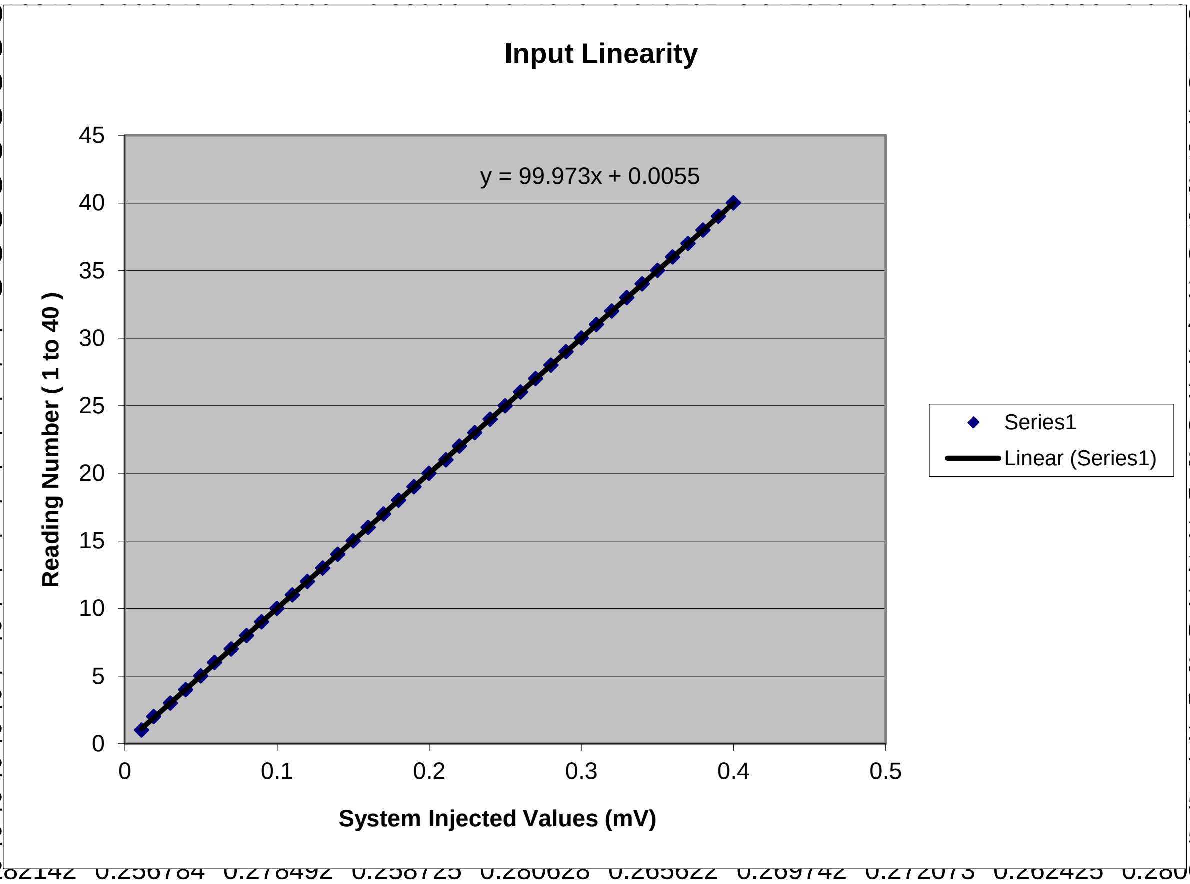

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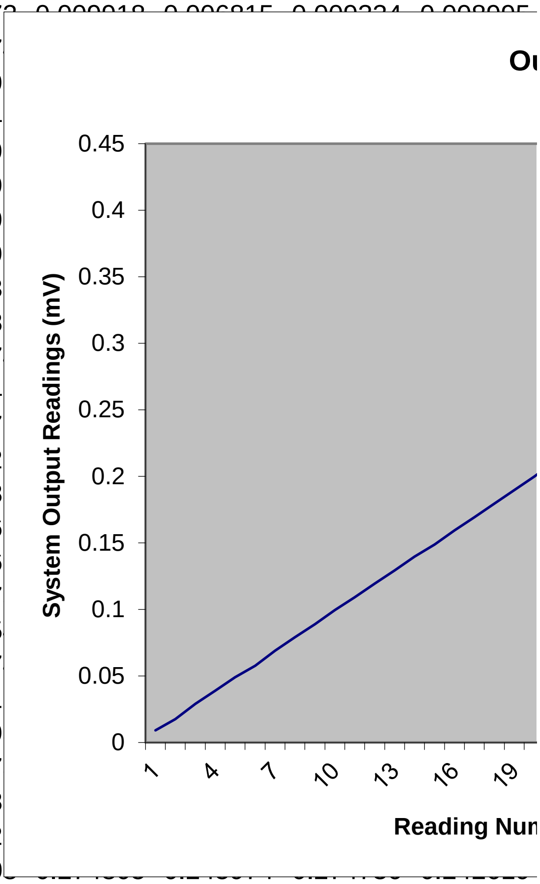

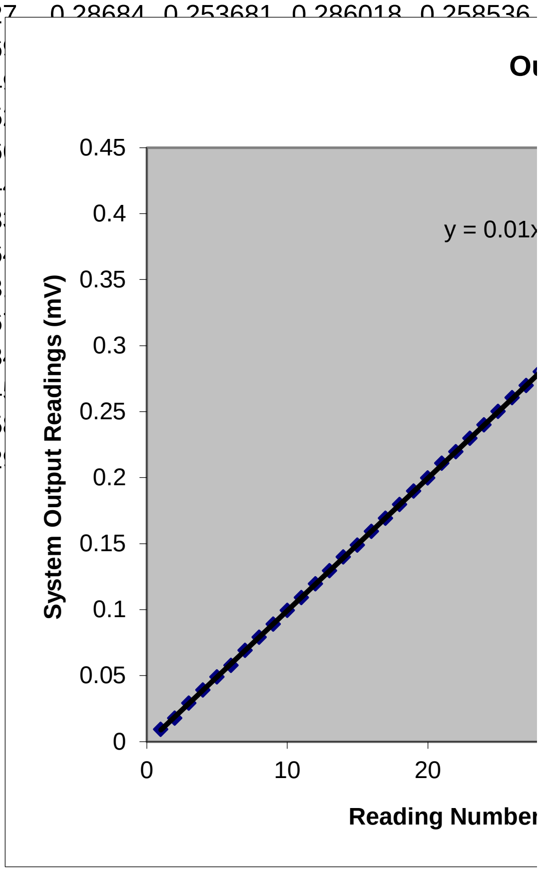

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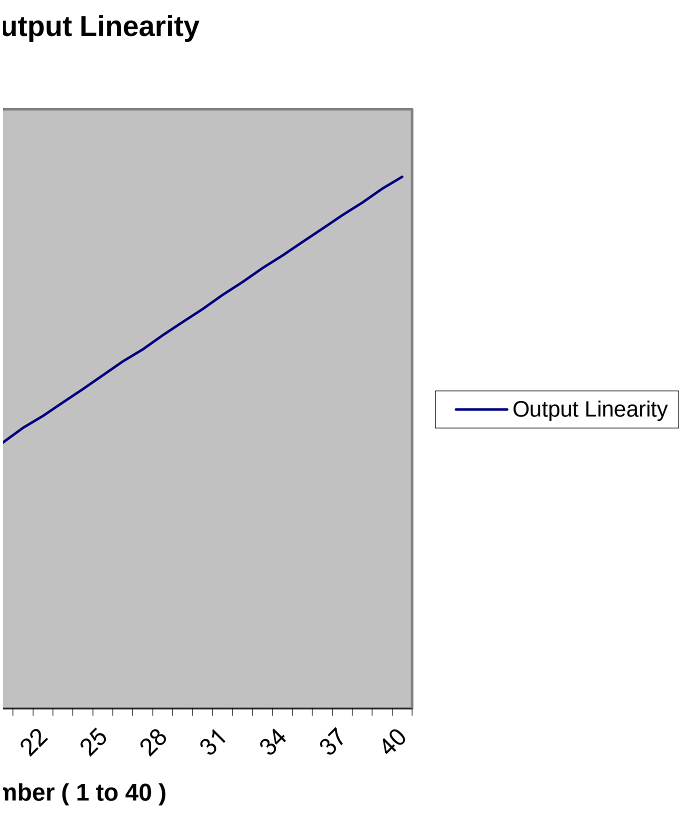

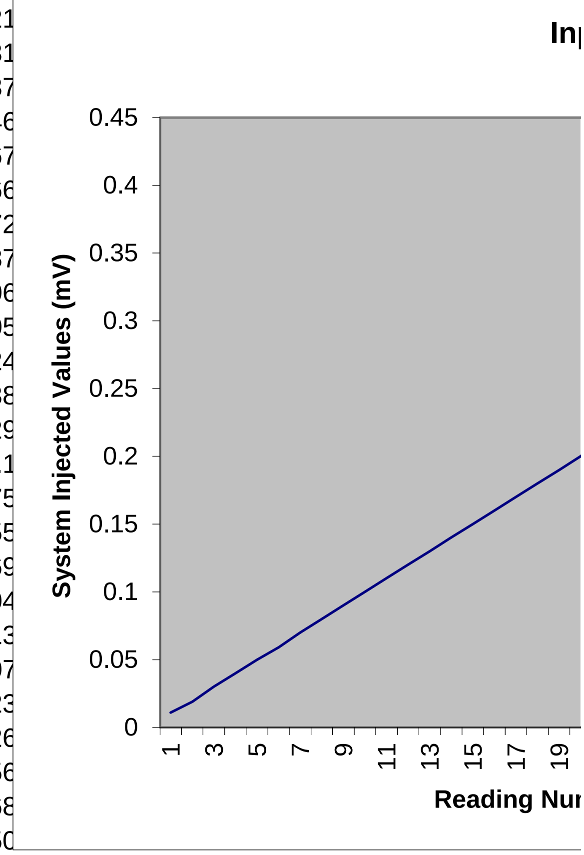

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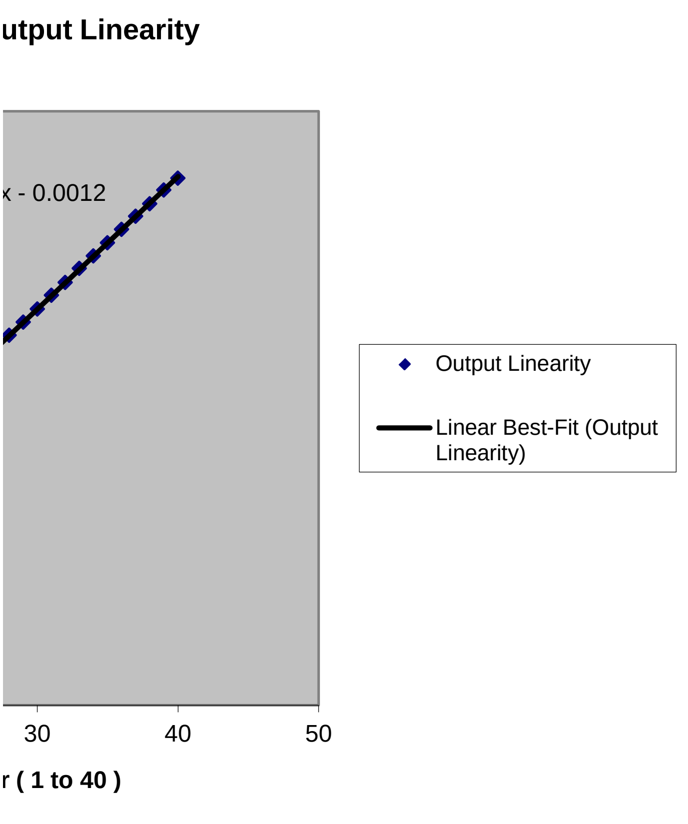

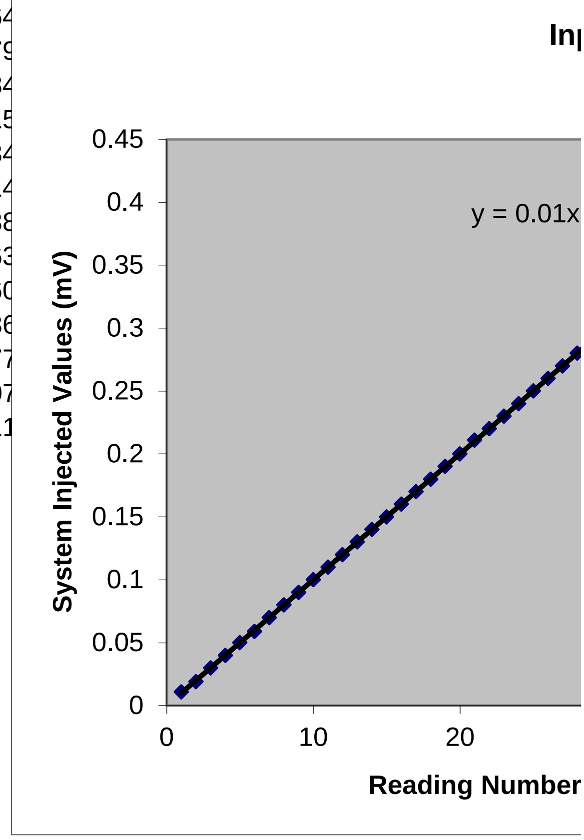

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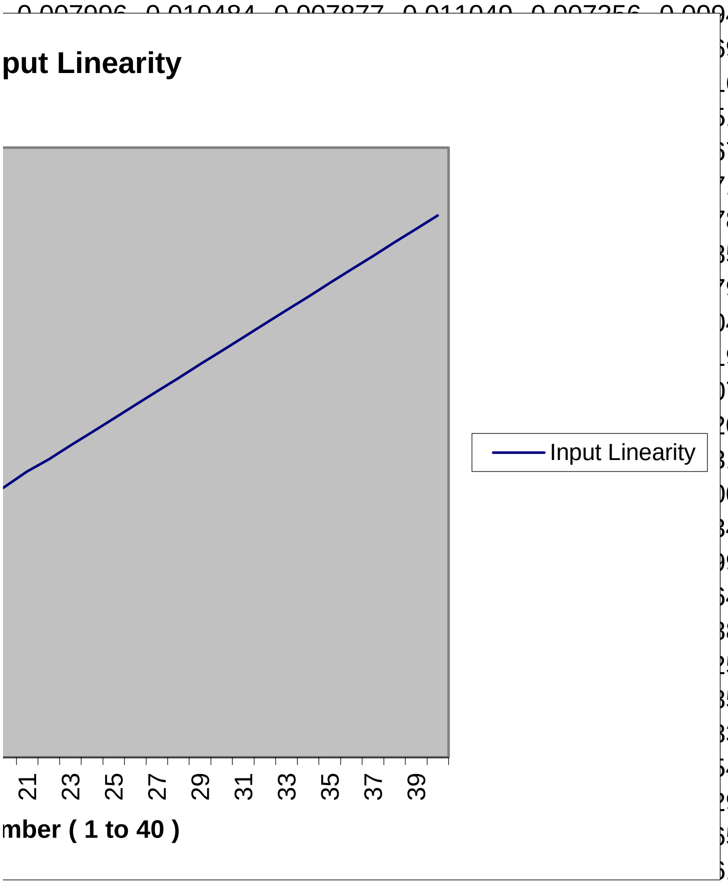

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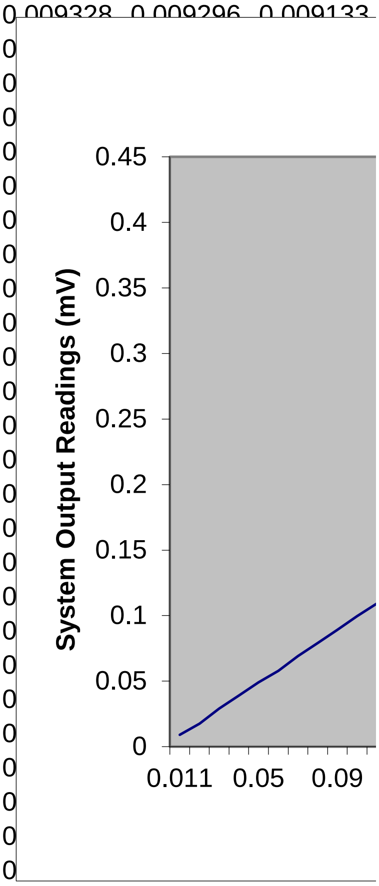

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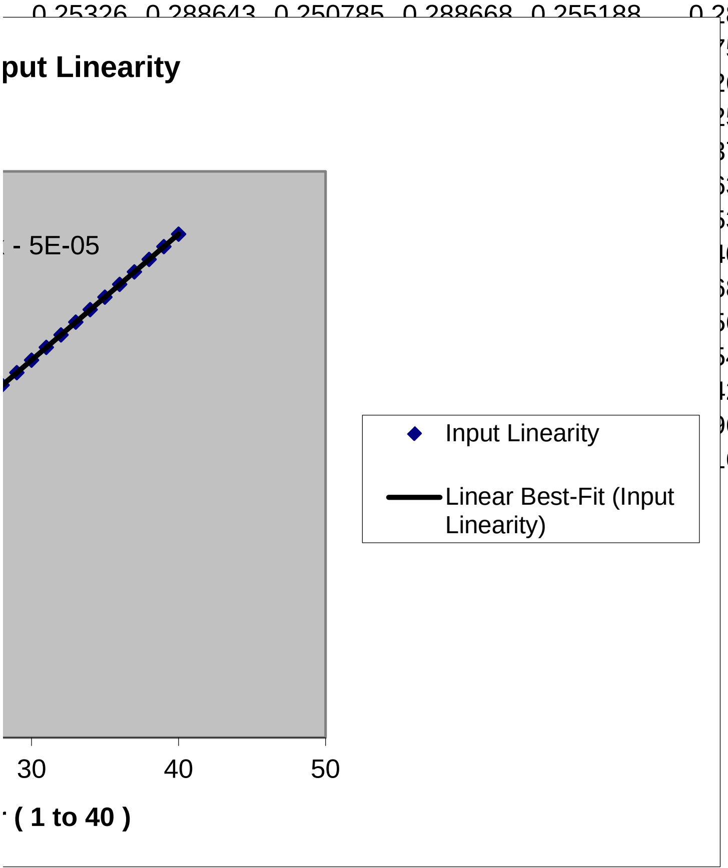

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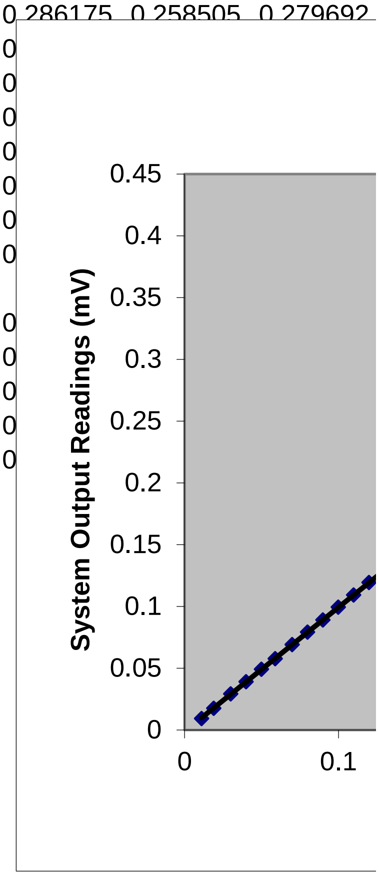

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							6	0.072293	0.07983
							7	0.097481	0.079906
							6	0.099485	0.099686
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							6	0.123015	0.114064
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							8	0.163166	0.15365
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							9	0.168348	0.188945
							9	0.184146	0.197293
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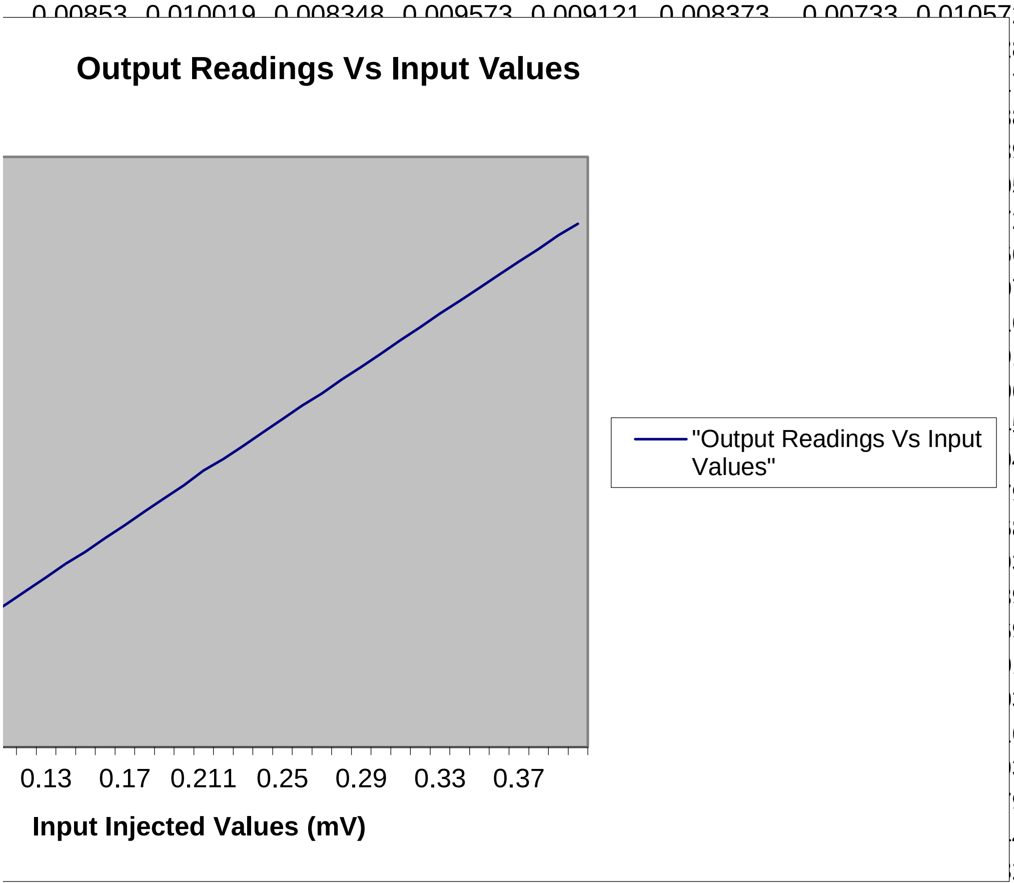

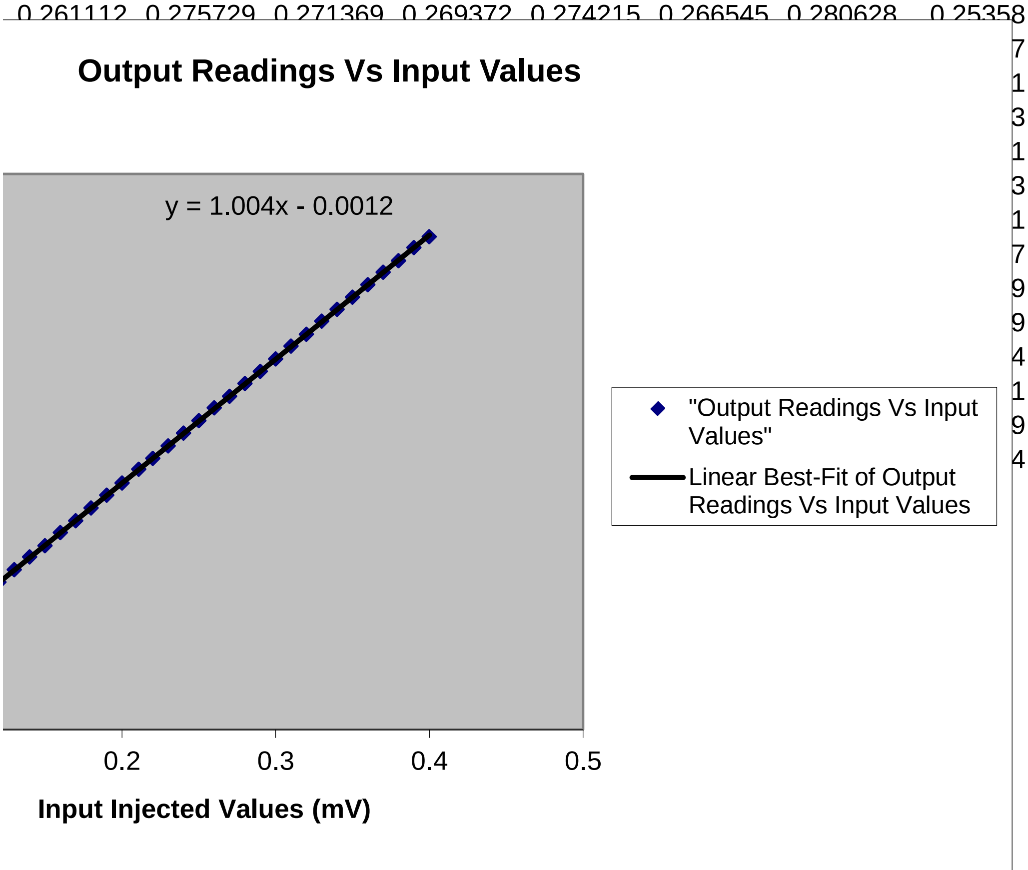

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0.139775	0.14	0.000225	14
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0.210794	0.211	0.000206	21
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0.135207	0.127173	0.142349	0.147186	0.127148	0.126834	0.144422	0.139673	0.126244	0.137286
0.163505	0.165622	0.160722	0.156998	0.163229	0.166332	0.157186	0.159805	0.168662	0.161106
0.13772	0.135151	0.137481	0.138417	0.135057	0.136438	0.136602	0.136784	0.135276	0.137682
0.117475	0.124209	0.126231	0.115597	0.116997	0.126294	0.118492	0.113574	0.120936	0.128191
0.12723	0.143141	0.14071	0.122921	0.133354	0.143536	0.134271	0.126652	0.138913	0.147136
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0.146753	0.13005	0.126244	0.147563	0.130452	0.129397	0.144673	0.143109	0.12402	0.134077
0.157996	0.163857	0.17044	0.159158	0.155151	0.168926	0.164943	0.157418	0.163549	0.168606
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Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
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0.127324	0.135678	0.146457	0.135471	0.123518	0.136099	0.14598	0.13956	0.127368	0.135534
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0.156281	0.158392	0.164655	0.163926	0.158612	0.156482	0.168178	0.169705	0.158857	0.156438
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0.126633	0.116181	0.118273	0.124937	0.125678	0.120025	0.119491	0.123329	0.124893	0.120031
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0.158178	0.167952	0.142274	0.130672	0.158003	0.168128	0.143059	0.130459	0.157299	0.165892
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
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0.148869	**0.121363**	**0.126646**	**0.152927**	**0.140704**	**0.120101**	**0.133266**	**0.150258**	**0.141112**	**0.121859**
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0.167776	0.167142	0.156954	0.15745	0.166922	0.166181	0.158643	0.159655	0.167921	0.16951
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Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
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0
0.411645

0.144121	**0.139196**	**0.124102**	**0.131721**	**0.151671**	**0.134969**	**0.123624**	**0.148725**	**0.149026**	**0.12549**
0.144033	0.143719	0.126771	0.136677	0.146746	0.137431	0.124077	0.143153	0.148109	0.127833
0.157481	0.162619	0.167261	0.162437	0.15718	0.165421	0.168166	0.157362	0.160798	0.169655
0.139102	0.139095	0.134931	0.135773	0.137443	0.136897	0.137217	0.13723	0.13669	0.136181
0.118386	0.120503	0.125314	0.121432	0.117406	0.126658	0.122412	0.117802	0.119856	0.125622
0.145559	0.13941	0.129315	0.141338	0.145942	0.132104	0.12968	0.144033	0.141709	0.130214
0.143587	0.168744	0.153046	0.139629	0.157054	0.17005	0.139497	0.143247	0.167035	0.154981
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.130666	**0.152085**	**0.140182**	**0.124472**	**0.14218**	**0.152827**	**0.130798**	**0.120402**	**0.150006**	**0.145992**
0.131432	0.149454	0.140333	0.148744	0.128712	0.136658	0.148744	0.135308	0.125628	0.145873
0.163317	0.157249	0.166765	0.168323	0.158361	0.160515	0.171382	0.164083	0.157117	0.163492
0.135283	0.136539	0.135471	0.135276	0.138222	0.138392	0.136734	0.136966	0.13794	0.137318
0.120207	0.116131	0.122205	0.12603	0.118794	0.118229	0.126828	0.121621	0.115754	0.120402
0.134253	0.146834	0.136263	0.126036	0.142261	0.145609	0.128172	0.132261	0.147167	0.139962
0.134265	0.150352	0.16701	0.149918	0.134686	0.16093	0.163128	0.139095	0.144956	0.167469
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.123417	**0.135044**	**0.152098**	**0.140107**	**0.124818**	**0.131665**	**0.151018**	**0.137387**	**0.121822**	**0.131815**
0.147155	0.127563	0.126721	0.145107	0.148398	0.132092	0.126451	0.144309	0.146809	0.13093
0.169837	0.160427	0.157067	0.166916	0.166244	0.157186	0.155835	0.165634	0.163021	0.15527
0.135546	0.138744	0.13956	0.136413	0.136677	0.137023	0.137374	0.1362	0.133266	0.136024
0.126954	0.125628	0.11865	0.122437	0.12821	0.123781	0.118794	0.124749	0.127839	0.120597
0.127041	0.136087	0.145798	0.137889	0.128153	0.135609	0.142946	0.137575	0.129736	0.137506
0.155075	0.135974	0.146175	0.163122	0.146131	0.132965	0.153568	0.168455	0.151665	0.1363
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.151954	**0.139366**	**0.123825**	**0.136137**	**0.151922**	**0.138549**	**0.125465**	**0.135678**	**0.152462**	**0.137299**
0.125226	0.14071	0.14571	0.13022	0.126633	0.14392	0.147054	0.132067	0.126269	0.143712
0.15919	0.167594	0.167952	0.158769	0.158021	0.155861	0.17059	0.167827	0.156652	0.160094
0.136181	0.13598	0.130157	0.135829	0.137406	0.133423	0.134171	0.138235	0.139322	0.136131
0.116621	0.124837	0.127481	0.118901	0.115873	0.121709	0.125327	0.121413	0.117971	0.124422
0.143957	0.136087	0.124523	0.136834	0.148361	0.136526	0.124422	0.139925	0.148744	0.133323
0.152293	0.16571	0.152663	0.139523	0.149705	0.163235	0.152035	0.135383	0.150553	0.162814
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.123712	**0.133273**	**0.149347**	**0.138995**	**0.124724**	**0.139623**	**0.154975**	**0.129975**	**0.123361**	**0.146564**
0.146903	0.130107	0.126055	0.144334	0.149215	0.129636	0.126558	0.144686	0.147004	0.128618
0.168166	0.163863	0.154592	0.158059	0.165528	0.16625	0.15669	0.161709	0.168436	0.165151
0.135276	0.138059	0.136746	0.13581	0.134598	0.137054	0.138719	0.135239	0.13669	0.136872
0.127915	0.118392	0.11679	0.125842	0.126796	0.119058	0.121539	0.127927	0.124699	0.116614
0.128254	0.14392	0.147148	0.131237	0.129912	0.142632	0.145038	0.13022	0.129139	0.142456
0.153166	0.137443	0.154315	0.168379	0.149956	0.134943	0.154202	0.166432	0.146162	0.135785
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.153574	**0.124969**	**0.127318**	**0.150835**	**0.145528**	**0.12321**	**0.131263**	**0.151727**	**0.141281**	**0.122023**
0.125829	0.144121	0.145069	0.125616	0.124215	0.14608	0.148386	0.128976	0.129253	0.148775
0.158128	0.161891	0.167701	0.163894	0.157186	0.160207	0.166872	0.161407	0.15603	0.161219
0.136721	0.133882	0.136307	0.137845	0.133769	0.134265	0.13581	0.138932	0.136124	0.135609
0.120345	0.126231	0.122519	0.118191	0.121834	0.126225	0.122161	0.117557	0.121677	0.127845
0.142613	0.128593	0.127789	0.143065	0.141784	0.124177	0.133511	0.143474	0.143449	0.128116
0.152362	0.163926	0.144623	0.133455	0.159171	0.169246	0.145477	0.135314	0.159397	0.16657
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.134083	**0.149447**	**0.137902**	**0.121156**	**0.138499**	**0.150302**	**0.137714**	**0.125459**	**0.136847**	**0.150634**
0.145534	0.127224	0.131828	0.14934	0.143882	0.127707	0.129516	0.148882	0.139642	0.12657
0.163863	0.161558	0.158467	0.162111	0.167883	0.162852	0.156451	0.165251	0.172431	0.161809
0.13772	0.139636	0.137494	0.134579	0.136796	0.13593	0.137092	0.134171	0.135006	0.134874
0.124856	0.11946	0.123128	0.126533	0.124347	0.118656	0.125452	0.129008	0.1224	0.116771
0.132544	0.147004	0.138097	0.12684	0.136005	0.146822	0.13767	0.12907	0.135503	0.146036
0.144786	0.139196	0.160283	0.165415	0.140854	0.136759	0.161928	0.16483	0.136112	0.137041
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.133486	**0.124102**	**0.145188**	**0.152117**	**0.134008**	**0.120666**	**0.140509**	**0.151759**	**0.131658**	**0.120408**
0.13434	0.146539	0.139095	0.122412	0.133411	0.147035	0.139699	0.127544	0.135879	0.148894
0.158059	0.169504	0.165107	0.158392	0.15995	0.165691	0.163687	0.156734	0.160019	0.164328
0.136281	0.135829	0.137889	0.139234	0.135999	0.136614	0.137852	0.137318	0.137023	0.134114
0.123028	0.126319	0.121018	0.116514	0.126275	0.128254	0.120747	0.118172	0.125408	0.12691
0.135446	0.125402	0.130157	0.146131	0.137406	0.128543	0.139699	0.143291	0.13397	0.129045
0.164372	0.162211	0.138807	0.139491	0.166828	0.162613	0.137833	0.142896	0.164353	0.165653
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.144121	**0.154171**	**0.131055**	**0.12081**	**0.145521**	**0.153474**	**0.130107**	**0.121193**	**0.148693**	**0.153191**
0.139629	0.126181	0.135879	0.147802	0.140534	0.126489	0.131313	0.148744	0.142173	0.127852
0.164667	0.157544	0.161407	0.170302	0.163951	0.158964	0.161489	0.168065	0.163342	0.158003
0.137041	0.137004	0.137487	0.132462	0.134994	0.134579	0.133907	0.135484	0.138216	0.139824
0.118392	0.121168	0.125892	0.126683	0.119925	0.118794	0.125647	0.125848	0.115389	0.11598
0.140647	0.146715	0.134906	0.128072	0.141778	0.144529	0.131187	0.127312	0.143945	0.146407
0.135038	0.141351	0.161106	0.159975	0.135829	0.14434	0.164472	0.163046	0.137155	0.143951
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.121263	**0.13407**	**0.152362**	**0.139121**	**0.123913**	**0.135905**	**0.152136**	**0.136602**	**0.121313**	**0.135879**
0.131055	0.147173	0.139699	0.124642	0.128279	0.145075	0.142286	0.124428	0.135094	0.149994
0.163285	0.165961	0.161608	0.157217	0.163116	0.169454	0.162996	0.15517	0.163511	0.170911
0.134259	0.137494	0.139611	0.140704	0.135509	0.136595	0.136018	0.135892	0.138053	0.136878
0.122984	0.124384	0.117381	0.120352	0.12831	0.125415	0.120082	0.119793	0.128178	0.124623
0.129397	0.126633	0.143945	0.144391	0.125798	0.126181	0.143725	0.147035	0.128543	0.126338
0.166715	0.162908	0.137513	0.144755	0.16865	0.151564	0.134271	0.146137	0.166432	0.154064
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646	0.411646
Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted

0.137312
0.137252
0.162571
0.136502
0.122324
0.136679
0.151439
0
0.411645
0

Chapter 3

Graphic User Interface (GUI) Development

The GUI provides a means to control the automated machine as well a means to capture, analyse and store data. See Appendix A for a screen capture of the GUI and Appendix C for the complete GUI source code. In order to perform the above two functions, reliable communication between the GUI and the Controller is imperative. As previously mentioned, the GUI communicates directly with the Communication Microcontroller (CM) which then in turn communicates with the Automation Microcontroller (AM).

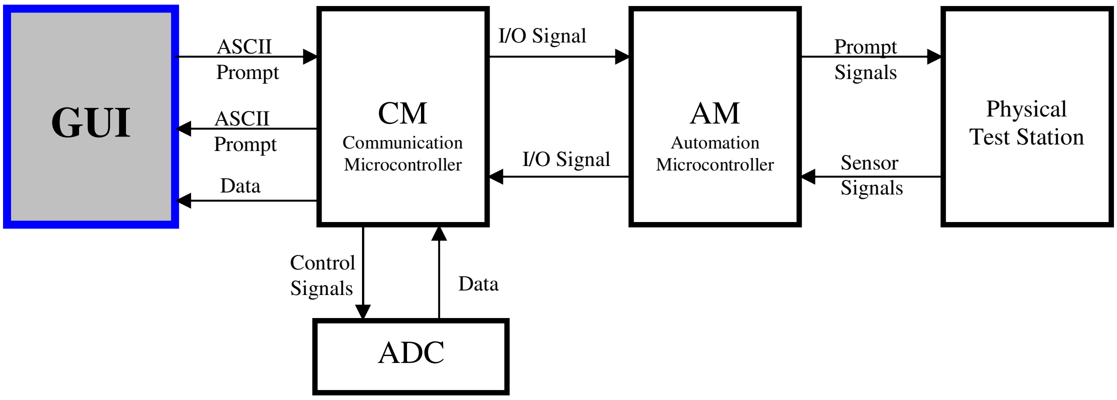


FIGURE 3-1: SYSTEM BLOCK DIAGRAM

In order to understand the function of the GUI, the communication between GUI and the CM has to first be discussed.

The GUI and the CM communicate serially using their respective serial ports which are setup to interact as required. In this chapter the author will discuss how data is processed from the point at which it is present in the GUI serial buffer as well as the prompts transmitted by the GUI to the controller, more specifically, the CM.

The interface between the GUI and the serial port (RS232) of a PC or Laptop using the Visual Basic 6 development environment is the MSComm component (only available in more recent versions of Visual Basic). Once enabled the properties of the MSComm component have to be set so that they mirror the settings for the CM serial port. Under Properties in the MSComm component, the serial port that is to be used must be specified. For the purposes of this project, CommPort 1 was chosen. Under Settings, a baud rate of 2400, no parity bit, eight data received bits and one stop bit was specified. See Figure 3-2, below for a screen capture of the input property box for the MSComm component.

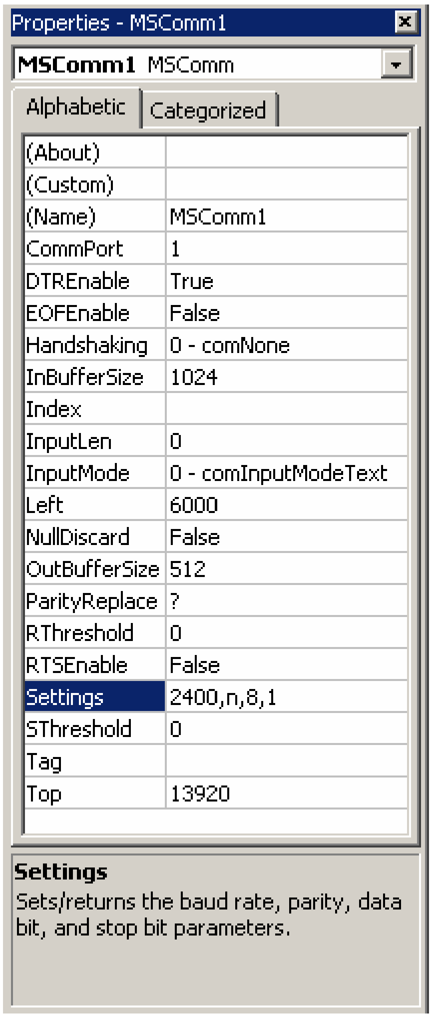


FIGURE 3-2: SCREEN CAPTURE OF THE INPUT PROPERTY FIELDS FOR MSCOMM1.

Along with MSComm1 settings, the serial port is initialised in the Form Load procedure using the statements in Code Extract 3-1, below.

```
'*******Initilise Serial Comm port 1*******
'Rec data
MSComm1.RThreshold = 1
MSComm1.InputLen = 1
MSComm1.DTREnable = False

MSComm1.Settings = "2400,N,8,1"

MSComm1.CommPort = 1
MSComm1.PortOpen = True
'Trans data
MSComm1.OutBufferCount = 0
'**** End Initilise Serial Comm port 1*****
```

CODE EXTRACT 3-1: SERIAL PORT INITIALISATION IN THE FORM LOAD PROCEDURE

For receiving data the first statement sets the threshold to 1, thus firing the Receive Event on every received byte. The second statement ensures that data is input one byte at a time. The third statement disables the DTR (Data Terminal Ready line), during communications, hence the DTR line is always Low (0). The fourth statement is included for redundancy in order to ensure the aforementioned settings. The fifth statement selects the communication port that is to be used and the sixth statement opens the selected port. Finally, the seventh statement clears the transmit buffer on loading of the GUI form.

The information that is transmitted and received can be divided into two categories. One being ASCII characters for control operations, event prompts and selections made and the other being data in the form of the High and Low Bytes of a sixteen bit word that represents the digitised volt-drop reading. See Appendix B for the complete list of ASCII commands and their respective function or event prompts.

The transmission of ASCII prompts from the GUI to the CM is accomplished by using the line of code below:

```
MSComm1.Output = "B"
```

Here the ASCII code for the character B is transmitted to the CM in order to signal that the END button has been clicked on the GUI. ASCII characters are not only transmitted on a click event on the GUI, but they are also transmitted to signal the beginning or the end of certain procedures as well as selections that have been made in the GUI input fields before the test can be started.

For any activity on the serial port or the associated buffers the OnComm procedure is initiated. The GUI has to decipher if this initiation occurred on the Send Event, Receive Event or any other activity. If,

```
MSComm1.CommEvent = comEvReceive
```

the OnComm procedure was initiated on the receive event. This means that data is present in the serial port buffer. The line of code below:

```
Let SerIn = MSComm1.Input
```

reads the serial port buffer and copies the data into the variable SerIn. This variable is read in the OnComm procedure as well as in various other parts of the analysis and calculation procedures without being altered. The analysis and calculation processes will be discussed later in this chapter.

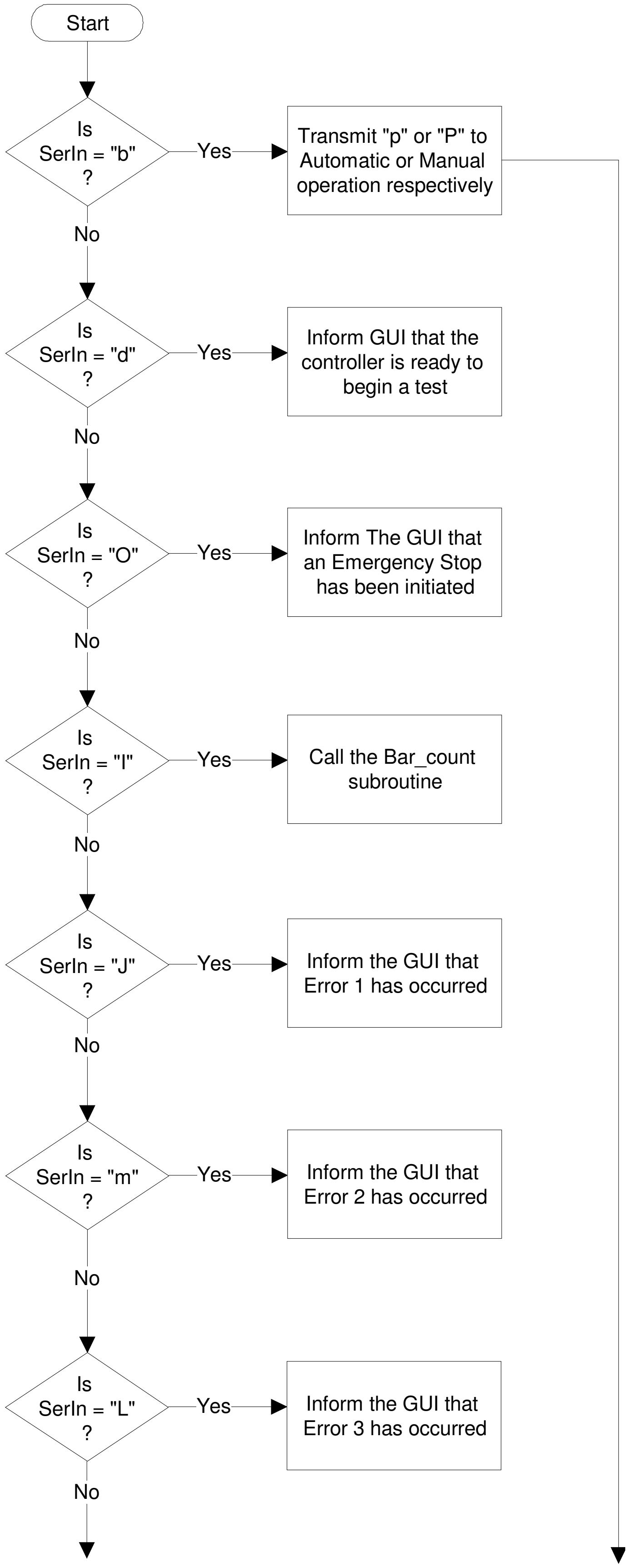
When in the OnComm procedure SerIn falls into a Case Select loop. Here the contents of SerIn is compared to all of the possible ASCII characters that are used as prompts and performs the tasks associated with the character that SerIn is equal to. When SerIn is equivalent to ‘z’, flag ‘Incomming_HighB_Flag’ is set. The setting of this flag alerts the GUI that upon the next initiation of the OnComm procedure that is due to a receive event, SerIn, will hold the high byte of the sixteen-bit, digitised volt-drop reading. SerIn will therefore not enter the case select loop.

When SerIn is equivalent to ‘y’, flag ‘Incomming_LowB_Flag’ is set to alert the GUI that on the next initiation of the OnComm procedure that is due to a receive event SerIn will hold the low byte of the sixteen-bit, digitised volt-drop reading. Here again, SerIn does not enter the case select loop. The high and low bytes are each transmitted as eight bits by the controller, however, once in the GUI serial buffer it is read as the letter or symbol that is the ASCII code representation of the eight received bits. For example, if the binary number ‘01100001’ was transmitted by the controller, the GUI will read it as the letter ‘a’. It is therefore necessary to convert the ASCII represented input to the decimal value that it represents in order to use the value in further calculations. This is accomplished in Visual Basic using the **Asc** function as shown below,

```
Low_Byte = Asc(SerIn)
```

This line of code converts the ASCII coded value held in variable SerIn into the decimal value representing the ASCII code and places it in the variable that holds the low byte of the acquired volt-drop reading.

The decimal value for the received high byte is acquired in the same manner as can be seen in the Code Extract that follows. Please note that the Code Extracts and Flow Diagrams that follow, represents the expected input prompts from the controller before the Additional Features. With the inclusion of the Additional Features, incoming prompts such as the ASCII code for “S” was added as a further case that is to be tested in the Case Select Loop. Figure 3-3 depicts the flow chart for the Case Select loop in the OnComm procedure and Code Extract 3-2 presents the related source code.


Start
Is SerIn = "b" ?
Yes
Transmit "p" or "P" to Automatic or Manual operation respectively
No
Is SerIn = "d" ?
Yes
Inform GUI that the controller is ready to begin a test
No
Is SerIn = "O" ?
Yes
Inform The GUI that an Emergency Stop has been initiated
No
Is SerIn = "I" ?
Yes
Call the Bar_count subroutine
No
Is SerIn = "J" ?
Yes
Inform the GUI that Error 1 has occurred
No
Is SerIn = "m" ?
Yes
Inform the GUI that Error 2 has occurred
No
Is SerIn = "L" ?
Yes
Inform the GUI that Error 3 has occurred
No

A (pp. 33)

B (pp. 33)

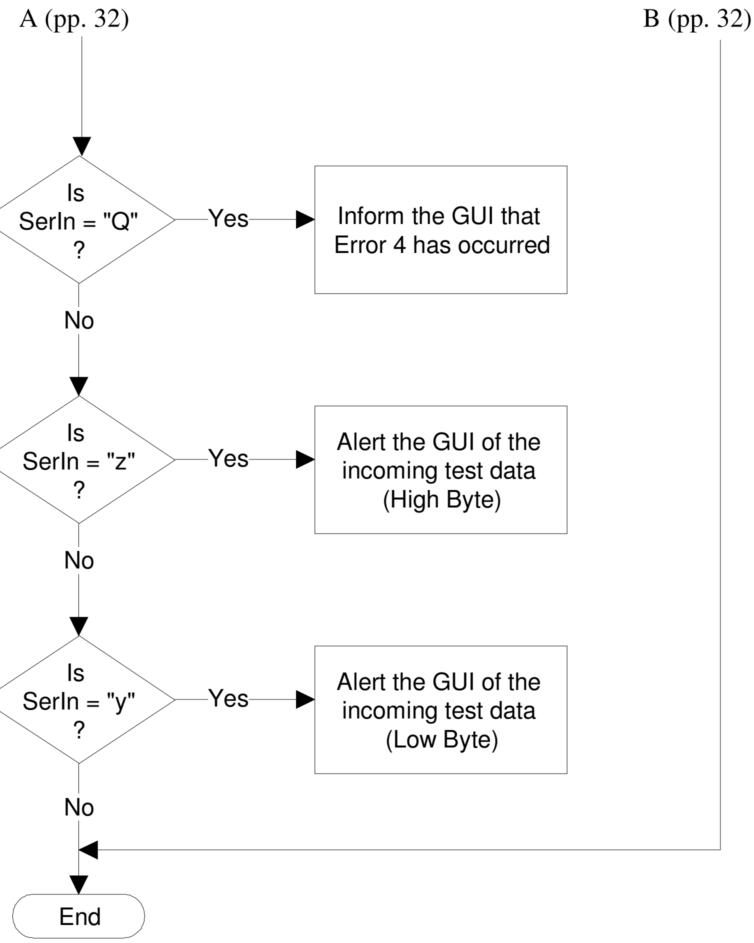


FIGURE 3-3: FLOW CHART FOR THE CASE SELECT LOOP

```
Private Sub MSComm1_OnComm()
If MSComm1.CommEvent = comEvReceive Then
Let SerIn = MSComm1.Input
If SerIn = "" Then
Let SerIn = "x"
End If

    If Incomming_LowB_Flag = True Then
    Low_Byte = Asc(SerIn)

    Let Incomming_LowB_Flag = False
    Let Incomming_HighB_Flag = False
    Call Calculation
    ElseIf Incomming_HighB_Flag = True Then
    High_Byte = Asc(SerIn)

    Let Incomming_HighB_Flag = False
    Else
    Select Case SerIn

    Case "b"
        MSComm1.Output = Auto_Man
```

```
 Case "d"
    Command5.BackColor = &H8000000F
    Let Command5.Caption = "Start"
    Command5.Enabled = True
    Let Command8.Enabled = True
    Screen.MousePointer = vbArrow
Case "O"
   Command8.BackColor = QBColor(12)
    Command7.BackColor = &H8000000F
    Let Command6.Enabled = True
    Let Command6.BackColor = &HFF8080
    Let Picture6.BackColor = &H8000000F

    Call TestEnd_States
    Let Emergency = True
    Command8.Enabled = False
    List1.FontBold = True
    List1.AddItem "Emergency Stop on Bar " & Text6.Text
    List1.FontBold = False
 Case "I"
    Call Bar_count
 Case "J"
    Let Command10.Enabled = True ' error1
    Command10.BackColor = QBColor(12)
    Frame14.ForeColor = QBColor(12)
    Frame14.FontSize = 10
    Frame14.FontBold = True
    Command9.Enabled = True
    Frame20.ForeColor = QBColor(10)
    Picture5.BackColor = QBColor(10)
    Frame21.ForeColor = QBColor(10)
    Command9.BackColor = &HFF8080
 Case "m"
    Let Command11.Enabled = True ' error2
    Command11.BackColor = QBColor(12)
    Frame16.ForeColor = QBColor(12)
    Frame16.FontSize = 10
    Frame16.FontBold = True
    Command9.Enabled = True

    Frame20.ForeColor = QBColor(10)
    Picture5.BackColor = QBColor(10)
    Frame21.ForeColor = QBColor(10)
    Command9.BackColor = &HFF8080
 Case "L"
    Let Command12.Enabled = True 'error3
    Command12.BackColor = QBColor(12)
    Frame17.ForeColor = QBColor(12)
    Frame17.FontSize = 10
    Frame17.FontBold = True
    Command8.Enabled = True
    Command7.Enabled = True
    Command7.BackColor = &HFF8080
    Command8.BackColor = &HFF8080
    Command8.BackColor = QBColor(12)
```

```
        Command7.BackColor = &H8000000F
        Let Command6.Enabled = True
        Let Command6.BackColor = &HFF8080
        Let Picture6.BackColor = &H8000000F
        Call TestEnd_States
        Let Emergency = True
        Command8.Enabled = False
        List1.FontBold = True
        List1.AddItem "Emergency Stop on Bar " & Text6.Text
        List1.FontBold = False
        Let Command12.Enabled = True
        Command12.BackColor = QBColor(12)

    Case "Q"
        Let Command13.Enabled = True 'error4
        Command13.BackColor = QBColor(12)
        Frame15.ForeColor = QBColor(12)
        Frame15.FontSize = 10
        Frame15.FontBold = True
        Command8.Enabled = True
        Command7.Enabled = True
        Command7.BackColor = &HFF8080
        Command8.BackColor = &HFF8080
    Case "z"
        Let Incomming_HighB_Flag = True
        Picture8.BackColor = QBColor(4)
        Picture9.BackColor = &H8000000F
    Case "y"
        Let Incomming_LowB_Flag = True
    End Select
    End If
End If
End Sub
```

CODE EXTRACT 3-2: ONCOMM EVENT RECEIVE

3.1 A walk through the GUI

The aim of this walk through is to lead the reader through the features, functions and code behind the Graphic User Interface. Screen captures will help the reader to understand how the GUI responds to user prompts and data that is received. See Appendix A for a true representation of the GUI and Appendix O for a GUI PowerPoint Presentation. The GUI is divided into two separate parts, one being the Test Setup Fields and the other being the Test In Progress Fields. Each of these will be discussed individually in the sections that follow.

3.1.1 Test Setup Fields

3.1.1.1 User Identification Frame

The input fields in this section are used to setup the system for the specific armature that is to be tested. See Figure 3-4A and Figure 3-4B. The User Identification frame is the location in which the details of the staff member that is to perform the test are entered.

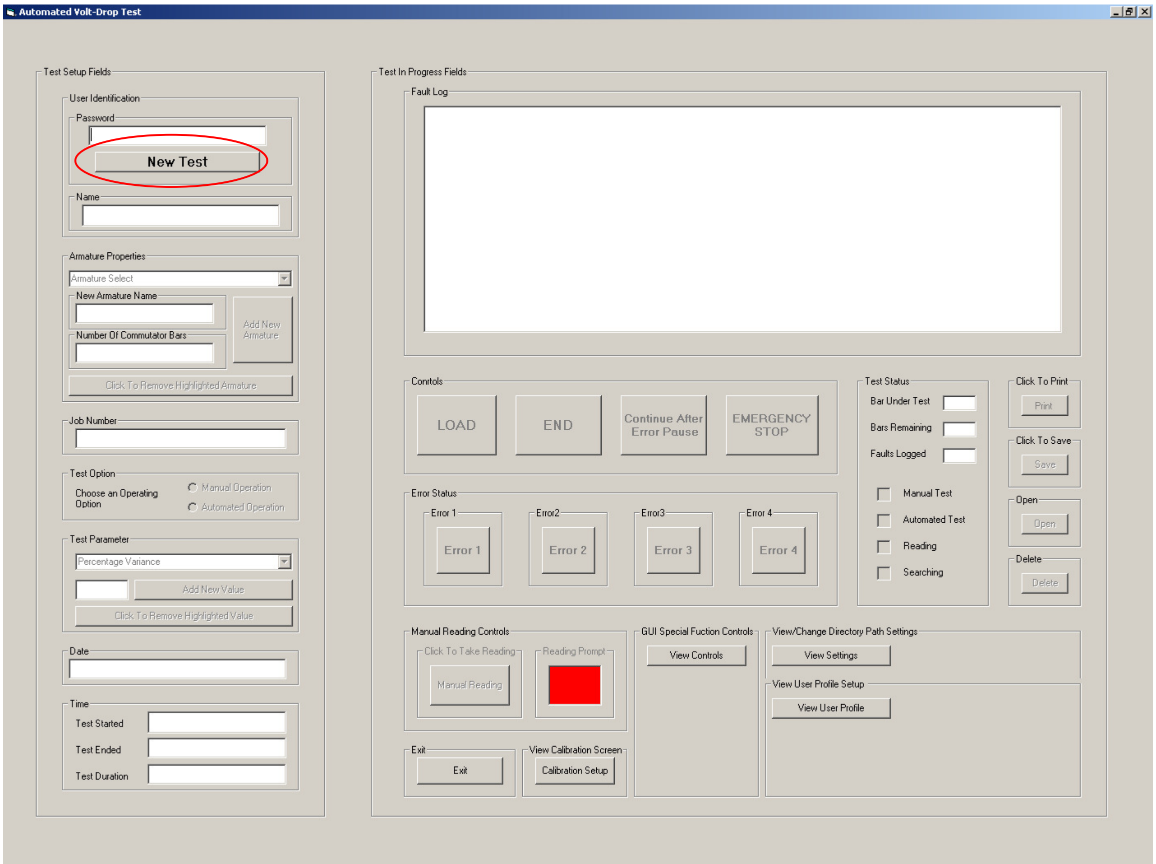


FIGURE 3-4A: INITIAL TEST SCREEN

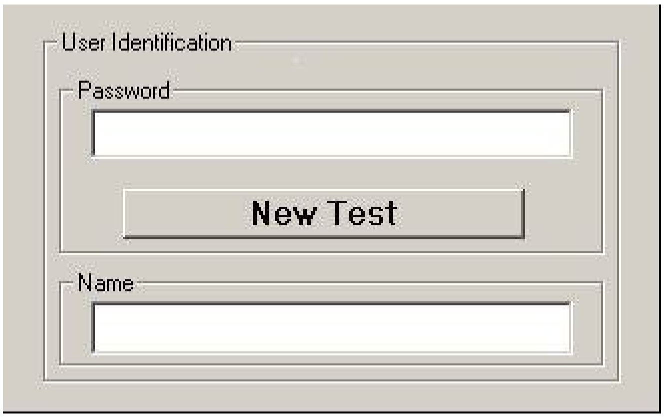


FIGURE 3-4B: USER IDENTIFICATION FRAME ON THE INITIAL TEST SCREEN

Initially, except for the New Test button encircled in Figure 3-4A, all the buttons and text input boxes are disabled. On clicking on the New Test button in the Password frame the Enter button is enabled and replaces the New Test button. See Figure 3-5A, and Figure 3-5B.

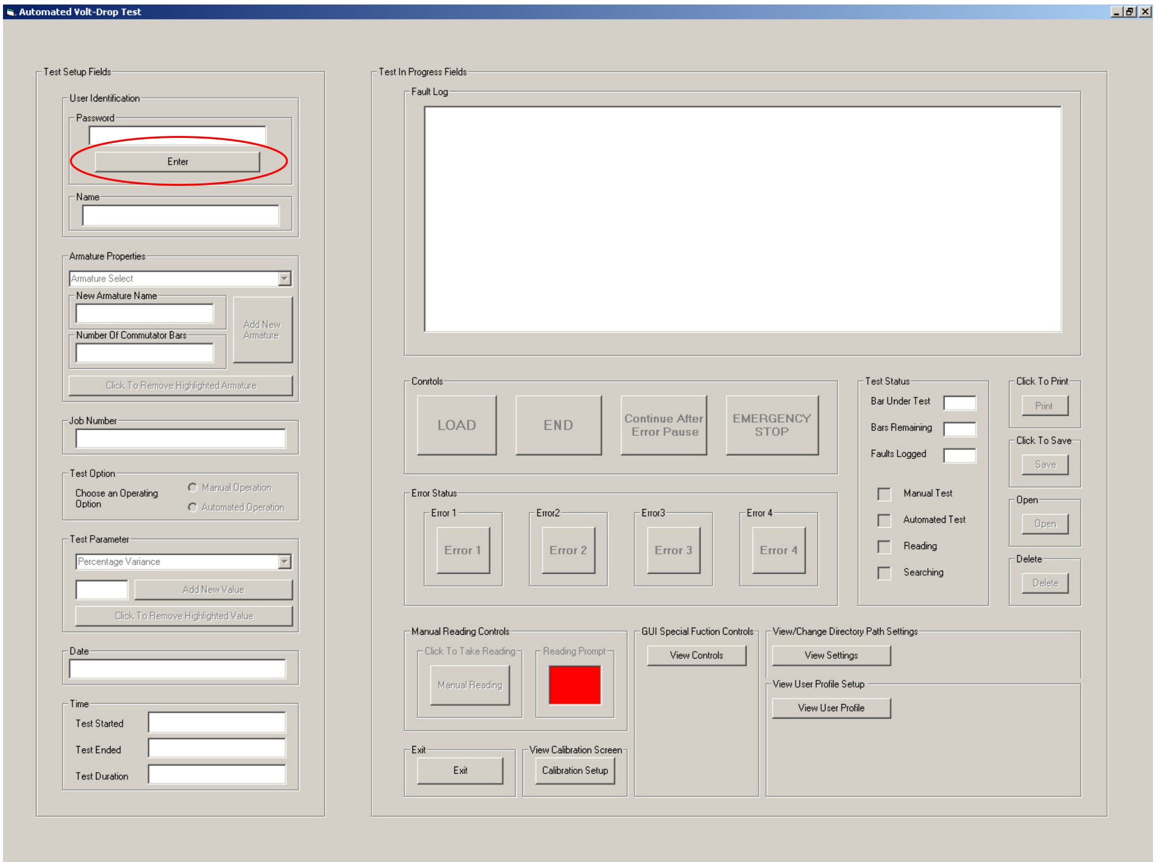


FIGURE 3-5A: INITIATE TEST SCREEN

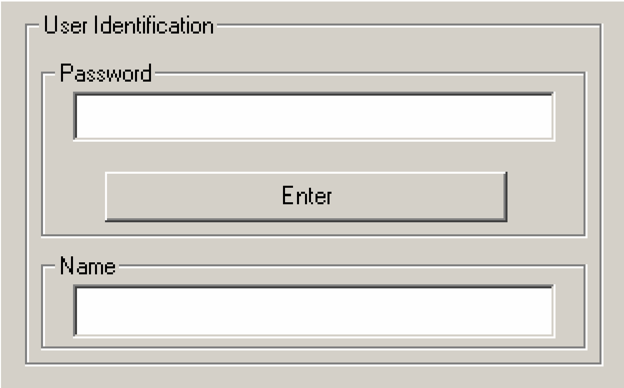


FIGURE 3-5B: USER IDENTIFICATION FRAME ON THE INITIATE TEST SCREEN

At this stage, except for the Enter button, all other control buttons are disabled and except for the Password text input box all the text input boxes are still disabled. To enable the GUI the correct user password has to be entered. This password was originally a generic password that was assigned to the system. Any staff member that was assigned to use this system was to use this password. This has subsequently been changed such that each user has a unique username and password that is chosen by the individual. The username and password is stored in a file on the PC or laptop hard-drive and is accessed and/or edited via the GUI whenever need be.

This login system is very much like the standard Windows® username and password login system except for the fact that only the password is entered in order to use the system. If the password is one that exists in the Username and Password file, the username that is associated with the entered password is displayed in the Name text box. This method is used to ensure accountability as the username displayed in the Name text box is the name that is printed in the test report and saved in the test history file. The username and password feature is discussed in detail in Chapter 6 under the heading, Multiple User Names and Passwords.

On entering the incorrect password GUI informs the user that the password is incorrect as well as the number of attempts that remain. See Figure 3-6A and Figure 3-6B.

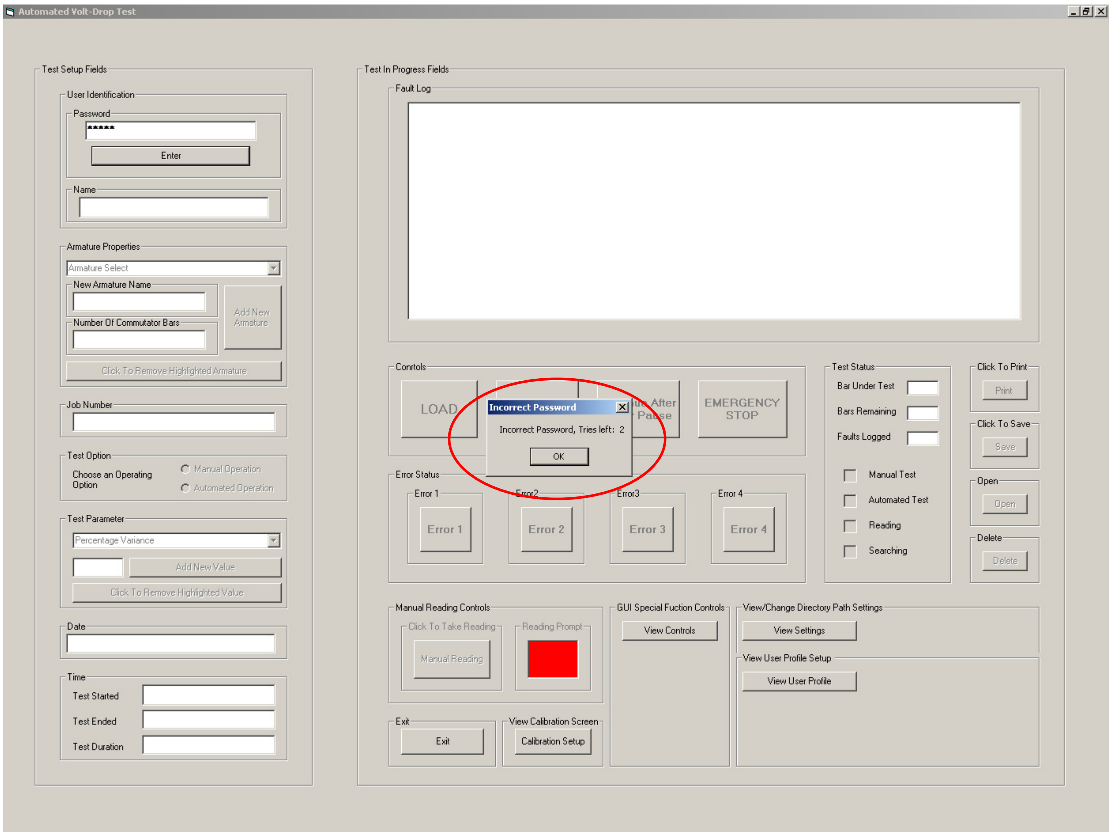


FIGURE 3-6A: GUI REPRESENTATION WHEN AN INCORRECT PASSWORD HAD BEEN ENTERED

FIGURE 3-6B: MESSAGE BOX INFORMING THE USER OF THE NUMBER OF TRIES THAT REMAIN

If, on the third attempt, an incorrect password is entered the message box depicted in Figure 3-7A appears informing the user that he/she is about to be locked out by the system.

FIGURE 3-7A: MESSAGE BOX INFORMING THE USER THAT HE/SHE HAS BEEN LOCKED OUT

On acknowledgement of this message (by clicking on the OK button) the Lock Out frame is activated. The Lock Out frame hides every input and output function of the GUI, except for the Administrator Password functionality. See Figure 3-7B. The administrator password is used by a member of staff that is responsible for the supervision of the tests as well as the test technicians. This password allows the administrator to access and edit properties such as the Armature Properties, Test Parameters, Directory path and Unlocking. A user with a basic user password does not have the ability to edit these properties. Note that only the administrator can unlock the system once it has been locked.

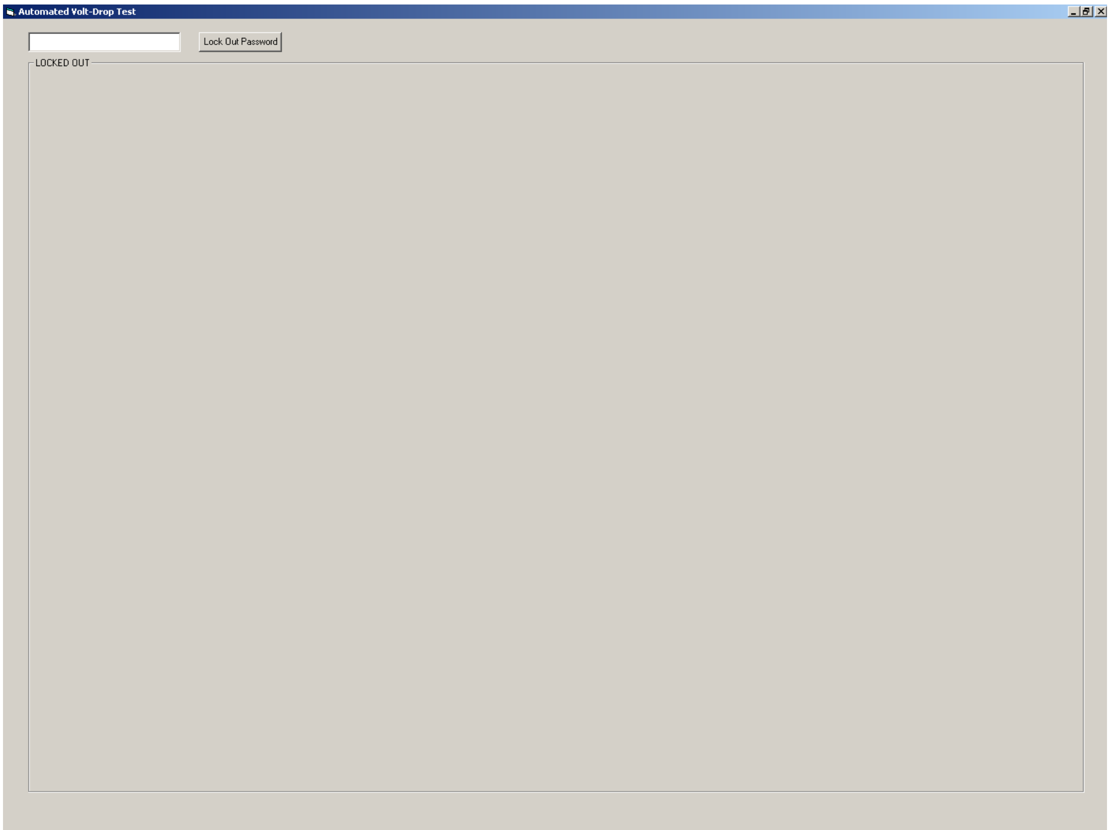


FIGURE 3-7B: LOCK OUT SCREEN

3.1.1.2 Armature Properties Frame

It is here that the user selects the armature type that is to be tested. See Figure 3-7C.

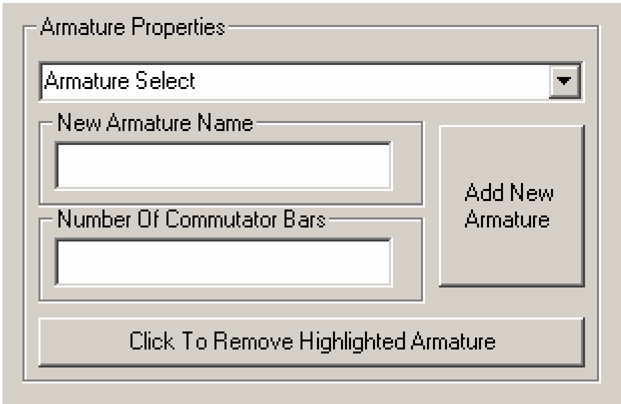


FIGURE 3-7C: ARMATURE PROPERTIES FRAME

The list of armatures is created by completing the New Armature Name and Number of Commutator Bars field and then clicking on the Add New Armature button. As mentioned previously this functionality is only available to the administrator, therefore upon clicking the above mentioned button, the user is asked for the administrator password before the new armature is added, see Figure 3-8A and Figure 3-8B. If an incorrect password is entered the new armature will not be added. For the removal of armatures from the list the Click To Remove Highlighted Armature functionality is used and is a functionality only available to the administrator. The reason for limiting access to these property fields is simply to exercise control over the test system. The user may only use the system and may not define any test limits and conditions other than those available to him/her.

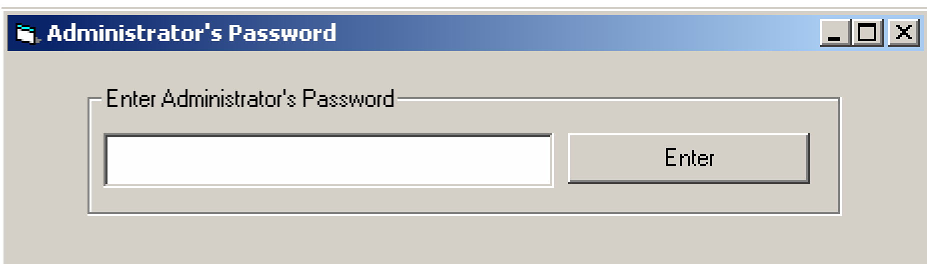


FIGURE 3-8A: ADMINISTRATOR'S PASSWORD PROMPT

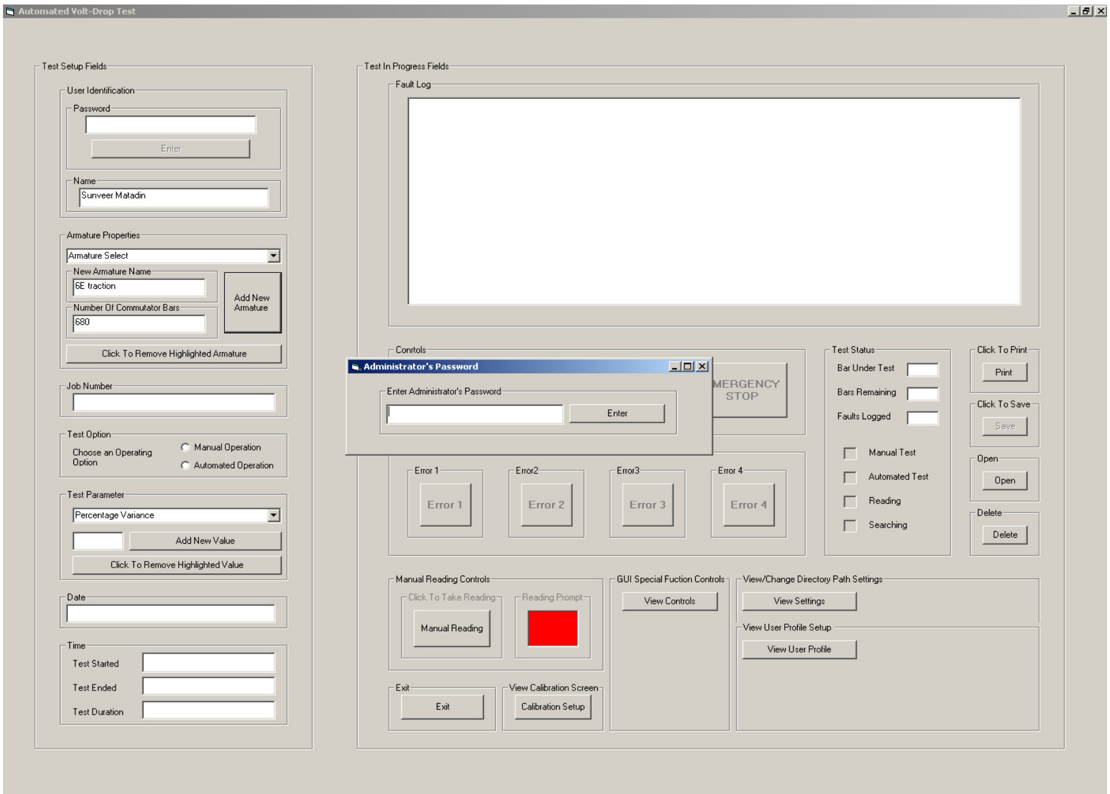


FIGURE 3-8B: GUI DISPLAYING THE ADMINISTRATOR'S PASSWORD PROMPT

All armatures appearing in the list are stored in a sequential file. This sequential file is accessed and/or edited when creating the list of armatures that are to be tested, adding a new armature to an existing list or deleting an armature from the list. The code extract below is responsible for the addition of a new armature to an existing file.

```
Private Sub Command3_Click()
If InputBox("Enter Administrators Password", "Administrators Password") = "AdminAutoSun6" Then
   If (Text4.Text <> "") And (Text5.Text <> "") Then
      Combo2.AddItem "Armature Name:   " & Text4.Text & "    Number of Bars:   " & Text5.Text
      Let a = Combo2.ListCount ' used as a record number, 1st item starts at 1
      Open Default Path & "Arm.TXT" For Append As #1
      Write #1, Text4.Text, Val(Text5.Text), (a)
      Let Text4.Text = ""
      Let Text5.Text = ""
      Close #1
   Else
   MsgBox "Enter new Armature Name and Number of Bars"
End If
Else: MsgBox "You are NOT Authorised to perform this action"
End If
End Sub
```

CODE EXTRACT 3-3: ADD NEW ARMATURE - COMMAND CLICK

The destination to which this file is saved is determined by **Default Path**. This path is specified in the Directory Path frame which will be discussed later in this chapter. The name of the file, as shown in Code Extract 3-3, is Arm. Data is written to this file using the Write statement. The data from the **Text4.Text** input box, which reflects the name of the new armature, the value of the data from the **Text5.Text** input box, which holds the number of bars on the commutator of the new armature, and the value that variable '**a**' holds is written into the file.

The data from the two input text boxes is also displayed in a Combo Box using the AddItem method. With reference to Code Extract 3-3,

```
Let a = Combo2.ListCount
```

assigns the value representing the number of items presently in the Combo Box to variable '**a**'. In this way, the last item added to the list is given the value that corresponds to the number of items in the Combo Box. For example, if the sixth armature is added to the Combo Box list the value returned by the ListCount method will be six.

The value that variable '**a**' holds is stored with the intention for it to be used as an index to access a particular armature and its associated data from the file when selected. In this way, each entry into the file is much like a record. When an item (armature) is selected from the Combo Box, it already has an index (the ListIndex) associated to it by virtue if its place in the Combo Box. This ListIndex is not to be confused with the index created when saving the record.

Referring to Code Extract 3-4, when an armature is selected, it's associated ListIndex is written into variable '**d**', the value in '**d**' is then incremented by one using **Let d = d + 1**. Each entry in the Arm file is read using the **Input #1, nam, num, cnt**, statement, after opening the file using **Open DefaultPath & "Arm.TXT" For Input As #1**. The value in variable '**cnt**' is compared to that of the value held in variable '**d**'. The reader should note that value read into variable '**cnt**' is the index that was created and assigned to variable '**a**' when saving each record. When the value in variables '**d**' and '**cnt**' are the same, the record holding the data for the selected armature has been identified. The data string read into '**nam**' holds the name of the selected armature and the value read into the variable '**num**' is the number of bars on the commutator of the selected armature. This value is read into Text Box 7 on the GUI which reflects the number of bars that remain to be tested. Each time a reading is taken this value is decremented by one until all the bars have been tested. Recall that '**d**' was incremented. The reason for this is as follows. The ListCount value which was assigned to '**a**' represented the number of items that was presently on the list when the last item was stored.

The number system for the ListCount method starts from one. Using the example from above, '**a**' will hold and store the value six for the sixth armature added to the list. Now, when selecting an armature, the value from the current ListIndex method (held in variable '**d**') is compared with the value of the stored ListCount method, (held in variable '**cnt**'). The ListIndex number system begins from zero. Again using the previous example, the sixth item in the Combo Box list will return a ListIndex value of five due to the number system starting at zero. So in order for the sixth item in the Combo Box list to return a ListIndex of six, the ListIndex value is incremented by one.

```
Private Sub Combo2_Click()
Dim d As Integer
Let d = Combo2.ListIndex
Let d = d + 1
Open DefaultPath & "Arm.TXT" For Input As #1
   Do While Not EOF(1)
   Input #1, nam, num, cnt
      If cnt = d Then
      Let Text7.Text = num
      Let Text6.Text = 0
      Let Text8.Text = 0
      Let No_of_Bars = Val(num)
      End If
   Loop
 Close #1
End Sub
```

CODE EXTRACT 3-4: COMBO BOX ARMATURE SELECT - COMMAND CLICK

The question that now arises is what happens when an armature (record) is deleted from the list? How is the saved index edited? See Code Extract 3-5.

```
Private Sub Command4_Click()
If InputBox("Enter Administrators Password", "Administrators Password") = "AdminAutoSun6" Then
  If MsgBox("Are You Sure That You Want to Delete The Selected Item?", vbYesNo) = vbYes Then
  Dim c As Integer

    Let b = Combo2.ListIndex
    Combo2.Clear
    If Dir(DefaultPath & "Arm.TXT") <> "" Then
      Open DefaultPath & "Arm.TXT" For Input As #1
      Open "Del" For Output As #2

         Do While Not EOF(1)
          Input #1, nam, num, cnt
           If cnt <> (b + 1) Then
           Combo2.AddItem "Armature Name:   " & nam & "    Number of Bars:   " & num
           Let c = Combo2.ListCount
           Write #2, nam, num, c
           End If
        Loop
      Close #1
      Close #2
      Kill DefaultPath & "Arm.TXT"
      Name "Del" As DefaultPath & "Arm.TXT"
    Else: MsgBox "No Armature Properties Found"
    End If
  End If
Else: MsgBox "You are NOT Authorised to perform this action"
End If
End Sub
```

CODE EXTRACT 3-5: CLICK TO REMOVE HIGHLIGHTED ARMATURE - COMMAND CLICK

Before clicking on the ‘Click to Remove Highlighted Armature’ button, an armature must have already been selected. The delete process is only initiated if the administrator’s password has been entered correctly. The process entails opening the Arm file to read data, opening a further file named ‘Del’ to write data into, then searching for the selected armature (record) and deleting it. Each record is read from Arm, its record (variable ‘**cnt**’) index is compared to the value of ListIndex method plus one (variable ‘**b**’).

If these two variables are not equal then that record is written into the Del file. This means that every record except the selected one is copied into the Del file hence, the

Del file holds all records except the omitted record. The selected record has been deleted from the list. The question still remains, how is the saved index values edited? Referring to Code Extract 3-5, the reader will notice that each time a record is copied into the Del file, it is copied with a new index using variable '**c**'.

```
Let c = Combo2.ListCount
Write #2, nam, num, c
```

The new index associated with each record is the value of the ListCount method for the new list being created during the delete process. The original content of the Combo Box is deleted and a new list is created using the AddItem method. As an example, if the third item in the old list is to be deleted, items one and two are copied into the Del file as their saved index (variable '**cnt**') is not equal to variable '**b**'.

When copying into the Del file, each item is also added (using the AddItem method) to the previously cleared (using the **Combo2.Clear** statement) ComboBox. Hence the stored index value using variable '**c**' is one for item one, as after this item was added to the Combo Box list, the ListCount method returned a value of one. In the same way, item two will have an index value of 2. Now, because item three is the item selected to be deleted, its saved index (variable '**cnt**') is equal to variable '**b**'.

When this occurs, the item (item three in this case) is not copied to the Del file, nor is it added to the Combo Box list. Hence the Combo Box List still contains two items and its current ListCount method value will still be two. When the fourth item is read and the index values compared, the values will not be equal. Item four is then added to the ComboBox list and also copied into the Del file. Once added to the ComboBox list, the ListCount method will return a value of three which is copied into variable '**c**' and saved in the Del file as the new index for the previously known item four, but now the current renamed item three.

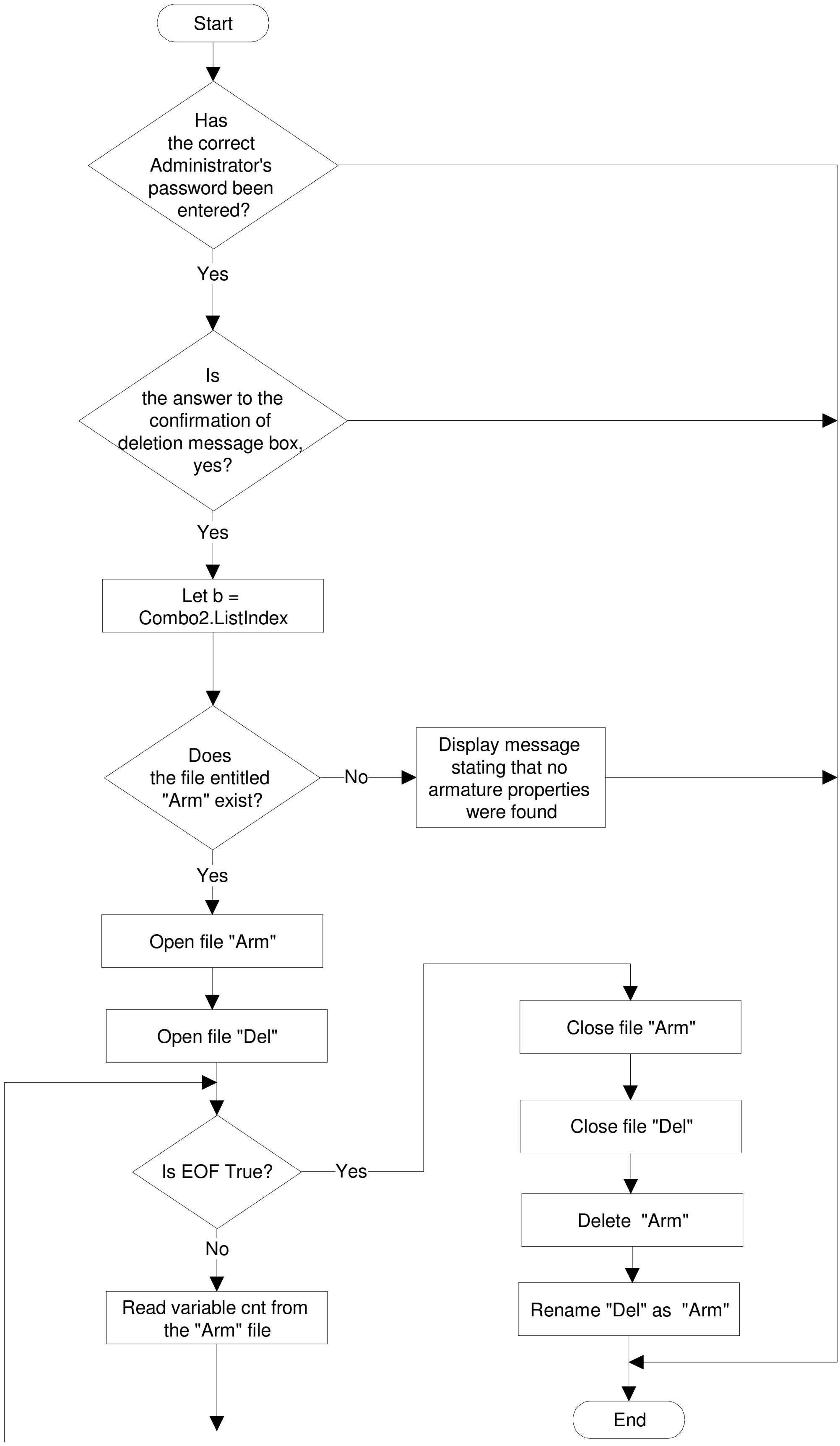
Hence item four, with an index value of four, from the Arm file is saved as item three with an index value of three in the Del file. Each item copied into the Del file from this point forward will be saved with a new index. After all the records (except the one selected to be deleted) from the Arm file has been copied into the Del file, the entire Arm file is deleted using the,

```
Kill DefaultPath & "Arm.TXT"
```

statement. The Del file is then renamed Arm using,

```
Name "Del" As DefaultPath & "Arm.TXT"
```

The new Arm file now contains all items except the one that was selected to be deleted. See Figure 3-9 for a flow chart of the delete process.


Start
Has the correct Administrator's password been entered?
Yes
Is the answer to the confirmation of deletion message box, yes?
Yes
Let b = Combo2.ListIndex
Does the file entitled "Arm" exist?
No
Display message stating that no armature properties were found
Yes
Open file "Arm"
Open file "Del"
Is EOF True?
Yes
No
Read variable cnt from the "Arm" file
Close file "Arm"
Close file "Del"
Delete "Arm"
Rename "Del" as "Arm"
End

A (pp. 49) B (pp. 49)

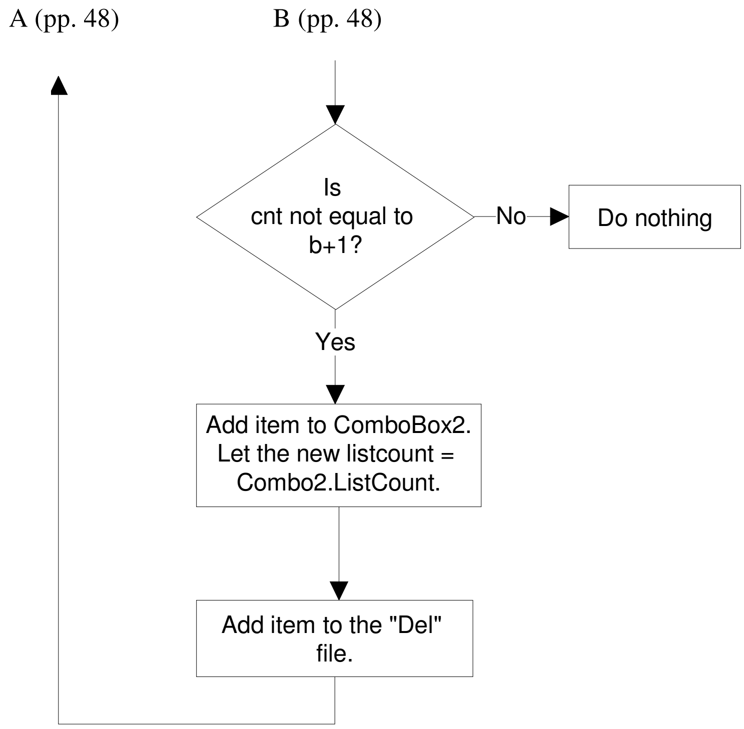


FIGURE 3-9: CLICK TO REMOVE HIGHLIGHTED ARMATURE COMMAND CLICK FLOWCHART

3.1.1.3 Job Number Property Frame

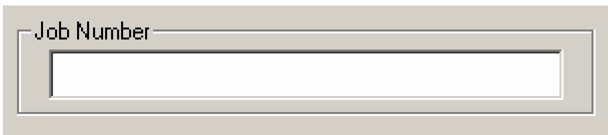


FIGURE 3-10: JOB NUMBER PROPERTY INPUT FRAME

It is in this input box that the armature serial number is entered. This serial number is reflected in the test report printout and it is also used as a file name under which the test results are saved. As will be discussed later in this chapter, tests are saved in files bearing the serial numbers of armatures as filenames in order to generate a test history for each armature. When a test is carried out on an armature with a file name (serial number) which does not appear in the file containing the list of armatures that were previously tested, that armature is added to the saved list, i.e. its serial number is added to a sequential file named '**Saved_List**'.

A sequential file bearing the name of the serial number of the armature is also created and it is here that the test results are saved. When saving a test for an armature with a serial number that already exists the content of the Job Number Property frame is compared with the list of serial numbers in the 'Saved_List' file. When a match is found that file is opened and the present test details are added to it. If no match is found then a new file is created and the name of the file is added to the 'Saved_List' file.

3.1.1.4 Test Option Property Frame

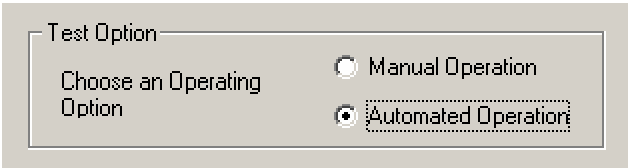


FIGURE 3-11: TEST OPTION PROPERTY FRAME

This property frame allows the user to choose between Automated and Manual modes by clicking on the appropriate option. Once a selection is made it is reflected in the Test Status property frame, as show on Figure 3-12 below.

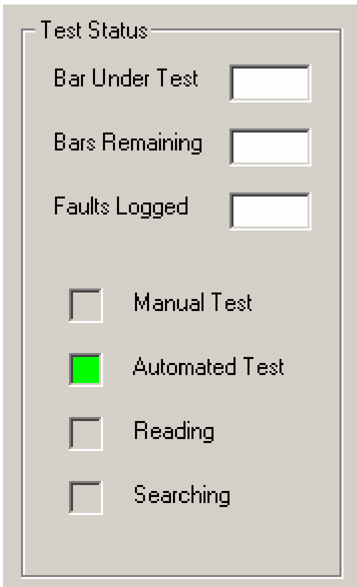


FIGURE 3-12: TEST STATUS PROPERTY FRAME

In Automated mode the entire system is enabled. This means that the controller, more specifically the Automation Microcontroller (AM), controls the mechanical system according to the commands from the GUI and the Communication Microcontroller (CM). In Manual mode, the automated control functionality of the system is disabled and the AM enters power-down mode. Only the data acquisition, analysis and storage functionalities of the system are available to the user. In this mode, the test technician is responsible for placing the test probes on the commutator bars and switching the test current using a footswitch. On selecting the Manual option, 'G' is placed into variable Auto_Man, using the statement:

```
Let Auto_Man = "G"
```

Auto_Man is read and the ASCII representation of its contents is transmitted to the CM when the test settings are being uploaded to the controller. The Load event is initiated on clicking the Load button on the GUI. More detailed discussions will follow later in this chapter. On selecting the Automated option, 'g' is placed into the Auto_Man variable.

3.1.1.5 Test Parameter Property Frame

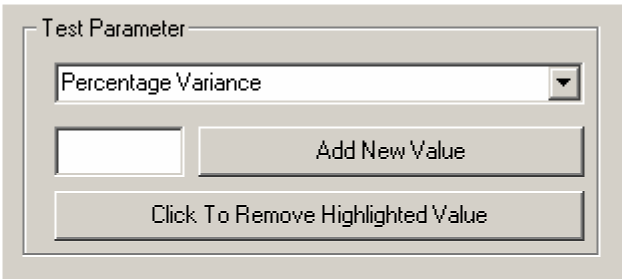


FIGURE 3-13: TEST PARAMETER PROPERTY FRAME

The Parameter Property Frame is where the user stipulates the allowable percentage variance (i.e. percentage difference) of present reading from the reference reading. This value is then stored in variable **Percentage** to be used in the Calculation subprogram. Different ranges can be added and removed from the available options by the administrator in exactly the same was way as in the Armature Properties

Frame. The operation of this frame is identical to that of Armature Properties Frame therefore the author will not enter into a discussion on the operation of this frame.

3.1.1.6 The Date and Time Frames

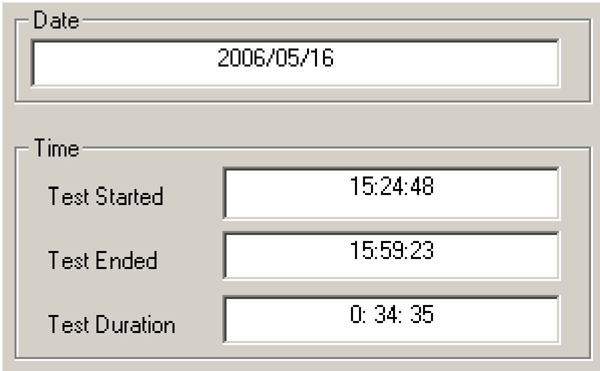


FIGURE 3-14: DATE AND TIME PROPERTY FRAME

These output fields reflect the date of a test and the test duration. On starting the test, by clicking the Start button, the date and the current time (Test Started) is uploaded from the PC's internal clock.

```
'********** load begin time and date********
            Let Text11.Text = Space(30) & Date

            Let Text12.Text = Space(20) & Time
            timed = Second(Time)
            timee = Minute(Time)
            timef = Hour(Time)
```

CODE EXTRACT 3-6: RECORDING THE TIME WHEN THE TEST WAS STARTED.

When a test ends, either naturally (when all the bars have been tested) or unnaturally (when an emergency stop has been invoked), the end time of the test (Test Ended) is uploaded from the PC's internal clock. The duration is computed as shown in Code Extract 3-7, below.

```
'************** Time&Date *************************
If Emergency = False Then

Let Text13.Text = Space(20) & Time
```

```
    timed = Second(Time) - timed
    If timed < 0 Then
    timed = 60 + timed
    timee = timee + 1
    End If

    timee = Minute(Time) - timee
    If timee < 0 Then
    timee = 60 + timee
    timef = timef + 1
    End If

    timef = Hour(Time) - timef
    If timef < 0 Then
    timed = 24 + timef
    End If
    Let Text14.Text = Space(20) & timef & ":" & Space(1) & timee & ":" &
Space(1) & timed
End If
'*************** End Time&Date *************************
```

CODE EXTRACT 3-7: CALCULATION OF THE DURATION OF THE TEST

3.1.2 Test In Progress Fields

3.1.2.1 Fault Log List

The Fault Log list is a list that displays each reading that falls outside the specified percentage variance range. It is also the screen that is used to display all relevant test information and test history that is retrieved from stored files.

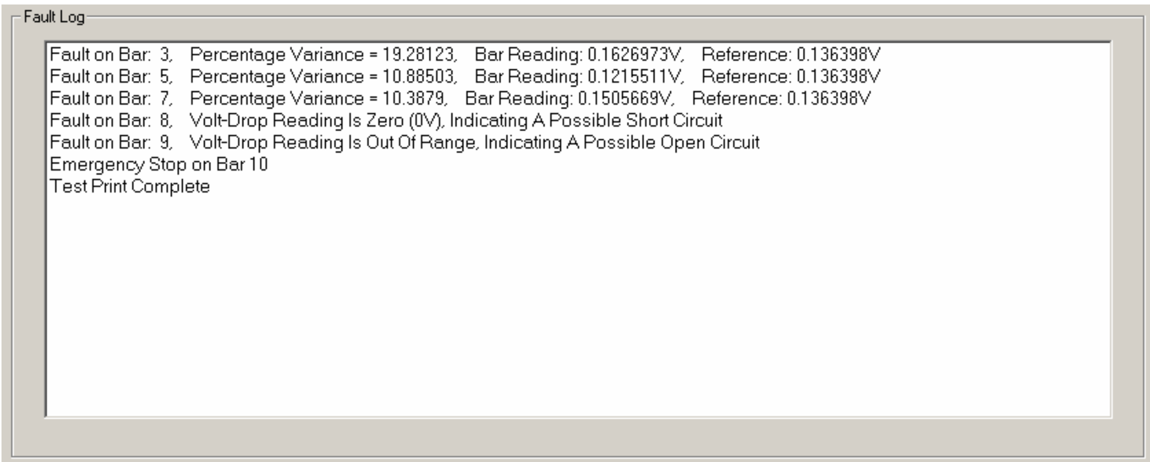


FIGURE 3-15A: THE FAULT LOG SCREEN DISPLAYING PRESENT TEST FAULTS

Figure 3-15A depicts a typical test fault log. This is what the user will see during the test as faults are recorded. Figure 3-15B below, illustrates the same test results that has been recalled from a stored file.

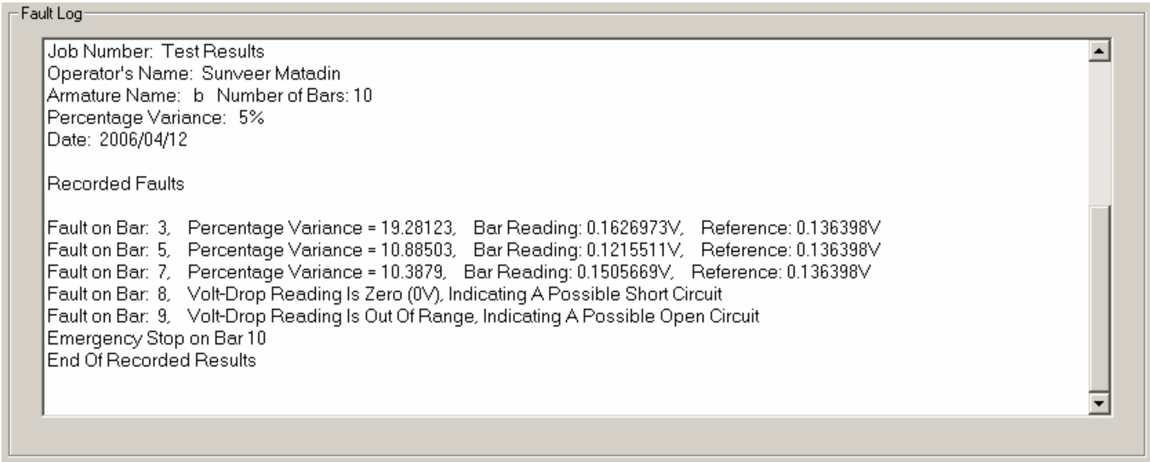


FIGURE 3-15B: THE FAULT LOG SCREEN DISPLAYING RETRIEVED FILE DATA

Figure 3-15B depicts a saved test that has been recalled in order to view the stored results. Critical information such as the job (serial) number, the operators name, the type of armature (the armature name and the number of bars on the commutator), the allowable percentage variance and the date of the test is displayed.

Under ‘Recorded Faults’, each fault is recorded with the following information: the number of the pair of bars on which the fault was recorded, the percentage variance from the reference reading, the actual volt-drop reading across the present two bars, the actual reference reading and, in the event of an emergency stop, the pair of bars on which such a stop was initiated.

3.1.3 The Control Commands

The control commands are used to prompt the controller, and where necessary the automated machine, to react to a user initiated event. There are three controls that may be used under normal test conditions when none of the system errors have occurred.

These are the Load/Start, End and the Emergency Stop controls as shown in Figure 3-16.

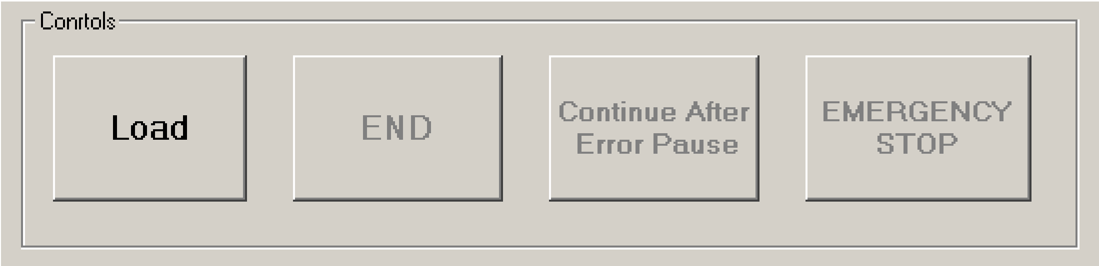


FIGURE 3-16: CONTROLS FOR NORMAL TEST CONDITIONS

In the event of an error, the two controls to be used are the Continue After Error Pause and the Manual Reading as shown in Figure 3-17A and Figure 3-17B. On an error that requires a manual reading to be taken, i.e. Error1 and Error2, the Manual Reading Control is enabled and the Reading Prompt turns green. A red Reading Prompt alerts the user that the system is not ready to take a manual reading whilst a green setting indicates to the user that the system has been prepared for a manual reading procedure. The user clicks on the Manual Reading button on the GUI when the reading is about to be taken. Thereafter the user presses a Manual Reading switch situated on the automated machine after the test current is switched on and the test probes are set in place. The volt-drop reading is then captured and processed.

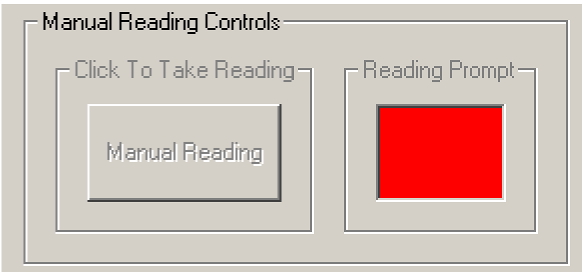


FIGURE 3-17A: DISABLED MANUAL READING CONTROL

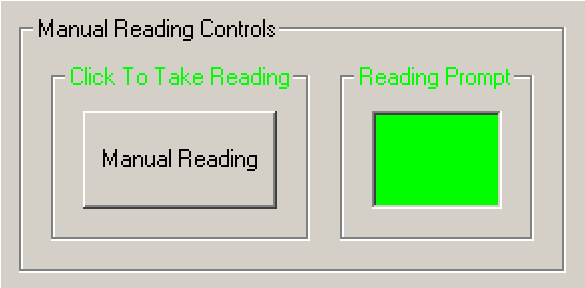
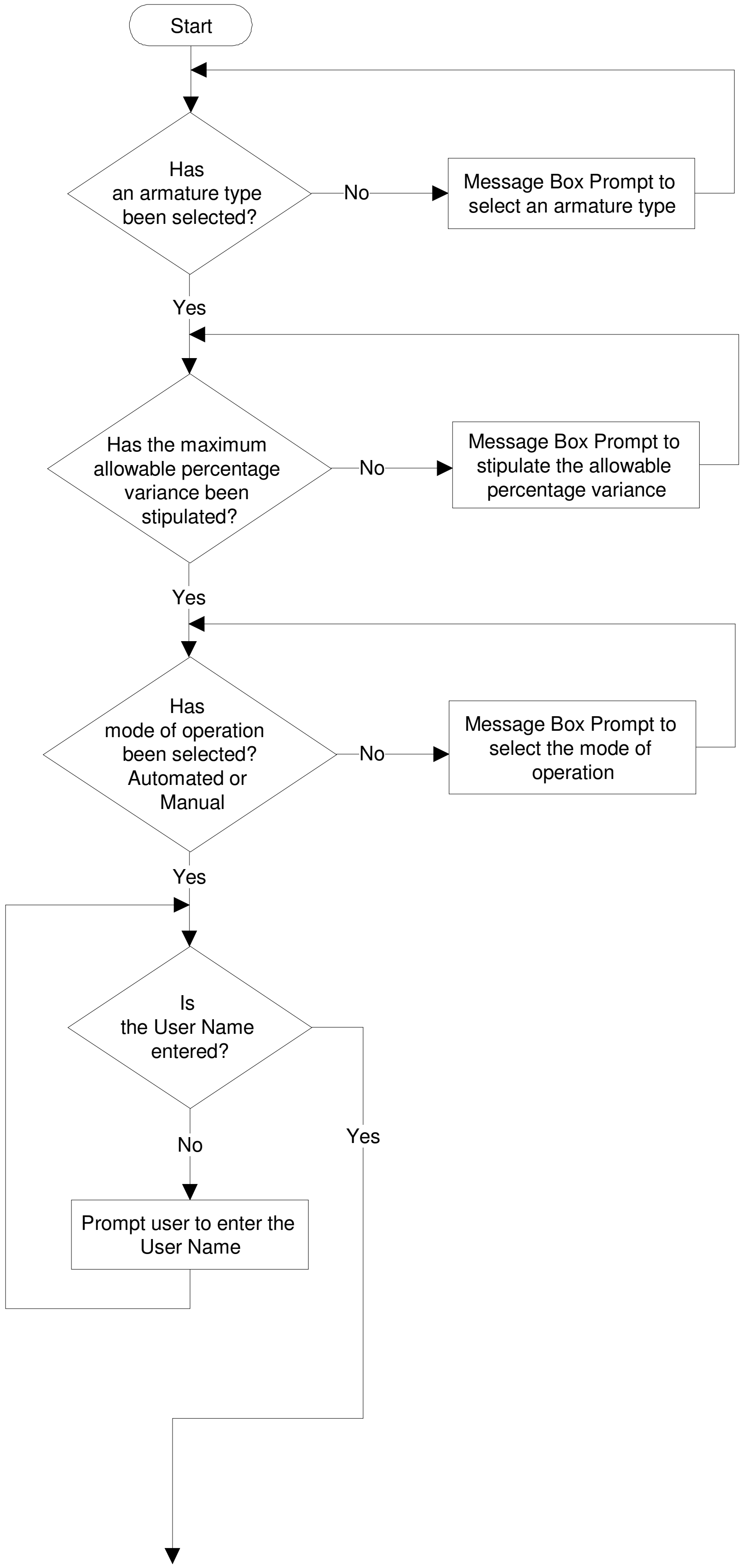


FIGURE 3-17B: ENABLED MANUAL READING CONTROL

Referring to Figure 3-16, the reader will notice that the first button in the Controls frame is the Load button and all the other control buttons are disabled. This is to ensure that all the data required for a test has been entered correctly in the Test Setup Fields as discussed earlier.

Once all the data has been entered the Load button is clicked to upload the applicable information to the controller (more specifically the Communications Microcontroller). All the input data fields on the GUI are disabled when the Load button is clicked in order to ensure that the input setting can not be altered during a test. If any input data field has not been completed when the Load button is clicked a message box or an input box appears prompting the user to enter the required data. See Figure 3-18A for the flow diagram relating to this process. Once the CM has received the information it acknowledges having done so by transmitting the ASCII code for the letter ‘d’ back to the GUI.

On receiving this, the Load button is replaced by the Start Button and the Emergency Stop Button is enabled as depicted in Figure 3-18B. When the user is ready to begin the test the Start button is clicked and ‘A’ is transmitted to the controller to begin. When the Start button is clicked it turns green, as shown in Figure 3-18C, and the mouse pointer changes to a pointer and hourglass signifying that the test is in progress.


Start
Has an armature type been selected?
No
Message Box Prompt to select an armature type
Yes
Has the maximum allowable percentage variance been stipulated?
No
Message Box Prompt to stipulate the allowable percentage variance
Yes
Has mode of operation been selected? Automated or Manual
No
Message Box Prompt to select the mode of operation
Yes
Is the User Name entered?
No
Yes
Prompt user to enter the User Name

A (pp. 58)

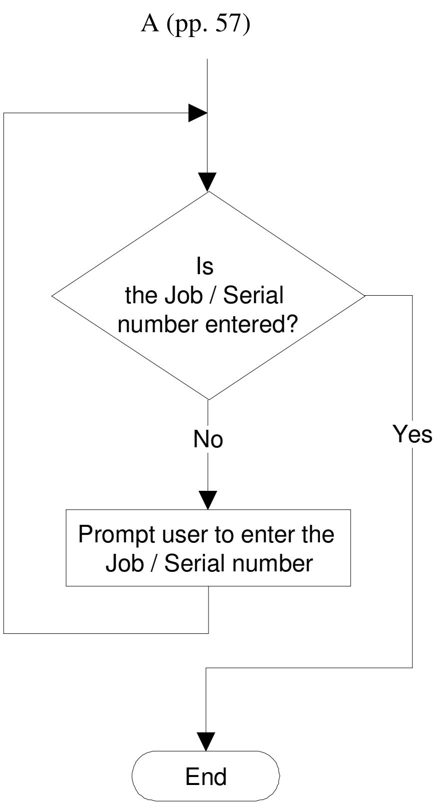


FIGURE 3-18A: DATA FIELD VERIFICATION PROCEDURE

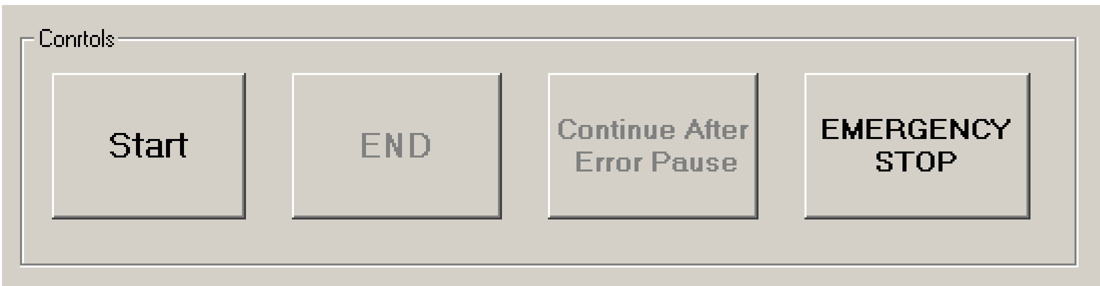


FIGURE 3-18B: START AND EMERGENCY STOP CONTROL ENABLED

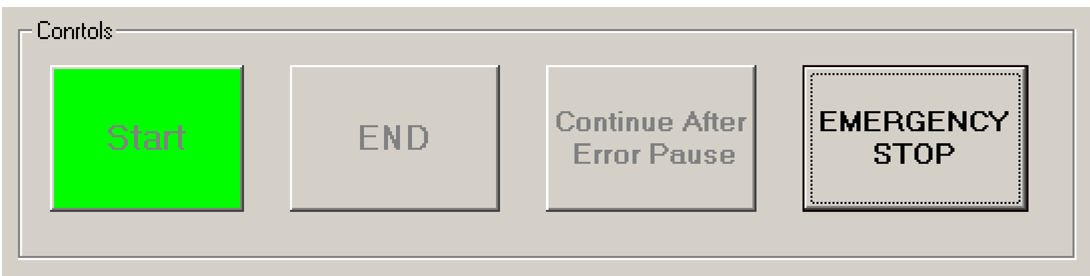


FIGURE 3-18C: START CONTROL BUTTON CLICKED TO BEGIN TEST

After the last pair of bars has been tested the End control button is highlighted in blue as shown in Figure 3-19A below. This alerts the user that the test is complete. The user must acknowledge this alert by clicking on the End button. The End control is also enabled and highlighted when an Emergency Stop is initiated. This is further discussed below.

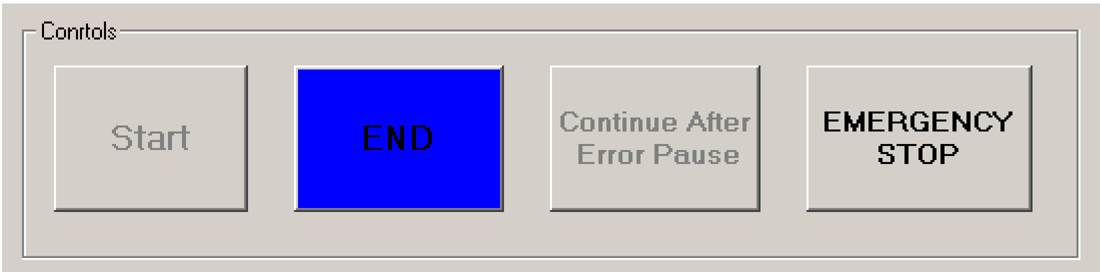


FIGURE 3-19A: END CONTROL HIGHLIGHTED BLUE TO ALERT USER

When the End control button is clicked, 'B' is transmitted to the controller and the End button is highlighted in green to signify the completion of the test. This signifies that the controller has entered powerdown mode and that the data is ready to be printed and saved or only saved. Referring to Figure 3-19B, the reader will notice that the Print and Save options are now enabled. All the output fields in the Test Status Frame and all the input fields in the Test Setup Frame are cleared. Further, all control and input buttons, except for the password Enter Button, are disabled. This allows the user to begin the next test once a valid password has been entered.

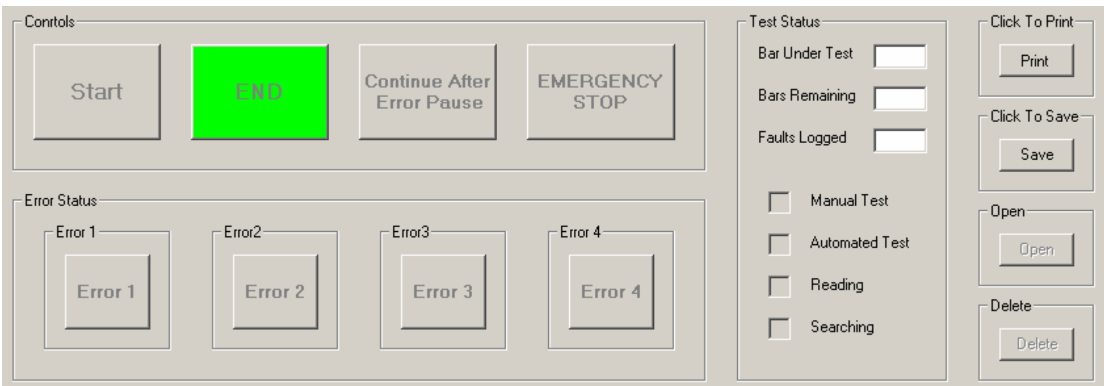


FIGURE 3-19B: END CONTROL HIGHLIGHTED GREEN AFTER ALERT IS ACKNOWLEDGED

When the detection unit, containing the test probes and optical sensor, is not raised to its initial position within the allocated time Error 4 is invoked and the Continue After Error Pause control, The Emergency Stop control as well as the Error 4 status display are enabled and highlighted as depicted in Figure 3-20.

The GUI is made aware of this error when the ASCII code for the letter ‘L’ is received. When this error occurs the user has to assess the problem and if the fault is not serious enough to abandon the test, the user will physically raise the unit to its initial position. Once this is done and the user is confident that the error was not due to an event that may be recurring, the user will click on the Continue After Error Pause control for the test to progress as usual. Once clicked all the control buttons and displays that were highlighted and enabled due to the error are disabled and are no longer highlighted. If the fault is deemed to be serious and possibly recurring in nature the user will then click on the highlighted Emergency Stop control to immediately stop the test.

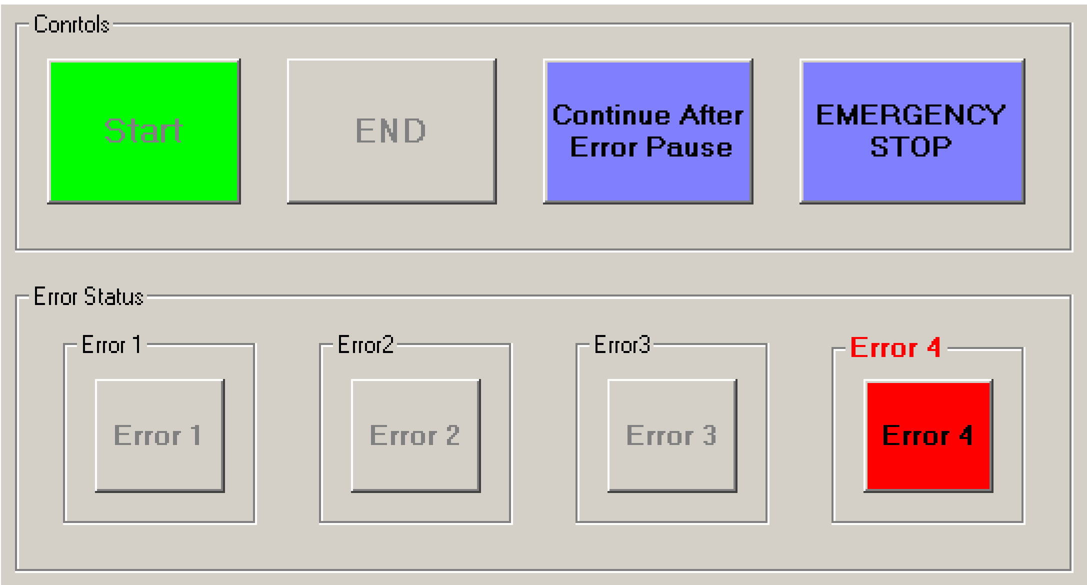


FIGURE 3-20: CONTINUE AFTER ERROR PAUSE CONTROL ENABLED FOR ERROR 4

The last control featured in the Controls frame is the Emergency Stop button. This functionality is enabled as soon as the test is started and remains enabled throughout the test. If at any point during the test, for whatsoever reason, the user decides that it is unsafe to continue with the test, an emergency stop can be evoked by clicking on the Emergency Stop control button. When clicked, the Emergency Stop control is highlighted in red, the End button is enabled and the ASCII code for the Letter 'F' is transmitted from the GUI to the CM. The CM then Sets (1) P0.5, which is connected to the AM P1.5 and P3.2 (External Interrupt 0). When the AM is interrupted due to External Interrupt 0 being triggered and P1.5 is High (1), the AM immediately initiates an emergency stop. The AM immediately halts the task that was being carried out, switches off the Test Current by Clearing (0) P2.7 and safely shuts the system down before entering Powerdown mode. The GUI reflects the fact that an Emergency Stop was evoked in the Fault Log and waits for the user to click the End button in order to end the present test.

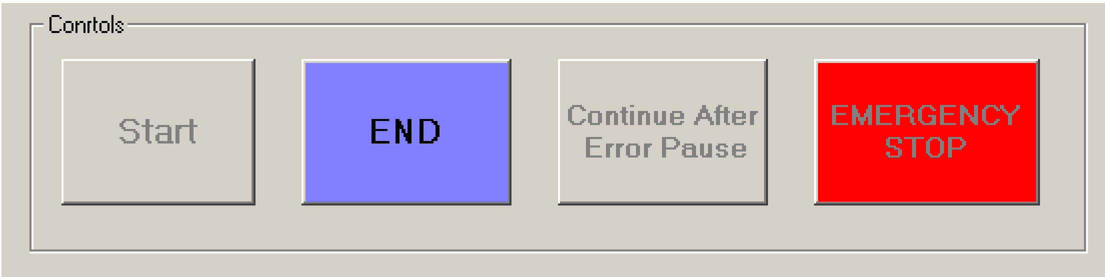


FIGURE 3-21: EMERGENCY STOP EVOKED

3.1.4 Error Status Frame

The Error Status Frame is where errors are reflected as or when they occur. When no errors have occurred, the frame looks like Figure 3-22, with each error status display being disabled.

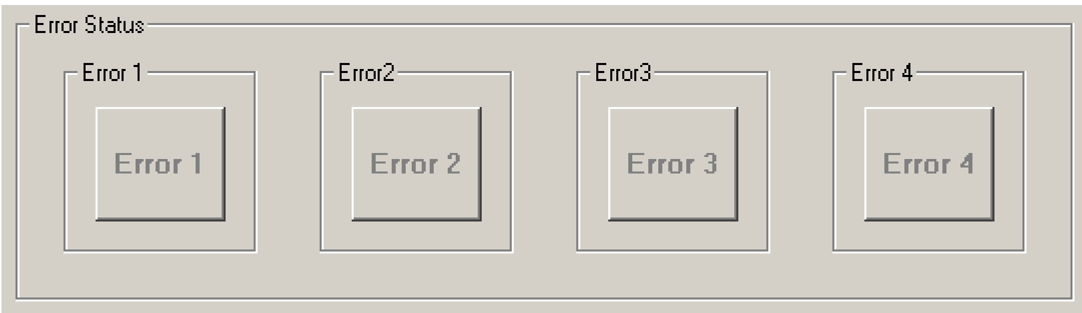


FIGURE 3-22: ERROR STATUS FRAME

When an error does occur the appropriate display is highlighted red and is enabled. Once the user clicks on the error a display message box pops up informing the user of the type of error, the cause, and possible steps to follow. Only once the error has been corrected and the controller communicates this to the GUI, will the highlighted display be disabled. Each error and flow charts depicting the steps taken when they occur will be discussed in detail in detail in Chapter 4. For the purposes of this discussion, the author will only concentrate on what events trigger these errors and on how the GUI reflects them.

Error 1 occurs when a pair of bars is not detected within an allocated time. The controller is responsible for the timing of this process and if the allocated time has elapsed before the next pair of bars are detected, the controller transmits the ASCII code for the letter 'J' to the GUI. When the GUI receives a 'J' it immediately enables and highlights the Error 1 display as well as the Manual reading control. As mentioned earlier, a detailed discussion concerning this, and all the other errors, will follow in Chapter 4. See Figure 3-23A for a representation of the Error 1 display. When the Error 1 display is clicked the following message appears in a message box:
"The next pair of bars has not been detected within the allowable period. A Manual Reading must now be taken"

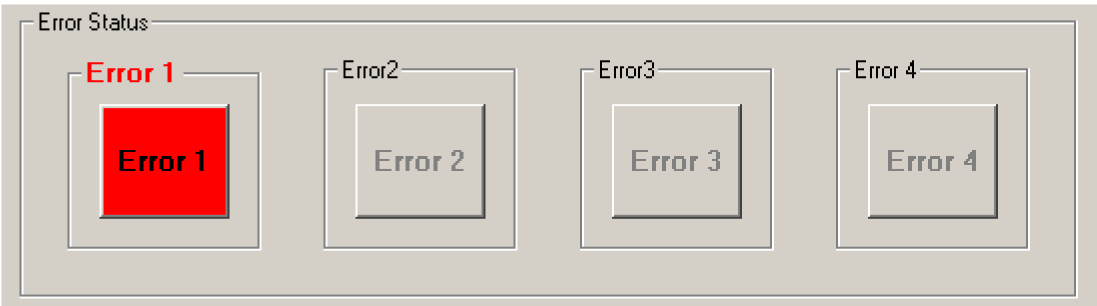


FIGURE 3-23A: ERROR 1 DISPLAY

Error 2 occurs when the detection unit has not been lowered onto the surface of the commutator within the allowable time. Here again the controller is responsible for the timing of this process and if the allocated time has elapsed before the detection unit has been lowered, the controller transmits the ASCII code for the letter 'm' to the GUI. On receiving this character the GUI highlights Error 2 and enables the Manual reading control.

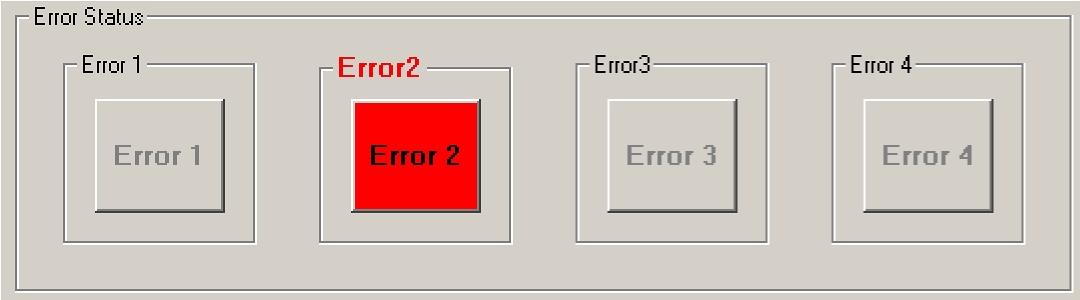


FIGURE 3-23B: ERROR 2 DISPLAY

When the Error 2 display is clicked the following message appears in a message box:
"The Test Probes have not been lowered within the allowable period. A Manual Reading must now be taken"
Error 3 occurs when the test current is switched on for a period longer than a predetermined allowable time. In this case the controller transmits the ASCII code for the letter 'L' to the GUI. Unlike the previous two errors, Error 3 initiates an immediate Emergency Stop (by transmitting the ASCII code for the letter 'F' to the controller) and enables the End control function. The GUI still however highlights Error 3 to inform the user that the Emergency Stop was initiated due to Error 3. On clicking the Error 3 display the following message appears in a message box:
"The Test Current has been switched on for too long, and as a safety measure an Emergency Stop has been invoked. Please Click End, check the device and Restart the Test"

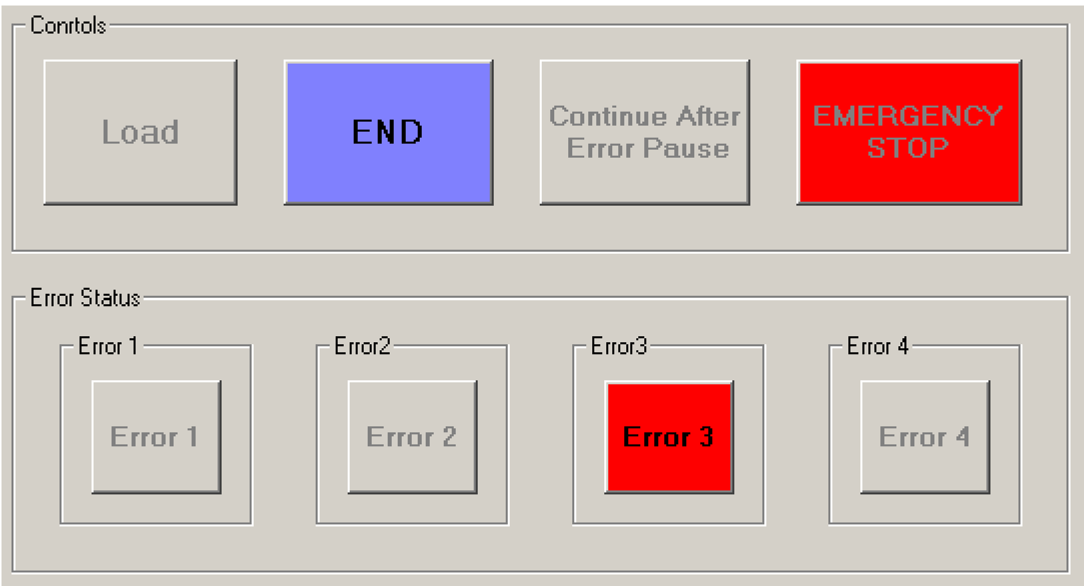


FIGURE 3-23C: ERROR 3 DISPLAY AND INVOKED EMERGENCY STOP

Error 4 was discussed in the explanation pertaining to the Continue After Error Pause Control, but for completeness the author will briefly discuss Error 4 here.
Error 4 occurs when the detection unit has not been raised to its initial position within the allowable time. When the allowable time has elapsed before the detection unit is raised to its initial position, the controller transmits the ASCII code for the letter 'Q' to the GUI. On receiving this the GUI highlights and enables the Error 4 display as well as the Continue After Error Pause and Emergency Stop controls as shown in Figure 3-20 and Figure 3-23D, below. The user then assesses the fault and elects to either continue with the test by clicking on the Continue After Error Pause button or stopping the test by clicking on the Emergency Stop button.

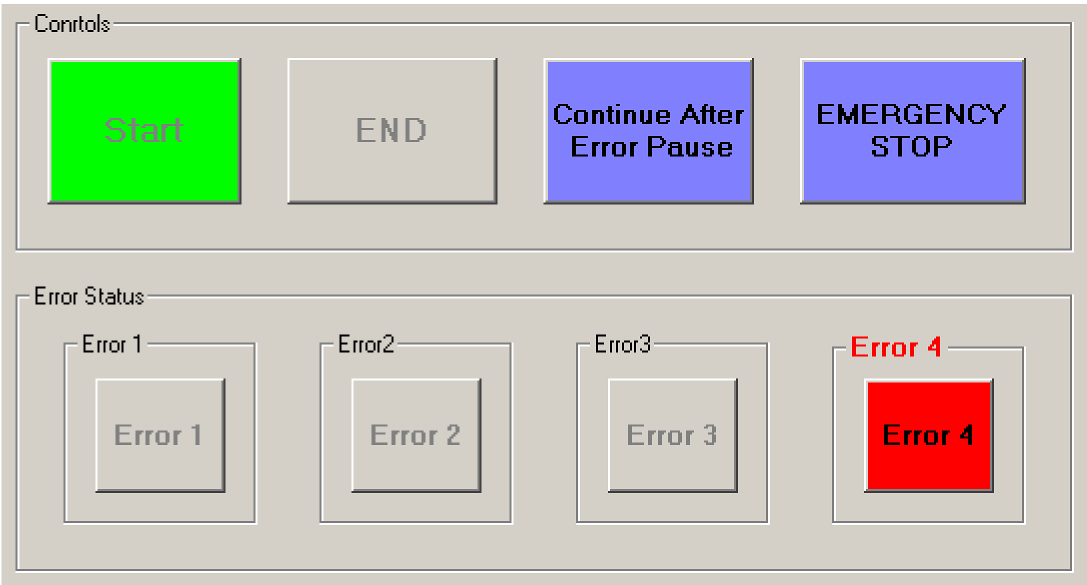


FIGURE 3-23D: CONTINUE AFTER ERROR PAUSE CONTROL ENABLED FOR ERROR 4

3.1.5 Test Status Display

The Status Display is responsible for the summary of the present test at any point in time. As can be seen from Figure 3-24, the information displayed includes the number of the pair of bars (i.e. first pair, second pair etc) that is currently under test, the number of pairs of bars that remains to be tested, the number of faults that were logged, the mode that the system is operating in (i.e. manual or automated) and the task that the system is presently performing (i.e. either searching for the next pair of bars or taking a reading).

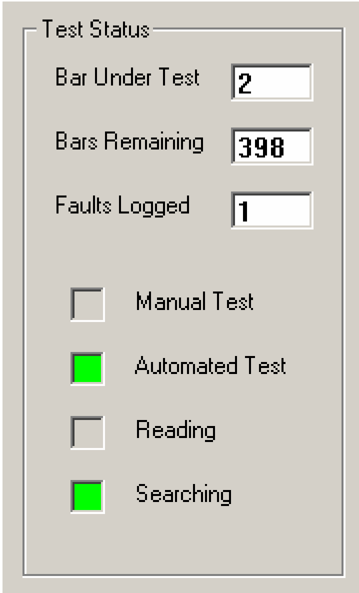


FIGURE 3-24: TEST STATUS DISPLAY

3.1.6 Recorded Test Data Option

The user has four options when it comes to the handling of recorded test data. These are the print, save, open and delete options. Each will be discussed individually in the subsections that follow. Below is a representation of which options are available at different stages of the process.

Figure 3-25A depicts the options available after the correct password is entered but before a test has started. Figure 3-25B depicts the options available while a test is in progress and Figure 3-25C depicts the options available at the end of a test.

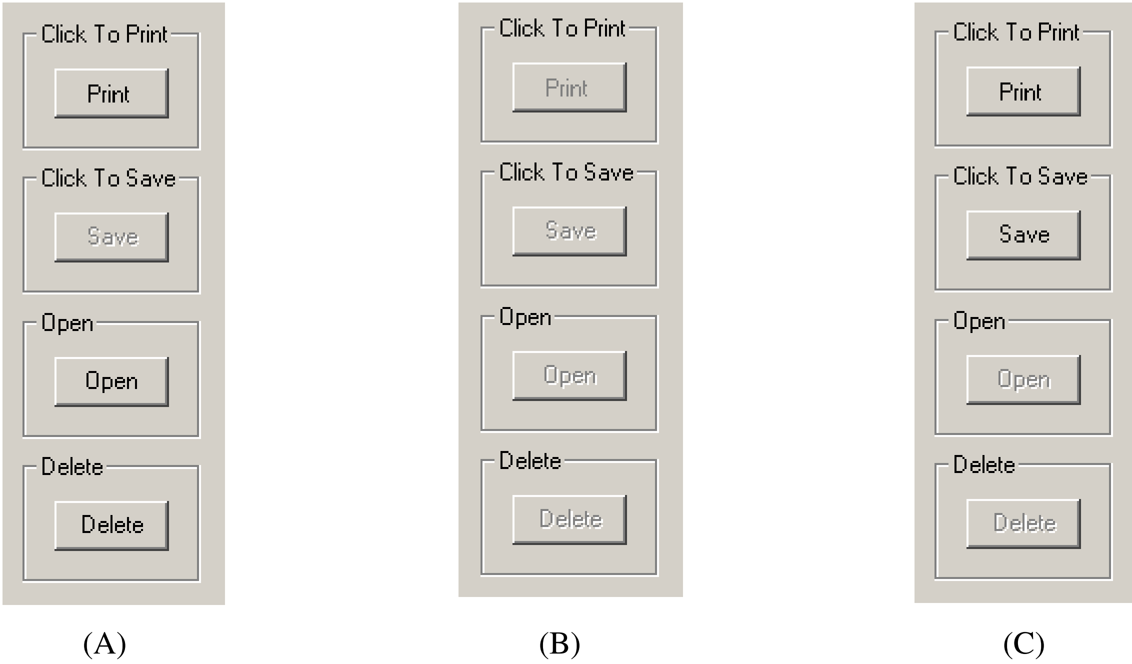


FIGURE 3-25: TEST DATA OPTIONS

3.1.6.1 Print Option

A printed test report is useful for three reasons. Firstly, a hard copy of a specific test or a test history of an individual armature can be made available. The second reason is that a written record travels with the armature after this test so that staff in the next stage of the process will have a written record of the test and failures recorded therein. The third use for a printed test report is that it aids in accountability, i.e. the technician that performs the test can be held accountable for the test and the results as his/her name appears in the test report as well as his/her signature acknowledging the faults.

The user may view and print saved test records by opening a specified file using the Open button. It is for this reason that the print option is made available to the user after the correct password is entered but before a test is started. When Print is clicked, all the data contained in the opened file is printed in the format shown in Appendix D. If a file was not opened, thus implying that no data is displayed when Print is clicked, the following message appears:

"No Data Available To Print"

Once a test is in progress the print option is disabled until the end of the test when it is again enabled. Here, when Print is clicked, only the data recorded during the test that was just completed is printed in the format shown in Appendix E. One of the main features of this new system is the fact that test data can be printed and stored. It is for this reason that when the user prints the present test the data is also automatically saved in the appropriate file.

3.1.6.2 Save Option

As mentioned above, when a completed test is printed it is also automatically saved therefore there is no need to click on the Save button. The Save button is useful when the user wishes to only save the present test data without having a printed copy.

A dual sequential file system is used to save a test record. The first sequential file is the one used to store the names or serial numbers of the armatures that have been tested and saved, in order to generate a list when required. This file is named **DefaultPath & "Saved_List.TXT"** as shown in Code Extract 3-8. DefaultPath is the specified location of the file named Saved_List. The above-mentioned list is available when the user clicks on the Open or Delete buttons.

The second sequential file is the one in which the test data is saved. The file name is the serial number of the armature under test. Each record added to this file has the following fields: the serial number of the armature, the name of the test technician, the type of armature, the allowable percentage variance specified for the test, the date of the test and recorded faults (if any) read by incrementing the index number of the Fault Log list and the actual fault logged on that pair of bars. In other words, each fault recorded in the Fault Log list is saved in the file with the test parameters and identification data fields preceding it. A typical record in the file is found below,

"matadin","sun 04/05","Armature Name: f Number of Bars: 50","Percentage Variance: 20%","2005/05/04","Emergency Stop on Bar 0"

The flow diagram for the Save event is depicted in Figure 3-26 and the code for this event is shown in Code Extract 3-8.

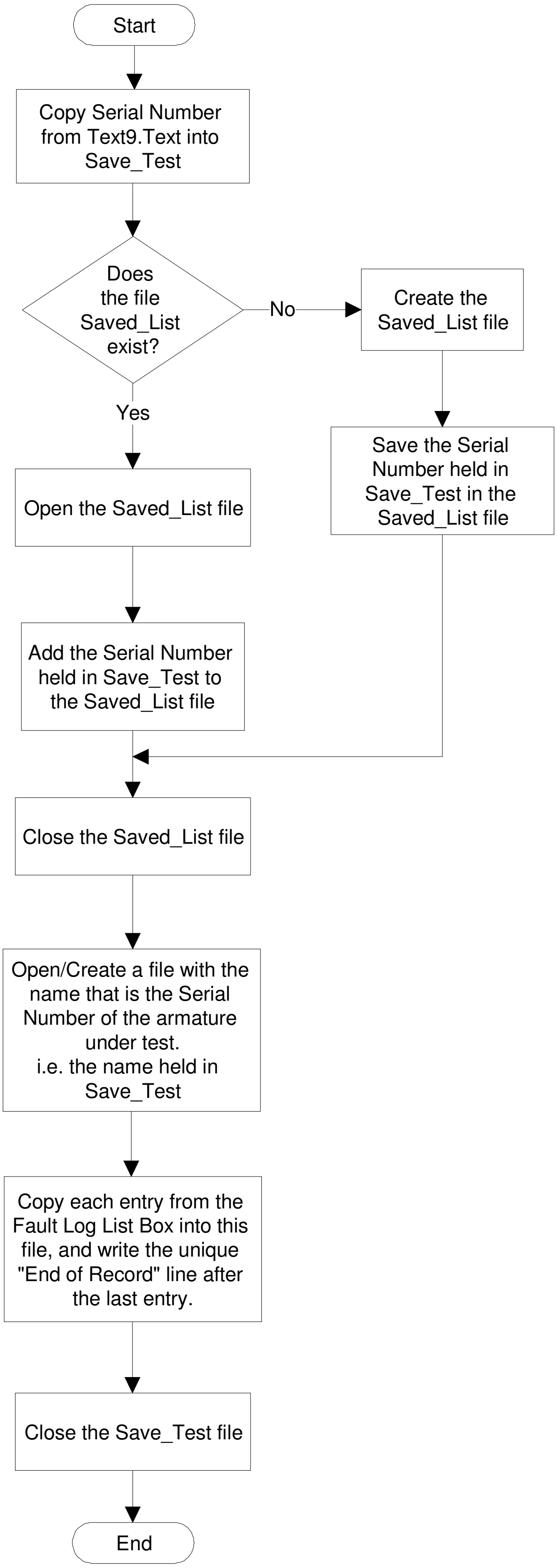


FIGURE 3-26: SAVE EVENT FLOW DIAGRAM

```
Private Sub Command15_Click()
Dim Add_Flag As Boolean
Command14.Enabled = False
Command15.Enabled = False
Let Add_Flag = False

Let Save_Test = Text9.Text

If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
   Open DefaultPath & "Saved_List.TXT" For Input As #7 ' file for the list of all jobs saved

      Do While Not EOF(7)
      Input #7, Add_list
         If Add_list = Save_Test Then
            Let Add_Flag = True
         End If
      Loop
   Close #7
      If Add_Flag = False Then
         Let Add_Flag = False ' redundant
         Open DefaultPath & "Saved_List.TXT" For Append As #7
         Write #7, Save_Test
         Close #7
      End If
Else
   Open DefaultPath & "Saved_List.TXT" For Append As #7
   Write #7, Save_Test
   Close #7
End If

   Open DefaultPath & Save_Test For Append As #5
   Let i = 0
   Do While i <= (List1.ListCount - 1)
      Write #5, Text9.Text, Text2.Text, Combo2.List(Combo2.ListIndex),
               Combo1.List(Combo1.ListIndex), LTrim(Text11.Text), List1.List(i)

      Let i = i + 1
   Loop
   Write #5, "End", "xxx", "xxx", "xxx", LTrim(Text11.Text), "End Of Recorded Results"
   Close #5

End Sub
```

CODE EXTRACT 3-8: SAVE - EVENT CLICK

After the last item from the Fault Log has been saved, a record containing 'xxx' in the user name, armature name and allowable percentage variance fields together with the serial number field is saved to indicate the end of a test record.

```
"End","xxx","xxx","xxx","2005/05/04","End Of Recorded Results"
```

3.1.6.3 Open option

This option is only available to the user after a valid password has been entered. By clicking on Open, the user may view any and all saved tests. When clicked an input box as shown in Figure 3-27 appears prompting the user to enter the serial number of the armature for which the test data is wished to be viewed. When this number has been entered all the recorded tests for that serial number i.e. the armature test history, are displayed on the Fault Log display.

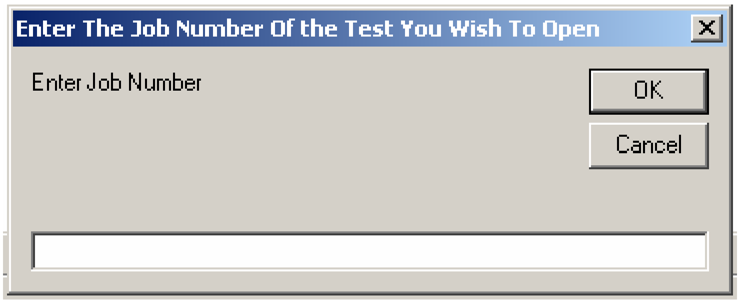


FIGURE 3-27: INPUT PROMPT WHEN 'OPEN' IS CLICKED

In order to refine the search, for example if a test on a specific date is required, the user enters 'Find' in the input box. A list of armature serial numbers appears as shown in Figure 3-28. This list is generated by reading the 'Save_List' file mentioned above.

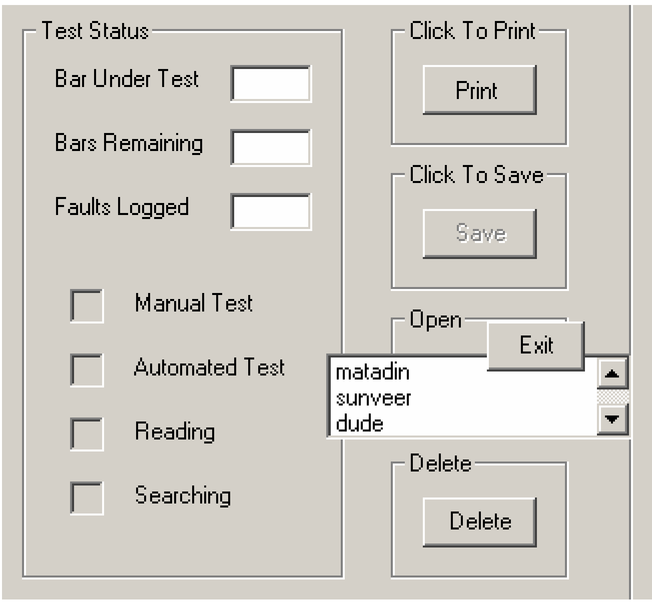


FIGURE 3-28: LIST OF SAVED SERIAL NUMBERS

By clicking on a serial number from this list a search is initiated. This search entails the opening of the file with the name matching the selected serial number, in this case matadin, reading through each record and displaying the dates on which tests were carried out on that armature, see Code Extract 3-9. All these dates along with a 'View All' option are displayed in a list box as depicted in Figure 3-29.

On clicking on a specific date the user may view the data recorded in the test (or tests) carried out on that armature on the specified date. By clicking on the 'View All' option a test history containing every test recorded and saved under the specified serial number is displayed, see Code Extract 3-10A and Code Extract 3-10B. The user clicks on the Exit button provided to exit from the Open procedure at any time.

```
Private Sub List2_Click()
Let Save_Test = List2.Text
List1.Clear
Let Dspl_Date = ""
List4.Clear
List4.AddItem "View All"
Open DefaultPath & Save_Test For Input As #5
   Do While Not EOF(5)
   Input #5, aa, bb, cc, dd, ee, ff
      If (Dspl_Date <> ee) And (bb <> "xxx") Then
         List4.AddItem LTrim(ee)
         Let Dspl_Date = ee
      End If
   Loop
   If List4.ListCount = 1 Then
   MsgBox "There are no items to View"
   List4.Clear
   Else
   List4.Visible = True
   End If
Close #5
End Sub
```

CODE EXTRACT 3-9: GENERATION OF A LIST OF DATES FOR A SPECIFIED SERIAL NUMBER

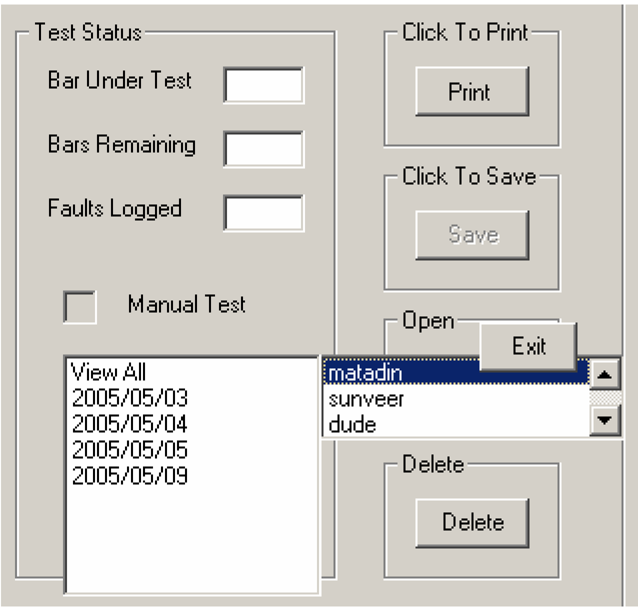


FIGURE 3-29: LIST OF TEST DATES FOR A SPECIFIED ARMATURE SERIAL NUMBER

```
Private Sub List4_Click()
List1.Clear
Let Test_Date = List4.Text
Call FopenSub
List2.Visible = False
List4.Visible = False
Command33.Visible = False
End Sub
```

CODE EXTRACT 3-10A: EVENT CLICK – ON THE DATE LIST

```
Public Sub FopenSub()

  If Test_Date = "View All" Then
      Open DefaultPath & Save_Test For Input As #5
        Let j = False
        Do While Not EOF(5)
          Input #5, aa, bb, cc, dd, ee, ff
            If j = False Then
              List1.AddItem "Job Number:  " & aa
              List1.AddItem "Operator's Name:  " & bb
              List1.AddItem cc
              List1.AddItem dd
              List1.AddItem "Date:  " & LTrim(ee)
              List1.AddItem ""
              List1.AddItem "Recorded Faults "
              List1.AddItem ""
              List1.AddItem ff
```

```
                    Let j = True
                  Else
                    List1.AddItem ff
                      If aa = "End" Then
                      Let j = False
                      List1.AddItem ""
                      List1.AddItem ""
                      End If
                  End If
              Loop
              Close #5
  Else
    Open DefaultPath & Save_Test For Input As #5
          Let j = False
          Do While Not EOF(5)
            Input #5, aa, bb, cc, dd, ee, ff
              If (Test_Date = LTrim(ee)) Then

                If j = False Then
                  List1.AddItem "Job Number:  " & aa
                  List1.AddItem "Operator's Name:  " & bb
                  List1.AddItem cc
                  List1.AddItem dd
                  List1.AddItem "Date:  " & LTrim(ee)
                  List1.AddItem ""
                  List1.AddItem "Recorded Faults "
                  List1.AddItem ""
                  List1.AddItem ff
                  Let j = True
                'End If
                Else
                  List1.AddItem ff
                    If aa = "End" Then 'xxx (or End) signals end of a test and all the fields for
                                        the next test has to be printed
                    Let j = False
                    List1.AddItem ""
                    List1.AddItem ""
                    End If
                End If
              End If
          Loop
    Close #5
  End If
'************************************************************************
'aa is the Job No field
'bb is the Operators Name field
'cc is the Armature Selection field
'dd is the Percentange Variance field
'ee is the Date field
'ff is the Recorded Faults field
'************************************************************************
End Sub
```

CODE EXTRACT 3-10B: FOPEN SUBPROGRAM CALLED IN CODE EXTRACT 3-10A

3.1.6.4 Delete Option

The delete option allows a user with administrative rights to delete a file with a specified serial number. When an armature is discarded it may be decided that the history of that armature is no longer relevant however, the opposite may also be true. The relevance of the history of a discarded armature can only be decided by the workshop management and maintenance engineers.

The Delete option works in much the same way as the Open option. All the records with the specified serial number are located when that serial number is entered into the input box prompt or, a list containing all the saved serial numbers is generated when "Find" is entered into the input box as depicted in Figure 3-30. The difference however is when the Delete button is clicked, the GUI requests the Administrator's password. If the password is entered correctly and a serial number is selected the GUI will ensure that the user is sure of his decision by prompting a response using a pop up box as shown in Figure 3-31.

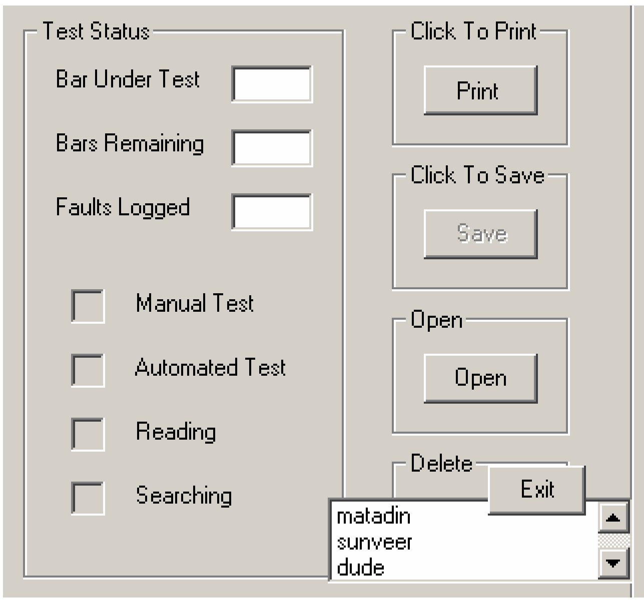


FIGURE 3-30: LIST OF SERIAL NUMBERS GENERATED ON THE DELETE CLICK EVENT

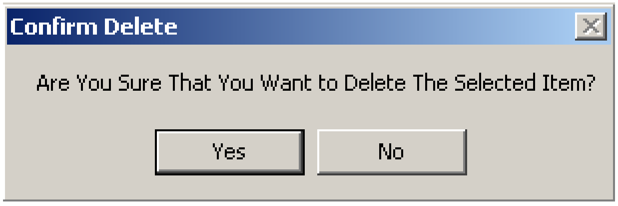


FIGURE 3-31: POP UP PROMPT ON SELECTING AN ITEM TO BE DELETED

If Yes is selected by the user the deletion process is initiated. This process entails the removal of the selected serial number from the sequential file that generates the list of saved serial numbers, i.e. **"Saved_List.TXT",** as well as removing the file that contains the test history saved under the name of the selected serial number. Removing the selected item from the **"Saved_List.TXT"** file is accomplished by reading this file and copying all items except the one selected into another file, in this case **"Saved_List_Del"**. At the end of this process, **"Saved_List.TXT"** is deleted and **"Saved_List_Del"** is renamed as **"Saved_List.TXT"**.

To delete the file containing the test history the following statement:

```
Kill (DefaultPath & Save_Test)
```

is used to remove the file with the name stored in **Save_Test** (which is the serial number of the selected item) using **DefaultPath** to locate it. See Figure 3-32, Code Extract 3-11A and Code Extract 3-11B, for the associated flow diagram and code respectively.

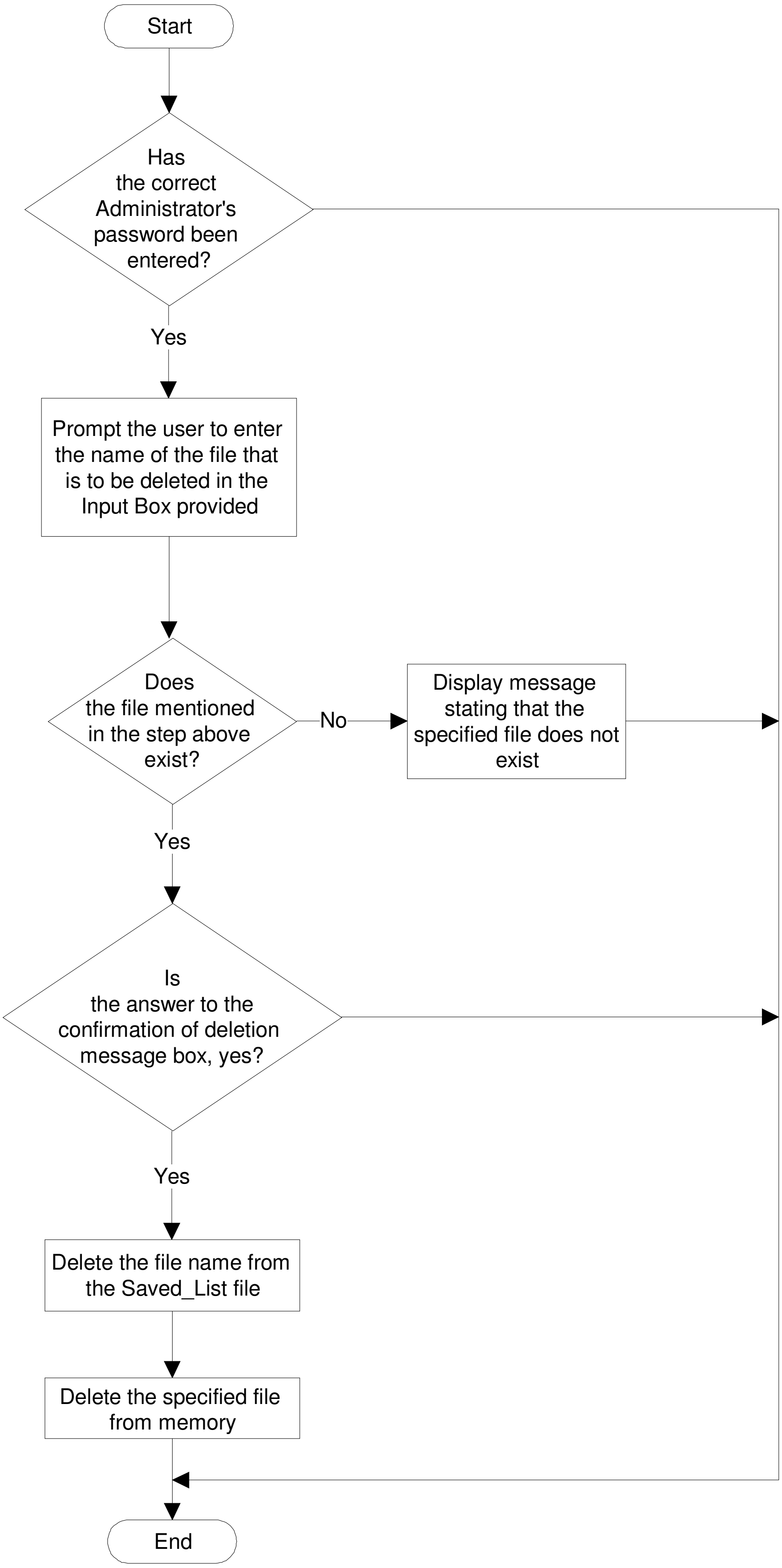


FIGURE 3-32: DELETE PROCESS FLOW DIAGRAM

```
Private Sub Command32_GotFocus()
If Form3.AdminPasswordFlag = True Then
Let Form3.AdminPasswordFlag = False
Save_Test = InputBox("Enter File Name", "Delete file")
   If Save_Test <> "" Then
      If Save_Test <> "Find" Then

         If Dir(DefaultPath & Save_Test) <> "" Then
            Open DefaultPath & Save_Test For Input As #5
               If MsgBox("Are You Sure That You Want to Delete The Selected Item?", vbYesNo,
                           "Confirm Delete") = vbYes Then
               Call Delete
               End If
            Close #5

         Else: MsgBox " File Does Not Exist", vbOKOnly, "Data Error"
         End If
      Else
      If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
      Open DefaultPath & "Saved_List.TXT" For Input As #7
      List3.Clear
         Let Del_Hold = ""
            Do While Not EOF(7)
            Input #7, Delx
               If Del_Hold <> Delx Then
               List3.AddItem Delx
               Let Del_Hold = Delx
               End If
            Loop
               If List3.ListCount <> 0 Then
               List3.Visible = True
               Command34.Visible = True
               Else
               MsgBox "There Are No Tests To View", vbOKOnly, "Data Error"
               End If
          Close #7
      Else: MsgBox "There Are No Tests To View", vbOKOnly, "Data Error"
      End If

      End If
   Else: MsgBox "Job Number Not Entered", vbOKOnly, "Enter Data"
   End If
'Else
'MsgBox " You are Not Authorised to use this fuctionality"
End If
End Sub
```

CODE EXTRACT 3-11A: DELETE FILE CODING

```
Public Sub Delete()
If Dir(DefaultPath & "Saved_List.TXT") <> "" Then
Open DefaultPath & "Saved_List.TXT" For Input As #7
   Open "Saved_List_Del" For Output As #8
      Do While Not EOF(7)
      Input #7, look
         If Save_Test <> look Then
            Write #8, look
         End If
      Loop
         Close #7
         Close #8
         Kill DefaultPath & "Saved_List.TXT"
         Name "Saved_List_Del" As DefaultPath & "Saved_List.TXT"
Else:  MsgBox "File Does Not Exist"
End If
If Dir(DefaultPath & Save_Test) <> "" Then
Kill (DefaultPath & Save_Test)
List1.Clear
End If
End Sub
```

CODE EXTRACT 3-11B: DELETE SUBPROGRAM CODING

3.1.7 Directory Path Specification

The Directory Path specifies the location where all files generated and accessed by the GUI are saved. This location is copied into the variable **DefaultPath** which precedes the file name. Using **DefaultPath** files can be saved on the local hard drive, written to removable data storage devices or, by mapping a network drive, files can be stored in allocated locations on the network.

The Directory Path settings can be viewed and reset via the Directory Path frame. The Directory Path frame is made visible by clicking on the View Setting button found on the View/Change Directory Path Settings Frame. The user can return to the View/Change Directory Path Settings Frame from the Directory Path Frame by clicking on the Exit Settings button. See Figure 3-33A and Figure 3-33B.

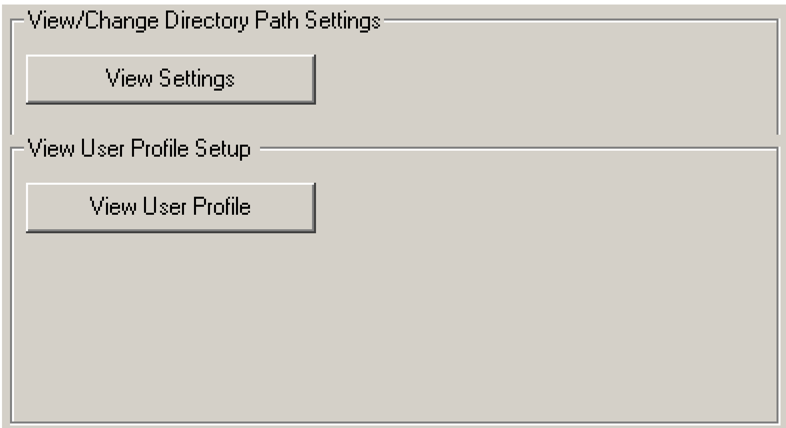


FIGURE 3-33A: DIRECTORY PATH SPECIFICATION

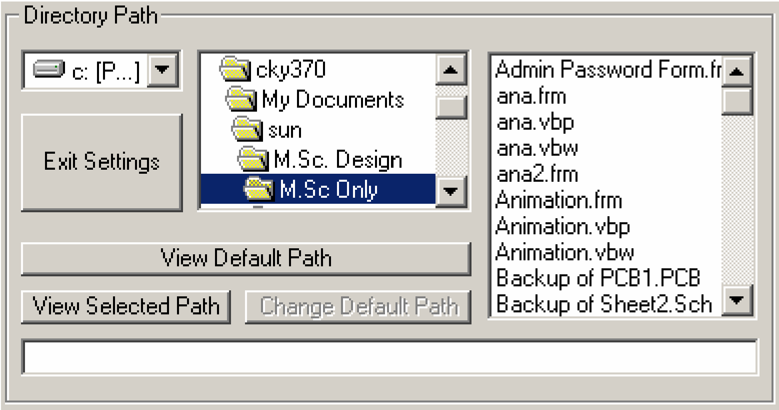


FIGURE 3-33B: DIRECTORY PATH SPECIFICATION

Visual Basic provides a simple approach for displaying drives, directories and files. All of these can be viewed using,

```
Private Sub Drive1_Change()
Let Dir1.Path = Drive1.Drive
End Sub
```

to display directories in the selected drive and

```
Private Sub Dir1_Change()
Let File1.Path = Dir1.Path
End Sub
```

to display files in the selected directory.

The Default Path can only be set or changed by an administrator. A directory path is selected using the drive, directory and file input boxes. The administrator then clicks on 'View Selected Path' to verify that this is the correct selected destination. When satisfied with the selected path the administrator clicks on Change Default Path. An input box, which prompts the administrator for the administrator's password, appears and if the correct password is entered, the selected path is saved as the new default directory path.

The default path can also be viewed by clicking on the 'View Default Path' button. The Default Path setting is dynamic (i.e. it can be changed when required and is not hard-coded) and points to the location in memory in which data can be saved. The Default Path itself also has to be saved in a file so that it can be referred to whenever the default path is required. The location of this file however, is static i.e. it is hard-coded and cannot be changed by the user nor the administrator.

The name and location of this file is **SavePath** and **"C:\Program Files\SavePath"** respectively. When the GUI is loaded for use each time it is initiated, the Form_Load procedure opens the **SavePath** file and copies its contents into the Default Path variable. See Code Extract 3-12. This is carried out on the onset of a test so that the Default Path variable can be accessed whenever the path is required instead of opening, reading and closing a sequential file each time it is required.

```
If Dir("C:\Program Files\SavePath") <> "" Then
   Open "C:\Program Files\SavePath" For Input As #10
   Input #10, DefaultPath ' holds the path to the saved files
   Close #10
Else
   MsgBox "Default Path is Not Valid, it has been changed"
   Command17.Enabled = False
End If
```

CODE EXTRACT 3-12: INITIALISING THE DEFAULT DATA PATH

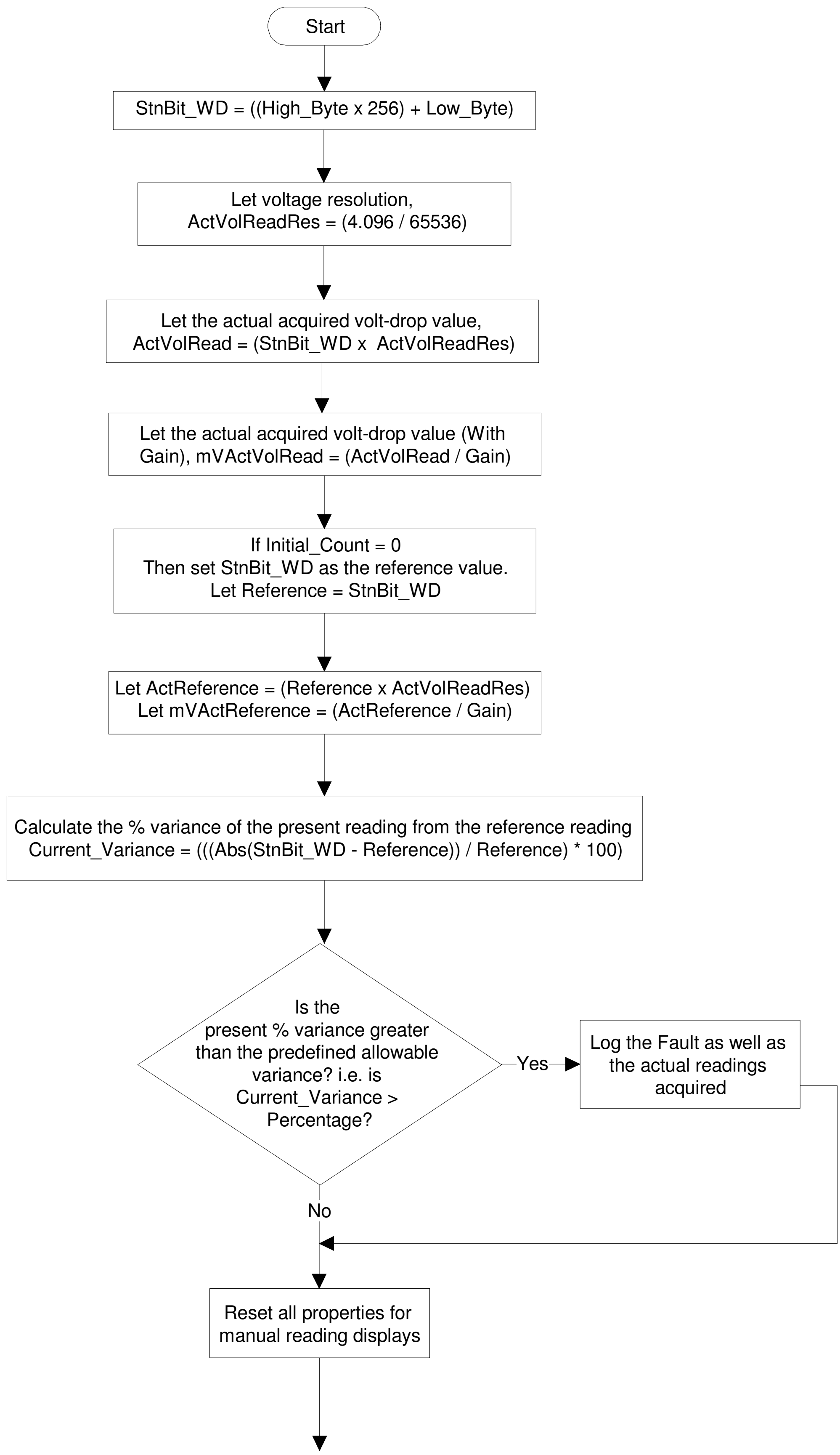
3.1.8 Exit Command

The exit command allows the user to exit from the GUI before a test is started or after the test has ended. The Exit functionality is disabled during a test.

FIGURE 3-34: EXIT COMMAND CLICK

3.2 Percentage Variance Calculation.

All the literature in this chapter thus far has concentrated on the activities of the GUI when being prompted by a user or the controller and the output commands or signals that are transmitted by the GUI to the controller based on the data received and calculations carried out by the GUI. One such calculation is carried out when the GUI receives the test data from the Analogue-to-Digital converter (ADC) via the CM. This is the calculation of the percentage variance of the present reading from the stored reference reading. This is arguably the most critical calculation as the need for the entire project has evolved around it. Referring to Code Extract 3-13, the author will discuss this subprogram in as much detail as possible.


Start
StnBit_WD = ((High_Byte x 256) + Low_Byte)
Let voltage resolution,
ActVolReadRes = (4.096 / 65536)
Let the actual acquired volt-drop value,
ActVolRead = (StnBit_WD x ActVolReadRes)
Let the actual acquired volt-drop value (With Gain), mVActVolRead = (ActVolRead / Gain)
If Initial_Count = 0
Then set StnBit_WD as the reference value.
Let Reference = StnBit_WD
Let ActReference = (Reference x ActVolReadRes)
Let mVActReference = (ActReference / Gain)
Calculate the % variance of the present reading from the reference reading
Current_Variance = (((Abs(StnBit_WD - Reference)) / Reference) * 100)
Is the present % variance greater than the predefined allowable variance? i.e. is Current_Variance > Percentage?
Yes
Log the Fault as well as the actual readings acquired
No
Reset all properties for manual reading displays

A (pp. 84)

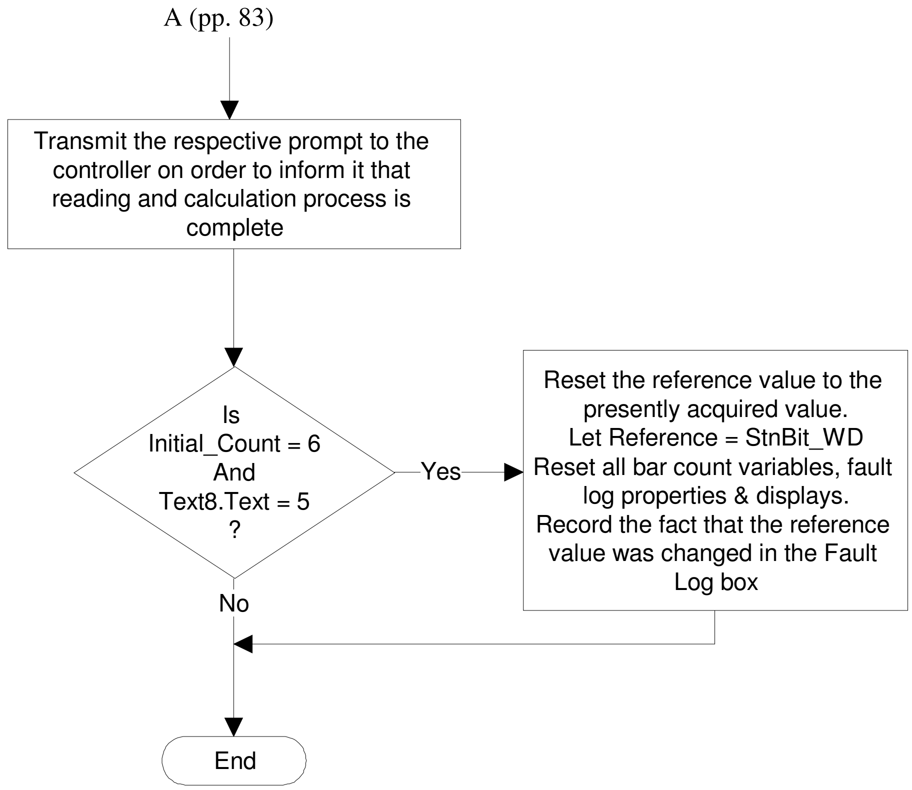


FIGURE 3-35: FLOW DIAGRAM FOR THE CALCULATION SUBPROGRAM

```
Public Sub Calculation()

Picture8.BackColor = QBColor(4)
Picture9.BackColor = &H8000000F

StnBit_WD = ((High_Byte * 256) + Low_Byte)

'*******************Actual Voltage Reading******************
Let ActVolReadRes = (4.096 / 65536)
Let ActVolRead = (StnBit_WD * ActVolReadRes)
Let mVActVolRead = (ActVolRead / Gain)

'*******************End Actual Voltage reagings*************

' set Reference value on first reading
If Initial_Count = 0 Then
   Let Reference = StnBit_WD
   Let ActReference = (Reference * ActVolReadRes)
   Let mVActReference = (ActReference / Gain)
End If

If Reference <> 0 Then ' checking if reference value = 0

' calc variance of current reading
   If Initial_Count > 0 Then
```

```
    Current_Variance = (((Abs(StnBit_WD - Reference)) / Reference) * 100)
    End If
    ' compare to selected % variance and log if a fault
    If (Current_Variance > Percentage) Then
    List1.AddItem "Fault on Bar:  " & Text6.Text & ",    Percentage Variance = " &
                    "Current_Variance & ",    Segment Reading: " & ActVolRead & "V" &
                    ",    Reference Reading: " & ActReference & "V"

    Let Text8.Text = Val(Text8.Text) + 1
    End If
    'end current reading and comparison

        Command9.Enabled = False 'disables man reading but and dsply
        Frame20.Enabled = False
        Picture5.BackColor = QBColor(12) '
        Frame21.Enabled = False

        Let Command10.Enabled = False ' error1
        Command10.BackColor = &H8000000F
        Frame14.ForeColor = &H80000012
        Frame14.FontSize = 8
        Frame14.FontBold = False

        Let Command11.Enabled = False ' error2
        Command11.BackColor = &H8000000F
        Frame16.ForeColor = &H80000012
        Frame16.FontSize = 8
        Frame16.FontBold = False

        MSComm1.Output = "E" ' to microcontroller

        Picture8.BackColor = &H8000000F
        Picture9.BackColor = QBColor(10)


    ' checking the 1st 5 readings to see if the ref reading is from a fault bar.

    Let Initial_Count = Initial_Count + 1

      If (Initial_Count = 6) And (Val(Text8.Text) = 5) Then
      Let Reference = StnBit_WD
      Let ActReference = (Reference * ActVolReadRes)
      Let mVActReference = (ActReference / 1000
      Let Text8.Text = ""
      Let No_of_Bars = ((Val(Text6.Text) + Val(Text7.Text)) - 1)
      Let Text7.Text = No_of_Bars
      Let Text6.Text = 1
      Let Initial_Error = True ' flag to indicate Ref value error.
      List1.FontBold = True
      List1.AddItem "Test Restarted, Bar 5 is reset as the Initial (First) Bar!"
      List1.FontBold = False
      End If


Else
```

```
MsgBox " The Recorded reference value is 0 Volts & is therefore not Valid. Please Restart this
            Test"
End If
End Sub
```

CODE EXTRACT 3-13: CALCULATION SUBPROGRAM

This subprogram has two objectives; the first is to calculate the percentage variance of a present reading from the reference reading whilst the second objective is centered around the reference reading itself. Consider this, what if the reference reading is in fact a fault reading, i.e. what if the reference reading is the reading across an open or short circuit or a damaged winding on the armature? The first step would be to check if the first reading recorded is very close or equal to zero volts.

This would indicate a short circuit and this value will therefore not be stored as a reference value. A true open circuit would be indicated by a reading that is very close or equal to the supply voltage. But the supply voltage and current is not the same for every type of armature tested due to the armature characteristics as well as the arc length between the test current supply probes on the commutator. Also considering that damaged and potentially problematic windings also have to be detected, there is no clear cut value that can be used to reject a reference reading (that is other than the reading for a short circuit). In order to detect that the reference value being used is indeed a value that was recorded on a fault winding, the GUI performs a check after the first five readings taken, after the reference reading.

This essentially means that this check is carried out on the sixth reading captured. Variable **Initial Count** keeps track of the number of readings taken and by recalling an earlier discussion regarding the Test Status display, the reader will remember that the number of faults recorded is displayed in a text box (Text8). Noting this, and as shown in Code Extract 3-13, in the event that the value in **Initial Count** is six and the value of Text8 is five,

```
If (Initial_Count = 6) And (Val(Text8.Text) = 5) Then
```

this event will indicate that five (5) faults have been logged immediately after the reference value was set.

If such an event occurs, the GUI will conclude that based on the last five captured readings, the reference value was set on a fault or damaged winding reading. The reference value is then reset to that of the value recorded on the present bar (which will be the sixth bar). The values in the Test Status display as well as the variables that hold the values that reflect the number of bars that remain to be tested and the bar presently under test, are also adjusted appropriately to reflect this change. The test is reset on the sixth bar and continues as normal from that point forward.

For all of the above to occur the data transmitted from the controller has to be converted, manipulated and passed through mathematical formulae in order to obtain usable values that can be compared, displayed and stored. The following discussion will cover the manner in which this is done. Recall, that ASCII codes are transmitted by the controller. These ASCII codes are then converted into their associated numerical values in the OnComm procedure using the Visual Basic **Asc** function, as shown below,

```
Low_Byte = Asc(SerIn)
```

and,

```
High_Byte = Asc(SerIn)
```

When the calculation subprogram is called by the OnComm procedure, the Low_Byte and High_Byte variables already contain the required numerical values. The first step in the calculation subprogram is to convert these two bytes of data into the original sixteen (16) bit word that was present in the ADC register before its transmission as two separate bytes to the CM. This is accomplished using:

```
StnBit_WD = ((High_Byte * 256) + Low_Byte)
```

Once the sixteen-bit word has been realised, it is then necessary to calculate the actual voltage that this word represents. This is accomplished by dividing the ADC reference value (which is also the maximum input ADC voltage) by the sixteen-bit word when each bit is equal to 1 (i.e. 1111 1111 1111 1111 which equals 65536). By doing this, the voltage-per-bit value is obtained, or the resolution in volts (stored in variable **ActVolReadRes**). With an ADC internal V_{Ref} of 4.096V and sixteen bit resolution, the smallest voltage increment that the input signal can broken down into is:

$$\text{Resolution in Volts} = 4.096 / 65536 = 62.5\mu V$$

This value is then multiplied by the value of the sixteen-bit word that was captured (**StnBit_WD**) to produce the actual voltage associated with the sixteen bit word. This actual voltage is then stored in variable, **ActVolRead**. Furthermore, the actual voltage is divided by the analogue gain to obtain the true voltage reading that is present on the bars before the analogue gain. Note that the variable named "Gain" holds the value of the analogue gain as set using the Instrumentation Amplifiers external gain resistor R_G.

```
Let ActVolReadRes = (4.096 / 65536)
Let ActVolRead = (StnBit_WD * ActVolReadRes)
Let mVActVolRead = (ActVolRead / Gain)
```

For the calculation of the percentage variance however, these actual voltage values are not used. The percentage variance is calculated using the numerical value of the sixteen bit words that are stored in variable **StnBit_WD** (which holds the value of present reading) and in variable **Reference** (which holds the value of the reference reading). This is done in order to use values as close to the original recorded values as possible and to decrease the probability of any errors that may arise by using values that have been rounded off. The equation below is responsible for the calculation of the percentage variance of the present reading from the reference reading.

```
Current Variance = (((Abs(StnBit_WD - Reference)) / Reference) * 100)
```

Abs is a Visual Basic function that produces the absolute value of a mathematical calculation. Here it is used to provide the absolute value for the difference between the present reading value (**StnBit_WD**) and the reference reading value (**Reference**), as either value may greater than the other for any reading taken. This value is then divided by the reference value and multiplied by a hundred to obtain the percentage variance.

The next step is to compare the percentage variance value (**Current Variance**) to the allowable or pre-selected percentage variance that was selected by the user. Recall that this pre-selected percentage variance is stored in variable, **Percentage**.

```
If (Current_Variance > Percentage) Then
List1.AddItem "Fault on Bar:  " & Text6.Text & ",    Percentage Variance = " &
                "Current_Variance & ",    Segment Reading: " & ActVolRead & "V" &
                ",    Reference Reading: " & ActReference & "V"
Let Text8.Text = Val(Text8.Text) + 1
End If
```

The statements above show the comparison of the two values. In the instance where **Current Variance** is greater than **Percentage**, a fault will be recorded in the Fault Log display.

Another subprogram that is executed on every bar is the calculation of the number of bars that remain to be tested. The Bar_count subprogram decrements the number of bars remaining to be tested (stored in variable No_of_Bars) by one each time the controller transmits an increment prompt (ASCII code for the letter 'I'). This increment prompt is transmitted by the controller before the rotation of the armature under test is initiated hence the total number of bars is decremented before the very first rotation.

With this in mind, the reader will follow that when the increment signal is transmitted by the controller before the last pair of bars is tested, the decremented value in Bar_count will be zero. After the last pair of bars has been tested and when the controller next sends an 'I' the decremented value will be less than one. It is at this point that the GUI signals to controller that the last bar has been tested and that the test must now end.

The prompt to the CM that signals that the last bar has been tested is the ASCII code for the letter 'P'. For every increment signal received by the GUI before the last one, the ASCII code for the letter 'p' is transmitted to the controller to indicate the last bar has not been tested and that rotation should be initiated. See Code Extract 3-14.

```
Public Sub Bar_count()
Let No_of_Bars = No_of_Bars - 1
If No_of_Bars < 0 Then ' <0 cos for the last bar this variable = 0
MSComm1.Output = "P"
Command6.BackColor = QBColor(9)
Command5.BackColor = &H8000000F
Command6.Enabled = True
Else
MSComm1.Output = "p"
Let Text7.Text = No_of_Bars
Let Text6.Text = Val(Text6.Text) + 1
End If
End Sub
```

CODE EXTRACT 3-14: BAR_COUNT SUBPROGRAM

3.3 The Remote Graphic User Interface (RGUI)

The Remote Graphic User Interface is used by authorised users in remote locations to view test records via the network, see Appendix F for a true representation of the RGUI and Appendix G for a printout of the associated code. The RGUI can only access information when the test station GUI stores data in a location on the network by mapping the network as a drive. The Default Path that is set on the RGUI must be the same as that of the GUI on the workshop floor. The RGUI only allows users to read and print information from saved files. Note that the format in which test data is displayed is exactly the same as the format in which the GUI displays retrieved file data as shown in Figure 3-37A and Figure 3-37B.

The user cannot edit, replace or delete files from remote location. The RGUI contains three fields, namely the Search Information field, Data Display field and Directory path field. The inputs and button prompts are much the same as those on the test station GUI. They carry out the same functions and operate in the exact same way. The only variation from the test station GUI is the File Names and Refined Search – Dates display lists. The File Names list and contents is the same as the list that appears on the test station GUI when the Open button is clicked. In the RGUI this list box is permanently displayed.

The Refined Search – Dates list and contents is the same as the list that appears when a serial number is clicked on in the serial number list on the GUI. Here as well, the difference is that this list box is permanently displayed on the RGUI. As in the GUI, when Open is clicked, an input box appears prompting the user to enter a serial number. If a valid serial number is entered all test results for that serial number will be displayed in the Data Display screen. If 'Find' is entered into the input box all the serial numbers of armatures are displayed on the RGUI in the File Names list.

Upon clicking on an item from this list, all dates on which tests were carried out on the selected armature as well as a 'View All' option appears in the Refined Search – Dates list. By clicking on a specific date the results of test(s) carried out on that date will be displayed in the Data Display screen. If 'View All' is selected, results of all tests carried out on the selected armature are displayed. All other functionalities that are available on the RGUI operate in the same manner as those on the GUI.

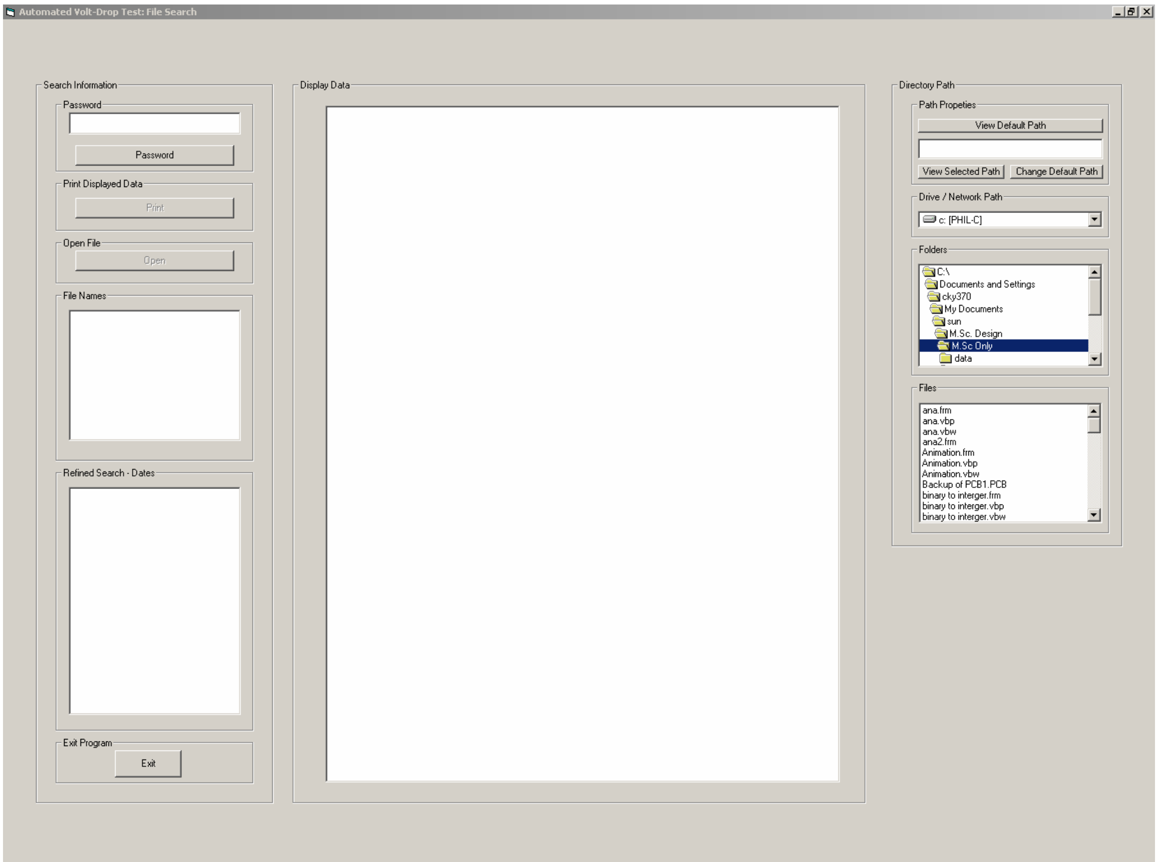


FIGURE 3-36: REMOTE GRAPHIC USER INTERFACE (RGUI)

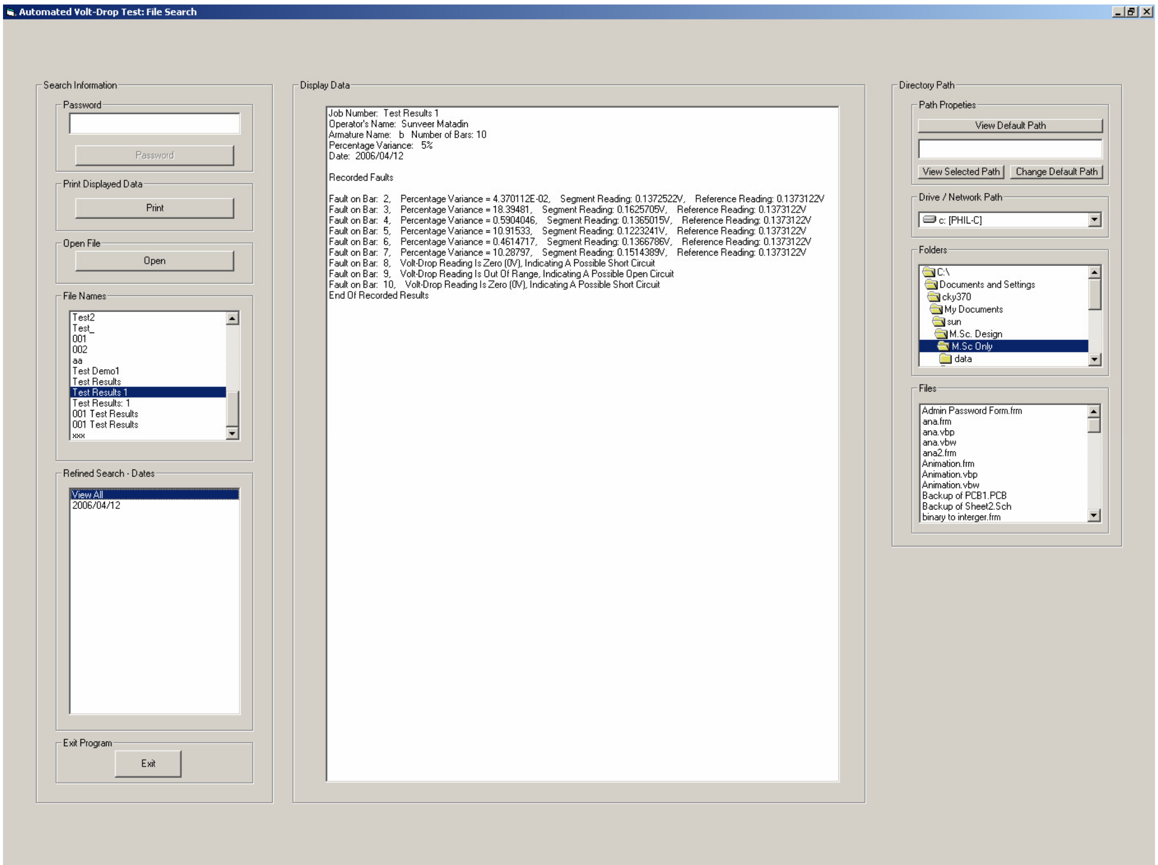


FIGURE 3-37A: REMOTE GRAPHIC USER INTERFACE (RGUI) DATA DISPLAY

Job Number: Test Results 1
Operator's Name: Sunveer Matadin
Armature Name: b Number of Bars: 10
Percentage Variance: 5%
Date: 2006/04/12

Recorded Faults

Fault on Bar: 2, Percentage Variance = 4.370112E-02, Segment Reading: 0.1372522V, Reference Reading: 0.1373122V
Fault on Bar: 3, Percentage Variance = 18.39481, Segment Reading: 0.1625705V, Reference Reading: 0.1373122V
Fault on Bar: 4, Percentage Variance = 0.5904046, Segment Reading: 0.1365015V, Reference Reading: 0.1373122V
Fault on Bar: 5, Percentage Variance = 10.91533, Segment Reading: 0.1223241V, Reference Reading: 0.1373122V
Fault on Bar: 6, Percentage Variance = 0.4614717, Segment Reading: 0.1366786V, Reference Reading: 0.1373122V
Fault on Bar: 7, Percentage Variance = 10.28797, Segment Reading: 0.1514389V, Reference Reading: 0.1373122V
Fault on Bar: 8, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
Fault on Bar: 9, Volt-Drop Reading Is Out Of Range, Indicating A Possible Open Circuit
Fault on Bar: 10, Volt-Drop Reading Is Zero (0V), Indicating A Possible Short Circuit
End Of Recorded Results

FIGURE 3-37B: REMOTE GRAPHIC USER INTERFACE (RGUI) DISPLAY FORMAT

Chapter 4

Microcontrollers and Embedded Programming

In this chapter the author will discuss the core of the controller. This core comprises a pair of microcontrollers that communicate with each other via their port pins in order to perform the appropriate physical tasks, at the precise time, based on information received from the GUI and transducers on the automated machine i.e. the Physical Test Station. Both are AT89S51 microcontrollers and are enhanced derivatives of the 8051 family. These microcontrollers were chosen on the basis of them having the following essential features: four eight pin input/output ports, 4K bytes of Flash memory, two external interrupts, two sixteen bit timers and a full duplex UART serial channel. For further information on this microcontroller, see Appendix H for a comprehensive datasheet.

A microcontroller is the bridge between software instructions (commands) and electrical hardware. Programs written in C, Assembly or any other compiler compatible language are compiled and assembled, and stored in microcontroller memory which currently is most likely to be EEPROM technology. The speed at which these programs are stepped through (or executed) is dependent on the length of time that one machine cycle takes to execute and the number of machine cycles that are required for each instruction to execute. Depending on the instruction, data is either processed or input and output ports are addressed to either read signals or produce signals from or to interfacing electrical hardware.

The length of time that one machine cycle takes to execute depends on the frequency of the oscillator that provides the clocking source for the microcontroller. This design is not time critical which means that commands based on processed information did not have to execute at a very rapid rate. It is for this reason that a 12MHz quartz crystal was chosen to drive the on-chip oscillator resulting in a machine cycle of one microsecond (1μs) duration. The tasks performed by these microcontrollers do not involve complex mathematical calculations or algorithms. It is for this reason that code was written in assembly language as opposed to a higher level programming language. The advantages that assembly language have over higher level languages for these types of applications (bit manipulation, logic operations and input/output port interaction) are execution speed and the efficient use of program memory space. The Acebus development environment was used to develop and simulate the code for both microcontrollers. This tool allows the developer to write, assemble, simulate and debug code written in assembly language. In the simulation environment code can be stepped through line-by-line and the changes in the respective registers, special function registers, input/output ports etc. are reflected accordingly. See Figure 4-1A and Figure 4-1bB for a screen captures of the Acebus development environment and Appendix I for a labeled representation of the development environment.

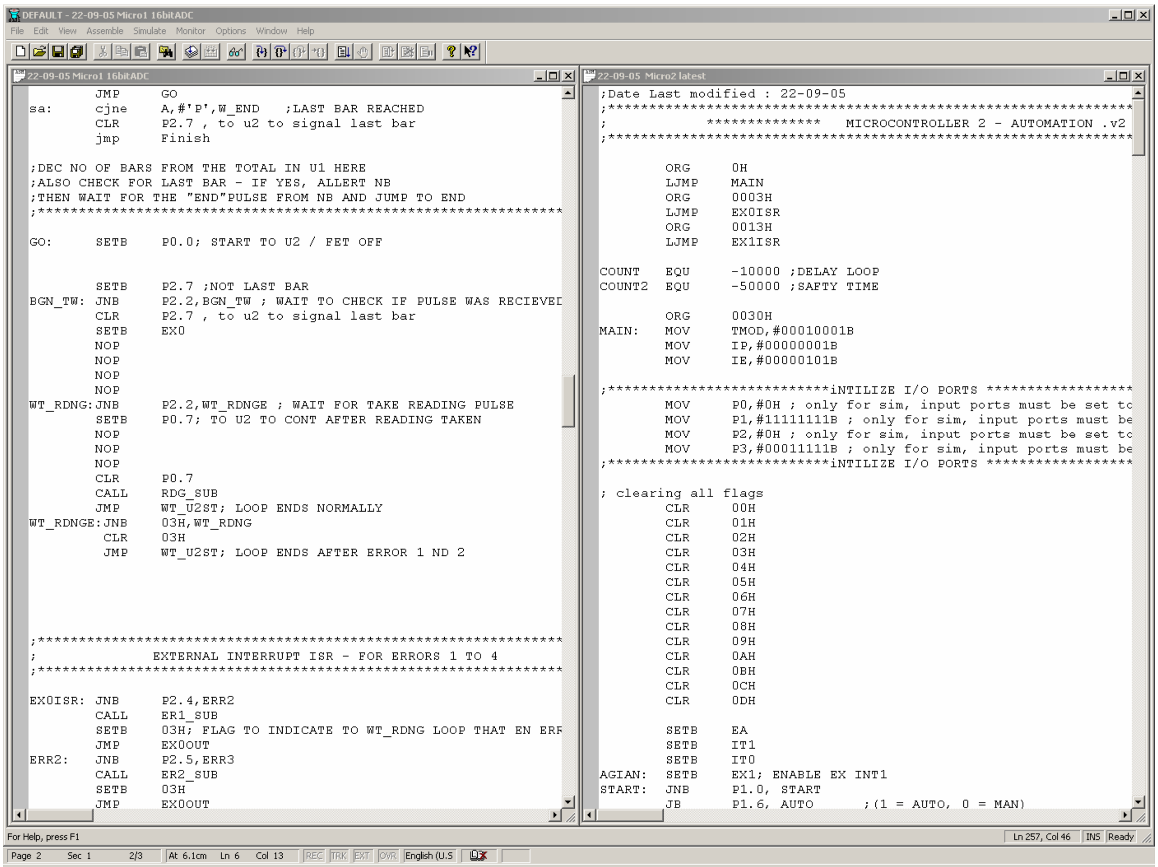


FIGURE 4-1A: SCREEN CAPTURE OF THE ACEBUS DEVELOPMENT ENVIRONMENT

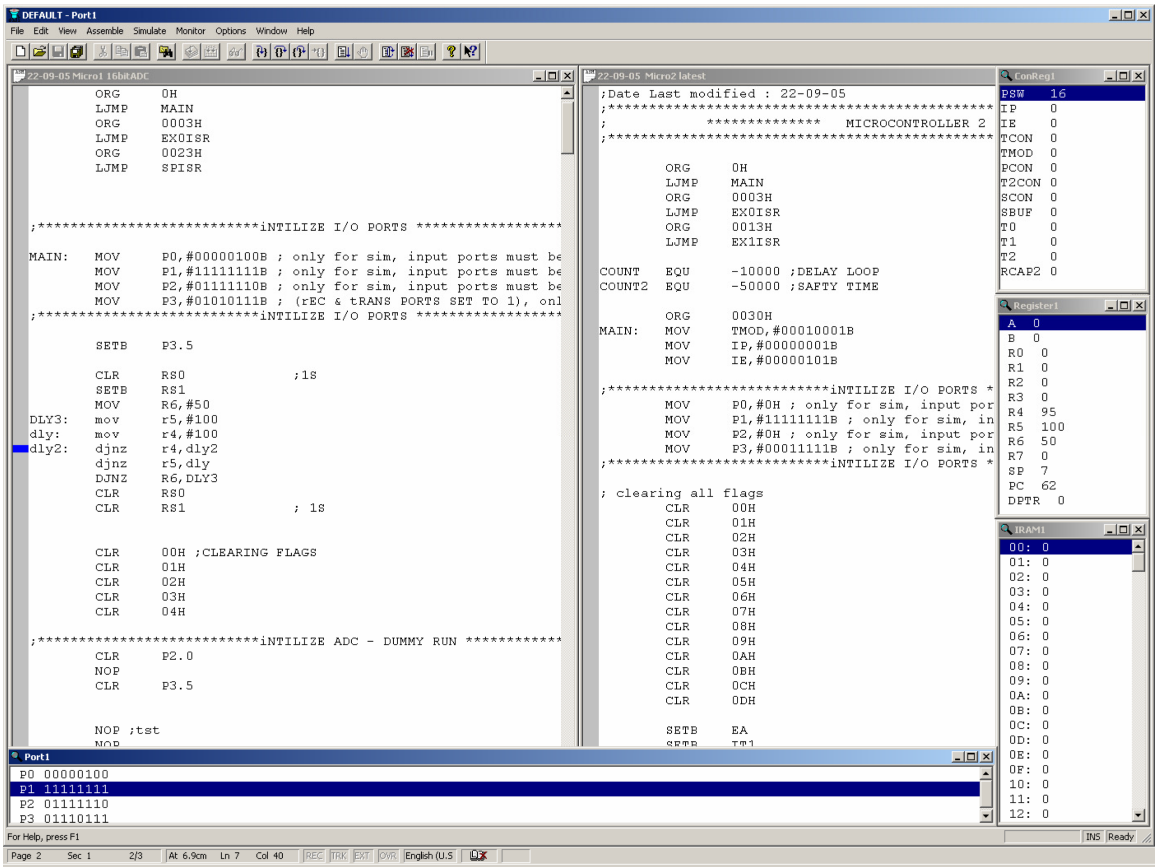


FIGURE 4-1B: SCREEN CAPTURE OF THE ACEBUS DEVELOPMENT ENVIRONMENT IN SIMULATION MODE

Each microcontroller has a specific function, one being communication and acquisition of data, as preformed by the Communication Microcontroller (CM) and the other being the control of the automation tasks, as performed by the Automation Microcontroller (AM).

4.1 The Communication Microcontroller

The Communication microcontroller communicates with the GUI via its onboard serial port and with the Automation Microcontroller and the Analogue-to-Digital Converter (ADC) via its input/output pins (I/O pins).

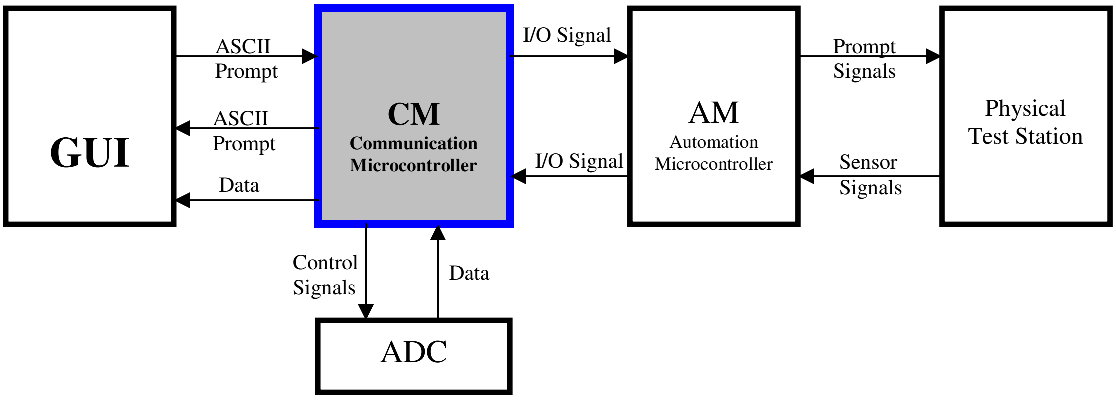
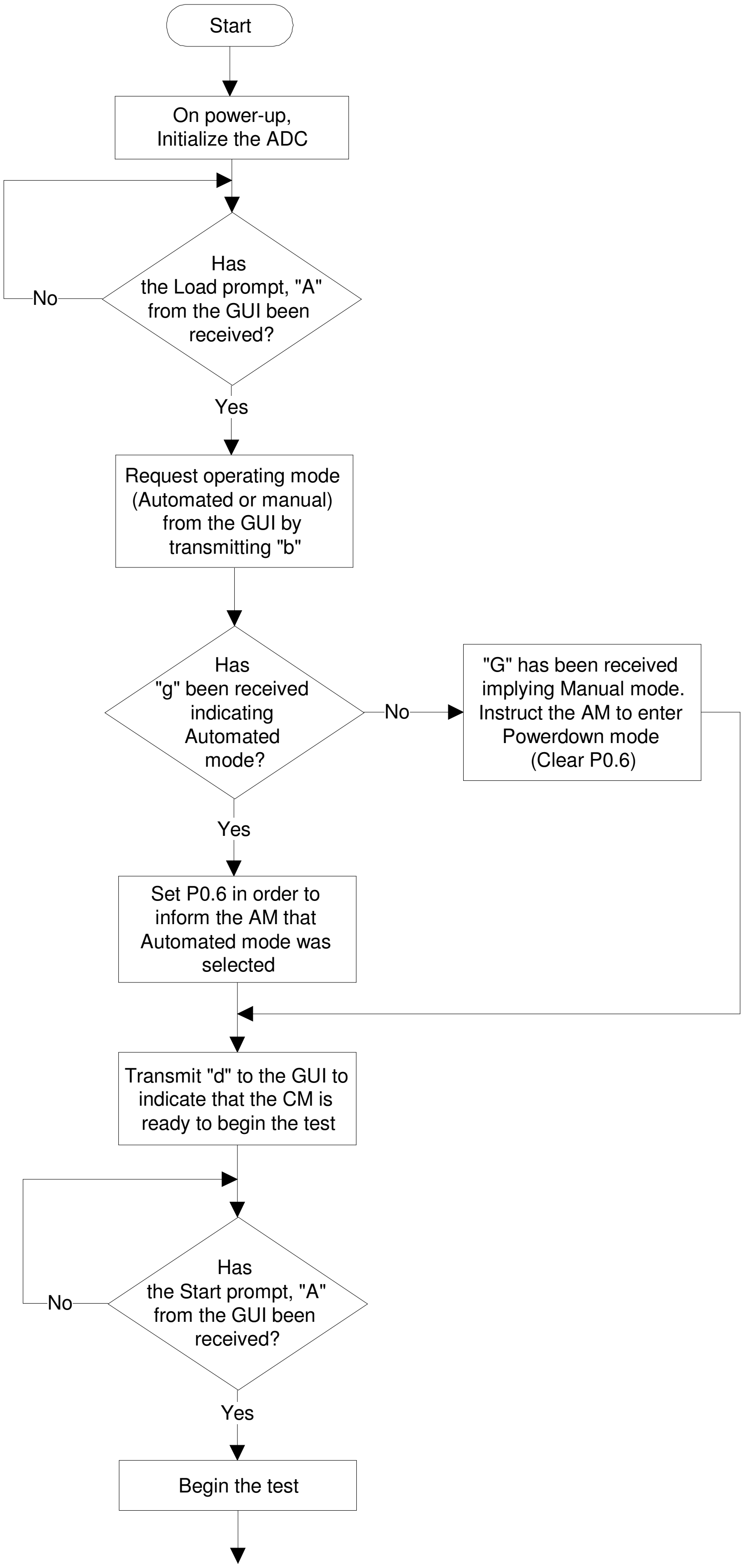


FIGURE 4-2: SYSTEM BLOCK DIAGRAM

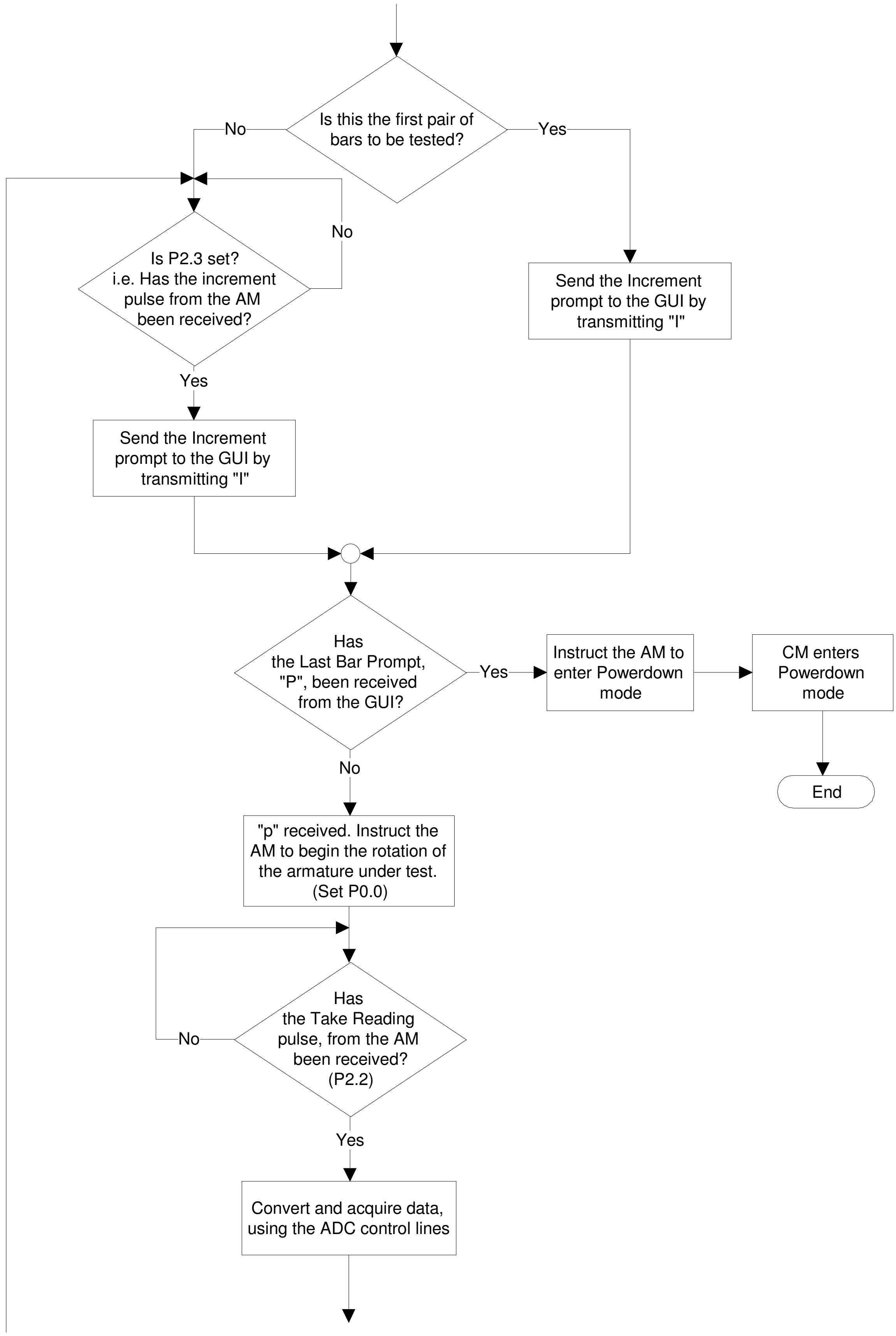
The function of the CM includes the transmission and reception of prompts to and from the GUI, the control of the ADC, the capture of data (high and low bytes) and storage thereof in two registers in its memory and the transmission of this data to the GUI for analysis. When the analysis is complete the GUI prompts the CM which in turn signals the AM to continue with the test.

While the AM is in control it communicates with the CM in the event of any system errors. If no errors occur, the AM will hand over control to the CM in order for the CM to take the volt-drop readings after the test current has been switched on and the test probes have been lowered onto the bars of the commutator. These readings are then transmitted to the GUI and so the process continues until the last pair of bars has been tested. See Figure 4-3 for the flow diagram for the CM. A discussion follows thereafter.


Start
On power-up, Initialize the ADC
Has the Load prompt, "A" from the GUI been received?
No
Yes
Request operating mode (Automated or manual) from the GUI by transmitting "b"
Has "g" been received indicating Automated mode?
No
"G" has been received implying Manual mode. Instruct the AM to enter Powerdown mode (Clear P0.6)
Yes
Set P0.6 in order to inform the AM that Automated mode was selected
Transmit "d" to the GUI to indicate that the CM is ready to begin the test
Has the Start prompt, "A" from the GUI been received?
No
Yes
Begin the test

A (pp. 98)

A (pp. 97)



B (pp. 99)   C (pp. 99)

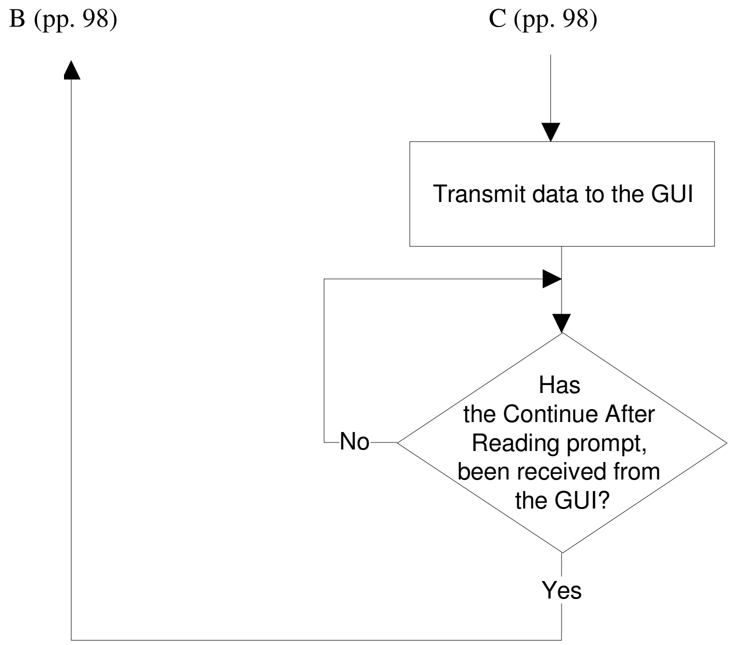


FIGURE 4-3: FLOW DIAGRAM FOR THE COMMUNICATIONS MICROCONTROLLER

On power up the CM initialises the ADC (i.e. the MAX 1166). Referring to the MAX 1166 datasheet, included as Appendix J, the ADC manufacturer's application information found on page 9 suggests that a 'dummy' conversion should be run in order to put the ADC in a known state after powering up from shut down. The CM then waits for the GUI to transmit a "Status: Ready" prompt, i.e. the ASCII code for the letter 'A'. When this has been received the CM transmits 'b' to the GUI to request the mode of operation in which the test is to be run. If a 'G' is received then the test is to be run in manual mode, the CM then informs the AM of this by Clearing (0) the CM P0.6 so that the AM can enter Powerdown mode.

The CM notes that the test is being run in manual mode by setting flag 04H in the bit addressable ram. This flag is tested in the CM Reading Subroutine in order to establish whether communication with the AM should be attempted. Recalling that AM is in Powerdown mode during a manual test any attempt by the CM to communicate with the AM will be futile and will ultimately leave the CM in a continuous wait loop as it will be waiting for communication signals from the AM that will never arrive. When flag 04H is tested in the Reading Subroutine and is found to be Set (1), the CM will not attempt to communicate with the AM as the test is being run in manual mode. However, if this flag is tested and is found to be Low (0) the CM will establish communication with the AM as the test will be running in automated mode. If a ‘g’ is received the test will be run in the automated mode. The AM will be informed of this by Setting (1) the CM P0.6. Once the CM captures the mode of operation it transmits a ‘d’ to the GUI to indicate that it is ready to begin the test. Recalling the discussion on the GUI Start control, it is after receiving the ‘d’ that the Start Button is enabled. On clicking the Start button an ‘A’ is transmitted by the GUI. On receiving this prompt (‘A’) the controller begins the test.

For the first pair of bars to be tested the CM transmits an increment prompt to the GUI, the ASCII code for the letter ‘I’ without waiting for an increment signal from the AM. However, after the first pair of bars has been tested, the CM will wait for the increment signal from the AM before transmitting the ‘I’ prompt to the GUI. The increment signal from the AM is signaled by setting its output P0.0, High (logic level 1). See Appendix K for a complete list of Input/Output port utilisations for both microcontrollers.

The input P2.3 of the CM which is directly connected to P0.0 of the AM is then also read as a High. This High state on the CM input pin is recognised as an increment signal from the AM. This signal from the AM serves to inform the GUI, via the CM, that the system is ready to test the next pair of bars. When the increment prompt is transmitted to the GUI, the Bar_count subroutine is called in order to ascertain whether the last pair of bars has been tested. If it has been tested, the GUI transmits a ‘P’ to the CM to acknowledge that the test has been completed. On receiving this prompt the CM in turn informs the AM that the test is over and that Powerdown mode should be entered into. After verifying that the AM has received the command to enter Powerdown the CM itself enters Powerdown.

Note that in manual mode, the CM does not read an increment pulse from the AM as the AM is in Powerdown mode. An increment signal is generated by the user pressing on a switch that is connected to P3.6 which sends the increment prompt to the GUI.

The end of a test is signaled by the reception of a ‘B’ prompt from the GUI. This prompt is transmitted when the END control button is clicked on the GUI. The prompt 'B' is transmitted regardless of the mode in which the test has been run. However, in the automated mode the CM does not wait for the receipt of this prompt to enter Powerdown as it is already aware of the end of the test due to the AM increment signal and the GUI Bar_count subroutine.

If the last pair of bars has not yet been tested, the GUI transmits 'p'. When the CM receives this signal it instructs the AM to begin the rotation of the armature under test by setting P0.0 High. The CM now waits for the AM to detect the next pair of bars, stop the armature rotation, switch on the test current and lower the test probes onto the detected bars. Once the AM receives a signal from the detection unit indicating that the test probes are on the commutator it signals the CM to take a reading. When the CM reads P2.2 as a High it calls the subroutine that captures the volt-drop reading for the pair of bars under test. This subroutine will be discussed in detail later in this chapter. The captured data is stored as a High byte and Low Byte in two registers in the CM memory (RAM). The CM then transmits each byte to the GUI where it is analysed. Upon completion of the calculation and the analysis process by the GUI, the GUI transmits an ASCII 'E' to the CM. This prompt serves to inform the CM that the data has been analysed and that the GUI is ready to proceed to the next pair of bars.

It should be noted here that as an additional feature, one hundred consecutive readings are captured at 1000μs intervals and averaged for each pair of bars. The CM and GUI Reading Subroutines were therefore modified to enable this functionality. The details and discussion offered in this chapter are aimed at providing an understanding of the basic features and concepts before the more complex additional features are discussed in Chapter 6.

On receiving this prompt, the CM informs the AM that it too is ready to proceed to the next pair of bars by setting its P0.7 High (1). On receiving a High on P1.7, the AM confirms that it is ready to proceed to the next pair of bars by setting its P0.1 High (1) which is the increment signal that the CM reads on its P2.3. When P2.3 is read as a High (1) the CM transmits the increment prompt ('I') to the GUI.

The CM follows this process until the last pair of bars has been tested or until any one of the four possible system errors interrupts the process flow. When such an interrupt is encountered there is a branch from the main program flow to an interrupt handling procedure (an ISR) that caters specifically for the encountered error. Once the error has been ‘handled’ control is handed back to the main program. These Interrupts, their associated Interrupt Service Routines (ISRs) and critical subroutines will be discussed in the sections that follow. See Appendix L for the source code for both the Communication and Automation microcontrollers.

4.1.1 Microcontroller Initialisation

On power up the microcontroller must perform an initialisation procedure to ensure that all the ports, timers and special function registers are set up appropriately to undertake the tasks that they are assigned. As the name indicates, the AT89S51 input/output ports can be used as either inputs that read signals from the interfacing digital system or outputs that transmit signals to the interfacing digital system. Each pin can be addressed independently and can therefore be configured individually as an input or an output pin. Pins can be configured as inputs by writing a logic level 1 (High) to their port latches. If a port latch contains the logic level 0 (Low), it will be configured as an output pin. Code Extract 4-1 shows the input/output port configuration for the CM as depicted in Appendix K.

```
MAIN:   MOV     P0,#00000100B
        MOV     P1,#11111111B
        MOV     P2,#01111110B
        MOV     P3,#01010111B
```

CODE EXTRACT 4-1: COMMUNICATION MICROCONTROLLER I/O PORT CONFIGURATION

Also to be initialised are the various Special Function Registers (SFRs) and Timers as shown in Code Extract 4-2.

```
MAIN2:  MOV     SCON,#01010000B
        MOV     TMOD,#20H
        MOV     TH1,#-13
        SETB    TR1
        MOV     IE,#10000000B
        MOV     IP,#00010000B
        SETB    IT0
```

CODE EXTRACT 4-2: INITIALISATION OF SPECIAL FUNCTION REGISTERS FOR THE CM

Special Function Registers are associated with specific microcontroller features, properties and settings. For example, the SCON SFR is used in conjunction with the serial port, the TMOD SFR is used in conjunction with the timers, and the IE and IP SFRs are used in conjunction with the interrupts. It is for this reason that the author has opted to discuss the initialisation of these SFRs when discussing their associated microcontroller features.

4.1.2 Serial Port

The serial port provides a means of data transmission and reception. A parallel-to-serial conversion takes place on transmission of data and a serial-to-parallel conversion takes place on reception of data. In other words, when data from a register which holds data as eight parallel bits needs to be transmitted serially, i.e. one bit after the other, a parallel-to-serial conversion needs to take place. And when receiving serially transmitted data and storing it in a register the opposite conversion, i.e. a serial-to- parallel conversion, must take place. See Figure 4-4A and Figure 4-4B.

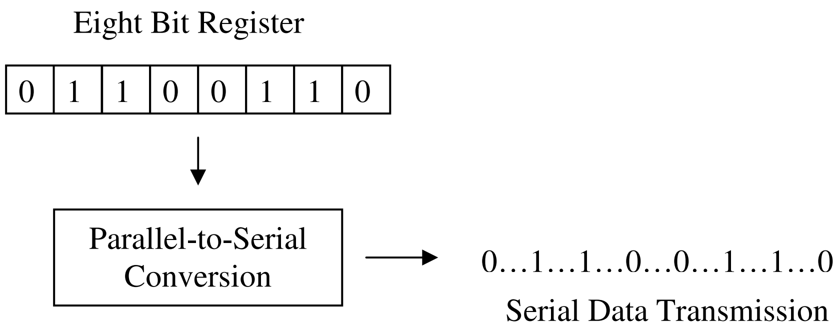


FIGURE 4-4A: SERIAL PORT DATA TRANSMISSION

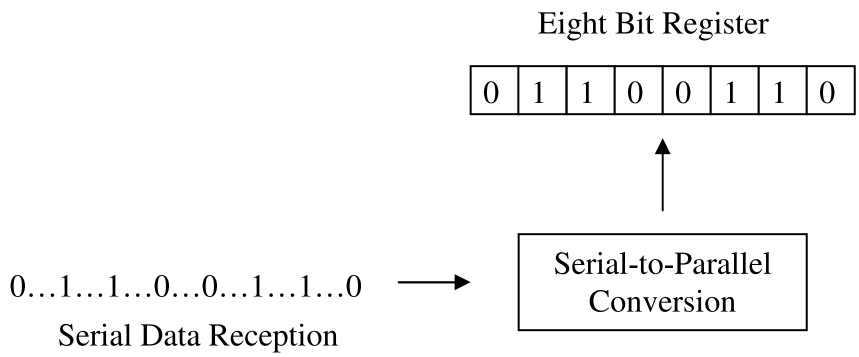


FIGURE 4-4B: SERIAL PORT DATA RECEPTION

The AT89S51 serial port features full duplex operation and two SFRs that provide access to the serial port. These are the SCON and the SBUF registers. SBUF, the serial port buffer, is in fact two individual buffers/registers. A write-only register is accessed when SBUF is written to when the data is to be transmitted and the read-only register that is accessed when SBUF is read from when data has been received. For example, the statement:

```
MOV     SBUF,A
```

transmits data from the general purpose register, i.e. the Accumulator (A), by copying the value from A to the SBUF register. Similarly using:

```
MOV     A,SBUF
```

received data is read from the SBUF register and copied into A. The SCON special function register, when initiated, sets the mode in which the serial port will operate as well as the individual bits that enable reception, sets flags etc. The statement:

```
MOV     SCON,#01010000B
```

initialises the serial port for operation in mode 1 by setting bits SCON.7 = 0 and SCON.6 = 1. The Receive Enable bit, SCON.4 is also set to enable the reception of characters.

Bit	Symbol	Address	Description
SCON.7	SM0	9FH	Serial Port mode bit 0
SCON.6	SM1	9EH	Serial Port mode bit 1
SCON.5	SM2	9DH	Serial Port mode bit 2
SCON.4	REN	9CH	Receive Enable
SCON.3	TB8	9BH	Transmit bit 8. Ninth bit transmitted in modes 2 & 3
SCON.2	RB8	9AH	Receive bit 8. Ninth bit received in modes 2 & 3
SCON.1	TI	99H	Transmit Interrupt flag
SCON.0	RI	98H	Receive Interrupt flag

TABLE 4-1: SERIAL PORT CONTROL (SCON) REGISTER SUMMARY
SOURCE: THE 8051 MICROCONTROLLER (REFERENCE BOOK)

The serial port can operate in one of four modes. In Mode 1 the serial port operates as an eight bit UART (Universal asynchronous receiver/transmitter) with variable Baud Rate. The baud rate is set to 2400 using Timer 1. In this mode, transmission and reception involves ten bits. The first bit being the start bit which is always a Low (0), followed by eight bits of data with the leading bit being the LSB and a stop bit which is always a High (1). Setting of the baud rate is discussed in this chapter under Timers i.e. Section 4.1.4.

```
MAIN2:  MOV     SCON,#01010000B
        MOV     TMOD,#20H
        MOV     TH1,#-13
        SETB    TR1
```

CODE EXTRACT 4-3: SERIAL PORT AND BAUD RATE INITIALISATION

4.1.3 Interrupts and Interrupt Service Routines (ISRs)

In real world applications, systems are required to respond to random events that may or may not occur and if they do occur the time at which they do so cannot be predicted. It is this random, unpredictable nature of the event that makes it difficult to program the event detection and handling as part of a process flow or main program. A normal program flow is defined and executes statement by statement, jumps, calls subroutines and returns from subroutines, hence leaving no allowance for random, unpredictable events.

The most efficient way to handle such events is to pause the normal program flow or the main program, which operates at base-level, jump to a location in memory in which code for handling the event resides (the Interrupt Service Routine), execute the ISR at interrupt-level and then return control to the main program. An Interrupt Service Routine is a block of code that is developed to handle the specific event that triggers its associated interrupt. A microcontroller has various interrupt sources which indicates that such an event has occurred. The AT89S51 has two External Interrupts, two Timer Interrupts and a Serial Port Interrupt. The CM however, only makes use of one external interrupt, External Interrupt 0, and the Serial Port Interrupt.

Whenever a specified event occurs, an interrupt is triggered. Each interrupt has an associated flag to signal that a specific interrupt has occurred. All flags, except the serial port interrupt flags, and level triggered external interrupts flags, are cleared by hardware, i.e. the programmer does not have to clear the flag using software because flags are automatically cleared when vectoring to the ISR. Edge triggered external interrupts flags are cleared by hardware and are therefore favored for this application.
When a serial port interrupt occurs the source of the interrupt, i.e. whether the interrupt was triggered on a receive or transmit event, needs to be verified. The only way of verifying this is by checking the status of each flag. The serial port flags must therefore be cleared in software after being checked.

Each interrupt also has an assigned location in memory in which its ISR should reside. See Table 4-2 below. When an interrupt occurs, the location in memory allocated to the associated interrupt is loaded into the Program Counter (PC). This value (location) is called the interrupt vector.

Interrupt	Flag	Vector Address
System Reset	RST	0000H
External Interrupt 0	IE0	0003H
Timer Interrupt 0	TF0	000BH
External Interrupt 1	IE1	0013H
Timer Interrupt 1	TF1	001BH
Serial Port Interrupt	RI or TI	0023H

TABLE 4-2: INTERRUPT VECTORS
SOURCE: THE 8051 MICROCONTROLLER

The reader will notice that each interrupt has only eight bytes of memory in which to code the ISR. In the event that an ISR is longer than eight bytes, a jump statement is used to direct the program counter to another location in memory. Note that the program counter (PC) holds the memory address of the next statement (instruction) that is to be executed.

```
ORG     0H
LJMP    MAIN
ORG     0003H
LJMP    EX0ISR
ORG     0023H
LJMP    SPISR
```

CODE EXTRACT 4-4: CM VECTORING ADDRESSES

Referring to Code Extract 4-4 on a system reset (or startup), the program counter is loaded with the Reset vector address (0000H), when at this location, the program counter is then loaded with the address of the MAIN label thus executing a jump to the location in memory where the main program resides under the label MAIN. When External Interrupt 0 is triggered, the PC is loaded with the External Interrupt 0 vector address (0003H).

When at this location, the PC is loaded with the vector address for the EX0ISR label. This label represents the beginning of the External Interrupt 0 ISR. The program then jumps to the location in memory where this label resides and executes each instruction in the ISR until the RETI (return from interrupt) instruction. This instruction signals the end of the ISR and hands over control to the main program so that it may continue from where it left off. All interrupts are handled in the same way.

4.1.3.1 Interrupt Enabling

The Interrupt Enable (IE) register is responsible for the enabling and disabling of all interrupts. Each interrupt is enabled and disabled individually by addressing the specified bit. However, if the Global enable/disable bit EA, is not set High (1), none of the individual interrupts can be enabled. Therefore by Setting (1) or Clearing (0) the Global enable/disable bit all individually enabled interrupts can be enabled or disabled at the same instant. Interrupts can be enabled or disabled anywhere in program code by using statements such as the following:

```
SETB EX0
SETB EA
CLR  EX0
```

or by addressing the entire IE register. all the interrupts can be individually enabled or disabled using one statement. This method is used most often when initialising the interrupts as shown in Code Extract 4-2 and in the statement below.

```
MOV     IE,#10000000B
```

This statement sets the Global enable/disable bit High (1), thus enabling the use of interrupts whenever they are individually enabled during the program. Table 4-3 presents a summary for Interrupt Enable register.

Bit	Symbol	Bit Address	Description (1=Enable, 0 = Disable)
IE.7	EA	AFH	Global enable/disable
IE.6	-	AEH	Undefined
IE.5	-	ADH	Undefined for the AT89S51
IE.4	ES	ACH	Enable Serial Port Interrupt
IE.3	ET1	ABH	Enable Timer 1 Interrupt
IE.2	EX1	AAH	Enable External 1 Interrupt
IE.1	ET0	A9H	Enable Timer 0 Interrupt
IE.0	EX0	A8H	Enable External 0 Interrupt

TABLE 4-3: INTERRUPT ENABLE REGISTER SUMMARY
SOURCE: THE 8051 MICROCONTROLLER

4.1.3.2 Interrupt priority

The events that trigger certain interrupts may be more critical than the events that trigger others, these critical events therefore demand immediate attention. This may entail the interruption of an already executing ISR that was triggered by an earlier event, i.e. the non critical ISR must be interrupted to hand over control to the more critical ISR. This is achieved by using the Interrupt Priority (IP) register. By setting the bit assigned to a certain interrupt High (1), that interrupt is assigned a high-level priority and can therefore interrupt the ISR of an interrupt with a low-level priority if required. The interrupt priority can be set when initialising the interrupts as shown in Code Extract 4-2 and in the statement below.

```
MOV     IP,#00010000B.
```

Referring to Table 4-4, for a summary of the IP register, the reader will notice that in the instruction above only bit IP.4 is set High (1). This means that of all the interrupts that are, or will be enabled, the serial port interrupt has the highest priority and its ISR takes precedence over any program, subroutine or ISR that is executing at the time.

Bit	Symbol	Bit Address	Description (1=High Level, 0 = Low Level)
IP.7	-	-	Undefined
IP.6	-	-	Undefined
IP.5	PT2	0BDH	Undefined for the AT89S51
IP.4	PS	0BCH	Priority for Serial Port Interrupt
IP.3	PT1	0BBH	Priority for Timer 1 Interrupt
IP.2	PX1	0BAH	Priority for External 1 Interrupt
IP.1	PT0	0B9H	Priority for Timer 0 Interrupt
IP.0	PX0	0B8H	Priority for External 0 Interrupt

TABLE 4-4: INTERRUPT PRIORITY REGISTER SUMMARY
SOURCE: THE 8051 MICROCONTROLLER

4.1.3.3 Polling sequence

A fixed polling sequence determines which of two interrupts having the same priority is serviced first, if these two interrupts are triggered at exactly the same time.
The polling sequence for the AT89S51 is:

- External Interrupt 0
- Timer Interrupt 0
- External Interrupt 1
- Timer Interrupt 1
- Serial Port Interrupt

4.1.3.4 External Interrupts

Signals from interfacing systems are processed by a digital system which then outputs a signal to one or both of the external interrupt port pins, P3.2 (pin 12) and/or P3.3 (pin 13). These interrupts can be triggered in two ways, i.e. low-level activation or negative (or falling) edge activation. In the former instance, an external interrupt is triggered when the interrupt pin is held Low (0). In the latter instance, the interrupt is triggered on a High-to-Low (1-to-0) transition. The activation mode is configured by setting or clearing the IT0 bit (which is associated with External Interrupt 0) and the IT1 bit (which is associated with External Interrupt 1) in the TCON SFR. By setting IT0 to 1 (High), as shown in Code Extract 4-2, External Interrupt 0 is configured to trigger on a negative edge.

```
SETB    IT0
```

The CM makes use of External Interrupt 0 by enabling and disabling it on demand and initialising it with a low-level interrupt priority and negative-edge activation. The function of this interrupt is to indicate and service system errors if or when they occur and to inform the GUI (by transmitting a ‘O’) when a manual Emergency Stop has been initiated by pressing on the Emergency Stop switch (on P3.2) on the Test Station or by the activation of a safety interlock. Once the GUI has been informed of an Emergency Stop, the CM enters Powerdown mode.

Recall from Chapter 2, Error1 occurs when a pair of bars is not detected within a specified time, Error2 occurs when the test probes are not present on the surface of the commutator within a pre-selected default time, Error3 occurs when the test current is not switched off after a pre-selected default time and Error4 occurs when the test probes are not raised to their original position within a specified time.

The AM is the first to recognise any errors should they occur as system monitoring signals produced by proximity switches and other transducers are input to the AM via the interfacing digital system. The AM then sets High (1) output pins that correspond to the error that has occurred. See Appendix K and Table 4-5.

Automation Microcontroller (AM) – Automation Control		
P2.6	(27)	**O** – Error 4 – Test Probes Not Raised.
P3.5	(15)	**O** – Error 1 – Pair Not Detected.
P3.6	(16)	**O** – Error 2 – Test Probes Not Lowered.
P3.7	(17)	**O** – Error 3 – Current On-Time Exceeded.

TABLE 4-5: TABLE OF THE AM ERROR OUTPUT INDICATION PINS

These output pins are connected to individual input pins on the CM as well as the External 0 interrupt as depicted in Appendix K and Table 4-6.

Communications Microcontroller (CM) – Communication & Signalling		
P2.4	(25)	**I** – Error 1 – Pair Not Detected.
P2.5	(26)	**I** – Error 2 – Test Probes Not Lowered.
P2.6	(27)	**I** – Error 3 – Current On-Time Exceeded.
P3.2	(12)	**I** – **External Interrupt 0** – All Error Inputs Connected here as well.
P3.4	(14)	**I** – Error 4 – Test Probes Not Raised.

TABLE 4-6: TABLE OF THE CM ERROR INPUT INDICATION PINS

When a system error occurs, the AM signals the CM by setting the associated pin High (1). When any one of the error lines go High (1) the interfacing digital system also triggers External Interrupt 0. The reason for this becomes apparent when looking at the flow diagram in Figure 4-5 and Code Extract 4-5.

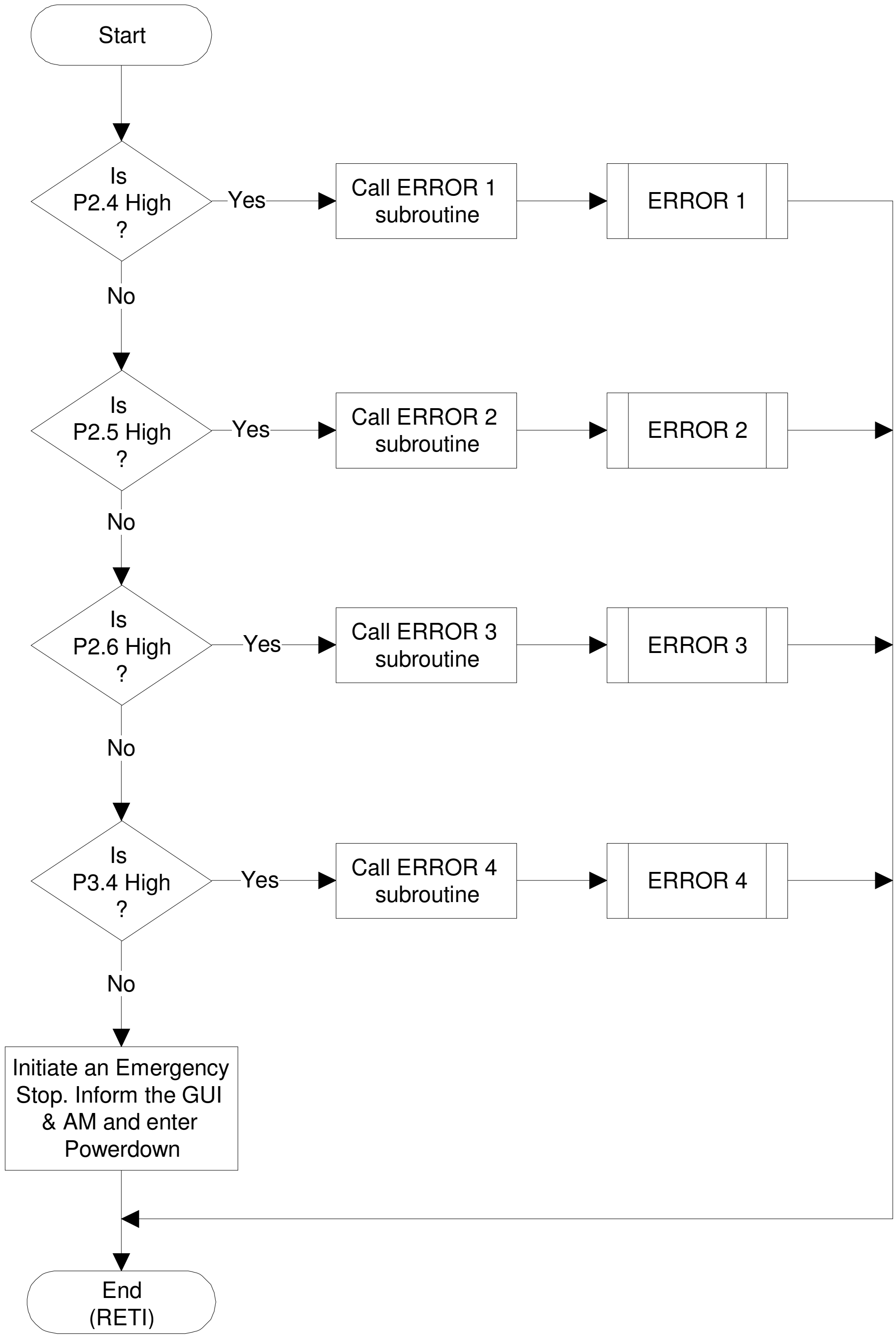


FIGURE 4-5: FLOW DIAGRAM FOR EXTERNAL INTERRUPT 0 – CM

```
;**********************************
;    EXTERNAL INTERRUPT 0 ISR
;FOR ERRORS 1 TO 4 & Emergency Stop
;**********************************

EX0ISR: JNB     P2.4,ERR2
        CALL    ER1_SUB
        SETB    03H
        JMP     EX0OUT
ERR2:   JNB     P2.5,ERR3
        CALL    ER2_SUB
        SETB    03H
        JMP     EX0OUT
ERR3:   JNB     P2.6,ERR4
        CALL    ER3_SUB
        JMP     EX0OUT
ERR4:   JNB     P3.4,EX0OUT
        CALL    ER4_SUB
EX0OUT: MOV     A,#'O'
        CALL    CH_OUT
        JMP     EXT
        RETI
```

CODE EXTRACT 4-5: CODE FOR EXTERNAL INTERRUPT 0 – CM

When the interrupt is triggered the External Interrupt 0 ISR is initiated. Once in the ISR, each input error pin is tested for a High (1) status and when an error pin is identified the associated subroutine is called to handle it. The error subroutines will be discussed in detail in the section entitled Subroutines i.e. Section 4.1.5.

4.1.3.5 Serial Port Interrupts

The serial port interrupt is triggered when any activity is detected on the serial port. When data is received the Receive Interrupt (RI) flag is set High (1) and when data is being transmitted the Transmit Interrupt flag is set High (1). The interrupt is triggered on either of these events. As previously mentioned, the RI and TI flags have to be cleared by software the reason for this will be discussed with reference to Figure 4-6 and Code Extract 4-6.

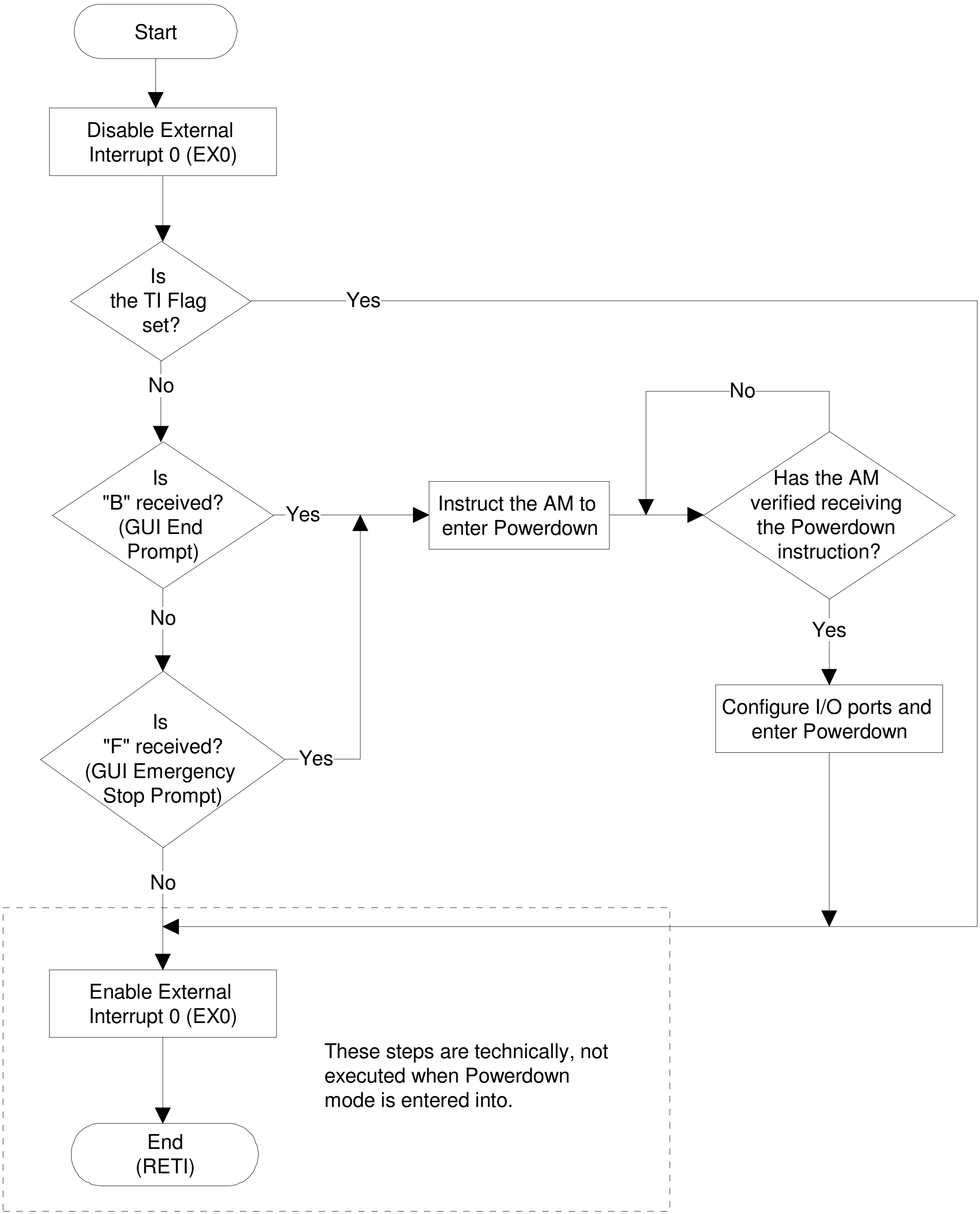


FIGURE 4-6: FLOW DIAGRAM FOR SERIAL PORT INTERRUPT – CM

```
;*********************************************
;       SERIAL PORT ISR
;*********************************************

SPISR:  CLR     EX0
        JNB     TI,REC
        ;CLR     TI; cleared in ch_out
        JMP     SP_OUT
REC:    NOP
SLCH_IN:JNB     RI,$
        CLR     RI
        MOV     A,SBUF
        CJNE    A,#'B',SPNXT ;END
ENDD:   SETB    P0.1; END TO U2
SP_END: JNB     P3.4,SP_END

        CLR     P0.1
        MOV     P0,#0H
        MOV     P1,#0H
        MOV     P2,#0H
        MOV     P3,#00000011B
        MOV     PCON,#00000010B;POWER DOWN
        NOP
        JMP     ED
SPNXT:  CJNE    A,#'F',SP_END3 ;EMERGENCY STOP
CRNT_E: SETB    P0.5
SP_ENDx:JNB     P3.4,SP_ENDx

        CLR     P0.5
        MOV     P0,#0H
        MOV     P1,#0H
        MOV     P2,#0H
        MOV     P3,#00000011B
        MOV     PCON,#00000010B;POWER DOWN
        NOP
        JMP     ED

SP_END3:JMP     SP_OUT
SP_OUT: SETB    EX0
        RETI

;*********************************************
```

CODE EXTRACT 4-6: CODE FOR SERIAL PORT INTERRUPT – CM

The CM receives prompts as well as transmits prompts and data. The only significant events that would require the main program to be interrupted are the End event or an Emergency Stop event prompt from the GUI. Hence an ISR only needs to be initiated on a receive event or only when the RI flag triggers the interrupt. As mentioned previously, the ISR is initiated on both the receive and transmit event.

A method of exiting the ISR on a transmit event is to check the status of the TI and RI flags. As show in Code Extract 4-6, the TI flag is tested and if it is found to be High (1) a jump to the end of and an exit from, the ISR is initiated. Control is then handed over to the point in the program from which it left off. If the TI flag is not found to be set, i.e. Low (0), then the RI flag is cleared and the received data is tested to verify if it corresponds to either the End ('B') or Emergency Stop ('F') prompt. If it does correspond, the AM is instructed by the CM to enter Powerdown. Once the CM verifies the AM having received this instruction, the CM configures its port pins appropriately before also entering Powerdown.

If the received data does not correspond to either of these conditions i.e. a 'B' or 'F', the ISR is exited and control is handed over to the main program at the point from which it left off. When the ISR is initiated on a receive event that is not an End or an Emergency Stop prompt, the point at which the main program was interrupted, was a waiting point for a prompt. When control is handed back to the main program, control is handed back at this waiting point. It is here that the received data is tested again to verify whether the received prompt is the prompt that the main program was waiting for at that point.

4.1.4 Timers

The AT89S51 features two sixteen-bit timers, Timer 0 and Timer 1, which can be used in any one of four modes as shown in Table 4-7. These timers make use of six special function registers, TCON, TMOD, TL0, TL1, TH0 and TH1. For this project, CM utilises Timer 1 in mode 2, auto-reload mode, to generate the required baud rate for the serial port and the AM utilises Timer 0 and Timer 1 in mode 1, as sixteen-bit timers. In both cases, the clocking source is the on-chip oscillator which is used for interval timing as opposed to an external clocking pulse which is used for event counting.

Mode	M1	M0	Description
0	0	0	13-Bit timer mode
1	0	1	16-Bit timer mode
2	1	0	8 – Auto-reload mode
3	1	1	Split timer mode – Timer 0 split into two 8-bit timers & Timer 1 is stopped

TABLE 4-7: TABLE OF TIMER MODES
SOURCE: THE 8051 MICROCONTROLLER

The selection between these two clocking sources is made by either setting the $C/\overline{T}$ bit in the TMOD SFR High (1) for interval timing using the on-chip oscillator or, by setting the $C/\overline{T}$ bit Low (0) for event counting using external clocking sources. When using interval timing the on-chip oscillator clocking source is followed by a divide-by-twelve stage. This means that the timer registers are incremented at a rate of 1/12th the frequency of the clocking source. For example, if a 12MHz crystal was used, as in this case, the on-chip oscillator will provide a clocking frequency of 12MHz before the divide-by-twelve stage. After the divide-by-twelve stage the clock rate will be 1MHz, or in terms of time, one microsecond (1µs).

As previously mentioned, the timer makes use of six special function registers. These SFRs along with their respective purposes are summarised in Table 4-8.

Timer SFR	Purpose	Address	Bit-Addressable
TCON	Control	88H	Yes
TMOD	Mode	89H	No
TL0	Timer 0 Low-Byte	8AH	No
TL1	Timer 1 Low-Byte	8BH	No
TH0	Timer 0 High-Byte	8CH	No
TH1	Timer 1 High Byte	8DH	No

TABLE 4-8: TIMER SPECIAL FUNCTION REGISTER SUMMARY
SOURCE: THE 8051 MICROCONTROLLER

The Timer Control Register (TCON) is the only one of the timer SFRs that is bit addressable. These registers contain status bits (timer flags) and control bits (timer triggers). It is necessary to Set (1) or Clear (0) each of these bits independently and at different times in order to control the timers. See Table 4-9 for the TCON register bit summary.

Bit	Symbol	Bit Address	Description
TCON.7	TF1	8FH	Timer 1 overflow flag
TCON.6	TR1	8EH	Timer 1 run-control bit
TCON.5	TF0	8DH	Timer 0 overflow bit
TCON.4	TR0	8CH	Timer 0 overflow bit
TCON.3	IE1	8BH	External Interrupt 1 edge flag
TCON.2	IT1	8AH	External Interrupt 1 type flag
TCON.1	IE0	89H	External Interrupt 0 edge flag
TCON.0	ITO	88H	External Interrupt 0 type flag

TABLE 4-9: TCON REGISTER SUMMARY
SOURCE: THE 8051 MICROCONTROLLER

A timer can be started or stopped using theTRx[1] bit. For example when using Timer 0, the statement:

```
SETB    TR0
```

is used to start the timer. The timer register(s) will increment by one from 0000H or from any pre-loaded value. The duration between each increment is determined by the clocking pulse, which as discussed above, provides a clocking pulse every 1µs for a 12 MHZ crystal. The timer is stopped by using the statement below.

```
CLR     TR0
```

Flags are used to indicate a timer overflow. For example, if Timer 0 is used as a sixteen-bit timer, when started, it will increment from 0000H or a pre-loaded value, every 1µs until it reaches the maximum sixteen-bit count, FFFFH. Once FFFFH has been reached, the counter beings counting from 0000H again. On the FFFFH to the 0000H transition the Timer 0 flag (TF0) is Set (1). This flag is set by hardware and is cleared by software after the status of the flag has been tested as shown below.

```
WAIT_T3:JNB     TF1,WAIT_T3
```

The use of timers for long interval timing is discussed in the sub-section entitled Timers and Timer Operation i.e. Section 4.2.4 in the Automation Microcontroller discussion.

[1] The ‘x’ in TRx represents 0 or 1, thus implying TR0 or TR1. From this point forward, an ‘x’ used in this form, in conjunction with any other register, will also represent a 1 or a 0.

The TMOD register is used primarily to set the mode of the timers during initialisation. After initialisation the TMOD register is generally not re-addressed. See Table 4-10 for a summary of the TMOD register.

Bit	Name	Timer	Description
7	GATE	1	Gate Bit
6	$C/\overline{T}$	1	Counter/Timer select bit. (1 = event counter, 0 = interval counting)
5	M1	1	Mode bit 1
4	M0	1	Mode bit 0
3	GATE	0	Timer 0 gate bit
2	$C/\overline{T}$	0	Timer 0 Counter/Timer select bit.
1	M1	0	Timer 0 Mode bit 1
0	M0	0	Timer 0 Mode bit 0

TABLE 4-10: TMOD REGISTER SUMMARY
SOURCE: THE 8051 MICROCONTROLLER

TH0 and TH1 are the respective Timer 0 and Timer 1 High byte registers, while TL0 and TL1, are the respective Timer 0 and Timer 1 Low byte registers. Depending on the mode in which the timers are used, the SFRs are written to when pre-loading values (and incremented at each clock pulse), and/or read from when recording the time that has elapsed.

The Communication Microcontroller uses Timer 1 to set the baud rate for the serial port. The baud rate is set by the overflow rate of Timer 1. Timer 1 is initialised in mode 2, 8-bit auto-reload mode, as shown using the second instruction in Code Extract 4-7. Referring to the third instruction in Code Extract 4-7, a reload value of -13 is stored in the Timer 1 high byte register (TH1). In this mode the Timer low byte register (TL1), is incremented by one from the pre-loaded value stored in the Timer high byte register, to FFH. On the Timer overflow, the Timer flag is set as usual but in mode 2, the re-load value that is held in the Timer high byte register, is reloaded into the Timer low byte and counting begins from this value to FFH. This cycle runs continuously.

```
MAIN2:  MOV     SCON,#01010000B
        MOV     TMOD,#20H
        MOV     TH1,#-13
        SETB    TR1
```

CODE EXTRACT 4-7: SERIAL PORT AND BAUD RATE INITIALISATION

The re-load value is determined by the required baud rate and the selected serial port mode that was set upon initialisation of the SCON SFR. With the serial port being initialised in mode 1, the default baud rate is 1/32 of the oscillator frequency. (Note that this value can be doubled by setting the SMOD bit in the Power Control (PCON) register, High [1]). The equation used to calculate the re-load value for a given baud rate when operating in a pre-selected serial port mode, is as follows:

$$\text{Default Rate} = \frac{\text{Timer Overflow Rate}}{\text{Clock Frequency Reduction Value}} \quad \text{……..} \quad 4\text{-}1$$

Source: The 8051 Microcontroller

Substituting the values

$$2400\ \text{KHz} = \frac{\text{Timer Overflow Rate}}{32} \quad \text{………} \quad 4\text{-}2$$

$$\text{Timer Overflow Rate} = 2400\ \text{kHz} \times 32 \quad \text{………} \quad 4\text{-}3$$

$$= 76800\ \text{kHz}$$

$$= 76.8\text{kHz} \quad \text{………} \quad 4\text{-}4$$

What now remains to be calculated is the number of clocking cycles, at 1MHz, it will take to provide an overflow every 76.8kHz.

$$\text{Number of clocks} = \frac{1MHz}{76.8kHZ} \quad \text{………} \quad 4\text{-}5$$

$$= 13.02$$

$$\approx 13\ \text{clocks}$$

Alternatively, using time instead of frequency,

from (4-4), $$\text{Time} = \frac{1}{76.8\text{kHz}} = 13.02\mu\text{s} \quad \text{………} \quad 4\text{-}6$$

$$\approx 13\mu\text{s}$$

and a clocking rate of

$$\frac{1}{1\text{MHz}} = 1\mu\text{s} \qquad \ldots\ldots\ldots \quad 4\text{-}7$$

The number of clocks, at a rate of 1μs, that is takes to produce an overflow after 13μs is:

$$\text{Number of clocks} = \frac{13\mu s}{1\mu s} = 13 \text{ clocks} \qquad \ldots\ldots\ldots \quad 4\text{-}8$$

This value (13) is multiplied by -1 and stored in the Timer high byte (TH1) register. Because an overflow occurs on the FFH-to-0H transition, using the negative of the calculated value, the assembler is told that the reload value is 13 less than 0. In this way, an overflow is forced after every 13 clocks, hence providing the required baud rate.

4.1.5 Subroutines

Subroutines are small programs that can be called by the main program, other subroutines as well as interrupt service routines (ISRs). They often consist of a block of code that is used more than once by the calling program. When developing and debugging a program, it is easier to divide the large and often complex program into smaller programs that are less complex. These smaller programs, or subroutines, are then called at will, to perform the task that they were designed to undertake before returning control to the calling program. A subroutine is initiated by using a CALL statement, for example:

```
CALL     DELAYLOOP
```

calls the subroutine labeled Delayloop. Each subroutine begins with a name or label which is used to identify the subroutine as well as its location in memory. A subroutine ends with a Return (RET) statement, which hands over control to the calling program at the instruction immediately following the CALL instruction.

At this point it is perhaps appropriate to discuss the difference between an Interrupt Service Routine (ISR) and a Subroutine. A subroutine is called at specific and predetermined points, using a CALL statement. The program then branches to the location in memory at which the called label resides. Instructions are then executed until the RET statement is reached at which point control is handed back to the calling program at the instruction immediately following the CALL instruction. The point from which the main program branches, as well as the point of return is predetermined and known.

By contrast, the Interrupt Service Routine (ISR), is not called using a CALL statement but rather initiated when its associated interrupt is triggered in response to an event. This event can occur at any time. It can therefore not be predicted or predetermined. When an interrupt occurs, the location in memory space allocated to the associated ISR is loaded into the Program Counter (PC).

This value (location) is called the interrupt vector. When vectoring to an interrupt, the main program (which may include subroutines), is paused as control is handed over to the ISR. After the interrupt has been handled, control is returned to the main program using the Return From Interrupt statement (RETI). Control is handed over at the point from which the program was initially interrupted so that it may continue from where it left off. As opposed to a subroutine, the point at which an interrupt occurs and returns, control is unknown and cannot be predetermined. Each of the subroutines used by the Communications Microcontroller will be discussed in the sections that follow.

4.1.5.1 The CH_OUT Subroutine

This subroutine is called when ASCII prompts and data are to be transmitted via the serial port. The data is loaded into the Accumulator register (A), prior to the CALL statement, as show below:

```
MOV     A,#'I'
CALL    CH_OUT
```

Recalling the discussion on the serial port interrupt, the reader is reminded that the serial port interrupt is triggered when either the RI or TI flag is set. When data is transmitted, the TI flag that is set to signal the end of transmission of a byte will be set High (1) thereby triggering the interrupt. In order to avoid the interrupt being triggered, it is disabled using the first statement in Code Extract 4-8. However, as previously described, it is still possible to transmit data with the serial port interrupt enabled and vectoring off to the serial port ISR when TI is set High (1).

This is due to the ISR being exited when the TI flag is read and found to be High (1). On exiting the ISR control is handed back to CH_OUT to continue as normal. A choice had to be made between the two options. On one hand the serial port interrupt can be disabled for the short transmission period. The advantage of doing this is that the program is more efficient as time is not wasted unnecessarily triggering interrupts, vectoring to the ISR and testing the status of the TI flag, only to exit the ISR and return to the subroutine exactly where it left off.

The disadvantage of this option is that when the serial port interrupt is disabled the system cannot respond to an Emergency Stop immediately. It will only respond to the serial port interrupt when it is enabled again after the transmission of the byte of data. This is because the RI flag will still be Set (1) and will remain so until it is Cleared (0) by software. Considering the fact that ten bits of data is transmitted at a rate of 13µs per bit, the worst case delay before the interrupt is handled is 130µs and will apply if the interrupt was triggered by the RI flag immediately after the serial port was disabled.

The second option is to leave the serial port enabled during transmission. The advantage of this is that the system can respond to an Emergency Stop immediately. The disadvantage is inefficiency due to the serial port interrupt being triggered and serviced every time data is to be transmitted

If an event that is serious enough to initiate an Emergency Stop, the probability of the Emergency Stop being initiated at the exact moment that data is being transmitted is minimal. This is because the number of times data is transmitted during a typical (no system errors) cycle is five (four times during transmission of data and once for the transmission of prompts) and the duration of each transmit operation is 130µs. The total time that the CM is transmitting data during a typical cycle is therefore 650µs. Considering the time taken to complete a typical cycle from the rotation of the armature to taking a reading to the rotation of the armature again, is approximately ten to fifteen seconds, depending on the speed of the armature drive motor and the detection unit drive motor, the probability of an error occurring during transmission of data for a typical cycle is:

$$\frac{650\mu s}{10s} \times 100 = 0.0065\% \qquad \ldots\ldots\ldots \qquad 4\text{-}9$$

The probability decreases if the typical cycle takes more than 10s (due to lower speeds of the drive motors).

Further, considering that the worst case delay from the time an Emergency Stop is initiated till the time it the serviced is 130µs which in real terms is almost negligible and the fact that the initiation of an Emergency Stop is an event that rarely occurs, option two was chosen (the option that involved the disabling and enabling of the serial port interrupt). In summary, efficiency was chosen over a low probability of an occurrence of an event that even if it occurred will cause no ill effect to the system as a whole.

```
CH_OUT: CLR     ES
        MOV     SBUF,A
TX2:    JNB     TI,TX2
        CLR     TI
        SETB    ES
        RET
```

CODE EXTRACT 4-8: CH_OUT SUBROUTINE

The second statement in this subroutine copies the value held in A into SBUF. Writing to SBUF in this manner begins transmission. In the third statement the TI flag is continuously tested in order to ascertain if the data has been transmitted. Recall that the TI flag is set when all data has been transmitted and SBUF is empty. Once transmission is complete, the TI flag is set High (1) and the test loop is exited. In the fourth statement, the TI flag is cleared and in the fifth statement the serial port interrupt is enabled. The RET statement exits from the subroutine and returns control to the calling program. See Figure 4-7 for the associated flow diagram.

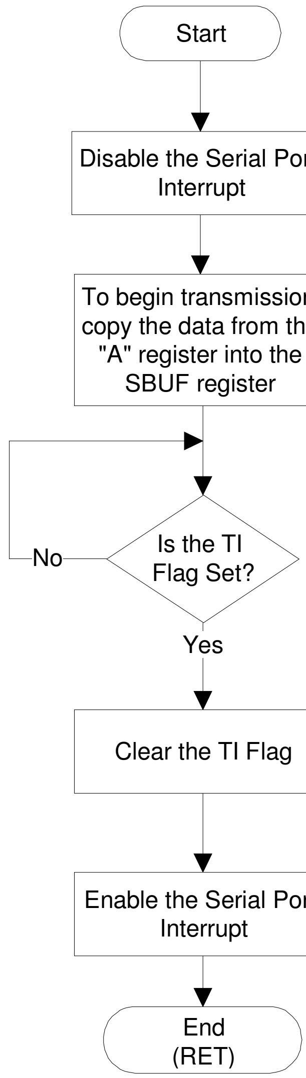
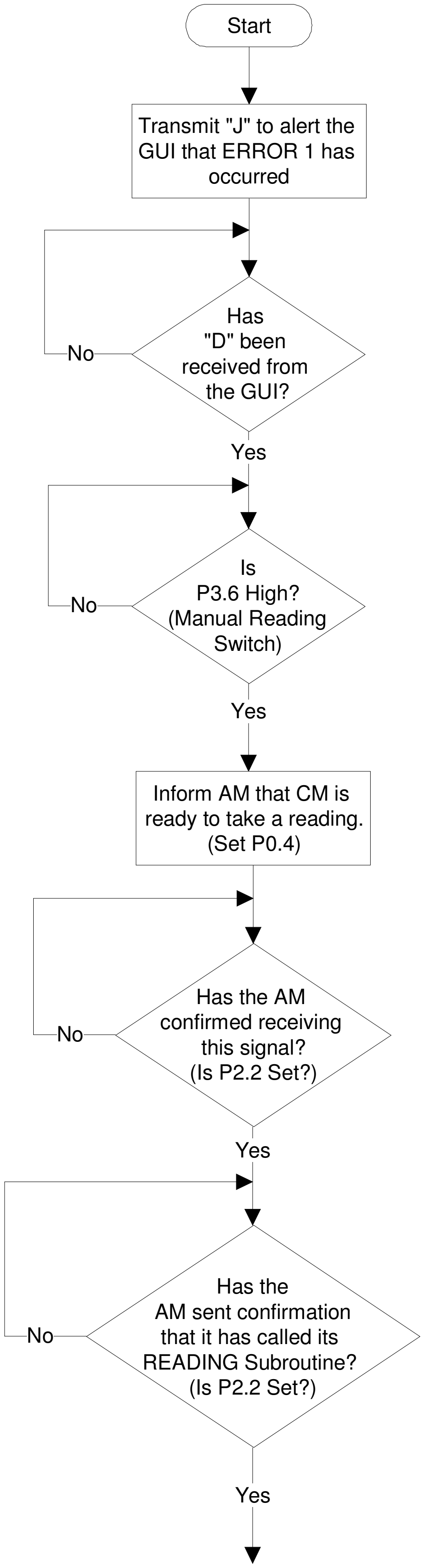


FIGURE 4-7: CH_OUT FLOW DIAGRAM

4.1.5.2 The Error 1 Subroutine

Error 1 occurs when a pair of bars is not detected within a predefined time. The AM alerts the CM to this error by triggering External Interrupt 0 as described earlier. The Error 1 subroutine is then called from the External Interrupt 0 ISR. If this error is to occur, it will do so before a volt-drop reading is taken. The error subroutine must therefore cater for a manual reading that is to be taken by the test technician. The execution of this process is described in the discussion that follows with reference to Code Extract 4-9 and Figure 4-8.


Start
Transmit "J" to alert the GUI that ERROR 1 has occurred
Has "D" been received from the GUI?
No
Yes
Is P3.6 High? (Manual Reading Switch)
No
Yes
Inform AM that CM is ready to take a reading. (Set P0.4)
Has the AM confirmed receiving this signal? (Is P2.2 Set?)
No
Yes
Has the AM sent confirmation that it has called its READING Subroutine? (Is P2.2 Set?)
No
Yes

A (pp. 128)

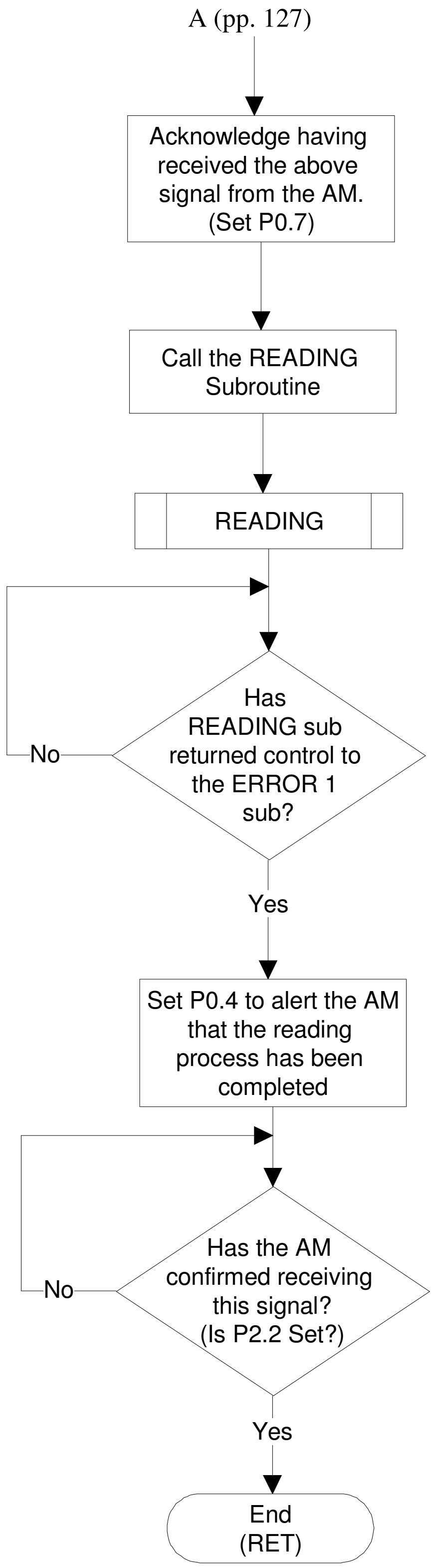


FIGURE 4-8: ERROR 1 FLOW DIAGRAM

```
;*******************************
;       ERROR 1 SUB
;*******************************

ER1_SUB:MOV     A,#'J'
        CALL    CH_OUT
E1E2:   NOP
MAN_RDG:CJNE    A,#'D',E1E2
        SETB    P0.3
TK_RDG: JNB     P3.6,TK_RDG
TK_RDG2:JB      P3.6,TK_RDG2

        SETB    P0.4
E1_CK1: JNB     P2.2,E1_CK1
        JB      P2.2,$
        CLR     P0.4

E3_RDNG:JNB     P2.2,E3_RDNG
        SETB    P0.7
        NOP
        NOP
        NOP
        CLR     P0.7
        CALL    RDG_SUB
        CLR     P0.3
        SETB    P0.4
E1_WT:  JNB     P2.2,E1_WT
        CLR     P0.4
        NOP
        NOP
        RET
;*******************************
```

CODE EXTRACT 4-9: ERROR 1 SUBROUTINE

The first step in this subroutine is to alert the GUI to the fact that Error 1 has occurred by transmitting ‘J’. The subroutine then enters a wait loop until the test technician acknowledges this error and signals his intention to take a manual reading by clicking on the Take Manual Reading button on the GUI. The GUI then transmits a ‘D’ to the CM. The CM then enters another wait loop where it waits for the test technician to press a switch connected to P3.6 when he/she has set the test probes in place on the pair of bars that are to be tested. Once this switch is pressed, the CM uses P0.4 to signal to the AM that it is ready to take a manual reading. The AM then checks whether the test current is switched on and if all is well, it will signal to the CM that it too is ready to take a reading by Setting (1) and Clearing (0) the CM P2.2. The AM then calls its Reading subroutine. Once called this subroutine signals to the CM that it has been called by again setting the CM P2.2 hence allowing it to exit the wait loop. The CM signals that it has received the message sent and that it is about to call its Reading subroutine by Setting (1) P0.7. At this point, the Reading subroutines for both the CM and AM are synchronised with each other. A volt-drop reading is then taken. The CM then signals the AM by Setting (1) P0.4 that the reading has been taken upon completion of its reading subroutine. When the AM receives this signal it responds by setting the CM P2.2 High (1). The Error 1 subroutine returns control to the calling program upon receiving this signal. Note that the CM P0.4 and P2.2 are used for communication with the AM where CM P0.4 transmits signals which are read by the AM P1.4 and CM P2.2 is used to read the status (signals) of the AM P0.0.

4.1.5.3 The Error 2 Subroutine

Error 2 occurs when the test probes do not reach the surface of the commutator within the allowable predetermined time. In terms of the CM when this error occurs the procedure that has to be followed is exactly the same as that of Error 1 as a volt-drop reading has not yet been taken. The route followed by the CM is to call the Error 1 subroutine from the point after it has transmitted ‘J’ to the GUI, i.e. from label E1E2, as shown in Code Extract 4-10.

```
;****************************
;       ERROR 2 SUB
;****************************

ER2_SUB:MOV     A,#'m'
        CALL    CH_OUT
        CALL    E1E2
        RET
;****************************
```

CODE EXTRACT 4-10: ERROR 2 SUBROUTINE

Referring to Code Extract 4-9 the reader will notice that the E1E2 label follows immediately after informing the GUI that Error 1 has occurred by transmitting ‘J’. This label is also the beginning point of the E1E2 subroutine. A subroutine within a larger subroutine, such as E1E2 is created by calling a label at any point before the

RET statement. This label is then regarded as the name and starting point for the smaller subroutine with the common RET statement being the end or return of control instruction. With this being the case all that the Error 2 subroutine has to do is alert the GUI that Error 2 has occurred by transmitting ‘m’ before calling the E1E2 subroutine.

4.1.5.4 The Error 3 Subroutine

Error 3 occurs when the allowable time for the Test Current to be switched on is exceeded. This occurs when the period of time measured from the instant that the microcontroller pulses the IGBT driver to switch on the Test Current till the instant that the microcontroller pulses the IGBT driver to switch off the Test Current, is greater than the default time. This is present because of the high test supply current used (350A to 400A). Such a system error may be dangerous to the test technician, nearby personnel and may also cause damage to the armature under test due to overheating. With this in mind, it was decided that the safest option is to immediately end the test on the occurrence of this error. As shown in Code Extract 4-11 the Error 3 subroutine simply informs the GUI that Error 3 has occurred by transmitting “L” (the GUI subsequently initiates an Emergency Stop) before jumping to the CRNT_E label, in the serial port ISR, in order to initiate the Powerdown procedure for both the AM and CM.

```
;******************************
;       ERROR 3 SUB
;******************************

ER3_SUB:MOV     A,#'L'
        CALL    CH_OUT
        JMP     CRNT_E ;IN SPISR
        RET
```

CODE EXTRACT 4-11: ERROR 3 SUBROUTINE

4.1.5.5 The Error 4 Subroutine

Error 4 occurs when the test probes are not raised to their initial position within the allowable time. The procedure for this error is not as complex as that for Error 1 and Error 2 because the volt-drop reading would have already been taken before this error occurs. As shown in Code Extract 4-12 the Error 4 subroutine informs the GUI that Error 4 has occurred by transmitting a ‘Q’, and waits for the test technician to attend to the fault. If the fault is not serious the technician will manually raise the test probes to the correct position before clicking on the Continue After Error button on the GUI. The GUI then transmits a ‘C’ to the CM. On receiving this prompt.(‘C’) the wait loop is exited and the AM is signaled to continue with the test using P0.4 and P2.2 as described earlier.

```
;***************************
;       ERROR 4 SUB
;***************************

ER4_SUB:MOV     A,#'Q'
        CALL    CH_OUT
E3E4:   NOP
WT_NBC3:CJNE    A,#'C',E3E4
        SETB    P0.4
E3_WT:  JNB     P2.2,E3_WT
        CLR     P0.4
        RET

;***************************
```

CODE EXTRACT 4-12: ERROR 4 SUBROUTINE

4.1.5.6 The Reading Subroutine

The Reading Subroutine is responsible for communication with the Reading subroutine in the AM, controlling the ADC via the ADC control lines, capturing the recorded data from the ADC and transmitting this data to the GUI.

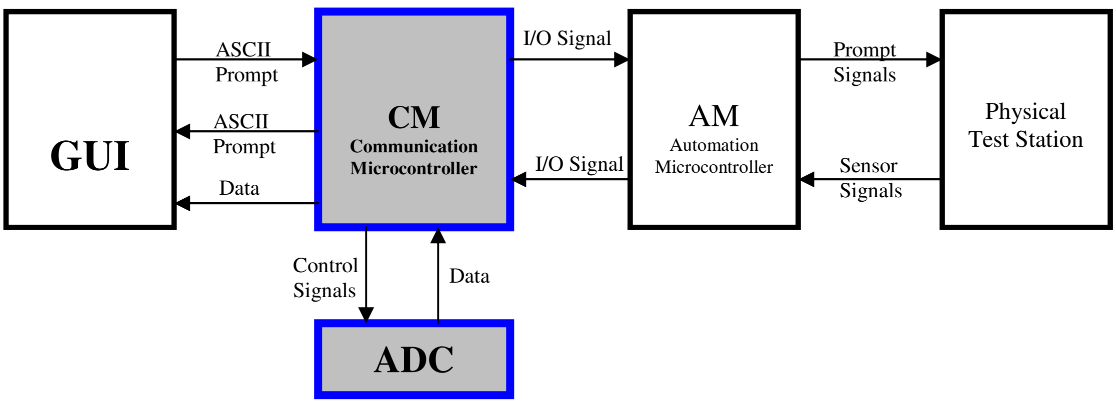
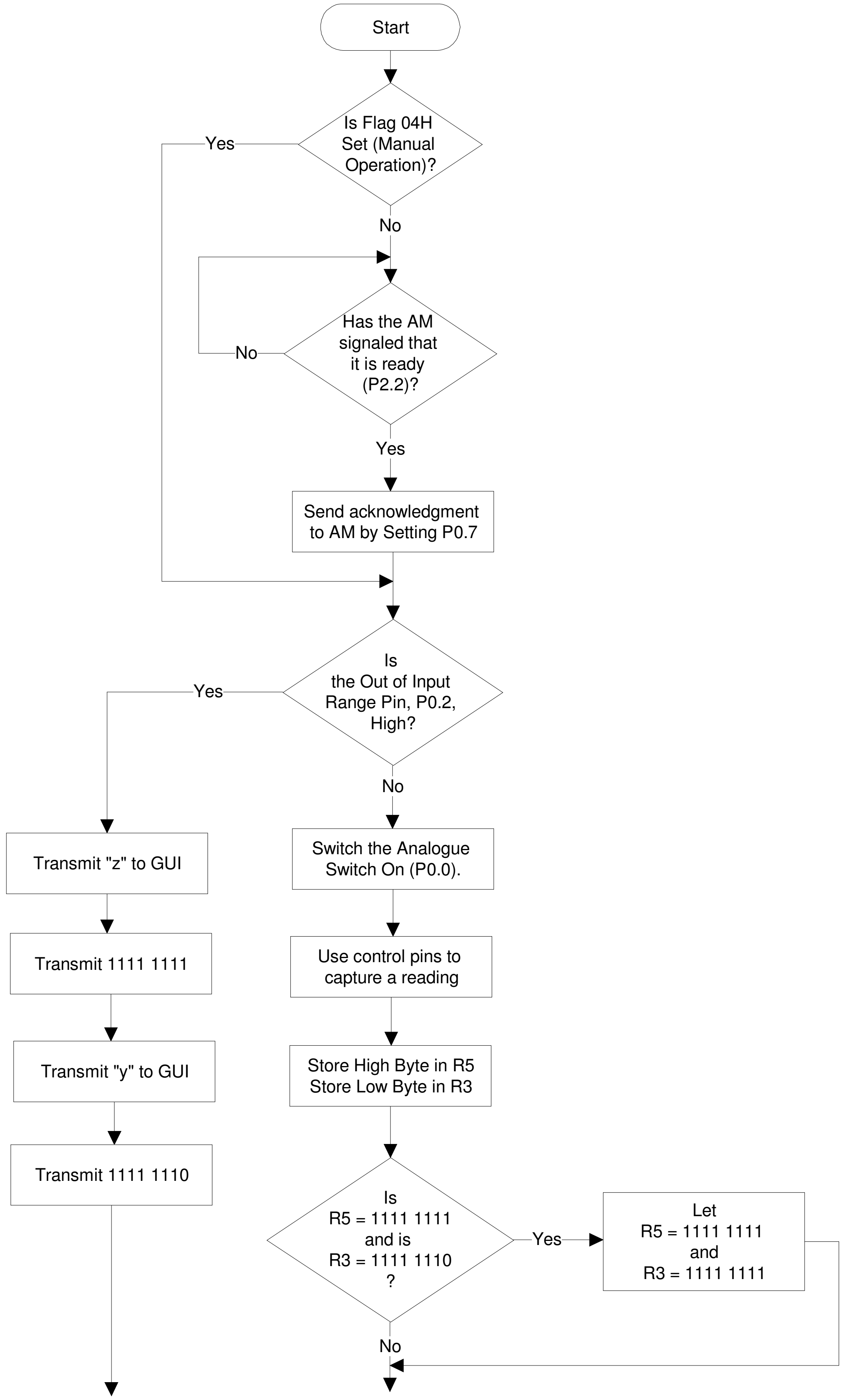


FIGURE 4-9: SYSTEM BLOCK DIAGRAM



A (pp. 134)

B (pp. 134)

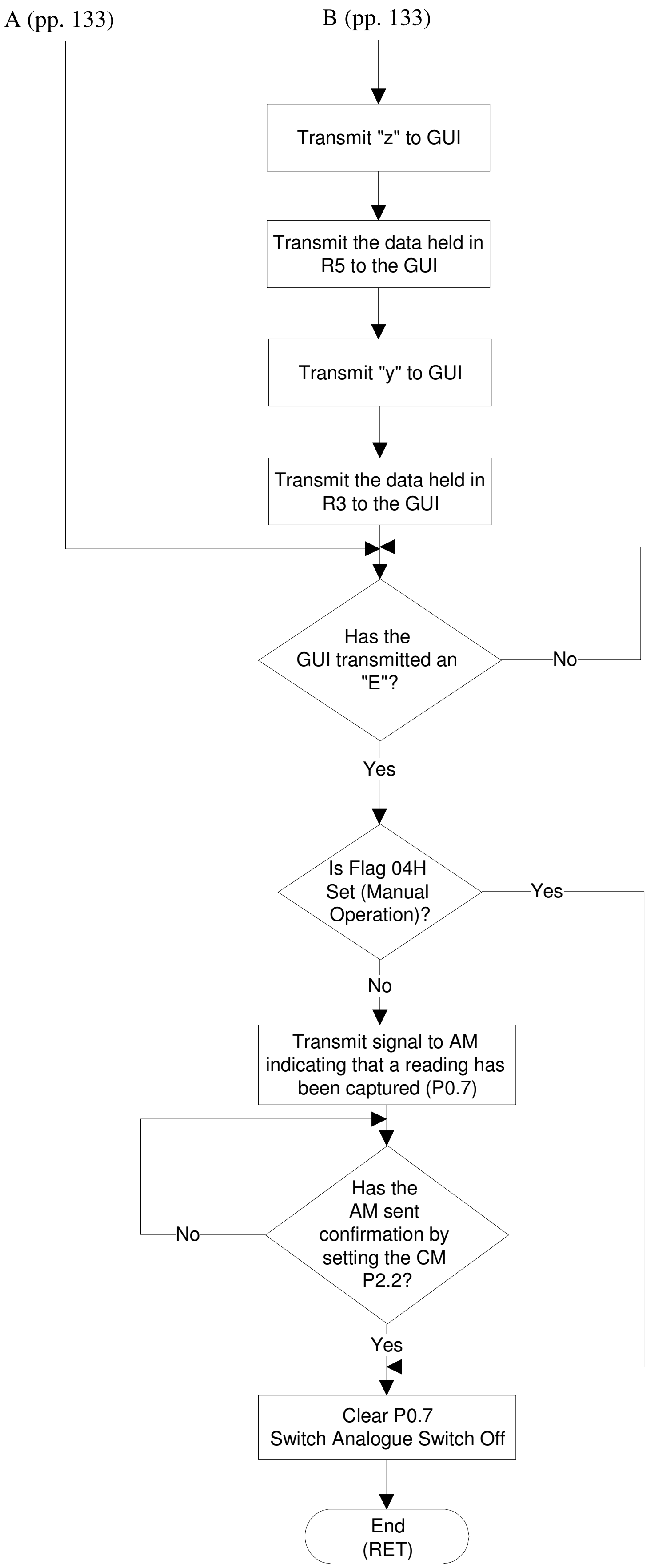


FIGURE 4-10: READING SUBROUTINE FLOW DIAGRAM

```
RDG_SUB:NOP

NO_NEG: JB      04H,NO_COM
        JB      05H,NO_COM
WT_RD:  JNB     P2.2,WT_RD ; WAIT FOR CURRENT - SWITCHED BY U2
        SETB    P0.7; TO U2 TO SIGNAL READY TO TAKE READING
        NOP
        NOP
        CLR     P0.7

NO_COM:  NOP


;EXTRA 1S DELAY IN Uc2 (X) 4 INPUT CCTRY

OV_CHK: JNB     P0.2,DWN ; for pcb, for tst cct, jb p0.2
        JMP     FET_ON
DWN:    LJMP    OVRVOL
FET_ON: SETB    P0.0 ; ANA SW ON


        CLR     P2.0

        CLR     RS0             ;20US
        SETB    RS1
        MOV     R6,#24
D4:     DJNZ    R6,D4
        CLR     RS0
        CLR     RS1             ;20US

;AQU MODE, p3,5 cleared 1us after p2.0 ***(CS fALLING eDGE 1)
        CLR     P3.5

        CLR     RS0             ;20US
        SETB    RS1
        MOV     R6,#20
D5:     DJNZ    R6,D5
        CLR     RS0
        CLR     RS1             ;20US
        NOP         ;Tcsl and tdh
        SETB    P3.5

        CLR     RS0             ;20US
        SETB    RS1
        MOV     R6,#24
```

```
D6:     DJNZ    R6,D6
        CLR     RS0
        CLR     RS1             ;20US

        CLR     P3.5; FOR STANDBY MODE ***(CS fALLING eDGE 2)



ADC_W:  JB      P2.1,ADC_W      ;EOC'

        SETB    P3.5
        SETB    P2.0; TO PUT DATA OUT
        CLR     P3.3;   ;HBEN - LOW BYTE
        NOP             ; EXTRA TIME BEFORE CS FORCED LOW
        CLR     P3.5; ***(CS fALLING eDGE 3)
        NOP             ;WAIT FOR VALID DATA,Tdo+Tdv (tdv = 0)
        CLR     P3.3;   ;HBEN - LOW BYTE redundancy

        CLR     RS0             ;20US
        SETB    RS1
        MOV     R6,#10
D7:     DJNZ    R6,D7
        CLR     RS0
        CLR     RS1             ;20US       nop

        MOV     R3,P1   ;HOLD L BYT
        SETB    P3.3    ;HBEN - HIGH BYTE
        CLR     RS0             ;20US
        SETB    RS1
        MOV     R6,#10
D8:     DJNZ    R6,D8
        CLR     RS0
        CLR     RS1             ;20US

        MOV     R5,P1   ;HOLD H BYT
        SETB    P3.5;**(CS 1ST RISING EDGE AFTER fALLING eDGE 3)

NA_CK:  CJNE    R5,#11111111B,OUT_RNG ;CHECK IF NOT ALLOWED CODE
        CJNE    R3,#11111110B,OUT_RNG
        MOV     R5,#11111111B
        MOV     R3,#11111111B

OUT_RNG:MOV     A,#'z'
        CALL    CH_OUT
```

```
OUT_H:  MOV     A,R5
        CALL    CH_OUT
        MOV     A,#'y'
        CALL    CH_OUT
OUT_L:  MOV     A,R3
        CALL    CH_OUT
WT_NBCT:CJNE    A,#'E',WT_100C; WAIT FOR CONTINUE FROM NB
        SETB    05H
        JMP     RDG_SUB
WT_100C:CJNE    A,#'S',WT_NBCT
        CLR     05H

RDG_END:JB      04H,NO_COM2
        JB      05H,NO_COM2
        SETB    P0.7; TO U2 TO CONT AFTER READING TAKEN
RG_END: JNB     P2.2,RG_END
        CLR     P0.7
        CLR     P0.0 ;ANA SW OFF
        JMP     NO_COM2

OVRVOL: MOV     A,#'z'
        CALL    CH_OUT
        MOV     A,#11111111B
        CALL    CH_OUT
        MOV     A,#'y'
        CALL    CH_OUT
        MOV     A,#11111110B
        CALL    CH_OUT

WT_NBC: CJNE    A,#'E',WT_100E ; WAIT FOR CONTINUE FROM NB
        SETB    05H
        JMP     RDG_SUB
WT_100E:CJNE    A,#'S',WT_NBC
        CLR     05H
RDG_EDS:JB      04H,NO_COM2
        JB      05H,NO_COM2
        SETB    P0.7; TO U2 TO CONT AFTER READING TAKEN
RG_EDS: JNB     P2.2,RG_EDS
        CLR     P0.7
        CLR     P0.0 ;ANA SW OFF
NO_COM2:RET
;*************************************************************
```

CODE EXTRACT 4-13: READING SUBROUTINE

The operation of this subroutine is discussed with reference to Figure 4-10 and Code Extract 4-13. Once called the first operation undertaken by this subroutine is to verify if flag 04H has been set. Flag 04H is set when the system is to be operated in Manual mode. When running in Manual mode the AM is in Powerdown and will therefore not respond to any communication signals from the CM. When operating in the Automated mode there is constant communication between the AM and the CM in order to maintain synchronisation.

When being operated in the Manual mode this communication is fruitless as the CM will be waiting for signals from the AM that will never be transmitted. The CM will therefore be caught in an endless waiting loop. The reason that 04H flag is tested is to ensure that the CM knows if it should communicate with the AM (as when it is in Automated mode) or if all its communication instructions should be skipped, when it is operating in Manual mode as discussed earlier in this chapter. Flag 05H is used to indicate that 100 successive readings are to be taken. This is an additional feature and will therefore be discussed in detail in Chapter 6.

If the system is in Automated mode, P2.2 is tested in order to verify that the AM has called and is presently executing its Reading subroutine and to ensure that it is ready to take a reading. The CM then confirms having received this signal by setting its P0.7 pin. As mentioned above, these steps are skipped when in Manual mode. Next, P0.2 is tested in order to verify that the reading about to be taken is within the maximum input range of the ADC and other interfacing circuitry. The exact mechanics behind this process will be discussed in detail in Chapter 5 under the section dealing with the interfacing analogue circuitry (Section 5.3). However, in order to facilitate a better understanding, the author will briefly discuss the principle and concept used.

Although the test is setup by the technician to record values within a particular range, 200mV to 350mV, the possibility exists that a volt-drop equal to the potential of the Test Supply can be recorded across a pair of bars. This will occur when the pair of bars being tested is connected to an open circuited winding. According to tests carried out by the author, the typical Test Supply potential when setting the aforementioned range, is between ten and fifteen volts (10V to 15V) depending on the type and rating of the armature under test. As will be explained in chapter five the first stage in the input circuitry is more than capable of handling these values as well as negative input potentials, as in the case when the polarity of the Test Supply Current, or the orientation of the input test probes is reversed. The ADC input stage however, cannot handle such potentials. The ADC absolute maximum rating for the input pin is positive 6 volts to negative 0.3V (+6V to -0.3V). It is for this reason that an Analogue Switch (MAX 4622) is placed on the ADC input line. This switch is only switched on by the CM when the interfacing analogue circuitry confirms that the potential on the ADC input line is safely within its operating range. This circuitry is explained in Chapter 5, Section 5.3.

If the CM P0.2 is High (1), the Analogue Switch is off due to the input value being out-of-range. In this case 1111 1111 (binary code) is transmitted as the High Byte and 1111 1110 (binary code) is transmitted as the Low Byte to the GUI as the reading for the pair presently under test. Upon receiving this value the GUI immediately recognises the out-of-range reading and displays a possible open circuit on this pair of bars. After this transmission the CM sits in a wait loop, waiting for the GUI to transmit the Continue Test prompt, i.e. ‘E’. Note that in order to facilitate the 100 reading additional feature, a second prompt is used to verify that all 100 readings have been captured. This prompt is the ASCII code for the character ‘S’. More details on this additional feature will be provided in Chapter 6.

If P0.2 is low, the Analogue Switch is switched on and the ADC can read the input potential. The ADC control pins are then prompted and read by the CM in order to capture a reading. The High Byte is stored in the CM register 5, R5 and the Low Byte is stored in the CM register 3, R3. See Appendix K for a list of the registers used for both the AM and CM.

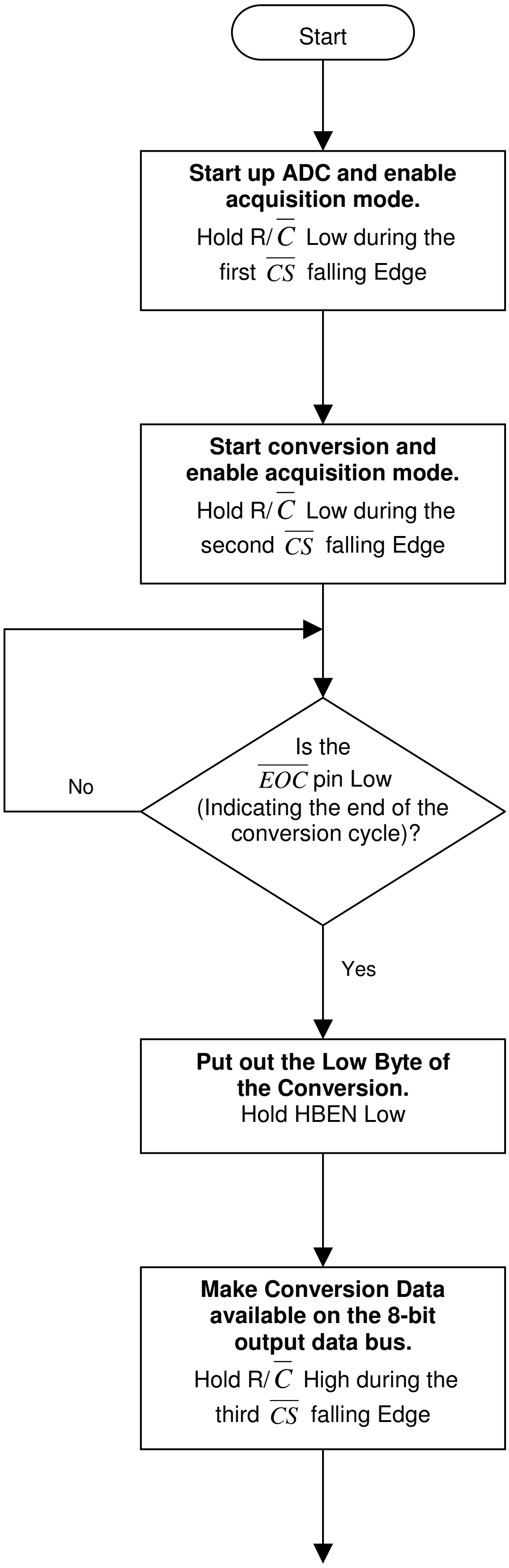
The next step is to check if R5 holds 1111 1111 and R3 holds 1111 1110. This is the previously mentioned out-of-range default value. If the default value has been recorded, the value held in R3 is changed to 1111 1111. This new value and the out-of-range default value should normally not be recorded on a non-fault bar. As discussed in Chapter 3, the ASCII code for the letter ‘z’ is transmitted to the GUI before the High Byte (the value held in R5) of the captured reading is transmitted to the GUI. The ASCII code for the letter ‘y’ is transmitted to the GUI before the Low Byte (the value held in R3) of the captured reading is transmitted to the GUI. The CM then waits for the GUI to process the transmitted data and inform the CM that it is ready to continue by transmitting an ‘E’ (the Continue Test prompt).

On receiving this prompt the CM again tests if flag 04H is set High (1). If it is not set High, then using P0.7 and P2.2 as described above, the CM communicates with the AM to inform it that the reading has been successfully captured, transmitted and analysed and that it should ready itself to proceed with the next task in the process. If the flag 04H is set, then this communication process is skipped as mentioned earlier. The CM then switches off the analogue switch on the ADC input line in order to protect the ADC in the event of an out-of-range input value on the next pair of bars. The subroutine is then exited and control is returned to the calling program at the statement immediately following the CALL instruction.

4.1.6 ADC Control

The ADC control pins and the associated connection pins on the CM are listed below. The $\overline{CS}$, Convert Start ADC input pin, is connected to the CM P3.5 pin which is configured as an output pin. The R/$\overline{C}$, Read/$\overline{Convert}$ ADC input pin is connected to the CM P2.0 pin which is configured as an output pin. The $\overline{EOC}$, End Of Conversion ADC output pin, is connected to the CM P2.1 pin which is configured as an input pin.

And finally, the HBEN, High-Byte Enable ADC input pin is connected to the CM P3.3 pin which is configured as an output pin. Figure 4-11 depicts the flow diagram that describes the process that is followed when the ADC captures a reading. Figure 4-12A depicts the flow diagram that shows the steps taken by the CM to implement the process followed in Figure 4-11. Figure 4-12B depicts the timing diagram for the ADC control process. See Appendix J to view the ADC (MAX 1166) datasheet.


Start
Start up ADC and enable acquisition mode.
Hold R/$\overline{C}$ Low during the first $\overline{CS}$ falling Edge
Start conversion and enable acquisition mode.
Hold R/$\overline{C}$ Low during the second $\overline{CS}$ falling Edge
Is the $\overline{EOC}$ pin Low (Indicating the end of the conversion cycle)?
No
Yes
Put out the Low Byte of the Conversion.
Hold HBEN Low
Make Conversion Data available on the 8-bit output data bus.
Hold R/$\overline{C}$ High during the third $\overline{CS}$ falling Edge

A (pp. 142)

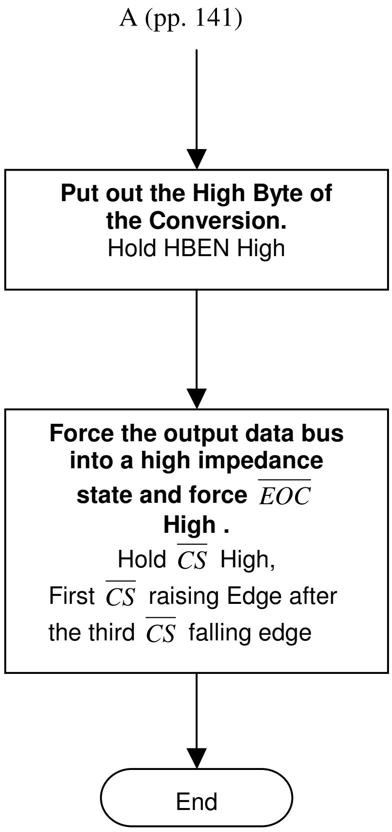
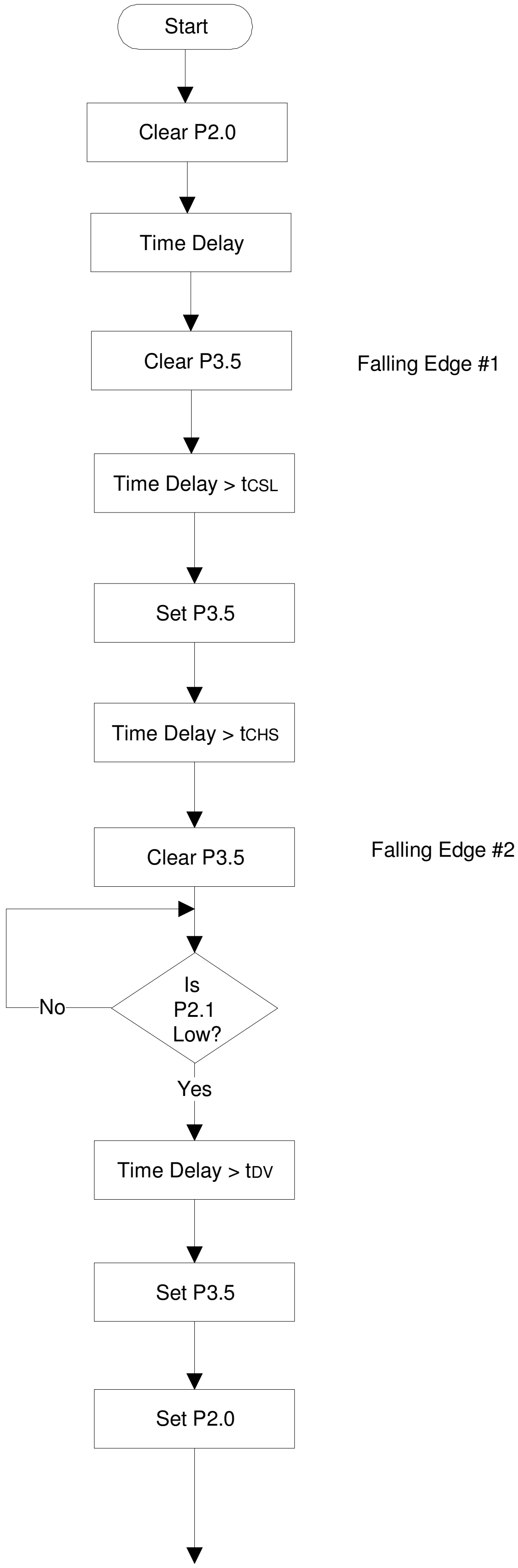


FIGURE 4-11: FLOW DIAGRAM FOR THE ADC CONTROL PROCESS


Start
Clear P2.0
Time Delay
Clear P3.5
Falling Edge #1
Time Delay > tCSL
Set P3.5
Time Delay > tCHS
Clear P3.5
Falling Edge #2
Is P2.1 Low?
No
Yes
Time Delay > tDV
Set P3.5
Set P2.0

A (pp. 144)

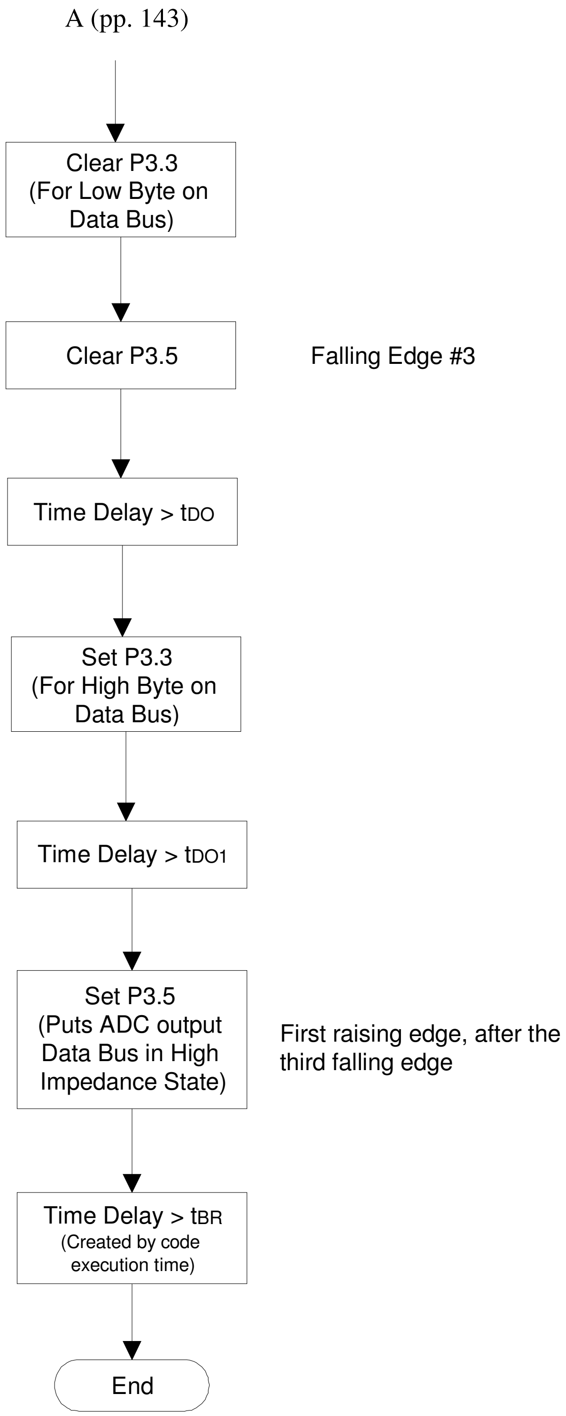
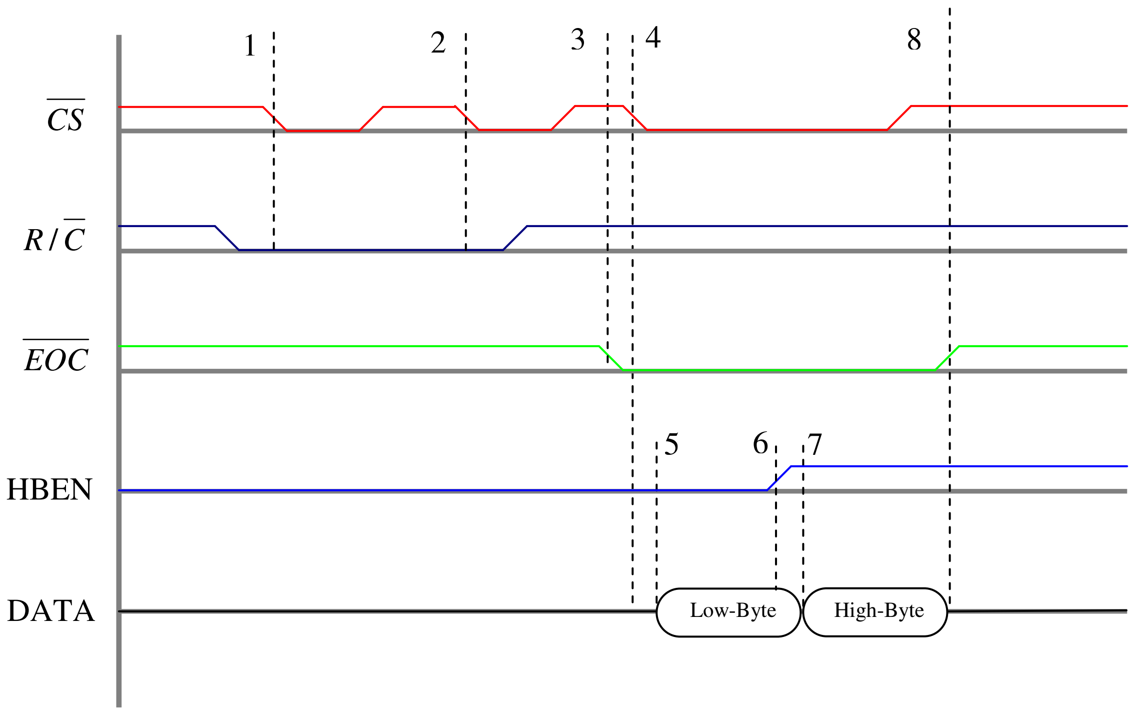


FIGURE 4-12A: FLOW DIAGRAM OF STEPS TAKEN BY THE CM TO IMPLEMENT THE ADC CONTROL PROCESS



1. $\overline{CS}$ Falling Edge 1
2. $\overline{CS}$ Falling Edge 2
3. $\overline{EOC}$ Drives Low To Signal The End Of Conversion
4. $\overline{CS}$ Falling Edge 3
5. Valid Data Low-Byte Placed On The 8-Bit Output Bus
6. HBEN Toggled From Low To High
7. Valid Data High-Byte Placed On The 8-Bit Output Bus
8. Data Bus Forced to High Impedance State and $\overline{EOC}$ Is Forced High, After the First Rising Edge of $\overline{CS}$ Following the Third Falling Edge

FIGURE 4-12B: TIMING DIAGRAM FOR ADC CONTROL PROCESS

The control process is as follows: to start up the ADC and enable acquisition mode, the R/$\overline{C}$ pin must be held low during the $\overline{CS}$ falling edge. This is the $\overline{CS}$ first falling edge. The above is accomplished by the CM by Clearing (0) P2.0 and after a short delay, also Clearing (0) P3.5. Both P2.0 and P3.5 would have been set at the end of the previous reading or acquisition cycle or in the case of the first reading to be taken, these ports would have been set by the ‘dummy’ conversion cycle as mentioned earlier. Next, to start a conversion and choose the ADC ‘Standby Mode’ option, R/$\overline{C}$ must remain Low (0) during the $\overline{CS}$ second falling edge. (The second $\overline{CS}$ falling edge will start the conversion process and the logic level of R/$\overline{C}$ during this falling edge will determine the mode of operation).

To accomplish this, after a delay that is greater than the stipulated t_{CS} (i.e. the minimum time that the $\overline{CS}$ pin should be held Low (0) before setting it High (1)) the $\overline{CS}$ pin is set High (1). Then after a delay that is greater than t_{CHS} (i.e. the minimum time that the $\overline{CS}$ pin should be held High (1) before setting it Low (0)) the $\overline{CS}$ pin is set Low (0) to produce the second falling edge. Note that the time between the first and second falling edge, t_{ACQ}, is the acquisition time and cannot be less than the stipulated 4.7µs. Hence the sum of t_{CSL} and t_{CHS} must be greater than or equal to t_{ACQ}, as shown in Figure 2, Page 8 of the MAX 1166 datasheet.

Note that for Standby Mode the R/$\overline{C}$ pin is held low during the second $\overline{CS}$ falling edge. In this mode the reference and buffer remain powered up after a conversion cycle. For Shutdown Mode the R/$\overline{C}$ pin is held high during the second $\overline{CS}$ falling edge. In this mode the reference and buffer are powered down after a conversion cycle. The advantage of Standby Mode over Shutdown Mode is that in the case of the Standby Mode there is no need to wait for the internal reference to wake up and settle and to run a ‘dummy’ conversion before a new acquisition and conversion cycle takes place. The ADC can simply exit Standby Mode and begin an acquisition and conversion cycle

After the $\overline{CS}$ second falling edge the CM waits to the $\overline{EOC}$ pin to drive Low (0). This signals the end of a conversion and occurs on the expiration of the conversion time,

t_{CONV}, following the $\overline{CS}$ second falling. When P2.1 is driven Low (0) the wait loop is exited and the Low-Byte can be put on the ADC eight–bit output bus. In order to read the Low-Byte certain conditions must first be satisfied. These are that the R/$\overline{C}$ pin must be held High on the $\overline{CS}$ third falling edge and the HBEN pin must be held Low. This is done as follows: after a delay of t_{DV}[2] (i.e. the minimum time that has to elapse after $\overline{EOC}$ is driven Low (0) and before the $\overline{CS}$ third falling edge), the $\overline{CS}$ pin can be driven Low (0) to produce the third falling edge. But this pin is not driven Low until it is first driven High (to recover from the last falling edge transition) and P2.0 is driven High.

After the third falling edge, a delay that is greater than t_{DO} is enforced to allow for valid data to be put on the eight-bit output bus. Then by setting HDEN High (1) and waiting for a period grater than t_{DO1} (i.e. the time that is required for valid data to be put on the eight-bit output bus after toggling HBEN), the High-Byte is put on the eight-bit output bus. After the CM has recorded and stored the high and low bytes of data that was output by the ADC, P3.5 is set High (1) hence driving the $\overline{CS}$ pin High (1). The process of driving the $\overline{CS}$ pin high after the $\overline{CS}$ third falling edge forces the ADC eight-bit output bus into a high impedance state and readies the device for the next acquisition and conversion on the next $\overline{CS}$ falling edge.

The $\overline{EOC}$ pin is also forced High (after a time delay determined by t_{EOC}) on this $\overline{CS}$ raising edge. Note that the next acquisition should be initiated after a delay period greater than t_{BR} (i.e. Bus Relinquish Time) as stipulated for best results by the manufacturer. This delay period is more than compensated for by the execution time for the CM instructions that follow before the next acquisition and conversion process is initiated.

[2] Note that the $\overline{CS}$ third falling edge can occur immediately after $\overline{EOC}$ is driven Low, as t_{DV} is stipulated as a minimum of 0ηs

4.2 Automation Microcontroller

The Automation Microcontroller (AM) controls the Physical Test Station based on input signals received from the Physical Test Station itself, as well as commands and prompts received from the CM and the GUI via the CM.

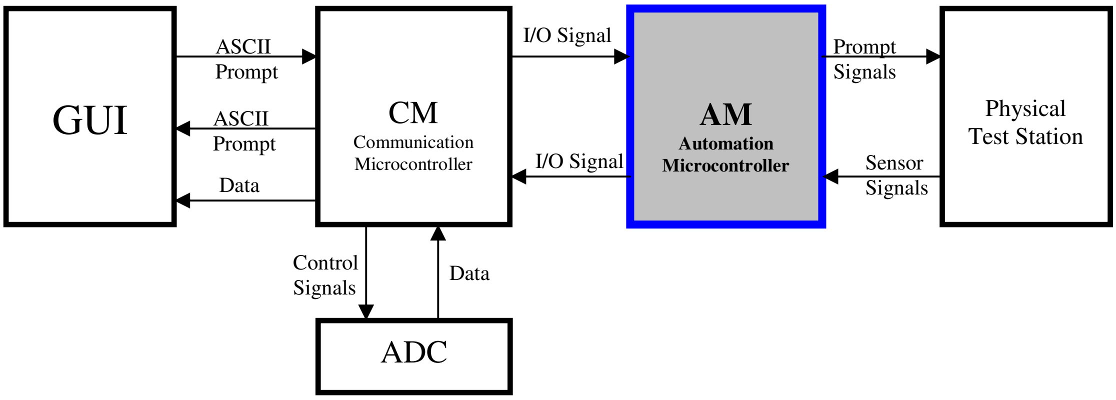


FIGURE 4-13: SYSTEM BLOCK DIAGRAM

This section will describe the tasks undertaken by the AM and the manner in which these tasks are executed. As the previous section, The Communications Microcontroller, provided detailed explanations on all the relevant microcontroller functionalities, such as Timers, Interrupts, Subroutines etc, this section will concentrate solely on discussing the AM's use of these functionalities to efficiently complete specific tasks. In order to provide an overview of the AM's process flow, a diagrammatic depiction is presented in the form of a flow diagram in Figure 4-15.

4.2.1 Explanation of functions, tasks and flow process

The program for the AM was developed using three control levels based on interrupts and interrupt priorities. The first level is the base level, where the Main program has control. Here the required initialisations are carried out as well as the control and timing of the Armature Drive Motor and the calling of Error 1 subroutine, should Error 1 occur. When a pair of bars is detected, External Interrupt 1 is triggered and the External Interrupt 1 Interrupt service routine assumes control thereby entering the second control level. The EX1 ISR is responsible for stopping the Armature Drive

Motor, the lowering and raising of the Detection Unit, switching of the Test Current, communication with the CM in order to capture the volt-drop readings and calling of error subroutines should the associated errors occur. The third level is the domain of the External Interrupt 0 (EX0) ISR. EX0 is assigned a higher priority than EX1 and can therefore interrupt the EX1 ISR as in the case when the test probes have reached the surface of the detected bars. In fact this is the function of EX0, i.e. to ascertain the status of the Detection Unit. When the test probes reach the surface of the bars EX0 is triggered, the Detection Unit Drive Motor is stopped, and the time period taken for the probes to be lowered to the surface of the bars is recorded in the EX0 ISR. EX0 is also triggered when the test probes have been raised to their initial position.

In summary, the base level allows for initialisations and also prompts the Armature Drive Motor to begin the rotation of the armature under test. When a pair of bars is detected EX1 is triggered and EX1s ISR is initiated as the second control level and assumes control from the base level. In the EX1 ISR, the Armature Drive Motor is stopped, the Detection Unit Drive Motor is prompted to lower the Detection Unit and the Test Current is switched on. The time taken for the test probes to reach the bars allows the test current to settle. Once the test probes on the Detection Unit reach the surface of the bars EX0 is triggered, the EX1 ISR is interrupted and the EX0 ISR executes, initiating control level three and assuming control from the EX1 ISR. When the EX0 ISR has stopped the Detection Unit Drive Motor and completed recording the relevant times, the ISR is exited and control is handed back to the EX1 ISR hence control level two.

The EX1 ISR then proceeds to communicate with the CM and a volt-drop reading is taken after which the Detection Unit Drive Motor is prompted to raise the Detection Unit. When the Detection Unit Drive Motor reaches its initial position EX0 is again triggered thereby initiating control level three and assuming control from the EX1 ISR and control level two. The EX0 ISR stops the Detection Unit Drive Motor and exits handing control back to EX1 ISR and control level two. EX1 ISR is then also exited and control is handed to the base control level and the Main program. Based on the commands from the GUI via the CM, the cycle is repeated until the last bar is tested. See Figure 4-14 for a diagrammatic representation of the above discussion. A more detailed explanation of the Automation Microcontrollers process flow follows after Figure 4-15.

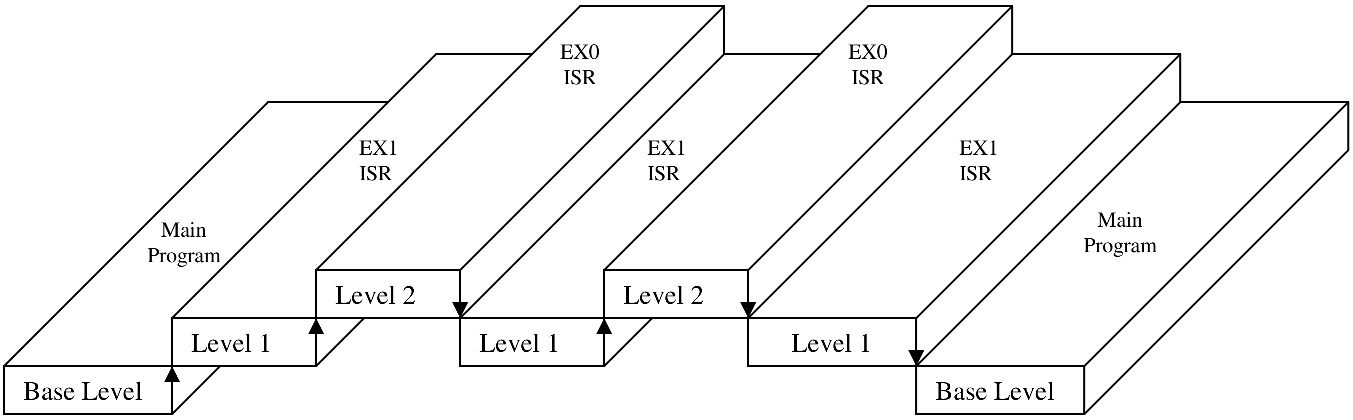
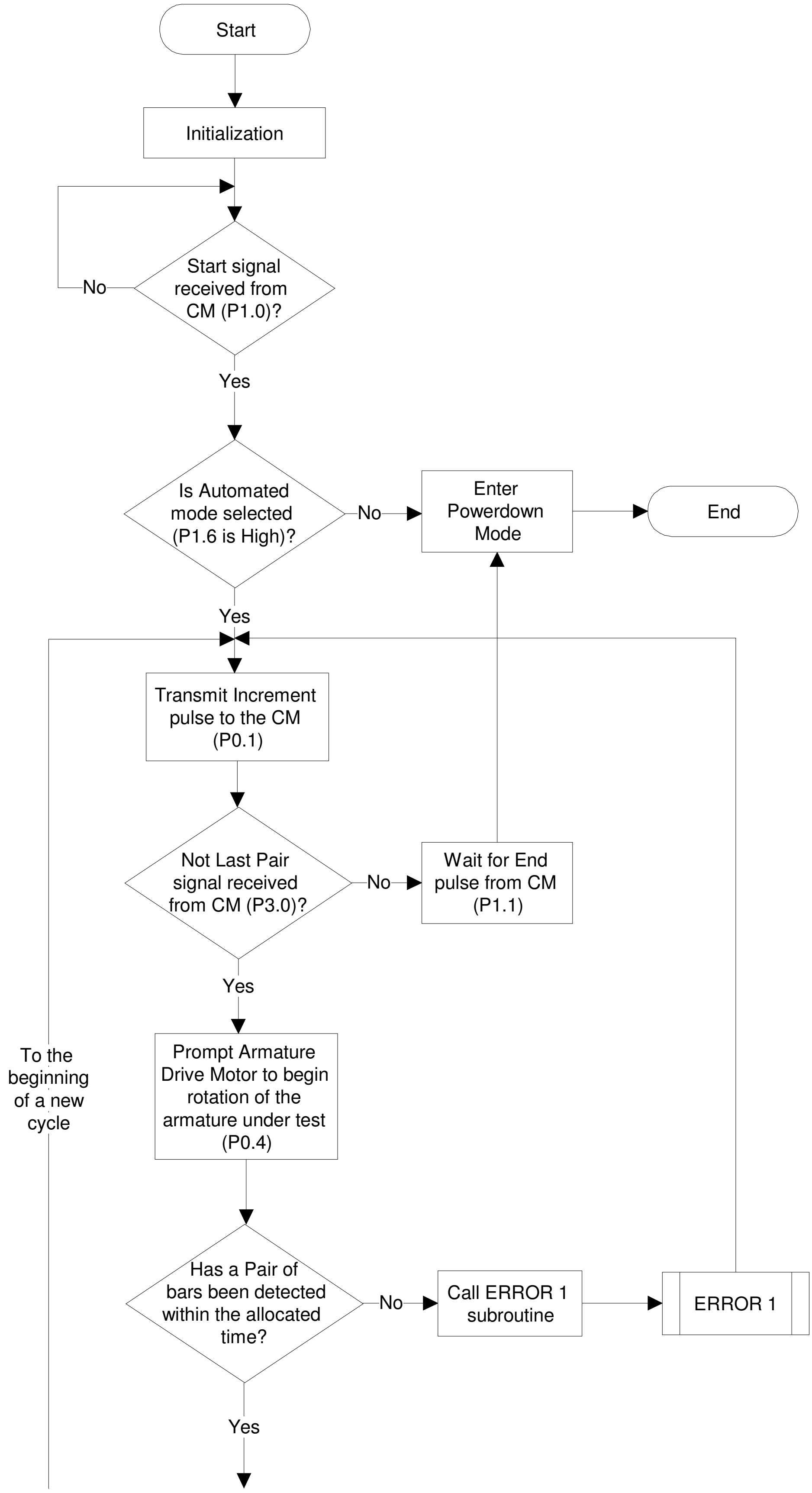
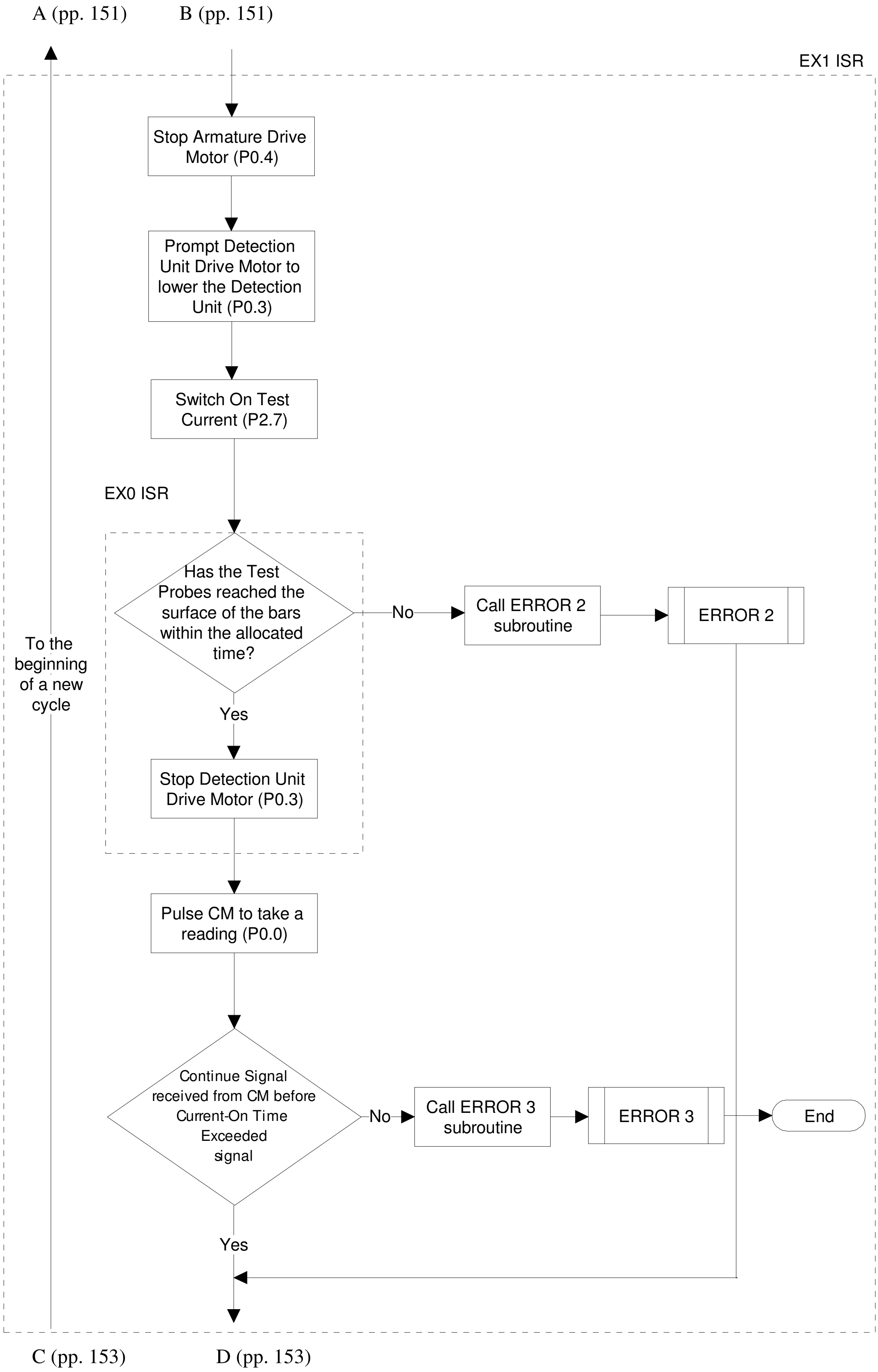


FIGURE 4-14: DIAGRAMMATIC REPRESENTATION OF THE THREE LEVEL CONTROL SYSTEM



A (pp. 152)   B (pp. 152)


A (pp. 151)
B (pp. 151)
EX1 ISR
Stop Armature Drive Motor (P0.4)
Prompt Detection Unit Drive Motor to lower the Detection Unit (P0.3)
Switch On Test Current (P2.7)
EX0 ISR
Has the Test Probes reached the surface of the bars within the allocated time?
No
Call ERROR 2 subroutine
ERROR 2
Yes
Stop Detection Unit Drive Motor (P0.3)
To the beginning of a new cycle
Pulse CM to take a reading (P0.0)
Continue Signal received from CM before Current-On Time Exceeded signal
No
Call ERROR 3 subroutine
ERROR 3
End
Yes
C (pp. 153)
D (pp. 153)

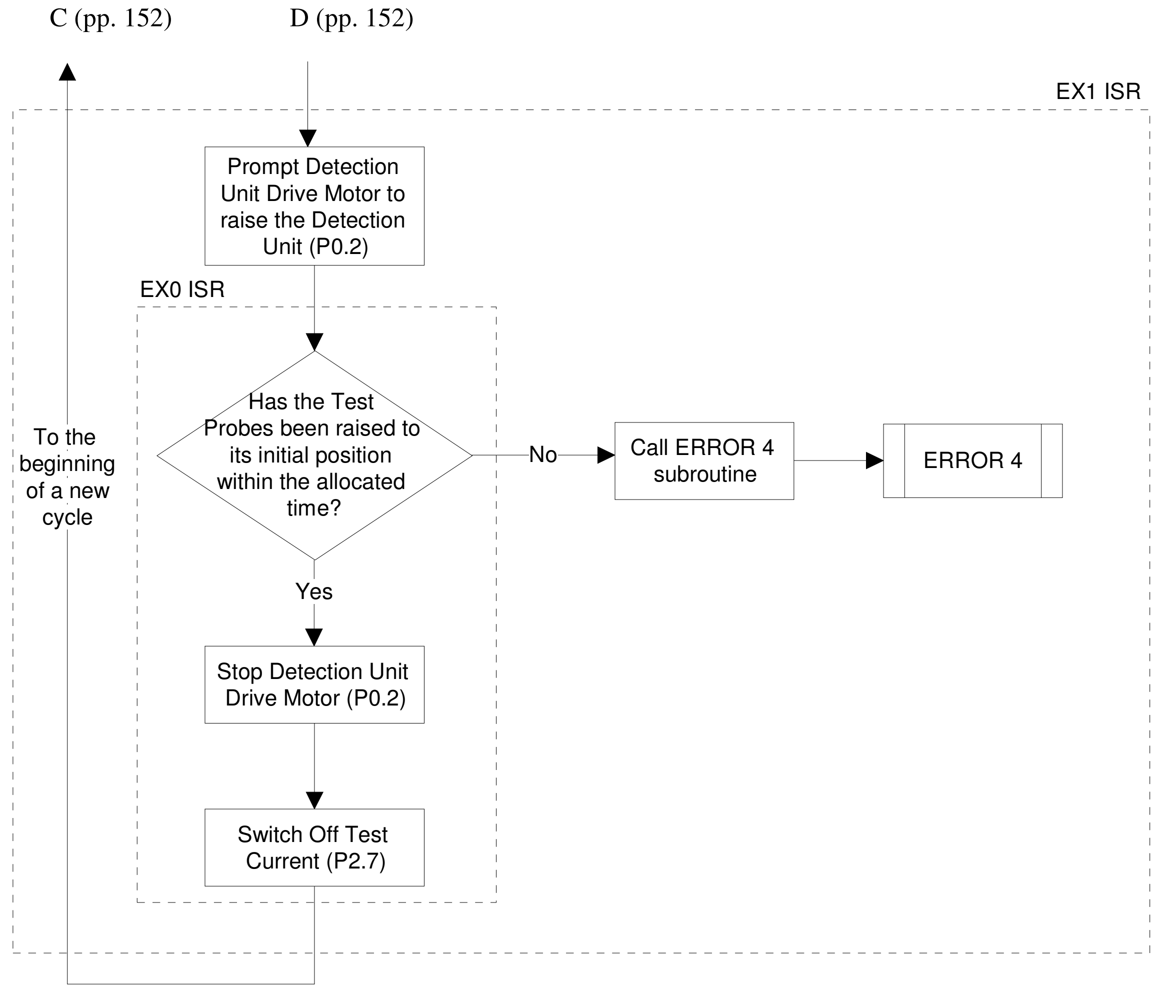


FIGURE 4-15: FLOW DIAGRAM FOR THE AUTOMATION MICROCONTROLLER

The AM first executes an initialisation process in which all the timers, interrupts and input/output ports that will be utilised for the duration of a test are initialised. Thereafter, the AM waits for the start pulse from the CM on P1.0. Upon receiving this pulse, the AM tests P1.6 to ascertain whether the test will be run in the Automated or Manual mode. If P1.6 is High (1) then the Manual mode has been selected and the AM initiates Powerdown mode. If P1.6 is Low (0) then Automated mode has been selected and the AM then Sets (1) and Clears (0) P0.1, which is responsible for signaling ‘Increment The Number Of Bars’.

The AM then waits for the GUI to inform it, via the CM, whether or not the last pair of bars has been tested. If P3.0 is Low (0), then the last pair of bars have been tested and the AM waits for the End command from the GUI via the CM. Once this is received, the AM enters Powerdown mode. If P3.0 is High (1), then the last pair has not been tested and the command is given to the Armature Drive Motor to initiate the rotation of the armature under test by setting P0.4 High (1). The AM then waits for the next pair of bars to be detected while timing the period between the initiation command and when the pair of bars has been detected. Detection of a pair of bars triggers External Interrupt 1 (EX1). If EX1 is not triggered before a maximum allowable time for detection is exceeded, Error 1 has occurred and the associated subroutine is called. Recall that Error 1 occurs when a pair of bars has not been detected within the maximum allowable time. The maximum allowable time for detection for each of the first three pairs is a preset value of 10 seconds.

The time duration recorded on the third pair of bars is stored to be used to calculate a tolerance or the maximum allowable time for the detection of a pair of bars after initiating the rotation of the armature under test. This new maximum allowable time will be the Detection Reference Time for the duration of the test. The time recorded on the third pair plus twenty percent is used as the reference value, i.e.

$$\text{Detection Reference Time} = \text{Third Pair Time Recording} \times 1.2$$

From the fourth pair of bars onwards, if EX1 is not triggered before the Detection Reference Time has expired, Error 1 subroutine is called. The use of the Detection Reference Time allows for greater control of the system as the unique reference value that is used for the duration of the test is based on the bar widths and spaces between the bars of the particular armature under test. In this way an error is detected sooner than if a preset value that catered for all armatures was used, hence the possibility of excessive damage to the system and the armature under test due to a system error is reduced. The reason that the Detection Reference Time is calculated based on the time recorded for the third pair of bars is simply because the system is given time to settle during the first and second cycles.

The question that now arises is what happens if a detection error occurs on the third pair of bars, i.e. when the time is being recorded to calculate the Detection Reference Time? The answer is that if Error 1 was called before External Interrupt 1 was triggered, then a time period will not be recoded as all time recordings is done by the

External Interrupt 1 interrupt service routine (ISR). The Error 1 subroutine does not have the capability to perform any time interval recording. Hence the value that will be used to calculate the Detection Reference Time will now be recorded on the next detection cycle, i.e. on the forth pair of bars. However, to introduce redundancy, the Error 1 subroutine also takes appropriate measures when this event occurs. Note that the use of timers to record time, set preset intervals and introduce delays is discussed in Section 4.1.4.

When a pair of bars has been detected before the Detection Reference Time has exceeded, hence triggering EX1, the rotation of the armature under test is immediately stopped by Clearing (0) P0.4. The rest of the process from this point onwards is executed in the External Interrupt 1 ISR. From this ISR, the signal to the Detection Unit Drive Motor to begin lowering the Detection Unit is given. The Test Current is also switched on by Setting (1) P2.7. The Test Current is switched on before the Test Probes on the Detection Unit reach the bars as opposed to when they are already on the bars. This is done to prevent large voltage spikes due to the switching of the large test current to the inductive load (i.e. the inductance (L) of the armature under test), from damaging the input circuitry.

The Test Probes must not be confused with the Test Current Probes. The Test Current Probes are the probes from which the Test Current is injected though the armature under test via an IGBT. The Test Current Probes are lowered onto the commutator and are fixed into place at the start of the test and are in no way attached to the Detection Unit. These probes are not raised off or lowered onto the commutator as in the case of the Test Probes on the Detection unit. The Test Current is switched on when a reading is to be taken and is switched off when a reading is complete and the Test Probes have been raised off the surface of the commutator.

The Test Current probes are never raised off the surface of the commutator at any time during the test. When the IGBT is switched off, the collapsing magnetic energy that is stored in the armature is dissipated via an onboard fly-back diode. Fly-back diodes are a standard feature on most modern IGBT units and are built into the semiconductor structure of the IGBT to provide onboard protection in a single unit. The Test Current is switched on between 2 and 4 seconds after it was last switched off depending on the speed of rotation and the spacing of the commutator bars. The low switching frequency allows for sufficient time for the stored magnetic energy to be dissipated via the onboard fly-back diode hence there is no arcing.

The spring mounted Test Probes are fixed onto the Detection Unit. These probes are lowered and raised when a reading is to be taken. A minute current flows through these test probes due to the extremely high input impedance of the Data Acquisition Module, more specifically the input impedance of the precision Instrumentation Amplifier, the INA 118, as discussed in Section 5.3. It is due to this high input impedance and the low Test Supply Voltage of typically +15VDC maximum that arcing does not occur when the test probes are raised off and lowered onto the commutator when the Test Current is flowing through the armature. Tests on the Data Acquisition Module proved that no arcing takes place when the test probes are raised off and lowered onto the commutator while a Test Current was allowed to flow through the armature.

The only undesirable electrical effect that would have to be catered for is the bouncing of the input signal due to the mechanical bounce created when spring loaded test probes make contact with the surface of the bars. This bounce will create oscillations in the input signal however, the amplitude of these oscillations should not exceed the amplitude of the input signal when it has settled. This means that although there will be oscillations due to the bounce, there will be no voltage spikes as created when switching the Inductive load. In order to cater for the above-mentioned oscillations, the ADC is instructed to perform acquisition and conversion only after a delay period has been enforced.

If the test probes on the detection unit do not reach the surface of the bars within a preset time then Error 2 occurs and the associated subroutine is called. When the test probes do reach the surface of the bars within the allocated time, the Detection Unit outputs a signal which triggers External Interrupt 0 (EX0). As mentioned previously, EX0 is assigned a higher priority than EX1. Error 2 will be initiated when the preset allowable time of ten seconds, for reaching the surface of the bars, expires before EX0 is triggered. If EX0 is triggered before the aforementioned time expires, the EX0 ISR is initiated. The EX0 ISR stops the Detection Unit Drive Motor and stores the time that was taken for the test probes to reach the surface of the bars by copying the values held in the timer registers. Once on the surface of the bars, the AM signals the CM that a volt-drop reading can now be taken be Setting (1), P0.0. The AM then waits for one of two signals from the CM. The first is the signal received on P1.7, which informs the AM that the reading has successfully been taken by the CM, transmitted to the GUI, analysed and stored. Now both the GUI and the CM are ready to proceed.

The second signal is received on P3.1, which informs the AM that the maximum allowable time that the Test Current can be switched on for an individual volt-drop reading has been exceeded. The timing of the Test Current on-time is carried out by external interfacing circuitry and is discussed in Section 5.1.6. If P3.1 is Set (1) before P1.7, Error 3 has occurred. The Error 3 subroutine is then called and due to the severity of the effects of such high currents being applied to the armature under test for a prolonged period of time, an Emergency Stop is automatically initiated and the AM immediately halts the task that was being carried out, switches off the Test Current by Clearing (0) P2.7 and safely shuts the system down before entering Powerdown mode. If however, P1.7 is Set (1) before P3.1 then the volt-drop reading will be captured with no system irregularities and the process flow continues as normal.

The next step is to prompt the Detection Unit Drive Motor to begin raising the test probes off the surface of the bars. Here again EX0 is triggered when the Detection Unit reaches its initial position. If, however, EX0 is not triggered before the maximum allowable time has elapsed Error 4 occurs and the associated subroutine is called. This maximum allowable predetermined time for this process is called the Unit Raising Reference Time. This period is derived by adding twenty percent of the time taken for test probes to reach the surface of the bars (during lowering) to the recorded time itself, i.e.

Unit Raising Reference Time = Recorded Test Probe Lowering Time x 1.2

When EX0 is triggered before the Unit Raising Reference Time expires, the Detection Unit Drive Motor is stopped and control is returned to the EX1 ISR, which in turn returns control to the Main program. The Main program then transmits an Increment signal to the GUI via the CM and waits for the response. This cycle continues until each pair of bars on the commutator of the armature under test has been tested.

4.2.2 Initialisation and main program

The Main program is responsible for performing all the required initialisations on startup. This includes the initialisations of the input/output ports, timers, interrupts and interrupt priorities. The above-mentioned initialisations can be viewed in Code Extract 4-14.

```
        ORG     0H
        LJMP    MAIN
        ORG     0003H
        LJMP    EX0ISR
        ORG     0013H
        LJMP    EX1ISR

COUNT   EQU     -10000 ;DELAY LOOP
COUNT2  EQU     -50000 ;SAFTY TIME

        ORG     0030H
MAIN:   MOV     TMOD,#00010001B
        MOV     IP,#00000001B
        MOV     IE,#00000101B

;*******iNTILIZE I/O PORTS ********
        MOV     P0,#0H
        MOV     P1,#11111111B
        MOV     P2,#0H
        MOV     P3,#00011111B
;*******iNTILIZE I/O PORTS ********
```

CODE EXTRACT 4-14: AUTOMATION MICROCONTROLLER INITIALISATION

The first six statements redirect the program counter (PC) to different locations in program memory (ROM), via labels, when vectoring off to the defined addresses (i.e. in this case 0H, 0003H, and 0013H). The starting location or address for a program is 0H, this is the system reset vector address. Once at this location, a Long Jump (LJMP) to the label Main is initiated. This label is the starting point of the Main program. Similarly, when interrupts are triggered, the PC is loaded with the default vectoring address of the associated ISR. Once at that address, the program is redirected to locations in memory where the associated ISR resides using LJMP statements. This is because the eight-byte provision made for ISR's is too small to cater for the ISR's needs. The main program memory space is available from 0030H, as the space from 0000H to 002FH is allocated to system reset and ISR code. The statement below,

```
MOV     TMOD,#00010001B
```

initiate the timers using the TMOD SRF. Both Timer0 and Timer1 are initialised as sixteen-bit timers. Interrupt priority is assigned using,

```
MOV     IP,#00000001B
```

where, as discussed earlier, External Interrupt 0 is assigned a higher priority than External Interrupt 1. The statement,

```
MOV     IE,#00000101B
```

is used to initialise the required interrupts which are, External Interrupt 0 and External Interrupt 1. Following these statements, the input/output ports are initialised by setting the port pins that are to be used as inputs High (1) and setting the port pins that are to be used as outputs Low (0). The EQU directive is used to assign a numeric value to the associated symbol. This symbol is then substituted whenever this value is to be used. For example, the statements below make use of COUNT2 symbol to access its associated numeric value which, referring to Code Extract 4-14, is 50 000. The negative sign implies 50 000 less than the timer overflow value of 0H.

```
MOV     R1,#HIGH COUNT2
MOV     R2,#LOW COUNT2
```

Here the high byte of -50 000 is loaded into register R1 and the low byte is loaded into register R2. The timer high and low byte registers are loaded in the same manner. See Appendix L for the AM source code. Following the initialisation steps, the Main program clears all flag bits (located in general purpose RAM) that are to be used in the program. This is done as a precaution. See Appendix K for a list of flags used. Following this step, the AM initiates and waits for communication signals from the CM. It then waits in a loop for the start signal from the CM. On receiving this signal it ascertains the mode of operation. Thereafter, the AM Clears (0) P0.5, in order to clear the D Flip-Flops that provide the interrupt trigger signal when a pair of bars have been detected. This is also a precautionary measure taken to ensure that the flip-flops are in a known state. The AM then enables the interrupts, transmits the increment signal (on P0.1) to CM and after an enforced delay created by calling the DELAYLOOP subroutine, it waits for a Continue pulse/signal (when the last pair of bars have not been tested) or an End signal (when the last pair of bars have been tested) on port pins P3.0 and P1.1 respectively. The DELAYLOOP subroutine is used often in the program to enforce a one second delay and will be discussed in length under Subroutines.

If a Continue pulse was received the AM then determines if the pair of bars to be tested is pair one, two or three or if it is pair four or above using flags 00H, 01H and 02H. This is done for the following reason. As the reader may recall, a Detection Reference Time is calculated using the values stored in the timer registers when the third pair was being tested. The Detection Reference Time is then used as a tolerance for the detection period for the fourth pair of bars onward. Hence if the AM ‘knows’ that pair four or greater is being tested, the Detection Reference Time is used as a reference instead of the preset maximum allowable time of ten seconds that is used for bars one, two and three.

After this point, the AM waits for either the maximum allowable time (using the appropriate value) to expire or External Interrupt 1 to be triggered when a pair of bars has been detected. The Main program does this by checking if the EX1 flag, 04H, has been set. This flag is set at the start of the EX1 ISR and serves to flag or signal the ISR execution event. Once the Armature Drive Motor has been prompted to start, the timers whose registers have been loaded with the appropriate values, are also started/triggered. Once the preloaded time has expired, the status of flag 04H is checked, as shown in Code Extract 4-15. The reason[3] that this flag is always tested at this point is that the preloaded time either expires due to an error or it is forced to expire by reloading the timer and R3 registers with values that are slightly less than the allowable time hence causing this allowable time to expire almost immediately after the EX1 ISR is exited.

[3]Note that the preloaded time always expires. Hence, a check has to be made to verify if it expired due to having exceeded the maximum allowable time or if it was forced to expire due the External Interrupt ISR.

When EX1 is triggered the timers are paused, the ISR handles the interrupt and control is returned to the timers which will resume their count from the new “forcing” reloaded value until the maximum allowable value has been reached. So upon completion of this count, the Main program has to check if EX1 had been triggered and if the ISR had been initiated by testing flag 04H. If EX1 ISR had indeed been initiated (flag 04H is High (1)) then no error would have occurred. However if flag 04H was Low (0) at this point, then the EX1 ISR had not been initiated before the maximum allowable time was exceeded and an error is reflected.

```
TMR_OUT:CLR      EX1
        JB      04H, NO_ERR1
        CALL     ERROR1

NO_ERR1:CLR      04H
        SETB     EX1
        JMP      AUTO
```

CODE EXTRACT 4-15: EXTERNAL INTERRUPT 1 FLAG 04 H TEST

Note that prior to exiting the EX1 ISR, the timers are reloaded with values that force the them to overflow almost immediately, hence eliminating the need to wait for the timer to count for the remainder of the preloaded duration, as shown in Code Extract 4-16.

```
EXR1OUT:MOV      TH1,#-10
        MOV      TL1,#-10
        MOV      R3,#1
        SETB     TR1
```

CODE EXTRACT 4-16: TIMER REGISTER RELOADED “FORCING” VALUES

If the predefined duration is exceeded before EX1 is triggered then Error I subroutine is called and upon regaining control from the subroutine the Main program loops back to the block of code below,

```
NLBAR:  JNB      P3.0,LBAR
        JMP      CONT
LBAR:   JNB      P1.1,NLBAR
        CLR      P0.1
        LJMP     END
```

CODE EXTRACT 4-17: START / RESTART LOOP

where it waits for a Continue or End signal from the CM. The Error 1 subroutine will be discussed in detail under the section entitled Subroutines. If the triggering of EX1 is first to occur then the program vectors to the EX1 ISR where the interrupt is handled and after completion of this process, the timers are reloaded and control is handed back to the Main program. From this point a jump is initiated and the Main program enters a wait loop where it waits for a Continue or End signal from the CM, as shown in Code Extract 4-17.

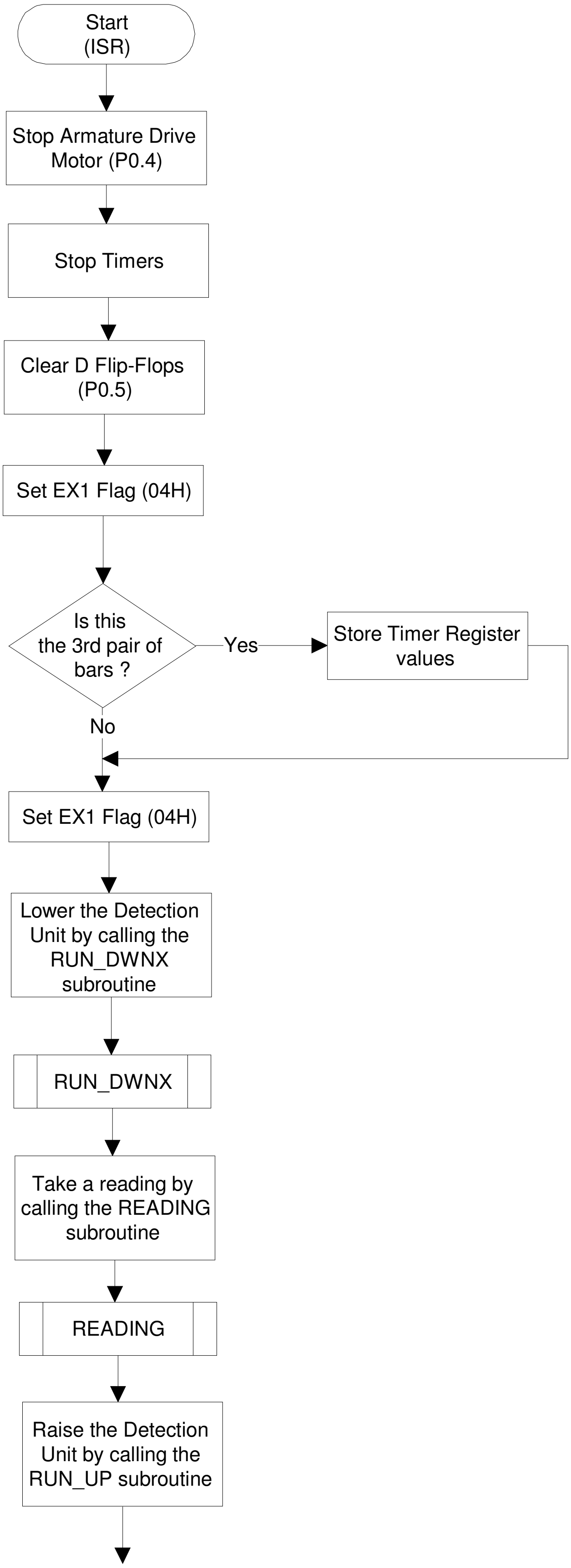
This entire process is repeated until the last pair bars have been tested and is identified as having been completed by the reception of an End signal from the CM.

4.2.3 Interrupts and Interrupt Service Routines (ISRs)

External Interrupt 1 and External Interrupt 0 are the only interrupts enabled for use by the AM. The interrupt priority is assigned such that External Interrupt 0 has a higher priority than External Interrupt 1 and can therefore interrupt the External Interrupt 1 Interrupt Service Routine (ISR) when the associated triggering event occurs. External Interrupt 1 is triggered on the detection of a pair of bars by the optical sensor. The EX1 ISR then takes control for the duration of that test cycle except for when External Interrupt 0 is triggered and EX0 ISR briefly assumes control. External Interrupt 0 is triggered when the test probes reach the bars under test, when the test probes are raised to their initial position, when an Emergency Stop is initiated by pressing the Emergency Stop switch (on P1.5) on the Test Station or if one of the systems Safety Interlocks are triggered. Safety Interlocks are switches on access points to the test area, e.g. gates or doors. When a gate or door is opened during a test, the Safety Interlock is triggered. This is a safety measure implemented to prevent unauthorised staff from entering the test area while a test is in progress. Each interrupt and the associated interrupt service routine will be discussed individually below.

4.2.3.1 External Interrupt 1 and External Interrupt 1 ISR

External Interrupt 1 is triggered when the optical sensors on the detection unit detects a pair of bars and signals this event via a D flip-flop and an interfacing digital network. On triggering this interrupt, the program is immediately paused and the program vectors off to the location in memory that is allocated to the EX1 ISR (0013H). Due to its size, eight bytes is too little space to contain the entire ISR. The ISR has to therefore be located elsewhere in memory and identified by a label. Once at the vectored address, i.e. 0013H, a long jump is initiated to the ISR using the label EX1ISR to identify the ISR's location in memory. The label is the beginning point of the ISR and once identified, the ISR executes and returns control to the interrupted program i.e. the Main program in this case using the Return Form Interrupt (RETI) statement. Figure 4-16 depicts the flow diagram for the EX1 ISR and Code Extract 4-18 shows the EX1 ISR coding.


Start
(ISR)
Stop Armature Drive
Motor (P0.4)
Stop Timers
Clear D Flip-Flops
(P0.5)
Set EX1 Flag (04H)
Is this
the 3rd pair of
bars ?
Yes
Store Timer Register
values
No
Set EX1 Flag (04H)
Lower the Detection
Unit by calling the
RUN_DWNX
subroutine
RUN_DWNX
Take a reading by
calling the READING
subroutine
READING
Raise the Detection
Unit by calling the
RUN_UP subroutine

A (pp. 165)

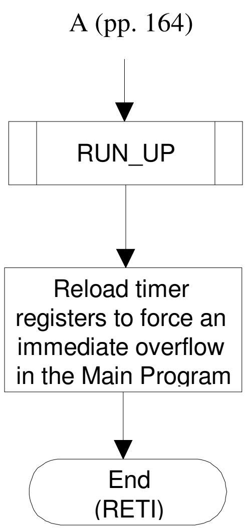


FIGURE 4-16: EXTERNAL INTERRUPT 1 ISR FLOW DIAGRAM

```
;********************************
; EXTERNAL INTERUPT 1 - ISR - v2
;********************************

EX1ISR: CLR     P0.4
        SETB    P0.5
        nop
        nop
        nop
        nop
        CLR     P0.5
        CALL    DELAYLOOP
        CLR     TR1
        CLR     TR0
        SETB    04H
        JNB     02H,RUN_DWN
        JB      05H,RUN_DWN
        MOV     R4,TH0
        MOV     R5,TL0
        MOV     B,R3
        MOV     R6,B
        SETB    05H

;****************************
;            DOWN
;****************************

RUN_DWN:CALL    RUN_DWNX

;****************************
;          READING
;****************************

        CALL    READING

;****************************
;         RUN_UP
;****************************

        CALL    RUN_UP

EXR1OUT:MOV     TH1,#-10
        MOV     TL1,#-10
        MOV     R3,#1
        SETB    TR1
        RETI
```

CODE EXTRACT 4-18: EXTERNAL INTERRUPT 1 ISR CODING.

On entering the ISR, the first task carried out is to stop the rotation of the Armature Drive Motor by Clearing (0) P0.4 and also stopping the Timers by Clearing (0) TR1 and TR0. The next task is to Clear (0) the D flip-flops that produce the triggering pulse. This is accomplished by setting port pin P0.5 High (1) for a short period before clearing it again. This is done to ensure that the D flip-flops are in a known state for the next detection cycle. The operation of the input detection circuitry will be discussed in Chapter 5. Next, the EX1 flag, 04H, is set. This indicates to the Main program that External Interrupt 1 was triggered and that EX1 ISR did execute.

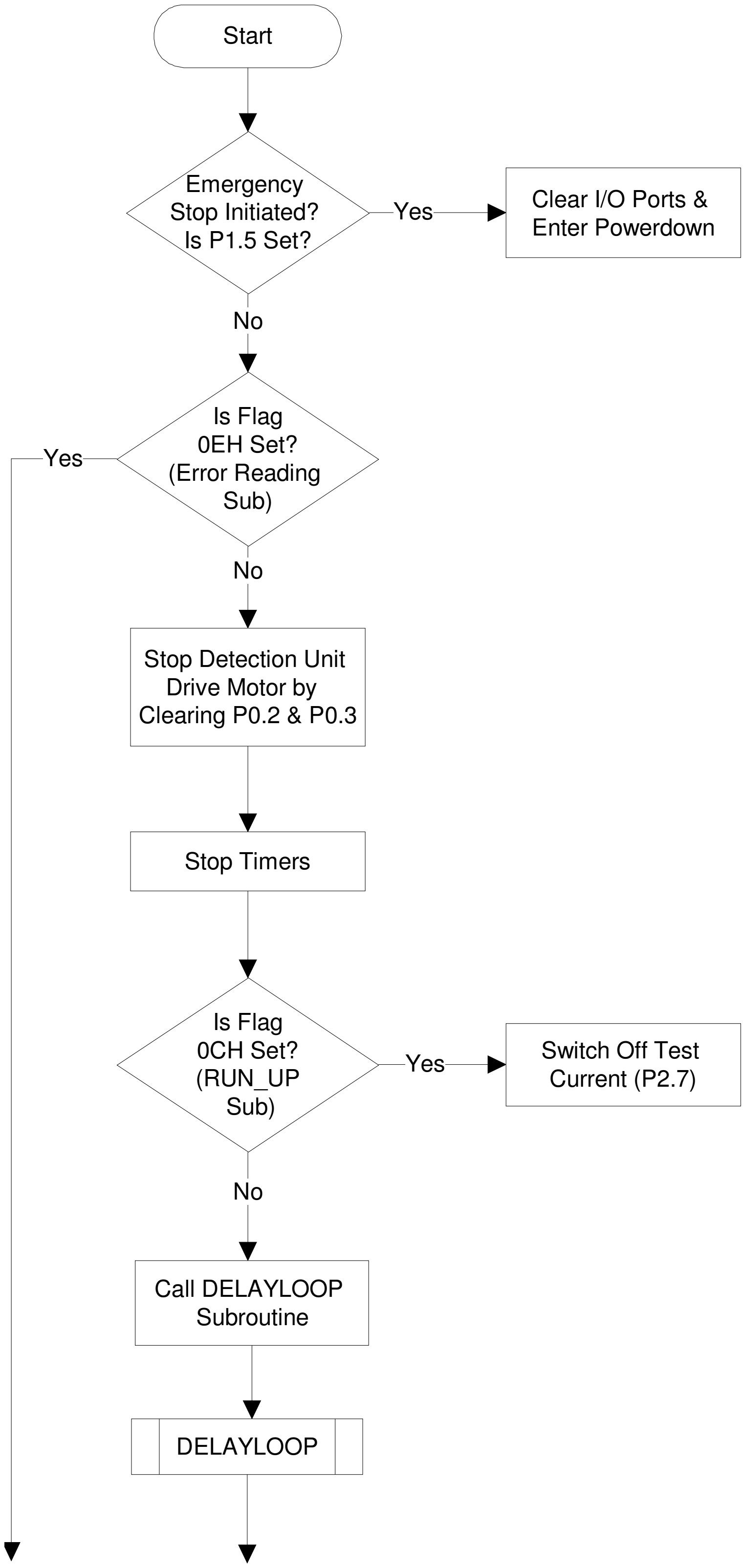
Following this, the ISR checks whether the pair of bars that were detected are the third pair. If it is the third pair, then the values that are stored in the timer registers are copied into registers R4 (high byte) and R5 (low byte). Further, the value stored in register R3 (Timer 1 overflow count) is copied into register R6 in Register Bank 0, see Appendix K. These values are used in the calculation of the Detection Reference Time. (Note that the use of Timers will be discussed later in the chapter under the section entitled Timers).

The Detection Unit Drive Motor is prompted to begin lowering the unit and the test probes onto the surface of the commutator by calling the RUN_DWNX subroutine. Once the test probes are on the surface of the bars the READING subroutine is called. This subroutine communicates with the CM READING subroutine in order to capture a volt-drop reading for that pair of bars. When the process reading is complete the RUN_UP subroutine is called to raise the bars to its initial position. Note that all subroutines will be discussed in the section entitled Subroutines.

Finally, prior to exiting the ISR and returning control to the Main program, the timer registers and the Timer 1 overflow count register, R3, is reloaded with values that will force an almost immediate timer overflow thereby forcing the maximum allowable time to be exceeded, as discussed earlier. Control is then returned to the Main program.

4.2.3.2 External Interrupt 0 and External Interrupt 0 ISR

External Interrupt 0 is triggered when the test probes on the Detection Unit has reached the bars under test (when the unit is being lowered), the test probes have been raised to their initial position (when the unit is being raised), when an Emergency stop has been initiated (by pressing the Emergency Stop switch on the Test Station) or if one of the systems Safety Interlocks are triggered. When triggered the program vectors off to 0003H where it is redirected using a jump statement to the location in memory where the label EX0ISR resides. The location of this label is the beginning point of the EX0 ISR code. An explanation of the EX0 ISR is provided with reference to Figure 4-17 for the EX0 ISR flow diagram and Code Extract 4-19.



A (pp. 170)   B (pp. 170)

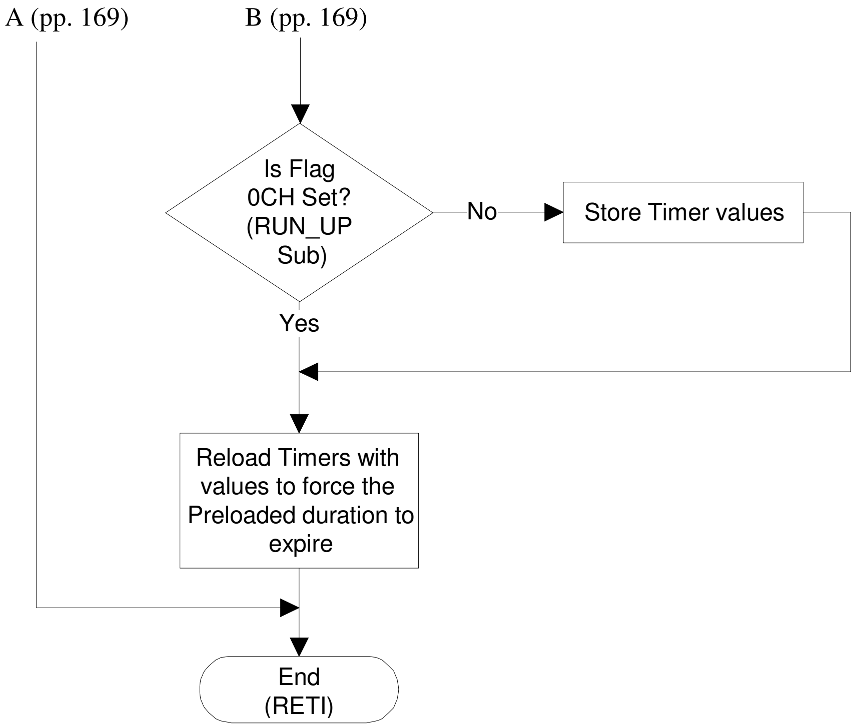


FIGURE 4-17: EX0 ISR FLOW DIAGRAM

```
;***********************************
;EXTERNAL INTERUPT 0 - ISR - v2
;***********************************

EX0ISR: jnb     P1.5,no_stop
        ljmp    end
no_stop:JB      0EH,IG
        CLR     P0.2
        CLR     P0.3
        CLR     TR1
        CLR     TR0
        JNB     0CH,S
        CLR     P2.7
S:      CALL    DELAYLOOP
        SETB    08H
        JB      0CH,EXR0OUT
        MOV     B,R3
        MOV     R7,B
        CLR     RS0      ;
        SETB    RS1      ;REG BANK 1
        MOV     R1,TH0
        MOV     R2,TL0
        CLR     RS0      ;
        CLR     RS1      ;REG BANK 0
EXR0OUT:CLR     0CH
        MOV     TH1,#-10
        MOV     TL1,#-10
        MOV     R3,#1
        SETB    TR1
IG:     RETI
```

CODE EXTRACT 4-19: EX0 ISR CODING

The first task undertaken by the interrupt service routine is to test port pin P1.5. If this pin is High (1) then EX0 was triggered by the initiation of an emergency stop or one of the systems Safety Interlocks was triggered. The ISR then jumps to the End label where the input/output ports are cleared and Powerdown mode is entered into. If P1.5 was Low (1) then the interrupt was triggered by the test probes reaching the surface of bars when being lowered or its initial position when being raised.

However, the ISR has to further ascertain if the interrupt was triggered while the ERROR READING PROCEDURE Subroutine was being executed by testing flag 0EH. This flag is Set (1) by the ERROR READING PROCEDURE Subroutine when a manual reading has to be taken due to an error and when it is Set (1), the EX0 ISR is to ignore the interrupt and exit the ISR. The ERROR READING PROCEDURE Subroutine will be further discussed later in this chapter. When flag 0EH is tested and found to be Low (0), the interrupt was not triggered during the execution of the ERROR READING PROCEDURE Subroutine. Both the raising and lowering motion is then stopped by Clearing (0) the port pins responsible for prompting the action, i.e. P0.2 and P0.3 respectively. Thereafter, the Timers are stopped by Clearing (0) TR1 and TR0. Following this, flag 0CH is tested. This flag is set by the RUN_UP subroutine to indicate that the Detection Unit was in the process of being raised at the moment of the interrupt.

If 0CH is set, i.e. High (1), the Detection Unit was being raised before the ISR, which means that a reading was already completed and the test probes are off the surface of the bars and at its initial position when this interrupt was triggered. It is then required that the Test Current is switched off, and this is accomplished by Clearing P2.7. If flag 0CH was not set, i.e. Low (0), then the interrupt was triggered when the test probes reached the surface of the bars in order to take a volt-drop reading. The Test Current is therefore left on. After this process a delay is enforced by calling the DELAYLOOP subroutine.

The EX0 flag, 08H, is then set to indicate that this interrupt has been triggered and that the associated ISR has executed. Next, flag 0CH is retested. In this case if the flag is not set (which implies that the interrupt was triggered when the Detection Unit was being lowered) the values in the timer registers are stored in Register Bank 1, register R1 (high byte) and R2 (low byte).

The Timer 1 overflow value that is stored in register R3 is copied into register R7 in Register Bank 0, see Appendix K. These values are recalled and used to calculate the Unit Raising Reference Time. Register Bank 0 is accessed using the Mode bits RS0 and RS1 in the Program Status Word Register (PSW), see Table 4-11 and Table 4-12. By setting RS0 =1 and RS1 = 0, the eight registers, R0 to R7 in Register Bank 1 can be accessed.

```
CLR     RS0     ;
CLR     RS1     ;REG BANK 0
```

And by resetting RS0 =0 and RS1 = 0, the eight registers, R0 to R7 in Register Bank 0 can be accessed

```
CLR     RS0     ;
SETB    RS1     ;REG BANK 1
```

. Note that Register Bank 0 is the default register.

Bit	Symbol	Bit Address	Description
PSW.7	CY	D7H	Carry Flag
PSW.6	AC	D6H	Auxiliary Carry Flag
PSW.5	F0	D5H	Flag 0
PSW.4	RS1	D4H	Register Bank Select 1
PSW.3	RS0	D3H	Register Bank Select 0
PSW.2	OV	D2H	Overflow Flag
PSW.1	-	D1H	Reserved
PSW.0	P	D0H	Even Parity Flag

TABLE 4-11: PROGRAM STATUS WORD REGISTER (PSW) SUMMARY SOURCE: THE 8051 MICROCONTROLLER

RS1	RS1	Bank	Address
0	0	0	00H – 07H
0	1	1	08H – 0FH
1	0	2	10H – 17H
1	1	3	18H – 1FH

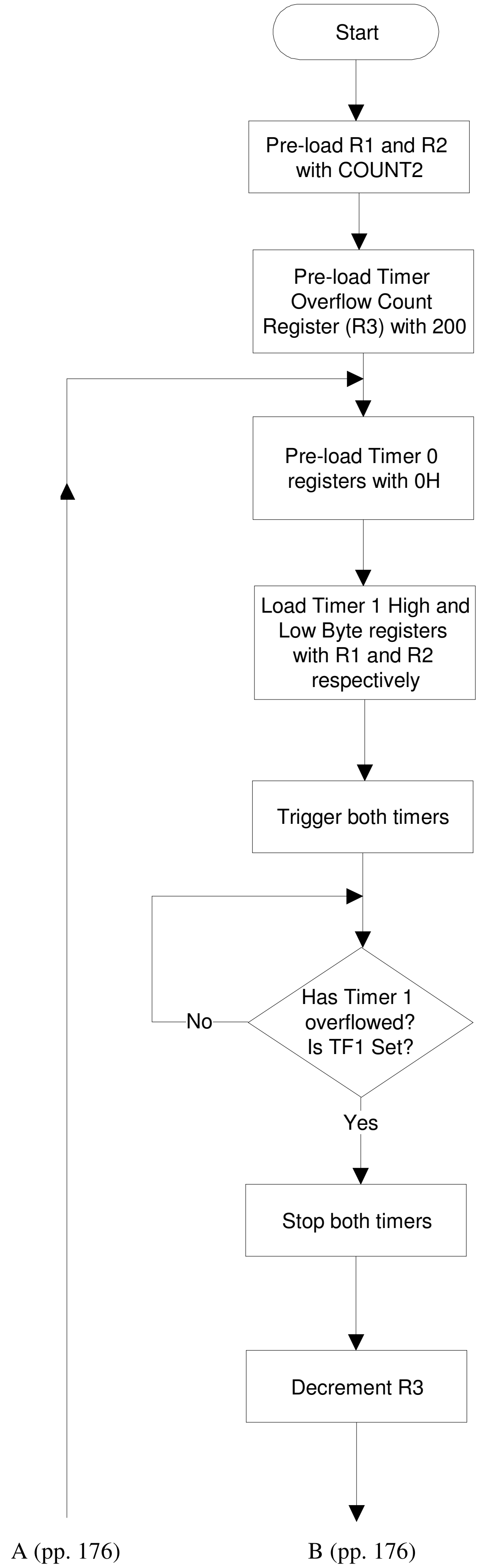
TABLE 4-12: REGISTER BANK SUMMARY – SOURCE: THE 8051 MICROCONTROLLER

Prior to exiting and returning control to EX1 ISR the timer registers and the Timer 1 overflow count register, R3, are reloaded to force an almost immediate timer overflow hence forcing the maximum allowable time to be exceeded, as discussed earlier. Control is then handed back to the EX1 ISR by executing the RETI statement.

4.2.4 Timers and Timer Operation

The Automation Microcontroller makes use of both Timer 0 and Timer 1 in the Sixteen-Bit Timer mode as initialised at the beginning of the program. This means that the timer counts in 1μs intervals from 0000H to FFFFH. On a FFFFH to 0000H transition an overflow occurs and the Timer Overflow Flag, TFx, is set. Both timers are used together with an overflow count register, R3, to time the duration of certain events/processes. The timer registers as well as the overflow count register are also reloaded with predefined values so that an event is allowed a maximum time in which to occur. Timer 0 is also used to enforce a delay of one second when the DELAYLOOP subroutine is called.

Timer 0 and Timer 1 are used to time how long an event takes to complete (when raising or lowering the Detection Unit) or how long an event takes to begin (When waiting for a pair of bars to be detected). To store the timer register and overflow count register values the following procedure is used referring to Figure 4-18 and Code Extract 4-20.



Start
Pre-load R1 and R2 with COUNT2
Pre-load Timer Overflow Count Register (R3) with 200
Pre-load Timer 0 registers with 0H
Load Timer 1 High and Low Byte registers with R1 and R2 respectively
Trigger both timers
Has Timer 1 overflowed? Is TF1 Set?
No
Yes
Stop both timers
Decrement R3
A (pp. 176)
B (pp. 176)

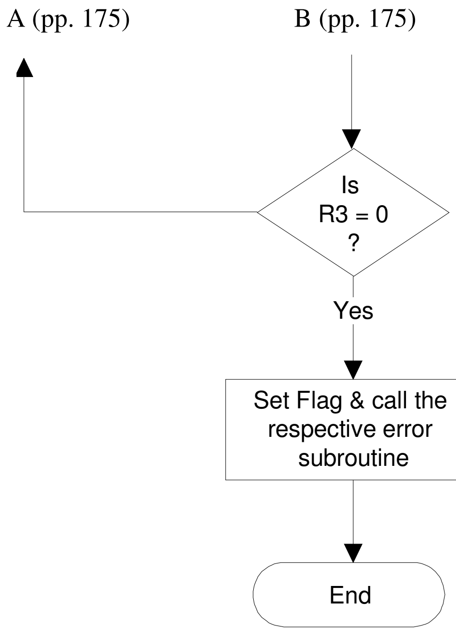


FIGURE 4-18: FLOW DIAGRAM FOR THE INTERVAL TIMING PROCEDURE

```
        MOV     R1,#HIGH COUNT2
        MOV     R2,#LOW COUNT2
        MOV     R3,#200
TMR2:   MOV     TH0,#0H
        MOV     TL0,#0H
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
        SETB    TR0
WAIT_T2:JNB     TF1,WAIT_T2
        clr     tr1
        CLR     TR0
        clr     tf1
        CLR     TF0
        DJNZ    R3,TMR2
```

CODE EXTRACT 4-20: CODING FOR THE INTERVAL TIMING PROCEDURE

The process begins with Timer 1 being preloaded with the values associated with the COUNT2 symbol, i.e. –50000. This value is negative because it has to be loaded as 50000 less than the overflow value which for a sixteen-bit counter is 0000H (recall that at an overflow occurs on a FFFFH to 0000H transition). Registers R1 and R2 are preloaded with the high and low bytes respectively of the COUNT2 value, i.e. –50000. R1 and R2 are later used to load the Timer 1 high and low byte registers respectively. Thereafter, the Timer Overflow Register is preloaded with 200. This means that a maximum of 200 cycles of 50000μs duration will be counted, i.e.

$$50000\mu s \times 200 = 10s$$

This 10s is the maximum allowable time for an event to occur or begin and is the default allowable period when an interval is being timed in order to store the duration. If this time is exceeded before the event is completed or has begun, the Error subroutine associated with the interval being timed is called.

After being loaded, Timer 1 is triggered and a count is started from the preloaded value to 0000H. While counting the Timer 1 Overflow Flag, TF1, is continuously tested in a loop. As soon as an overflow occurs, TF1 is set High (1) and the test loop is exited. The timer is stopped and the overflow flag is Cleared (0). Register R3 is then decremented to indicate that one 50000μs cycle has been completed. R3 is then tested to check if it holds a value of zero, indicating that 200, 50000μs cycles have been completed, hence implying that the 10s maximum allowable time has been reached.

If this is the case, the timer has exceeded the maximum allowable time before the event being timed has occurred, therefore not stopping the timer in order to store the value. When this occurs the Error subroutine associated with the interval being timed is called. For every completed 50000μs cycle for which R3 does not hold zero after being decremented, a jump is initiated to the point where the timer registers are reloaded and then triggered to begin the next 50000μs cycle. The reader will note that Timer 0 is also triggered and stopped at the same time that Timer 1 is triggered and stopped. The only difference in the use of these two timers is that when being reloaded, Timer 1 registers are reloaded with –50000, i.e. 50000 counts below 0000H, and Timer 1 registers are reloaded with 0H. The explanation is provided with reference to Figure 4-19.

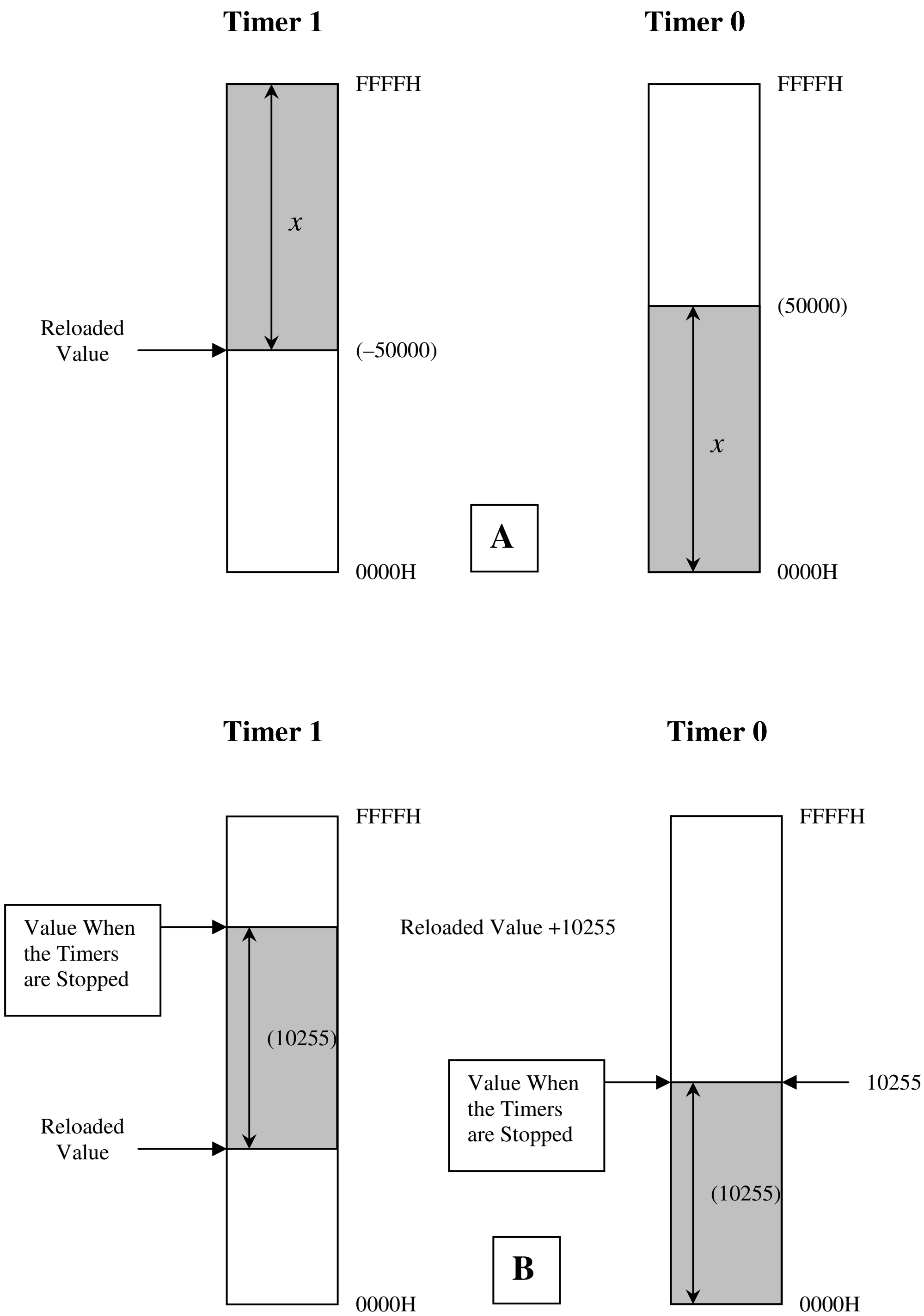


FIGURE 4-19: TIMER REGISTER OPERATION

When the stored timer register and overflow count register, R3, values are used to calculate the Detection Reference Time and the Unit Raising Reference Time, the calculation subroutine (which will be discussed under Subroutines) subtracts the value remaining in R3 from the initially loaded 200, producing the number of 50000μs cycles that were completed during the interval that was timed. The number of cycles is not an accurate indication of the entire interval. For example, in the event that the timers were stopped due to an expected event 10255μs after the last 50000μs was completed and this cycle was the tenth cycle. The overflow count register, R3 will only hold the value after the last timer overflow i.e. 200 – 10 = 90. After being processed by the calculation subroutine, the value to be reloaded into the timers and overflow count register will be 200 –90 = 10. Because the reloaded value is just

$$10 \text{ cycles x } 50000\mu s = 0.5s$$

and not the true value of,

$$10 \text{ cycles x } 50000\mu s + 10255\mu s = 510255\mu s = 0.510255s,$$

it is obvious that the 10255μs that was counted just before the timers were stopped is 'lost'. In order to capture the most accurate time for an interval this "lost" time must also be captured. This is where Timer 0 is important. Referring to Figure 4-19a, it is shown that when the timers are being loaded, Timer 1 registers are loaded –50000, i.e. 50000 counts below 0000H. At the same time, Timer 0 is loaded with 0000H. When the timers are started they both count up from their preloaded values. When Timer 1 reaches the FFFFH to 0000H transition and overflows, Timer 0 registers holds 50000. In this way Timer 0 is performing a positive count/timing, beginning at 0000H of the same period that is being counted/timed by Timer 1 from its preloaded value.

Figure 4-19b provides a true representation of the timer register values for the example given above. After the ten 50000μs cycles have been completed the timer registers are reloaded as described above, i.e. Timer 1 with a preloaded value and Timer 0 with 0000H. The timers are then triggered and the both begin the counting/timing process. When the an event occurs that stops the timers, Timer 1 registers hold a value that is equal to the preloaded value plus the period that was just timed i.e. 10255μs. Or, put differently, Timer 1 registers hold a value that is 10255 counts closer to the FFFFH to 0000H transition than the preloaded value. But at the same instant Timer 0 registers holds exactly 10255. This is because the Timer 0 registers were loaded with an initial starting point of 0000H and timed the exact period that Timer 1 did. This value, stored in the Timer 0 registers are used by the calculation subroutine to calculate the reload value for the time interval that has to be counted after the ten cycles have elapsed, hence providing a true reflection of the interval time.

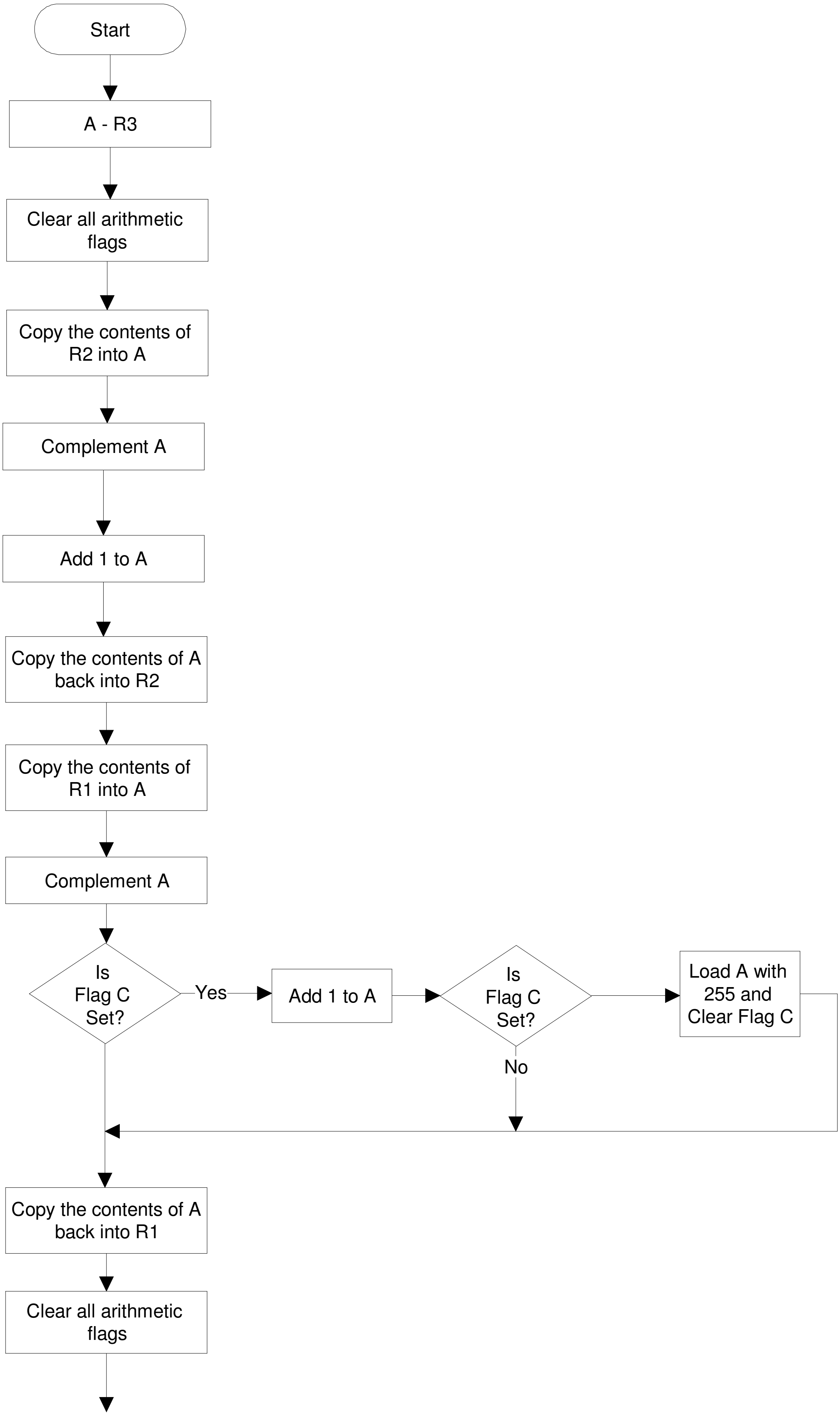
Although it is good engineering practice to obtain the most accurate values as possible, for the purposes of this project, such accuracy is not imperative as a twenty percent time duration is added to the recorded time (as an allowable tolerance) by adding twenty percent more cycles to the recorded completed cycled. This will be discussed in CALC_TIME subroutine. When counting down or timing an interval for which a calculated preloaded value is being used to verify that an event is completed or begins, before the preloaded interval expires, the use of only one timer is necessary.

Here, the calculated number of 50000µs cycles, which included the twenty percent tolerance, is loaded into register R3 and the registers of the timer being used is loaded with –50000 i.e. the same value used when recording the time interval. The timer is then triggered and at the end of each 50000µs the timer overflow flag is Set (1) and R3 is decremented until zero is reached. When zero has been reached the timer registers are reloaded with the calculated remainder value and again triggered. If after this duration has expired the expected event has not began or been completed, the error subroutine associated with the expected event is called. If the event has started or has been completed before this interval is exceeded, the timers and overflow count register are reloaded with values that will force an almost immediate overflow when control is handed back, as described under Interrupts and Interrupt Service Routines.

4.2.5 Subroutines

4.2.5.1 The CALC_TIME Subroutine

This subroutine, as mention earlier, is used to calculate the reload values for the timer and overflow count registers when timing the completion or beginning of an event that has been allocated a maximum allowable preset time. Before the CALC_TIME subroutine is called, the calling program loads, 200 into register A in order to calculate the number of overflow counts/cycles that occurred. Further, the stored high byte timer value is loaded into Register R1, the stored low byte timer value is loaded into register R2 and the overflow count register value is loaded into R3. Referring to Figure 4-20 and Code Extract 4-21 the calculation procedure is as follows.


Start
A - R3
Clear all arithmetic flags
Copy the contents of R2 into A
Complement A
Add 1 to A
Copy the contents of A back into R2
Copy the contents of R1 into A
Complement A
Is Flag C Set?
Yes
Add 1 to A
Is Flag C Set?
Load A with 255 and Clear Flag C
No
Copy the contents of A back into R1
Clear all arithmetic flags

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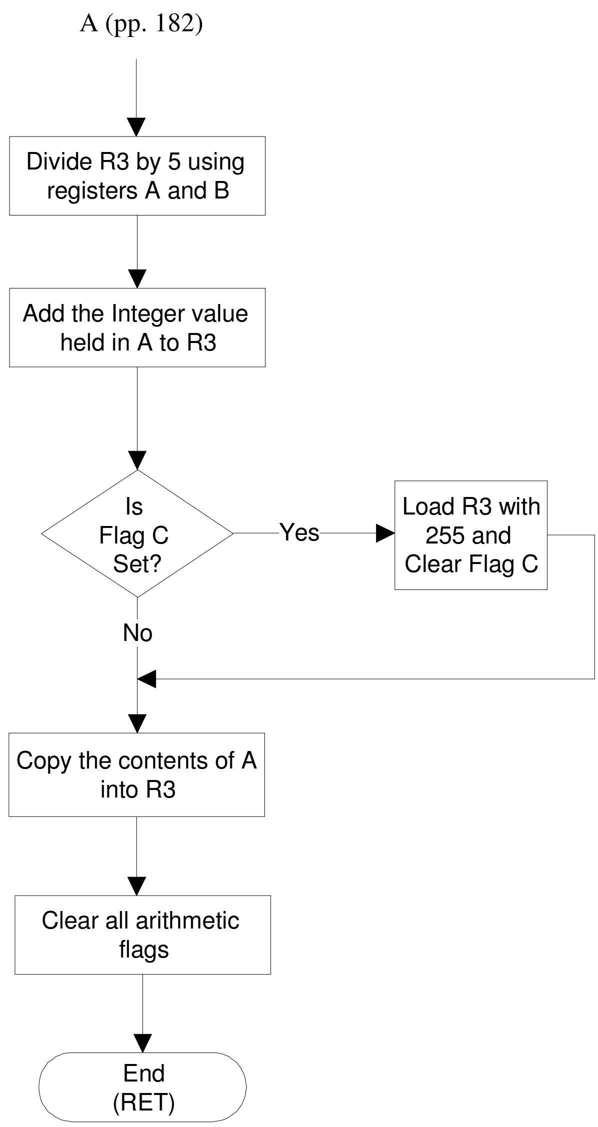


FIGURE 4-20: CALC_TIME SUBROUTINE FLOW DIAGRAM

```
;*******************************************
;                CALC_TIME
;*******************************************
        CALC_TIME:          CLR     C
                            SUBB    A,R3
                            MOV     R3,A
                            CLR     C
                            CLR     AC
                            CLR     OV

                            MOV     A,R2

                            CPL     A
                            ADD     A,#1
                            MOV     R2,A

                            MOV     A,R1
                            CPL     A
                            JNC     SUM
                            CLR     C2
                            ADD     A,#1
                            JNC     SUM
                            MOV     A,#255
        SUM:                MOV     R1,A

                            CLR     C
                            CLR     AC
                            CLR     OV


        GO1:        MOV     A,R3
                    MOV     B,#5
                    DIV     AB
                    ADD     A,R3
                    JNC     TOLL
                    MOV     R3,#255
                    CLR     C
        TOLL:       MOV     R3,A
                    CLR     OV
                    CLR     AC
                    RET
```

CODE EXTRACT 4-21: CALC_TIME SUBROUTINE CODING

The first calculation performed is to establish the number of overflow counts that had taken place. This is done by subtracting the value held in register R3 from the value held in register A, i.e. 200, as preloaded by the calling program. Register A is loaded with 200 because 200 was loaded into register R3 when the interval was being timed.

Register R3 was then decremented on the timer overflow every 50000 counts. So subtracting the contents of R3 from 200 produces the number of over flow cycles.
Next, all the arithmetic flags, i.e. C, CY, OV are Cleared (0). Following this, the reload value for the timer registers is calculated. Recall that the reload values for the timer registers are negative so as to load a value that is the required amount less than 0000H. The calculation of this negative value is accomplished by finding the 2's compliment[4] of the value that was originally recorded and stored in Timer 2 registers. This calculation will now be discussed.

The contents of register R2 which holds the timer register low byte value is copied into register A. The contents of register A is then complimented. Note that register A and B are used extensively during this subroutine. This is because certain instructions can only be performed using these registers. For example, the compliment instruction cannot be performed using any other register apart from register A. One (1) is then added to the contents of register A before the contents is copied back into Register R2.

The contents of Register R1, which holds the timer register high byte value, is then copied into register A where it is complimented. The Carry Flag C, which is Set (1) when there is an overflow of an eight bit register, is then tested to determine if there was an overflow of the timer low byte register R2 when one was added to it.
Example: If R2 contained 1101 1100 before one was added to it, it would contain 1101 1101 after one was added to it and the Carry Flag C will not be set.

i.e. 1101 1100 + 1 = 1101 1101 , and C = 0

However, if R2 contained 1111 1111 before one was added to it, it would contain 0000 0000 after one was added to it and the Carry Flag C will be set.

i.e. 1111 1111 + 1 = 0000 0000 , and C = 1

[4]A negative of a binary number is the 2's compliment of its corresponding positive number. To calculate the negative value using the 2's compliment system, the original positive binary number has to be first complimented (this is 1's compliment), before one (1) is added to the Least Significant Bit (LSB).

When the C is tested and found to be High (1) an overflow of R2 is implied and one has to be added to the contents of A. If C was found to be Low (0), the contents of A is left as is. See Figure 4-21 for numerical examples using the discussed calculation process.

Next a twenty percent tolerance is added to the calculated number of cycles that are held in register R3. This is accomplished by copying the contents of R3 into register A and loading register B with 5. Register A is then divided by register B leaving the integer part of quotient in register A and the remainder in register B. The contents of R3 is then added to the contents of A which should be twenty percent of the original value held in R3. If the Carry Flag C is Set (1) after this addition, implying an overflow, A is simply reloaded with 255 (or FFH) which is the largest value than can be counted to before an overflow in an eight bit register. Finally, the contents of A is copied back into R3, all arithmetic flags are cleared and the subroutine is exited using the RET statement.

Example 1: Without Low Byte Overflow

			High Byte	Low Byte
(Ten Thousand) =	10 000	=	0010 0111	0001 0000

[Low Byte,1's Compliment]
Compliment of Low Byte = 1110 1111

[Low Byte,2's Compliment]
Compliment of Low Byte + 1 = 1111 0000 , C = 0 [Note: No overflow]

[High Byte,1's Compliment]
Compliment of High Byte = 1101 1000

16-Bit Word, High & Low Byte = 1101 1000 1111 0000 = 55 536

16-Bit Value = 1111 1111 1111 1111 = 65 535 = FFFH

Overflow Value = 0000 0000 0000 0000 = 0 = 0000H

=> The number of counts from 0000H to the FFFFH to 0000H transition
= FFFFH + 1 = 65535 + 1 = 65536,
because it takes one count more from FFFFH to reach 0000H, hence forcing an overflow

The calculated reload value = 55 536, which is 10 000 less than 0000H
i.e. 65 536 + (–10 000) = 55 536

FIGURE 4-21: EXAMPLE 1: CALCULATION OF TIMER REGISTER RELOAD VALUES USING THE 2'S COMPLIMENT[4] METHOD.

Example 2: With Low Byte Overflow

		High Byte	Low Byte
256	=	0000 0001	0000 0000

[Low Byte,1's Compliment]
Compliment of Low Byte = 1111 1111

[Low Byte,2's Compliment]
Compliment of Low Byte + 1 = 0000 0000 , C = 1 [Note: Overflow]

[High Byte,1's Compliment]
Compliment of High Byte = 1111 1110

[Due to Carry Flag, C being Set (1)]
Compliment of High Byte + 1 = 1111 1111

16-Bit Word, High & Low Byte = 1111 1111 0000 0000 = 65 280

16-Bit Value = 1111 1111 1111 1111 = 65 535 = FFFH

Overflow Value = 0000 0000 0000 0000 = 0 = 0000H

=> The number of counts from 0000H to the FFFFH to 0000H transition
= FFFFH + 1 = 65535 + 1 = 65536 ,
because it takes one count more from FFFFH to reach 0000H, hence forcing an overflow

The calculated reload value = 65 280, which is 256 less than 0000H
i.e. 65 536 + (–256) = 65 280

FIGURE 4-21: EXAMPLE 2: CALCULATION OF TIMER REGISTER RELOAD VALUES USING THE 2'S COMPLIMENT[4] METHOD.

4.2.5.2 The READING Subroutine

The READING Subroutine for the AM has only two functions. The first is to ensure constant communication with the CM READING Subroutine using port pins P0.0 and P1.7, in order to synchronise both microcontrollers during a volt-drop reading procedure. If this is not done the AM will ‘run away’ or continue executing statements while the CM is busy taking a reading causing the two microcontrollers to lose synchronisation with each other leading to an instability in the system.

The second function of this subroutine is to test port pin P3.1 in order to establish whether the Test Current On time is exceeded. If port pin P3.1 is High (1) then the Test Current On time has been exceeded and the Error 3 subroutine is called. See Code Extract 4-22.

```
;****************************
;        READING
;****************************
READING: SETB     P0.0

RD_WT:   JNB      P1.7,RD_WT
         CLR      P0.0
         NOP
         NOP
         CALL     DELAYLOOP
         SETB     P0.0
RDNG0:   JNB      P1.7,RDNG0
         CLR      P0.0
         CALL     DELAYLOOP
RDNG:    JNB      P1.7,RDNGX
         JMP      RDNGOK
RDNGX:   JNB      P3.1,RDNG
         CALL     ERROR3
         CLR      P0.0
         JMP      OUT2
RDNGOK:  SETB     P0.0
         NOP
         NOP
         CLR      P0.0
         NOP
         NOP
         JNB      P3.1,cnt_chk
         CALL     ERROR3
cnt_chk: RET
```

CODE EXTRACT 4-22: READING SUBROUTINE CODING

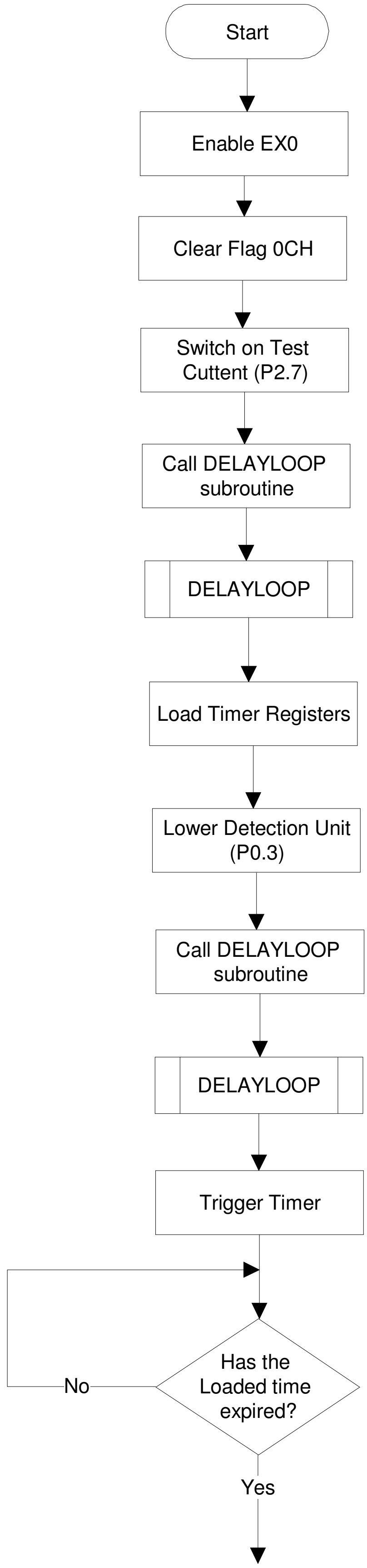
4.2.5.3 The RUN_DWNX Subroutine

The role of this subroutine is to lower the Detection Unit that houses the test probes onto the surface of the bars within a predefined time of 10s. If the lowering process is not completed within this time, a system fault has occurred and the Error 2 subroutine is called. The operation of this subroutine is discussed below with reference to Figure 4-22 and Code Extract 4-23.

Firstly, External Interrupt 0 is enabled so that an interrupt can be generated when the test probes are on the bars to be tested and when the test probes are raised to their initial positions. Flag 0CH is cleared as a safety precaution. The Test Current is then switched on by Setting port pin P2.7. The DELAYLOOP subroutine is then called to enforce a one second delay before the timers are loaded with the appropriate values and are triggered. The reason a delay is enforced, is to ensure that the switching times, in this case turn-on times, for the various devices such as the Detection Unit Drive Motor and the test current switch (an IGBT) are catered for before the process continues. In other words the system is forced to wait for the devices to be switched on before it continues.

A one second delay is excessive for the devices being switched here and indeed for most modern electrical switches where the worst-case turn-on and turn-off times are in the order of a few hundred milliseconds. However in order to make the system flexible in terms of replacing system components a worst case delay of one second was used to cater for almost any type of switching device turn-on and turn-off times. Note that all subroutines will be discussed in the section entitled Subroutines. Following this, the Timer registers are loaded with the 10s maximum allowable time before the Detection Unit Drive Motor is prompted to begin lowering the Detection Unit by Setting P0.3.

The timer is triggered and the ISR then waits for the timer to overflow as in the Main program and then test flag 08H. This flag is set by EX0 and signals that the interrupt was triggered and the associated ISR has executed. If flag 08H is Set (1), then EX0 has been triggered when the test probes reached the surface of the bars before the maximum allowable time had been exceeded. The program can therefore continue as normal. If however flag 08H was not Set (1) when it was tested the maximum allowable time had been exceeded before EX0 was triggered hence signaling Error 2. The Error 2 subroutine is the called to handle the error.


Start
Enable EX0
Clear Flag 0CH
Switch on Test Cuttent (P2.7)
Call DELAYLOOP subroutine
DELAYLOOP
Load Timer Registers
Lower Detection Unit (P0.3)
Call DELAYLOOP subroutine
DELAYLOOP
Trigger Timer
Has the Loaded time expired?
No
Yes

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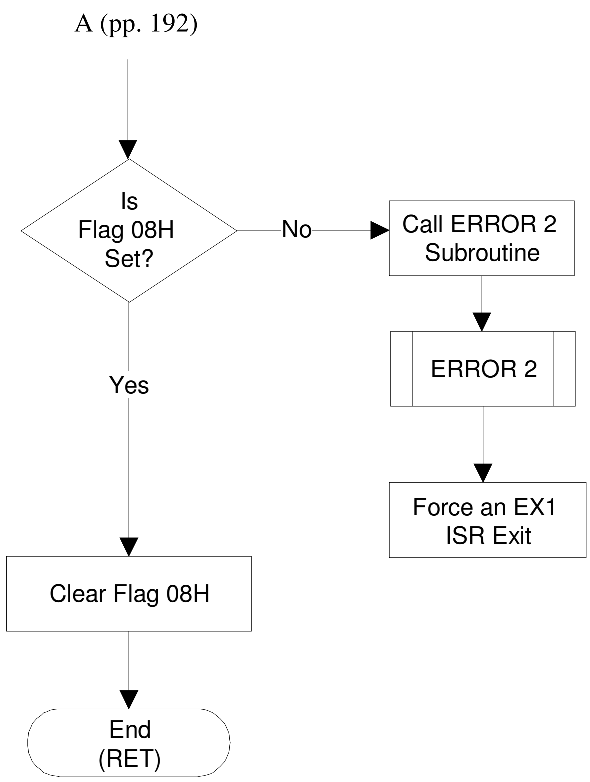


FIGURE 4-22: RUN_DWNX SUBROUTINE FLOW DIAGRAM

```
;**********************************
;   DOWN - LOWER DETECTION UNIT
;**********************************
RUN_DWNX:SETB    EX0
          CLR     0CH
         SETB    P2.7; CUTTENT ON
         CALL    DELAYLOOP
         ;JB      06H,DECT_2
         MOV     R1,#HIGH COUNT2
         MOV     R2,#LOW COUNT2
         MOV     R3,#200

         SETB    P0.3
         CALL    DELAYLOOP
TMR2:    MOV     TH0,#0H
         MOV     TL0,#0H
         MOV     TH1,R1
         MOV     TL1,R2
         SETB    TR1
         SETB    TR0
WAIT_T2:JNB      TF1,WAIT_T2
         clr     tr1
         CLR     TR0
         clr     tf1
         CLR     TF0
         DJNZ    R3,TMR2
         SETB    07H
         JMP     TMR_OUT2

TMR_OUT2:JB       08H,NO_ERR2
          CALL    ERROR2
          SETB    EX0
          JMP     EXR1OUT

NO_ERR2:SETB     EX0
         CLR     08H
         RET
```

CODE EXTRACT 4-23: RUN_DWNX SUBROUTINE CODING

4.2.5.4 The RUN_UP Subroutine

The RUN_UP Subroutine is called when the Detection Unit has to be raised off the surface of the bars to its initial position. Once the subroutine is called, External Interrupt 0 is enabled so that it may be triggered when the unit has reached its initial position. Flag 0CH is Set (1) to indicate to the EX0 ISR that the raising event is in process (for the reasons discussed earlier). Registers R1, R2 and R3 from Register Bank 0 are then loaded with the appropriate values from registers R1 and R2 (in Register Bank 1) and Register R7 respectively, for use in the CALC_TIME Subroutine in order to calculate the reload values. Following this, the Detection Unit Drive Motor is prompted by Setting (1) port pin P0.2 to begin raising the unit.

The timer is then triggered to begin the count. The subroutine then waits for the preloaded interval to expire either due to the Detection Unit not being raised to its initial position in the maximum allowable time or due to Detection unit reaching its initial within the maximum allowable time hence triggering EX0. The EX0 ISR loads the timer and overflow count registers with values that force the interval to expire prematurely. In order to determine which of the aforementioned events occurred when the interval expired, flag 08H is tested.

This flag is Set (1) when External Interrupt 0 is triggered and the EX0 ISR executes implying that the Detection Unit did reach its initial position within the preloaded interval. When 08H is tested and it is not Set (1) the indication is that the Detection Unit did not reach its initial position within the preloaded interval. This signals that Error 4 has occurred and therefore the Error 4 subroutine is called. Prior to exiting, the relevant flags are Cleared (0) and the subroutine is exited by executing the RET instruction. See Figure 4-23 and Code Extract 4-24.

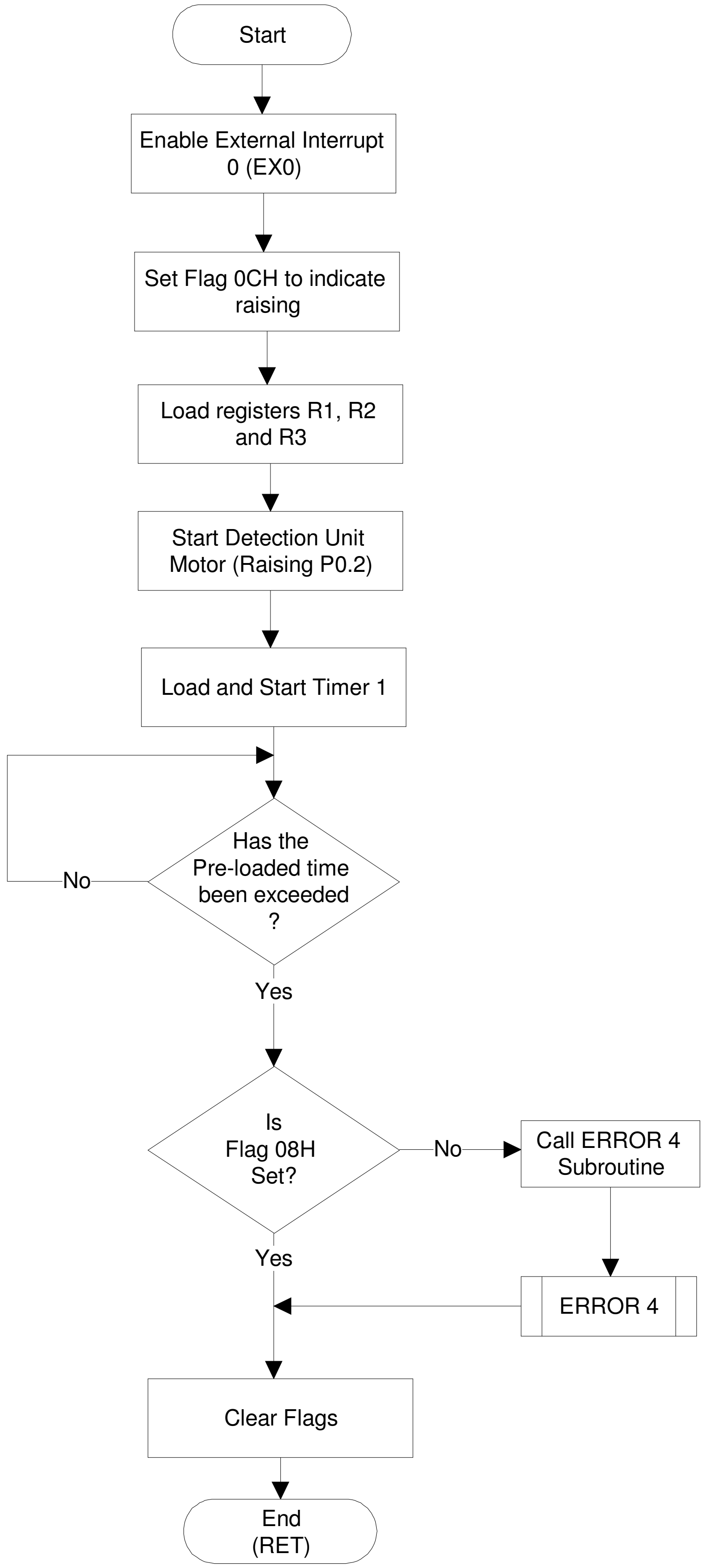


FIGURE 4-23: RUN_UP SUBROUTINE FLOW DIAGRAM

```
;***********************************
;       RUN_UP SUB
;***********************************
RUN_UP: SETB    EX0
        SETB    0CH
DECT_3: CLR     RS0;
        SETB    RS1;    REG BANK1
        MOV     A,R1
        MOV     B,R2
        CLR     RS0;
        CLR     RS1;    REG BANK0
        MOV     R1,A
        MOV     R2,B
        MOV     A,R7
        MOV     R3,A
        MOV     A,#200
        CALL    CALC_TIME
        SETB    P0.2
        CALL    DELAYLOOP
CNT_DN: MOV     TH1,#HIGH COUNT2
        MOV     TL1,#LOW COUNT2
        SETB    TR1
WAIT_D: JNB     TF1,WAIT_D
        clr     tr1
        clr     tf1
        DJNZ    R3,CNT_DN
        JB      08H,TMR_OUT3
        MOV     TH1,R1
        MOV     TL1,R2
        SETB    TR1
WAIT_DX:JNB     TF1,WAIT_DX
        clr     tr1
        clr     tf1
        SETB    07H
TMR_OUT3:       JB      08H,NO_ERR3
                JB      0DH,NO_ERR3
                CALL    ERROR4
                SETB    EX0
                JMP     OUT2
NO_ERR3:CLR     08H
        CLR     0DH
OUT2:   SETB    EX0
        CLR     0CH
        CLR     0DH
        CLR     08H

        RET
```

CODE EXTRACT 4-24: RUN_UP SUBROUTINE CODING

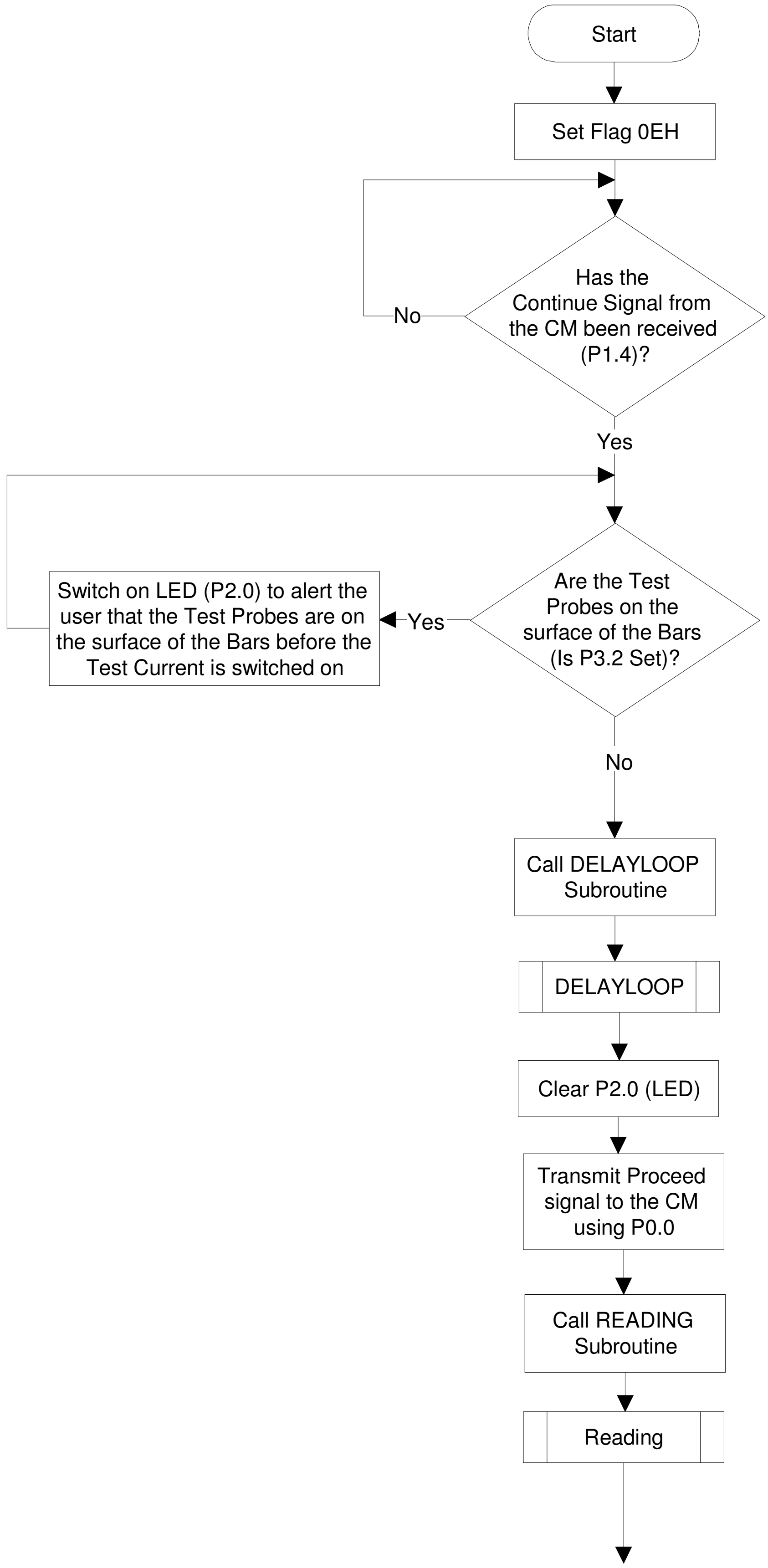
4.2.5.5 The ERROR READING PROCEDURE Subroutine

This subroutine is called by error subroutines that require a manual test to be taken, i.e. Error 1 and Error 2. Recall that when an automatic volt-drop test is taken by the Test Station, the test current is switched on before the test probes are to reach the surface of the bars and switched off after the test probes have been raised off the surface of the bars (for reasons discussed earlier). This same process has to be followed when a manual test is to be taken, however, there is no guarantee that the test technician will always abide by this. Thus, the process has to be enforced.

This is the main role of this subroutine, i.e. to ensure that the test probes are not on the surface of the bars when the Test Current is switched on and off. Note that although a volt-drop reading has to be taken manually due to the error, the test is still been run in Automated mode hence the Test Current is still switched on by the controller and not the test technician. Recall that in Manual mode the Test Current is switched on by the test technician using a footswitch. The process is enforced by pausing the system and alerting the test technician, by lighting up a lamp/LED on P2.0, when the test current is being applied before the test probes are on the surface of the bars. Note that when a manual reading is being taken the lamp/LED on P2.0 will also be on if the Detection Unit, hence the Test Probes are in the initial position, i.e. fully raised, before lowering. This is to ensure that the technician investigates the possible causes of Error2, i.e. a possible malfunction of the Detection Unit drive motor, or a mechanical malfunction before continuing.

Only when the test technician raises the test probes off the bars and below the initial position before switching on the Test Current will the alert lamp/LED on P2.0 be switched off and the process be allowed to continue. The same will apply when the test probes are being raised off the surface of the bars after a reading has been taken. The Test Current will not be switched off until the test probes have been raised off the surface of the bars. As long as the test probes remain on the surface of the bars after the volt-drop reading was taken the alert lamp/LED on P2.1 will inform the test technician that the test probes should be raised. The ERROR READING

PROCEDURE Subroutine is discussed below with reference to Figure 4-24 and Code Extract 4-25.



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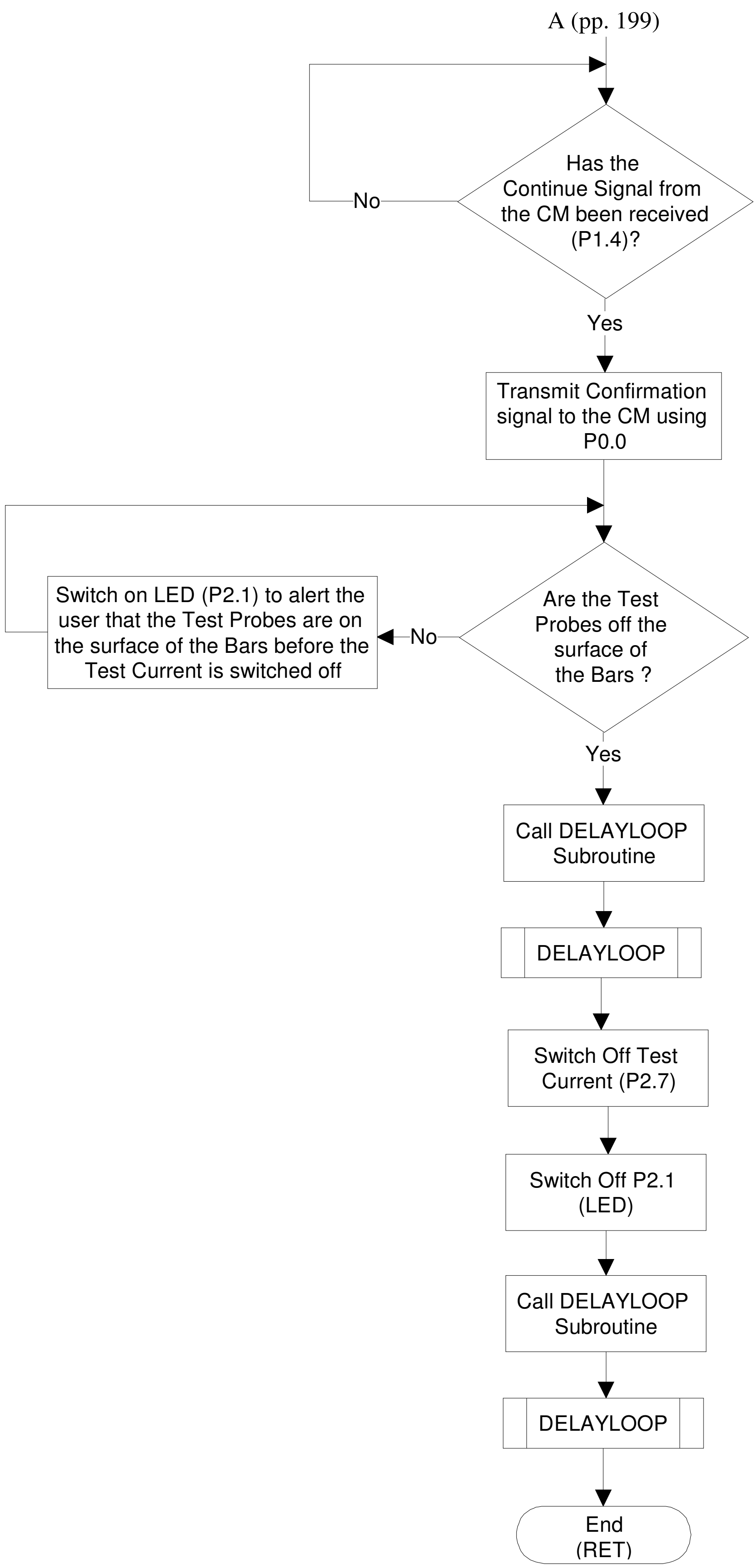


FIGURE 4-24: ERROR READING PROCEDURE SUBROUTINE FLOW DIAGRAM

```
;*****************************
;     ERROR READING PROCEDURE
;*****************************

ER_I_SW:SETB     0EH
E1_CK1: JNB      P1.4,E1_CK1
AGN:    JB       P3.2,ON_I
        SETB     P2.0
        JMP      AGN
ON_I:   CALL     DELAYLOOP
        SETB     P2.7
        CLR      P2.0
PRBS_WT:JB       P3.2,PRBS_WT
        CALL     DELAYLOOP
        JB       P3.2,PRBS_WT
        SETB     P0.0
        NOP
        NOP
        CLR      P0.0
        CALL     READING
E1_HLD: JNB      P1.4,E1_HLD
        SETB     P0.0
        NOP
        NOP
        CLR      P0.0
AGN2:   JB       P3.2,OF_I
        SETB     P2.1
        JMP      AGN2
OF_I:   CALL     DELAYLOOP
        CLR      P2.7
        CLR      P2.1
        CALL     DELAYLOOP
        CLR      0EH
        RET
```

CODE EXTRACT 4-25: ERROR READING PROCEDURE SUBROUTINE CODING

Once called the ERROR READING PROCEDURE Subroutine Sets (1) flag 0EH, to indicate to the EX0 ISR that it has been called, and waits for a proceed signal from the CM Error 1 subroutine on P1.4. When received, port pin P3.2 is tested to establish whether the test probes are on the surface of the bars or at its initial position i.e. in a fully raised position. Recall that port pin P3.2 is the External Interrupt 0 trigger pin however in this case only the status of the pin is being tested. When P3.2 is Low (0) the test probes are either on the surface of the bars or at its initial position. In this case the program/process pauses, waiting for the test probes to be positioned between the surface of the bars and the Detection Unit's initial position, by the test technician. The pausing and incorrect position of the Test Probes are indicated by the lighting up the alert lamp/LED on P2.0. When P3.2 is High (1), the test probes are not on the surface of the bars nor are they in the initial position. Although it is important to test if the test probes are on the surface of the bars before the test current is switched on it is equally important to test if the Detection Unit, hence the test probes are fixed in its initial position. The reason for this is that Error2 indicates that the test probes did not reach the surface of the bars within the allowed time due to the Detection Unit not moving from its initial position caused by a malfunction of the Detection Unit drive motor or a mechanical malfunction. When the Detection Unit and the test probes are between the surface of the bars and the initial position it indicates that the test technician has assessed the possible cause of the error. Once the test probes are in the correct position a delay is enforced, the Test Current is switched on (P2.7) and a proceed signal is transmitted to the CM before the READING subroutine is called. The ERROR READING PROCEDURE Subroutine then waits for a continue signal from the CM on P1.4 which indicates that the volt-drop reading has been captured. Once received, the AM confirms receipt of this signal by Setting (1), P0.0. Before the test current is switched off P3.2 is again tested to ascertain whether the test probes are on the surface of the bars.

As described above, if the test probes are on the surface of the bars the program/process is paused waiting for the test probes to be raised by the test technician and this is indicated by lighting up the alert lamp/LED on P2.1. When P3.2 is High (1) the test probes are not on the surface of the bars nor are they at the initial position. A delay is then enforced, the Test Current is switched off, the lamp/LED on P2.1 is switched off and further delay is enforced before the subroutine is exited using the RET statement.

4.2.5.6 The ERROR 1 Subroutine

This subroutine is called when Error 1 occurs due to a pair of bars not being detected within the maximum allowable preset time. The discussion that follows is with reference to Figure 4-25 and Code Extract 4-26.

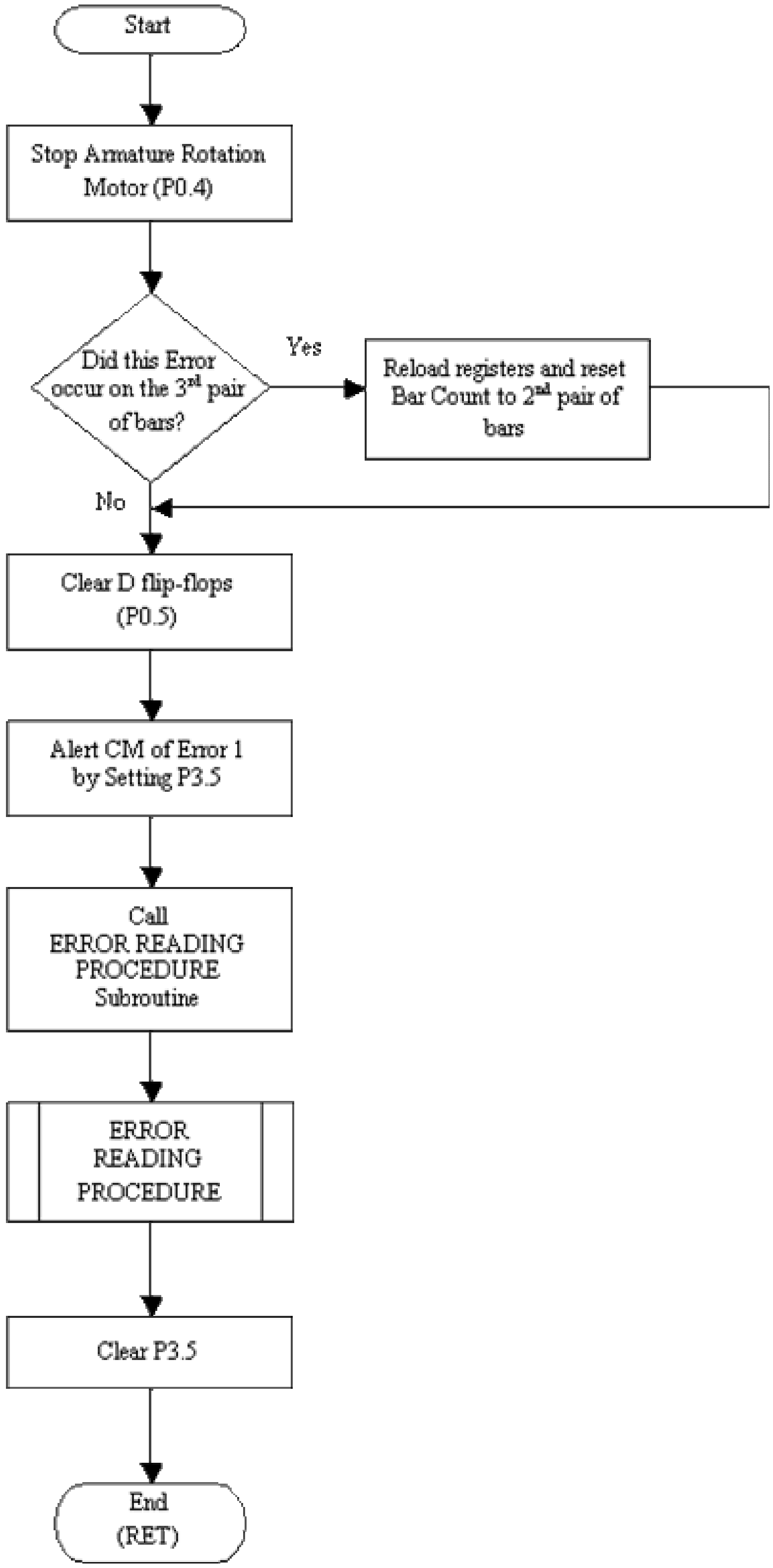


FIGURE 4-25: ERROR 1 SUBROUTINE FLOW DIAGRAM

```
;********************************
; ERROR 1 - BARS NOT DETECTED
;********************************
ERROR1: CLR     P0.4
        JB      05H,S1
        JNB     02H,S1
        MOV     R4,#HIGH COUNT2
        MOV     R5,#LOW COUNT2
        MOV     B,#200
        MOV     R6,B
        CLR     05H
        CLR     02H
        SETB    00H
        SETB    01H
S1:     SETB    P0.5
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        CLR     P0.5
        SETB    P3.5
        CALL    ER_I_SW
        CLR     P3.5
        RET
```

CODE EXTRACT 4-26: ERROR 1 SUBROUTINE CODING

When called, the first task undertaken is to stop the Armature Drive Motor by Clearing (0) port pin P0.4. Then, as a safety measure the subroutine checks if it was called on the third pair of bars cycle, i.e. on the cycle that a reference time is stored in order to calculate the Detection Reference Time. If this is the case then the storage registers are reloaded with the default maximum allowable time of 10s and the bar count that detects the third pair of bars is reset to the second pair.

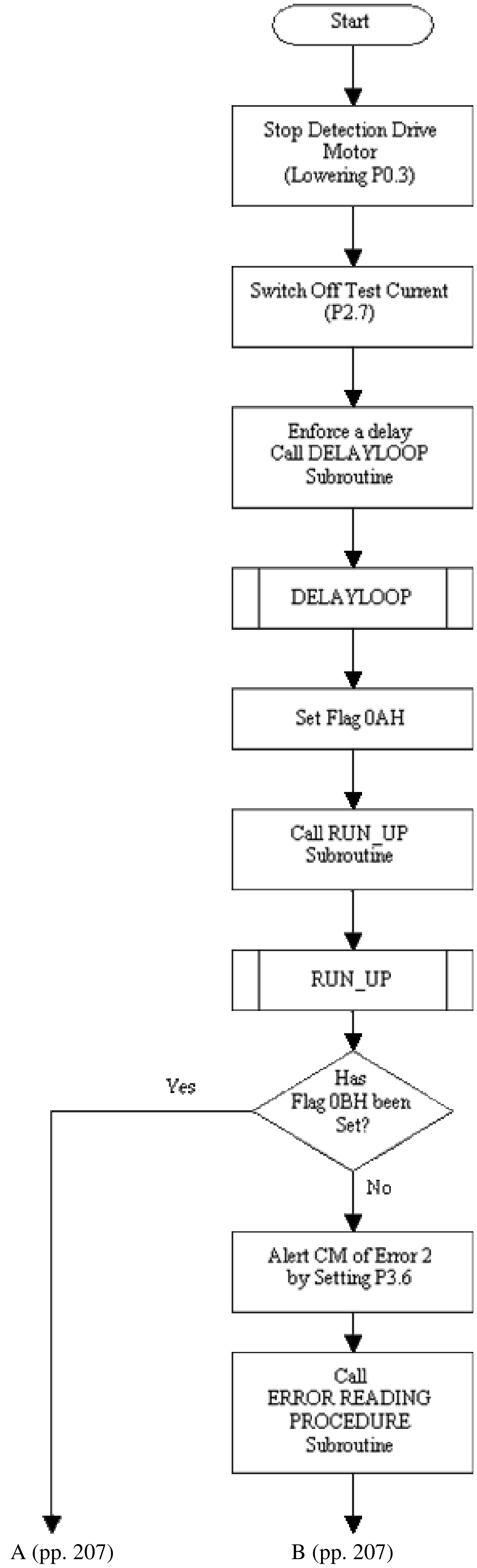
This is done so that the reference time used to calculate the Detection Reference Time, is stored on the next pair cycle i.e. the fourth pair. Because of the reset, the fourth pair of bars is recognised as the third pair. If this subroutine was not called on the third pair cycle the above steps are simply skipped. Following this, the D flip-flops that trigger External Interrupt 1 when a pair of bars is detected are cleared to put them in a known state for the next cycle by Setting (1) and Clearing (0) port pin P0.5.

The CM is then notified that Error 1 has occurred by Setting (1) port pin P3.5. This is done so that the CM can inform the GUI that Error 1 has occurred which is then displayed. Also, the CM calls its Error 1 subroutine to synchronise with the AM Error 1 subroutine.

Next, the ERROR READING PROCEDURE Subroutine is called in order to record the volt-drop reading. Once the ERROR READING PROCEDURE Subroutine is completed and returns control to the Error 1 subroutine, port pin P3.5 is Cleared (0). Control is handed back to the calling program by executing the RET statement.

4.2.5.7 The ERROR 2 Subroutine

The ERROR 2 Subroutine is called by the AM when the test probes do not reach the surface of the bars under test within the maximum allowable time. The discussion that follows is with reference to Figure 4-26 and Code Extract 4-27.


Start
Stop Detection Drive Motor (Lowering P0.3)
Switch Off Test Current (P2.7)
Enforce a delay Call DELAYLOOP Subroutine
DELAYLOOP
Set Flag 0AH
Call RUN_UP Subroutine
RUN_UP
Has Flag 0BH been Set?
Yes
No
Alert CM of Error 2 by Setting P3.6
Call ERROR READING PROCEDURE Subroutine
A (pp. 207)
B (pp. 207)

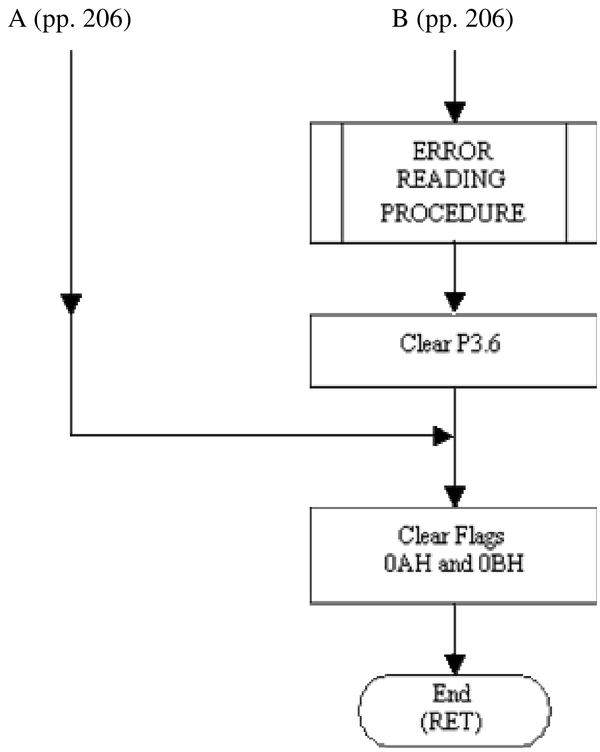


FIGURE 4-26: ERROR 2 SUBROUTINE FLOW DIAGRAM

```
;**************************
;         ERROR 2
;TEST PROBES NOT LOWERED
;**************************

ERROR2: CLR     P0.3
        CLR     P2.7
        CALL    DELAYLOOP
        SETB    0AH
        CALL    RUN_UP
        JB      0BH,E2_OUT
        SETB    P3.6
        CALL    ER_I_SW
        CLR     P3.6
E2_OUT: CLR     0AH
        CLR     0BH
        RET
```

CODE EXTRACT 4-27: ERROR 2 SUBROUTINE CODING

Once called, this subroutine first stops the Detection Unit Drive Motor from lowering the Detection Unit by Clearing (0) port pin, P0.3. The Test Current is then switched off by Clearing (0) port pin P2.7. After a delay is enforced, flag 0AH is Set (1) to signal to the Error 4 subroutine that the Error 2 subroutine has been called. Following this, the RUN_UP subroutine is called to raise the Detection Unit to its original position using the time recorded for the error lowering process. In the event that there is also an error when raising the Detection Unit, and Error 4 is handled by calling the Error 4 subroutine, Flag 0AH is used to indicate if the Error 4 subroutine was called during the raising process called from the Error 2 subroutine.

If this is the case, the Error 4 subroutine will also handle Error 2. Next flag 0BH is tested. Flag 0BH is Set (1) by the Error 4 subroutine to indicate that it had been indirectly called from the Error 2 subroutine and that it has already signaled the CM and called the ERROR READING PROCEDURE Subroutine to record a manual volt-drop reading. If this flag is not Set (1), the ERROR 2 Subroutine alerts the CM that this error has occurred by Setting (1) port pin, P3.6.

The CM, upon receiving this signal, will call its ERROR 2 Subroutine in order to notify the GUI of the error and to synchronise with the AM. Next, the ERROR READING PROCEDURE Subroutine is called to facilitate a manual reading. On receiving control from the ERROR READING PROCEDURE Subroutine, port pin P3.6 is cleared along with flags 0AH and 0BH. Finally control is returned to the calling program by executing the RET statement.

4.2.5.8 The ERROR 3 Subroutine

Error 3 occurs when the Test Current on time has been exceeded. This is regarded by the system as a critical error and therefore enforces an Emergency Stop, hence a system shut down. As soon as Error 3 occurs the AM The ERROR 3 Subroutine informs the GUI via the CM. The GUI then displays this error before taking the relevant steps in preparation for a system shut down before signaling the CM and AM to do the same. The discussion that follows is with reference to Figure 4-27 and Code Extract 4-28.

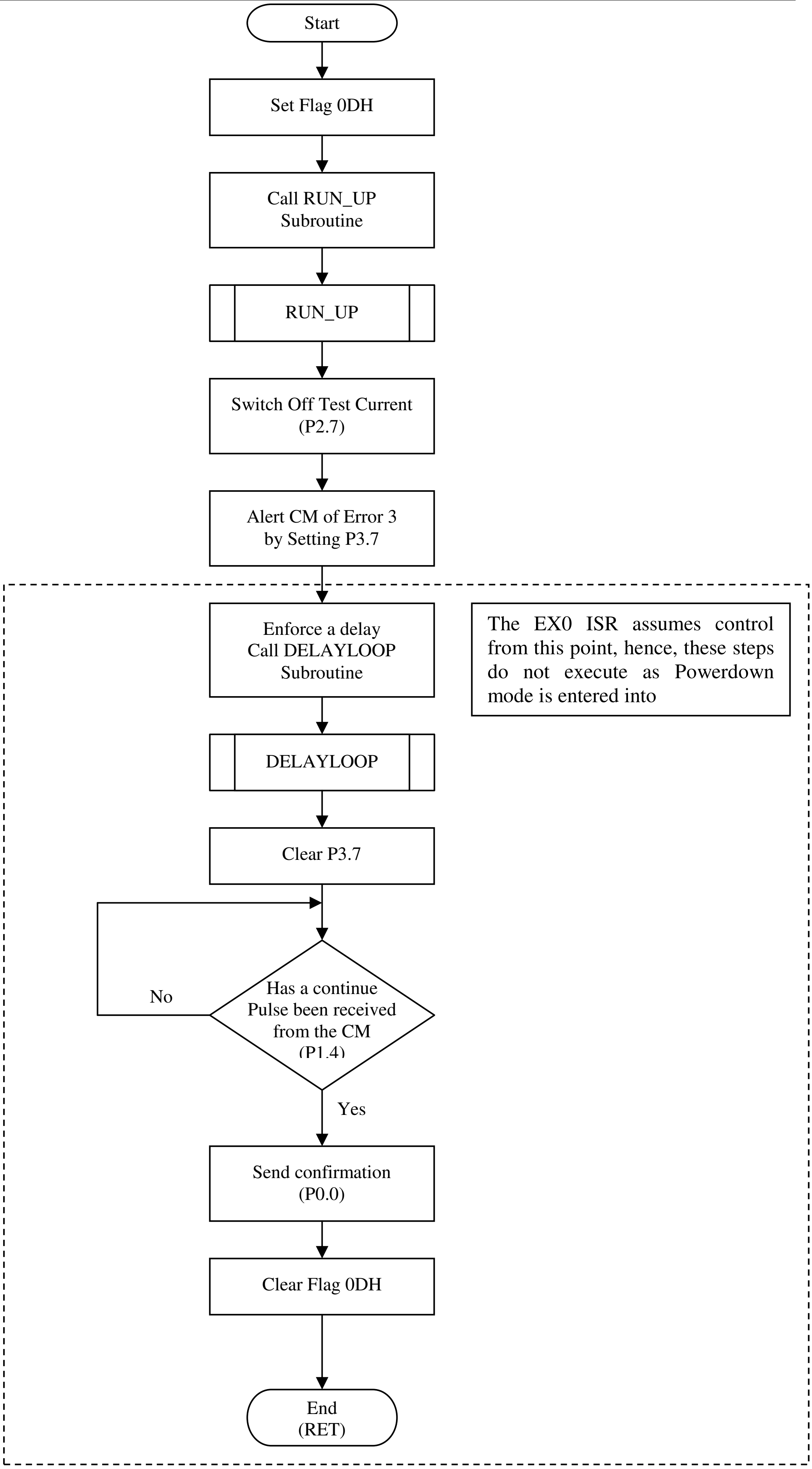


FIGURE 4-27: ERROR 3 SUBROUTINE FLOW DIAGRAM

```
;****************************
;           ERROR 3
;TEST CUTTENT TIME EXCEEDED
;****************************

ERROR3: SETB    0DH
        CALL    RUN_UP
        CLR     P2.7
        SETB    P3.7
        nop
        CALL    DELAYLOOP
        CLR     P3.7
E3_HLD: JNB     P1.4, E3_HLD
        SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        CLR     0DH
        RET
```

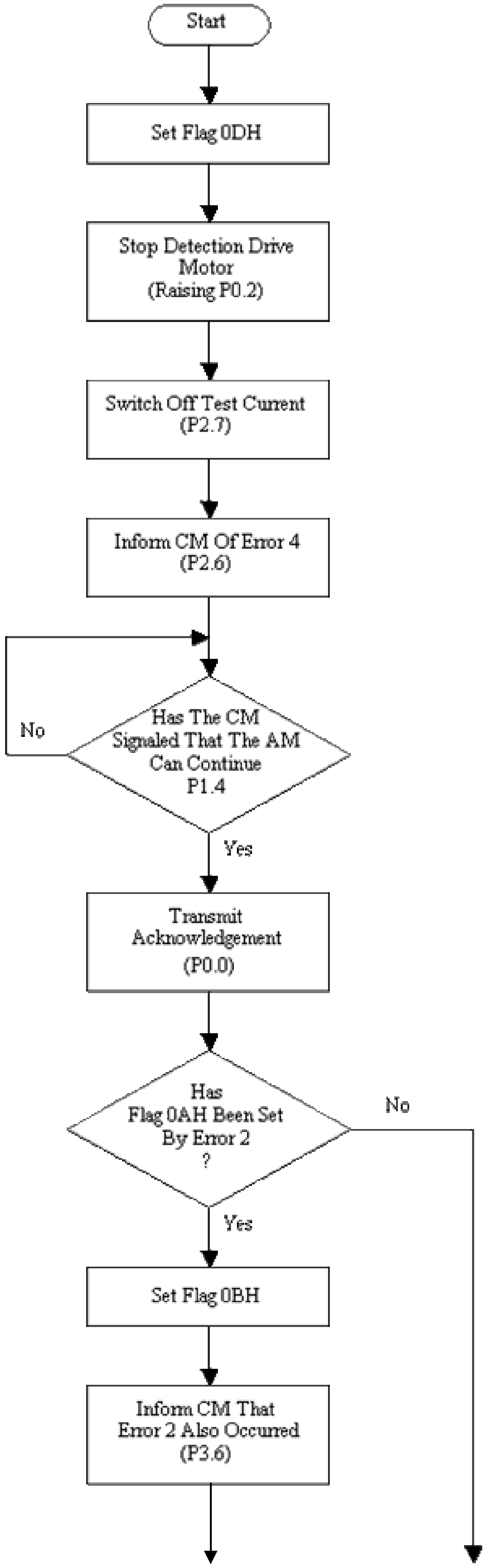
CODE EXTRACT 4-28: ERROR 3 SUBROUTINE CODING

When called, the ERROR 3 Subroutine first Sets (1) flag 0DH to indicate that it has been called due to the associated system error. The reason for Setting (1) this flag will be discussed shortly. Following this step, the RUN_UP subroutine is called so that the test probes are raised off the surface of the bars before the Test Current is switched off as programmed in the ERROR 3 Subroutine. The question that now arises is what happens if there is an error when the Detection Unit hence the test probes are being raised, i.e. it does not reach its initial position in the maximum allowable preset time? Well, Error 4 would have occurred and the associated subroutine i.e. the ERROR 4 Subroutine would be called to handle it appropriately.

This will however halt the system until the test technician arrives at the Test Station and assesses the problem. The time taken to assess the problem will only add to the time for which the Test Current is switched on, which is undesirable as Error 3 calls for an immediate system shut down. This is were flag 0DH plays its role. If the Error 4 subroutine is called while Error 3 has occurred, the Error 4 subroutine is immediately exited. This is because when flag 0DH is tested at the start of the Error 4 subroutine, it will be High (1). If the Error 4 subroutine was called to handle Error 4 at any point other then when Error 3 has occurred, this flag will not be set hence allowing the Error 4 subroutine to execute as normal. The next step in the Error 3 subroutine is to switch off the Test Current, alert the CM that that Error 3 has occurred and enforce a delay. The CM will inform the GUI that Error 3 has occurred. Following this, the steps reflected in the flow diagram in Figure 4-27 and Code Extract 4-28 would technically be executed, however, since this error enforces an emergency stop both the CM and the AM are informed via their respective interrupts. Because the interrupts are triggered and the associated ISRs assume control the remaining instructions are not executed as the AM is forced to Clear (0) its input/output ports and enter Powerdown mode.

4.2.5.9 The ERROR 4 Subroutine

This subroutine is called when the Detection Unit hence the test probes do reach their initial position within the maximum allowable time. The discussion that follows is with reference to Figure 4-28 and Code Extract 4-29.



A (pp. 214) B (pp. 214)

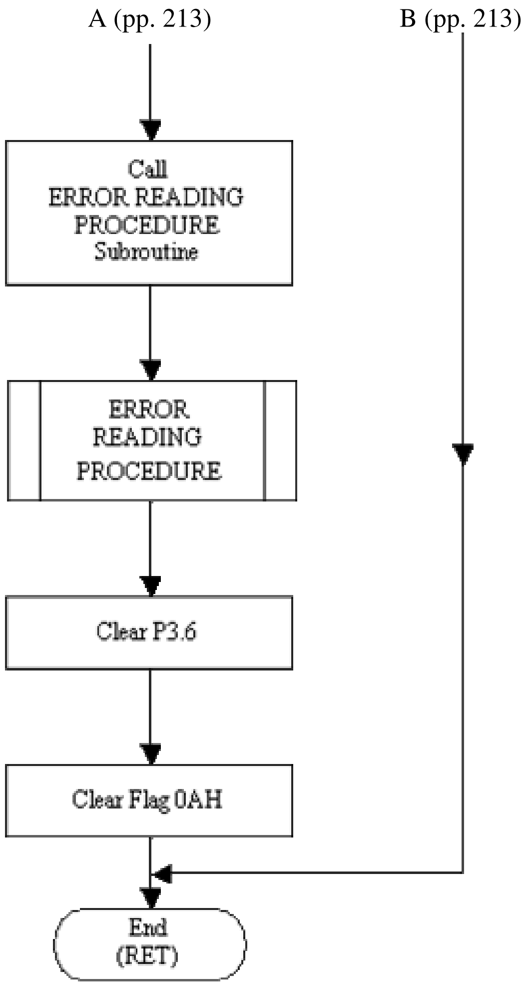


FIGURE 4-28: ERROR 4 SUBROUTINE FLOW DIAGRAM

```
;******************************
;        ERROR 4
;TEST PROBES NOT RAISED
;******************************
ERROR4: JB      0DH,E4_OUT
        CLR     P0.2
        CLR     P2.7
        CALL    DELAYLOOP
        SETB    P2.6
        nop
        CALL    DELAYLOOP
        CLR     P2.6
E4_HLD: JNB     P1.4,E4_HLD
        SETB    P0.0
        NOP
        NOP
        CLR     P0.0
        JNB     0AH,E4_OUT
        SETB    0BH
        SETB    P3.6 ;TO MIC1
        CALL    ER_I_SW
        CLR     P3.6
        CLR     0AH
E4_OUT: RET
```

CODE EXTRACT 4-29: ERROR 4 SUBROUTINE CODING

When entered into, the ERROR 4 Subroutine first sets flag 0DH for the reasons mentioned in the ERROR 3 Subroutine discussion above. Next the Detection Unit Drive Motor is stopped from raising the Unit by Clearing (0) port pin P0.2. The Test Current is then switched off by Clearing (0) port pin P2.7. Following this, the CM is informed of Error 4 having occurred by setting port pin P2.6. The ERROR 4 Subroutine then enters a wait loop where it waits for the CM's ERROR 4 Subroutine to inform it that it may continue by setting port pin P1.4.

Once Set (1), the ERROR 4 Subroutine acknowledges having received this signal by Setting and Clearing P0.0. Flag 0AH is then tested to establish if Error 4 has occurred during the Run_UP procedure that was called by the ERROR 2 Subroutine. (Recall that when an error occurs while the Detection Unit is being lowered, i.e. Error 2, the RUN_UP subroutine is called to raise the Detection Unit to its original position using the time recorded for the error lowering process.) If flag 0AH is Set (1), then Error 4 did indeed occur during the RUN_UP procedure that was called by the ERROR 2 Subroutine and the steps then taken by the ERROR 4 Subroutine handles Error 2 as well. The ERROR 2 Subroutine is then simply exited when control is handed back to it due to flag 0BH being Set (1), as described earlier in the ERROR 2 Subroutine discussion. The steps taken are as follows. First flag 0BH is Set (1) in order to inform the ERROR 2 Subroutine that the ERROR 4 Subroutine has already handled Error 2.

Then the CM is informed that Error 2 has occurred by Setting (1) port pin P3.6 and the ERROR READING PROCEDURE Subroutine is called to capture a volt-drop reading. Port pin P3.6 is then Cleared (0) along with flag 0AH. The subroutine is then exited by executing the RET instruction. If flag 0AH was found to be Low (0) when it was tested the implication is that Error 4 did not occur during the ERROR 2 Subroutine and the ERROR 4 Subroutine is simply exited.

4.2.5.10 The DELAY LOOP subroutine

The DELAY LOOP subroutine is called whenever a delay has to be enforced, for example, when the system needs to be paused in order to allow for a device to be switched on or off after their specified switching time. Although the delay is set to be one second it can easily be shortened or increased by loading new values onto the Timer 0 and timer-overflow-count, R0, registers. The discussion that follows is with reference to Figure 4-29 and Code Extract 4-30.

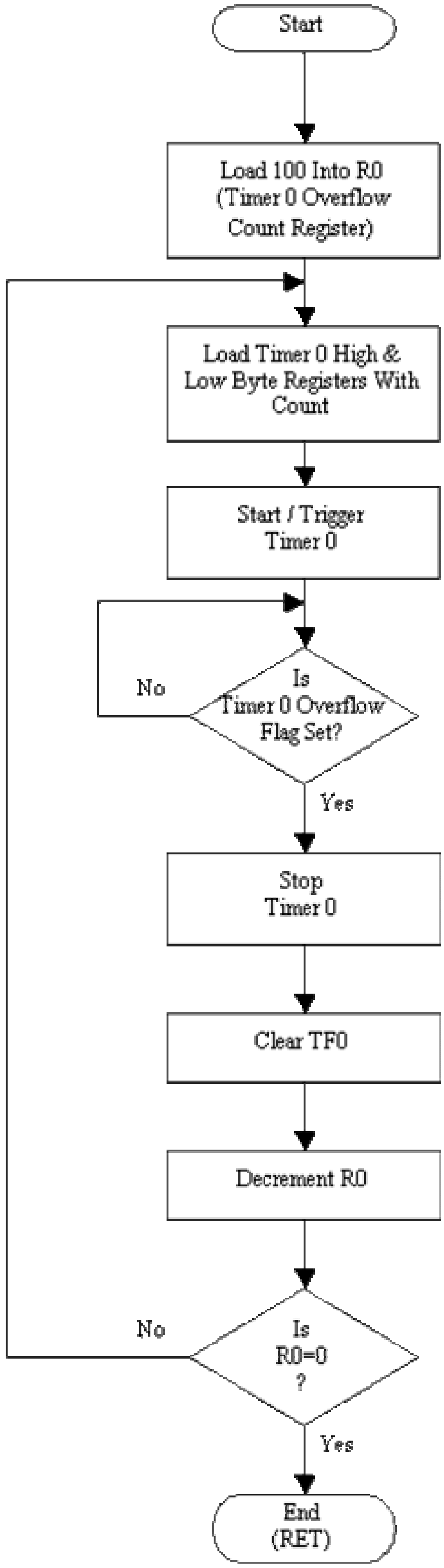


FIGURE 4-29: DELAY LOOP SUBROUTINE FLOW DIAGRAM

```
;************************************************
;                    DELAY LOOP
;************************************************
DELAYLOOP:       MOV     R0,#100 ;1SEC = 100X10000
RPT:             MOV     TH0,#HIGH COUNT
                 MOV     TL0,#LOW COUNT
                 SETB    TR0
DLY:             JNB     TF0,DLY
                 CLR     TR0
                 CLR     TF0
                 DJNZ    R0,RPT

                 RET
```

CODE EXTRACT 4-30: DELAY LOOP SUBROUTINE CODING

Once called the timer-overflow-count register, R0, is loaded with a value of 100. The Timer 0, high and low byte registers are the loaded with the value (i.e.10 000) assigned to the COUNT symbol as initialised using the EQU directive in the main program. The high byte of the value (i.e.10 000) assigned to the COUNT symbol is loaded into the Timer 0 high byte register and the low byte of the value (i.e.10 000) assigned to the COUNT symbol is loaded into the Timer 0 low byte register. The timer is then triggered to begin the count. Recall that each count is one microsecond, hence 10 000 counts implies 10 000µs.

The DELAY LOOP subroutine then enters a waiting loop where it waits for the Timer 0 Overflow Flag (TF0) to be Set (1). This signals that the timer has overflowed implying that 10 000µs has elapsed. The timer is then stopped by Clearing (0) TR0 followed by TF0 also being Cleared (0). The timer-overflow-count register, R0, is then decremented and tested to check if the value it holds is zero. If the value is higher that zero, the Timer 0 registers are reloaded (i.e. with a value of 10 000) and the timer is triggered to restart the cycle. If R0 does hold a value of zero then one second has elapsed and the subroutine is exited by executing the RET instruction.

In summary R0 is decremented after each 10000µs cycle (due to a timer overflow) until it holds a value of zero. Hence, 100 10000µs cycles would have been counted.

$$1 \text{ second} = 100 \times 10000\mu s$$

Chapter 5

Hardware Design

This chapter discusses the hardware design that enables the software that is executing within the embedded mirocontrollers and the GUI to be transformed into physical pulses and signals that control actuators that initiate the motion of objects in the physical world. Hardware also converts, conditions and monitors signals that are produced by transducers, which monitor the external environment, into signals and pulses that are decipherable and understood by the embedded microcontrollers.

This enables the system to respond to various inputs by executing the appropriate blocks of code in response to specific events. The author used the Protel Design Environment to draw schematics and develop the layout and routing of the PCB (Printed Circuit Board). The controller circuit was drawn in modules that link to each other using Netlables (this is a functionality that is available in the Protel Development Environment). The “Bottom-Up” design approach was used to develop this schematic. This approach involves drawing modules on independent sheets and using a Master Sheet (Entitled “Master” in this design) to facilitate linking between all schematic sheets using the above-mentioned Netlables.

Drawing schematics in modules that link to each other makes the circuit easy to understand and modify if need be, as it is uncluttered and easy to isolate a problem area. Each module will be discussed independently however, the reader will be informed as to how the module being discussed is connected to interfacing modules. The complete circuit schematic which includes all the modules discussed can be found in Appendix M, all datasheets can be found in Appendix J, and all test results are presented in Chapter 7.

5.1 Digital System Design

The digital system includes all digital circuitry, from the embedded controllers to the logic gates and drivers that are used in signal conditioning and level shifting respectively. The first modules to be discussed will be the Automation Microcontroller module and the Communication Microcontroller module. In both cases the 40 pin AT89S51 microcontroller was used.

5.1.1 The Communication Microcontroller Module

The Communication Micrcontroller module interfaces and communicates with the ADC by pulsing and reading the ADC control pins, HBEN, $\overline{CS}$, $\overline{EOC}$ and R/$\overline{C}$ as well as receiving the 8 bit output from the ADC parallel output bus. This module also communicates with the Automation Microcontroller, reads the status on the Manual Reading switch and reacts to a forced emergency stop whether it was initiated by pressing the Emergency Stop switch or by the activation of any one of the four safety interlocks. See Figure 5-1 for a representation of the Communication Microcontroller Module and Appendix M for the complete circuit schematic.

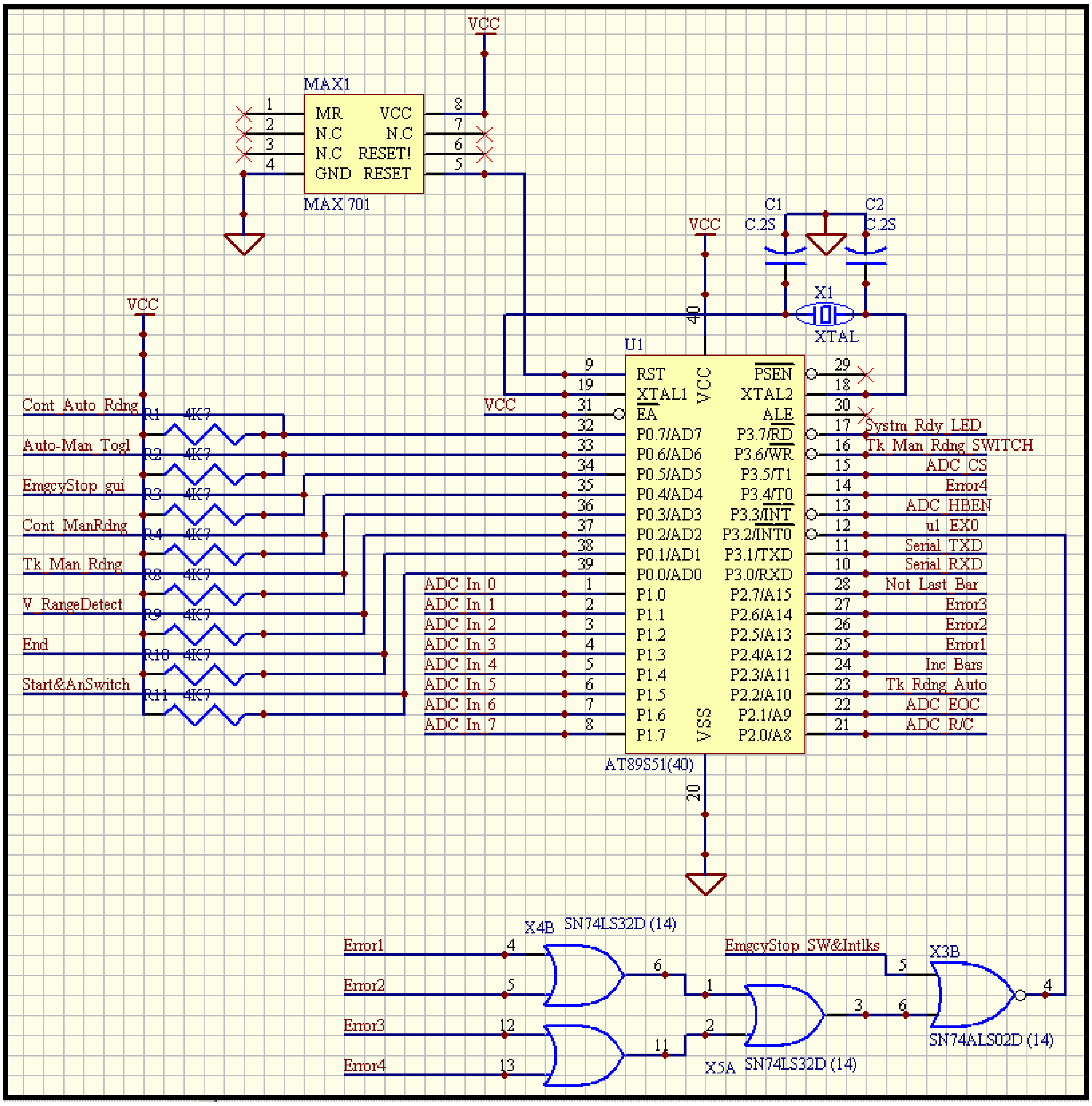


FIGURE 5-1: THE COMMUNICATION MICROCONTROLLER MODULE.

The on-chip oscillator is driven by a quartz crystal X1 with the aid of two stabilising capacitors (C1 and C2). Using a 12MHz crystal and noting that each machine cycle is 12 oscillator periods, each machine cycle is calculated to be 1µs in duration, as shown below.

$$T = \frac{1}{12MHz} = 83.33333 \text{ x}10^{-9}$$

$$T_{\text{Machine Cycle}} = 83.33333 \text{ x}10^{-9} \text{ x } 12 \text{ periods} = 1\mu s$$

The reset pin (9) of the microcontroller is connected to the Reset pin of MAX 701 (see Appendix J for a complete datasheet for the MAX 701). The MAX 701 is a supervisory circuit that monitors the supply to the microcontroller in order to detect Brown-out conditions. A Brown-out[5] occurs when the supply falls to a level that is appreciably lower than the normal supply level for a prolonged amount of time. This will cause components that are powered by this supply to behave erratically and unpredictably. In the event of a Brown-out, which in the case of the MAX 701 is anything equal to or less than 4.65V, the Reset pin of the MAX 701 goes High (4.65V or the present available positive logic High voltage) and is held at this level until the supply returns to its normal rating.

This procedure effectively holds the microcontroller in a Reset state until the supply is within its normal operating range. Note that holding the Reset pin (9) of the AT89S51 high (1) for at least two machine cycles effectively resets the microcontroller. The MAX 701 also provides a Reset-On-Power-up pulse to the microcontroller. This ensures that the microcontroller is in a known state on power-up i.e. all its input/output ports, internal registers, special function registers, program counter etc. are loaded with the default reset values reflected on Page 6 of the AT89S51 datasheet found in Appendix J.

The author originally used the RC network depicted in Figure 5-2 to provide the reset pulse on power-up. But the author's experience has shown that this network behaves erratically and is therefore unreliable in environments where EMI (Electromagnetic Interference) is a factor.

The MAX 701 solved the EMI related problems, specifically relating to Reset-On-Power-up. There were various other methods adopted to negate the effects of EMI on the circuit as a whole. Some of these include, but are not limited to, proper PCB layout and design, which involved, amongst other things, placing the microcontrollers in the center of the board and the quartz crystals as close to the microcontroller oscillator pins (XTAL1 and XTAL2) as possible.

[5] Brown-out refers to the condition where the rms supply voltage falls to a value that is appreciably lower than the normal value but not zero. In the case of a Black-out, the supply falls to zero, i.e. there is a complete loss of the supply.

Reduced track lengths, avoiding 90° bends in tracks, routing power and signal tracks away from each other, designing multilayer PCBs with paired power and ground planes, placing 0.1µF capacitors across all ICs with the addition of a 4.7µF capacitor directly across the microcontrollers. Along with these, the circuit was kept compact and a common grounded guard ring was routed around the edge of the PCB.

The first line of defense against EMI is the metal enclosure in which the circuit is housed. Keeping the size of the holes on the enclosure as small as possible and ensuring that the lid makes proper electrical contact with the rest of the enclosure, this metal enclosure forms a Faraday Cage around the circuit. To further reduce the impact of EMI via conductors from the external environment, shielded cables were used.

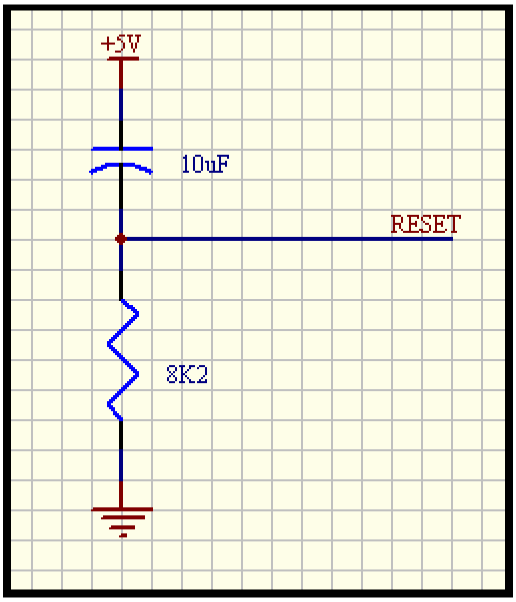


FIGURE 5-2: PREVIOUSLY USED POWER-UP RC NETWORK

Port 0 of the AT89S51 is an open drain input/output port hence the use of external pull-up resistors. Ports 1, 2 and 3 all have internal pull-ups. The basic input/output port structure is depicted in Figure 5-3 and is sourced from *The 8051 Microcontroller*, by I. Scott Mackenzi.

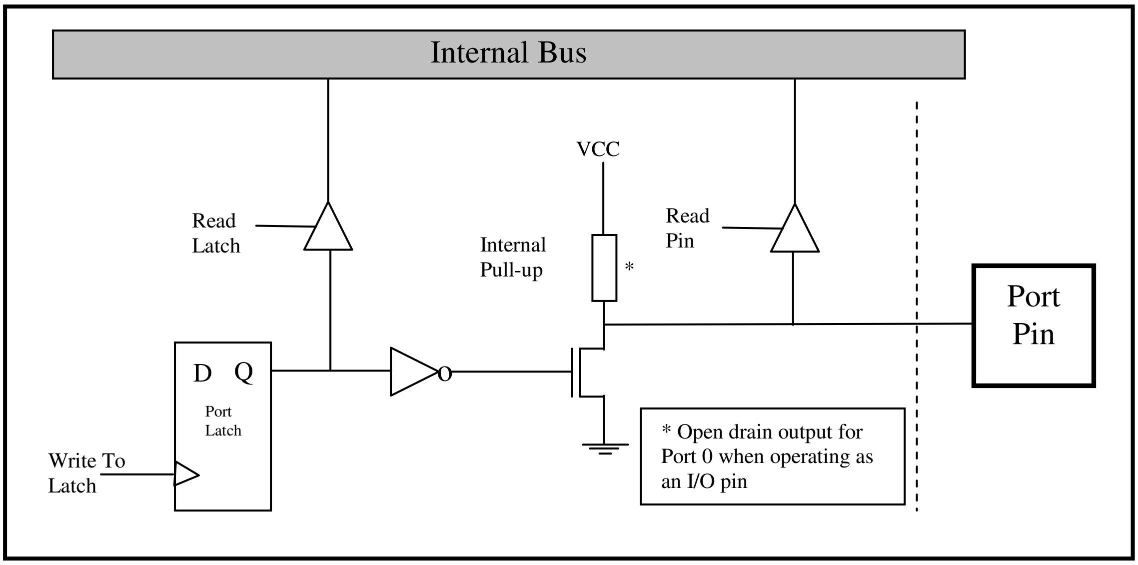


FIGURE 5-3: INPUT/OUTPUT PORT STRUCTURE – SOURCE: *THE 8051 MICROCONTROLLER*

When used as an output port, writing a 1 (high) to the latch, switches off the FET holding the port pin high (VCC) via the pull-up (internal or external) resistor. When a 0 (low) is written to the latch the FET is switched on pulling the port pin to ground (V_{DS} to be exact). When used as in input, 1 (high) must be written to the latch to switch off the FET. In this way, only the load on the port pin can determine its state. For example, if the load on the port pin was the output of a TTL logic IC, when the IC output is high (1), typically 3.4V, a small current will flow producing the required 1.6V drop across the pull-up resistor to keep the Port pin at 3.4V. The potential read on the Port pin will therefore be a high (1). When the IC output is low (0) the potential on the IC pin will be a maximum of 0.4V.

This will allow a maximum current of 4mA to 8mA (depending on the type of IC and the maximum current it can sink during an output low, I_{OL}) to flow from VCC through the pull-up resistor down to ground via the load IC. This current flow will produce the required 4.6V potential drop across the pull-up resistor such that when the port pin is read, it would reflect a potential of 0.4V implying a logic level low (0). Port 1 is the input port for the 8 bit wide parallel ADC output, with port pin P1.0 set up as the LSB (Least Significant Bit) and port pin P1.7 set up as the MSB (Most Significant Bit). Ports 0, 2 and 3 are used as inputs and outputs as required. This facilitates communication with the Automation Microcontroller, control of the ADC, reading of switches, switching of LEDs and also communication with the GUI via serial port pins P3.0 and P3.1.

The interconnections between the Automation and Communications microcontrollers are summarised in the respective Microcontroller Port Utilisation tables found in Appendix K. The connections from the Communications Microcontroller to other devices are also summarised in the Communications Microcontroller Port Utilisation table found in Appendix K. Note that the $\overline{EA}$ (External Access) pin is connected to VCC. This is because when the $\overline{EA}$ pin is held low (0) the microcontroller executes programs from external ROM whilst holding the pin high (1) forces the microcontroller to execute programs from internal ROM.

The input to External Interrupt 0, P3.2, is an OR and NOR gate network which allows any of the system errors (Error 1, 2, 3 or 4) or an Emergency Stop, labeled "*EmgcyStop_SW&Intlks*", (initiated by pressing the Emergency Stop switch or triggering a Safety Interlock) to trigger the interrupt. The Emergency Stop signal is an input to both microcontrollers that enforces a complete system stop by interrupting both microcintrollers forcing them to enter a safe shutdown procedure before entering power-down themselves. This Emergency Stop is initiated by the triggering of switches (push-button and interlock) on the physical system and should not be confused with the Emergency Stop that is initiated by clicking on the Emergency Stop button on the GUI, although both events yield the same end result. Including Emergency Stop triggers from various sources makes the entire system safer in the occurrence of an undesirable or dangerous event. The Emergency Stop is generated by an independent network which will be discussed later in this chapter.

5.1.2 The Automation Microcontroller Module

The Automation Microcontroller module is responsible for the control of all the system's actuators which include the Armature Drive Motor and the Detection Unit Drive Motor as well as the switching of the Test Current Supply via an IGBT. It also receives input signals from the physical system to indicate the system status and the occurrence of events whether desirable or undesirable.

These input signals include the signal indicating the detection of a pair of bars, labeled "*u2_EX1_Bar_Dect*", the signal that indicates that the Detection Unit has reached its initial position, labeled "*Detect_Unit_Switches*", as well as Emergency Stop signals, labeled "*EmgcyStop_gui*" and "*EmgcyStop_SW&Intlks*". All of the above mention signals, except "*EmgcyStop_gui*", are generated by independent networks all of which will be discussed later in this chapter. The "*EmgcyStop_gui*" signal is generated by the Communication Microcontroller to inform the Automation Microcontroller that an Emergency Stop has been initiated via the GUI. See Figure 5-4 for a representation of the Automation Microcontroller Module and Appendix M for the complete circuit schematic.

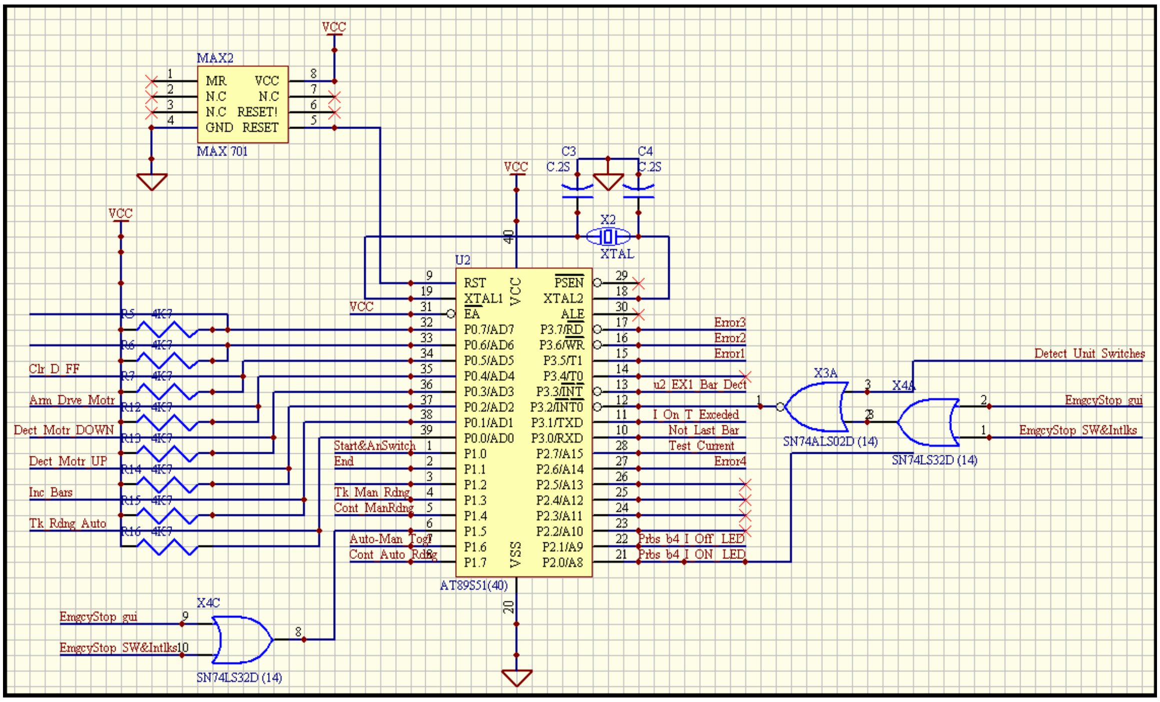


FIGURE 5-4: THE AUTOMATION MICROCONTROLLER MODULE

The Automation Microcontroller is set up in exactly the same way as the Communications Microcontroller. The interconnections between the Automation and Communications microcontrollers are summarised in the respective Microcontroller Port Utilisation tables in Appendix K. The connections from the Automation

Microcontroller to other devices are also summarised in the Automation Microcontroller Port Utilisation table in Appendix K.

The input to External Interrupt 0, P3.2, is an OR and NOR gate network which triggers the interrupt in the occurrence of any of the two Emergency Stop events ("*EmgcyStop_gui*" and "*EmgcyStop_SW&Intlks*") or the occurrence of the bar detection event ("*Detect_Unit_Switches*"). The input to port pin P1.5 is also an OR gate with "*EmgcyStop_gui*" and "*EmgcyStop_SW&Intlks*" as input signals. The reason for this becomes apparent when the reader recalls the discussion in Chapter 4 concerning the External Interrupt 0 ISR for the Automation Microcontroller.

The first task undertaken by the interrupt service routine is to test port pin P1.5. If this pin is High (1) then EX0 was triggered by the initiation of an emergency stop".

As soon as External Interrupt 0 (EX0) is triggered, the associated ISR first checks if P1.5 is High (1), indicating that any one of the Emergency Stop sources had been triggered. If this is the case, the system shut down and controller power-down procedures are entered into. If this not the case and P1.5 is Low (0) then the interrupt was triggered due to the detection of a pair of bars, i.e. the"*Detect_Unit_Switches*" signal. Hence this port pin is only used to decipher whether an interrupt was initiated due to an emergency stop or the detection of a pair of bars.

5.1.3 The Bar Detection Module

The Bar Detection module is responsible for alerting the Automation Microcontroller when a pair of bars has been detected. The actual detection of each copper bar on the commutator of the armature under test is undertaken using optical sensors that detect the reflection of an emitted laser beam. The Omron E3X-NA11 amplification unit together with the Omron E32-DC200 fiber optic unit (with reflective sensors) was used to carry out this task. See Appendix J for complete datasheets. The combination of these two units allow for the accurate detection of a copper bar from a distance of between 50mm and 70mm above the surface of the commutator. See Figure 5-5 and Figure 5-6 for images of the commutator and the copper bars that are to be detected.

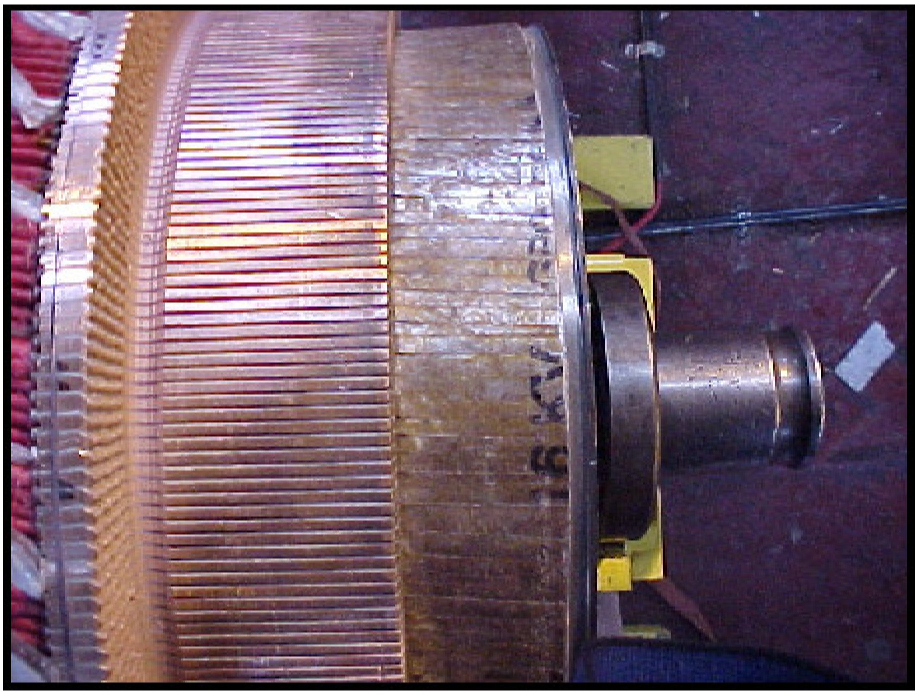
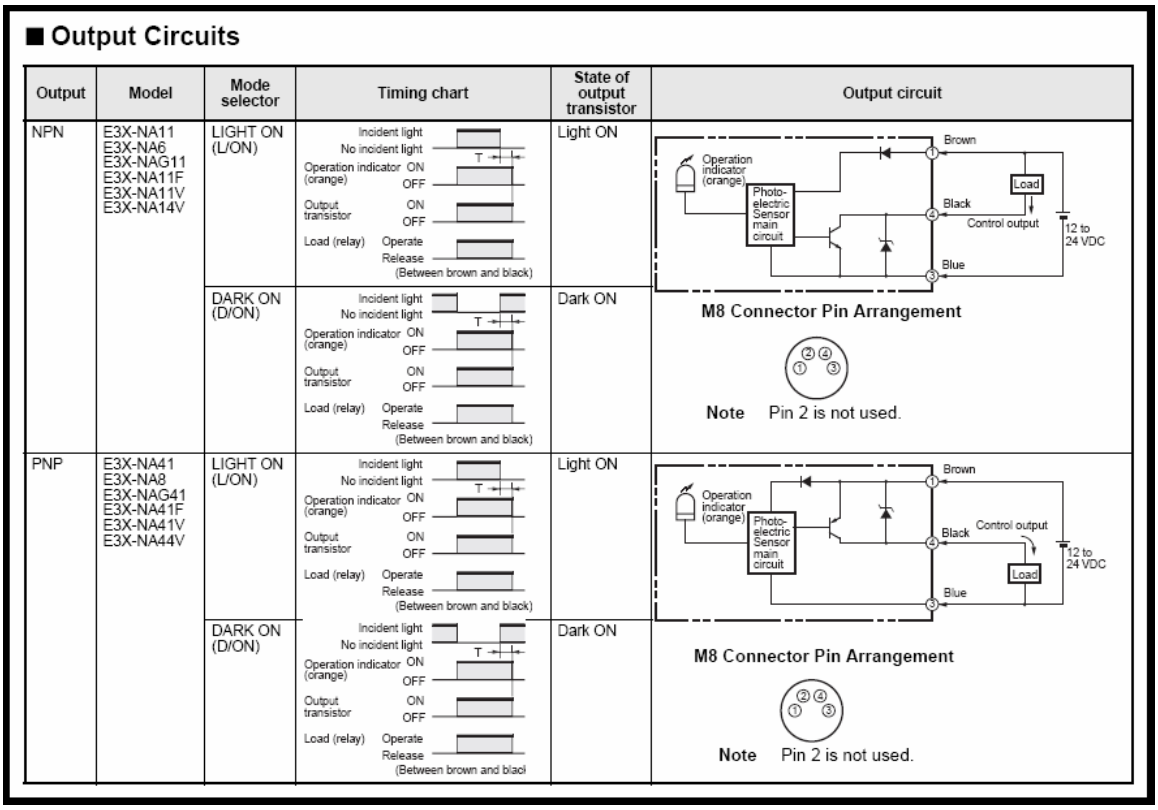


FIGURE 5-5: TYPICAL COMMUTATOR OF AN ARMATURE UNDER TEST

FIGURE 5-6: COPPER BARS ON A COMMUTATOR

The above images depict a typical commutator, however in this case, the reader will notice that there are grooves present between each copper bar. Grooves are created by a process called Undercutting which entails the use of a motorised, revolving, circular saw blade typically 20mm in diameter. These grooves are not present in all commutators that are to be tested. In some instances the armature that is to be tested still has an epoxy resin (from the VIP stage of the armature refurbishing process) between the bars. Due to the Turning stage (using a lathe) in the armature refurbishing process the surface of the commutator is smooth, with the copper bars and the epoxy resin being exactly the same level. It is for this reason that a high accuracy proximity sensor was abandoned. After testing various sensors, the optical sensor produced the best results and proved to be the most reliable means of detecting the copper bars.

The sensor is set on Light On mode. In this mode, an open collector NPN transistor, which is the output of the Omron E3X-NA11, is switched on when a reflected beam is detected by the reflective sensor. See Figure 5-7 below, for an extract from the device datasheet (see the complete datasheet in Appendix J), that illustrates the modes of operation and the device output circuit.



■ Output Circuits

Output	Model	Mode selector	Timing chart	State of output transistor	Output circuit
NPN	E3X-NA11 E3X-NA6 E3X-NAG11 E3X-NA11F E3X-NA11V E3X-NA14V	LIGHT ON (L/ON)	Incident light / No incident light; Operation indicator (orange) ON / OFF; Output transistor ON / OFF; Load (relay) Operate / Release (Between brown and black)	Light ON	Operation indicator (orange); Photo-electric Sensor main circuit; Brown; Black; Load; Control output; Blue; 12 to 24 VDC
		DARK ON (D/ON)	Incident light / No incident light; Operation indicator (orange) ON / OFF; Output transistor ON / OFF; Load (relay) Operate / Release (Between brown and black)	Dark ON	M8 Connector Pin Arrangement Note Pin 2 is not used.
PNP	E3X-NA41 E3X-NA8 E3X-NAG41 E3X-NA41F E3X-NA41V E3X-NA44V	LIGHT ON (L/ON)	Incident light / No incident light; Operation indicator (orange) ON / OFF; Output transistor ON / OFF; Load (relay) Operate / Release (Between brown and black)	Light ON	Operation indicator (orange); Photo-electric Sensor main circuit; Brown; Black; Control output; Load; Blue; 12 to 24 VDC
		DARK ON (D/ON)	Incident light / No incident light; Operation indicator (orange) ON / OFF; Output transistor ON / OFF; Load (relay) Operate / Release (Between brown and blacl	Dark ON	M8 Connector Pin Arrangement Note Pin 2 is not used.

FIGURE 5-7: OPERATIONAL MODES AND THE OUTPUT CIRCUIT FOR THE OMRON E3X-NA11

The optical sensors are supplied with +15V and the outputs from these sensors provide a clock pulse to respective positive-edge-triggered D flip-flops. The output of the D flip-flops provide the two inputs to the NAND gate which in-turn triggers the External Interrupt 1 pin on the Automation Microcontroller when driven low (0). This signal, "*u2_EX1_Bar_Dect*", must go low (0) only when a PAIR of bars has been detected. It must return to high (1) when the D flip-flops are cleared by the Automation Microcontroller and go low (0) again when the next pair or bars are detected. The network shown in Figure 5-8A fulfils the above triggering requirements. See Figure 5-9 for a timing diagram for the bar detection network.

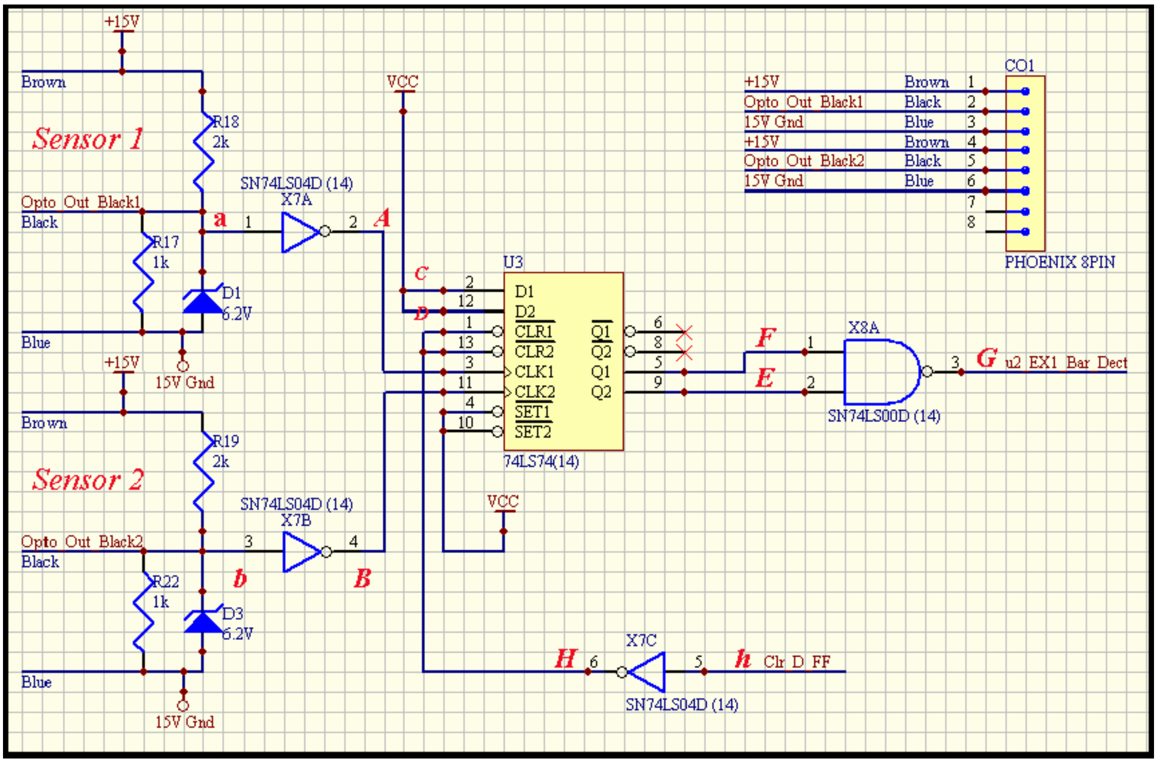


FIGURE 5-8A: BAR DETECTION NETWORK

The voltage divider resistor-network ensures that 5V is present at the output when the transistor is off (implying that no bars have been detected) and 0V (V_{CE} to be exact) is present at the output when the transistor is on (implying that a bar has been detected). A 6.2V zener diode, with a very low response time, or a Tranzorb, depending on the operating environment, is placed in parallel with the output resistor for protection purposes to ensure that the output of the voltage divider resistor-network will not exceed 6.2V.

Initially, the network that was used as a level shifter to provide a TTL level input to the digital interface from the optical sensor output of 0V to 15V was a simple series resistor and zener diode network as depicted in the figure below.

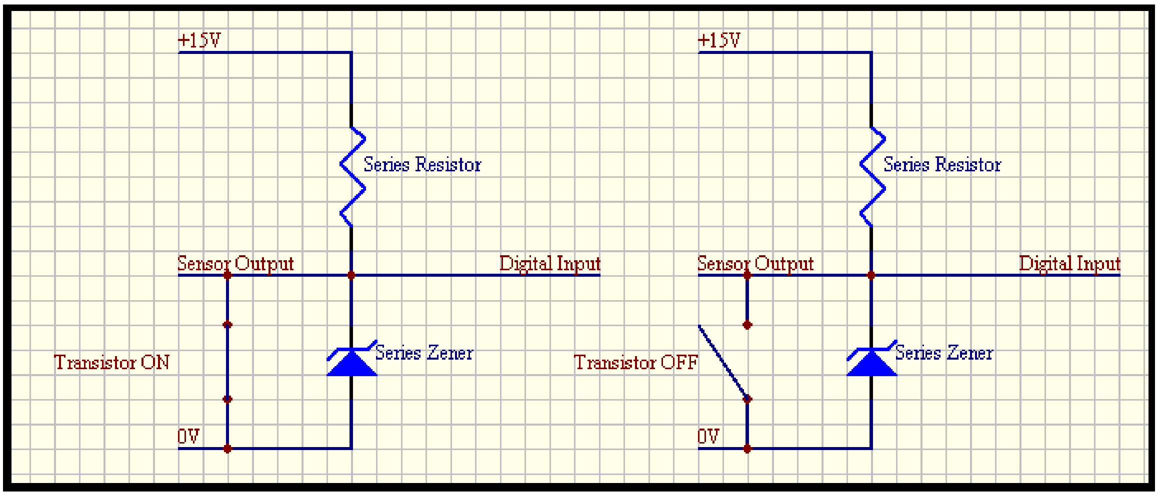


FIGURE 5-8B: INITIAL LEVEL SHIFTER NETWORK

It may seem like an adequate solution, however, when one considerers the fact that the zener diode has response time, although very small, one will become aware of a potential problem that may arise when using this series network. The instant that the NPN transistor in the output circuit of the optical sensor is switched off, the zener diode is still essentially “off” as it does not respond instantaneously to the applied source. Ideally, the zener diode will be seen as an open circuit to the rest of the network for this period of time.

This being the case, the output of this series network, which is the input to the NOT gate, will for all intents and purposes, be pulled up to +15V by the series resistor which acts as a pull-up resistor for the period before the zener diode responds or “switches on”. This +15V input is well above the absolute maximum rating for the IC and will ultimately damage it. The author used the word ultimately because, due to the very small response time of the zener diode, the IC will only be exposed to +15V for a very short period. The IC may therefore not be damaged instantly however, repeated exposure to such high input potentials will damage the IC over time.

It is for the above reason that the voltage divider comprising of a 1kΩ and 2kΩ with adequate protection was used. This network produces a 5V drop across the 1KΩ resistor when a +15V source is applied.

$$V_{R1K} = \frac{1K}{1K + 2K} \text{ x } 15V = 5V$$

This network ensures that the input to the NOT gate is exposed to a maximum of 6.2V which is within recommended operating range for the IC.

The output of the resistor-zener network enters a NOT gate which inverts the signal producing an output high (1) when a bar has been detected and a low (0) when no bars have been detected. The output of this NOT gate clocks a positive-edge-triggered D flip-flop whenever a bar has been detected. Because the D input of the flip-flop is tied high (Vcc) when clocked, the output of the flip-flop, Q, goes high. The output of the D flip-flop provides the input to the NAND gate which triggers the external interrupt pin on the Automation Microcontroller. The microcontroller clears both D flip-flops, in order to put them into a known state, as soon as it enters the Interrupt Service Routine (ISR) that it vectored to when a pair of bars have been detected.

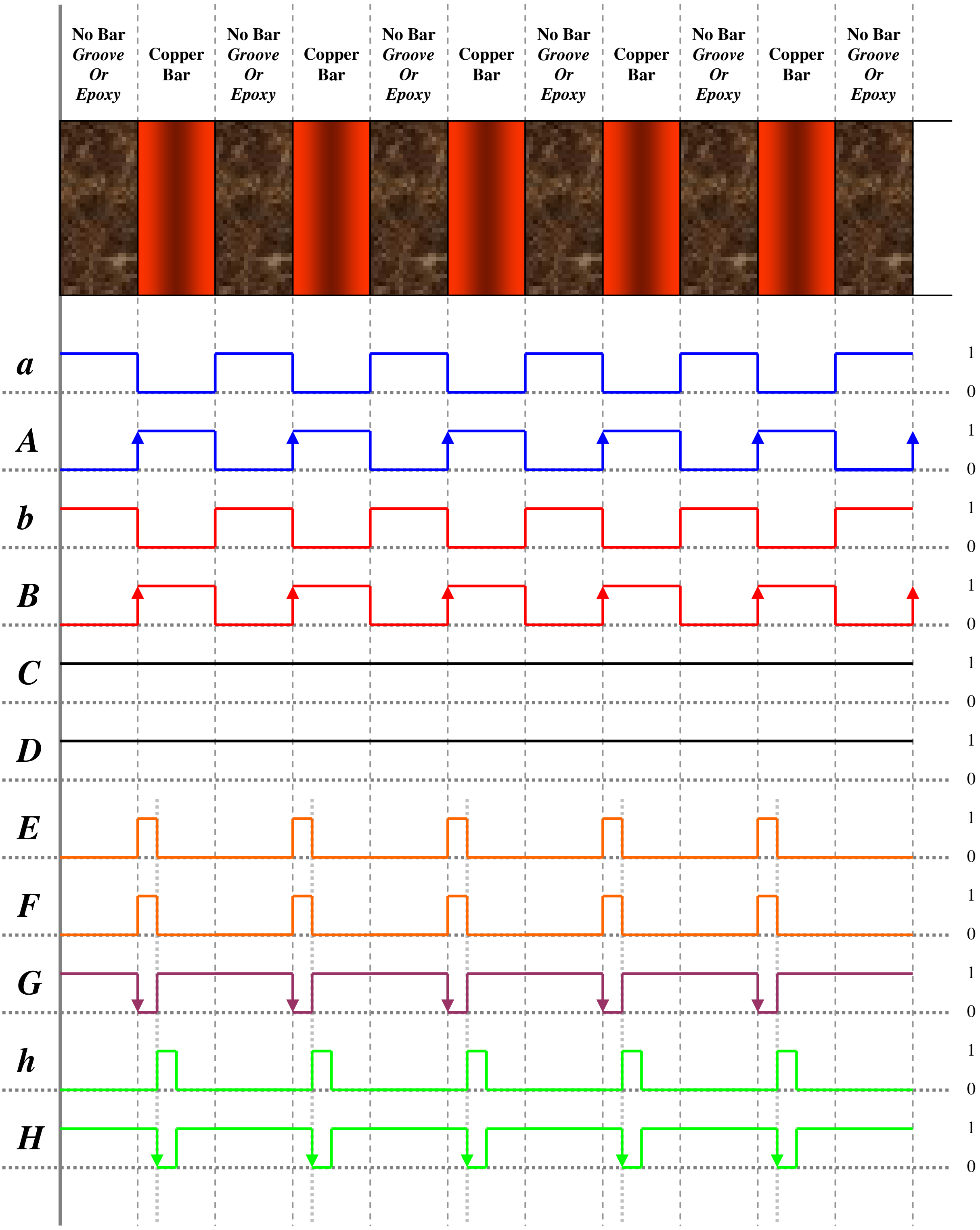


FIGURE 5-9: TIMING DIAGRAM FOR THE DETECTION NETWORK

The discussion that follows is with reference to Figure 5-9 and Figure 5-8A and describes the operation of the Bar Detection module. Assume that the commutator is rotating slowly and Sensor 1 detects a bar, the output of the NOT gate [point A] is high (1). The low-to-high transition (positive edge) clocks the D flip-flop producing an output [at point F] that is also high (1). If, at this point, Sensor 2 has not yet detected a bar the output of the NAND gate remains high (1). The commutator will continue slowly rotating with Sensor 1 directly over it's bar until Sensor 2 detects a bar. For the purposes of this explanation, assume that Sensor 2 has also detected a bar at the same time that Sensor 1 has detected a bar (Ideal situation with an ideal commutator) the output of the NOT gate [point B], is high (1). The low-to-high transition (positive edge) clocks the D flip-flop producing an output [at point E] that is high (1). With both the inputs to the NAND gate being high (1), the output [at point G] goes low (0).

This high-to-low transition (negative edge) triggers External Interrupt 1 of the Automation Microcontroller. The microcontroller clears both flip-flops in the associated ISR. When rotation begins again, control is handed back to the Bar Detection module. At this point both sensors indicate that they detect a bar. This is because the Armature Rotation Drive Motor was stopped as soon as both bars were detected. The outputs of the NOT gates at both point A and point B are now high (1). These high outputs however, do not clock the D flip-flops as they are positive edge triggered. Since the clock did not go low (0) before going high (1), the outputs of the flip-flops remain cleared (0) implying that the output of the NAND gate remains high (1). As the commutator rotates the sensors will pass over the groove (or epoxy resin gap) between a pair of consecutive bars.

This causes the output of the sensors to produce a low (0), via the NOT gates. On the detection of the next bar, a low-to-high transition will be created and this positive edge will again trigger the D flip-flops. Its is thus clear that the Bar Detection module only detects the NEXT pair of bars to be tested by using positive edge triggered flip-flops to reject the high (1) signal from the sensors when they are still over the pair of bars that were previously detected. Note that, although theoretically both bars should be detected at the exact same time by their respective optical sensors, this is not the case practically. There are two reasons for this, one being that when the commutator is undercut some of the copper is also cut into producing bars and gaps of varying widths. The other reason is dirt, spots or marks on a bar that do not allow for the reflection of the laser. If the bars and the gaps between bars were the exact same width throughout the circumference of the commutator and the commutator was clean, as in the case of a new commutator, both bars will be detected at the exact same time.

5.1.4 Mechanical Switch Input Module

This project makes use of both mechanical switches and inductive proximity switches. Inductive proximity switches are used where a high number of repetitive on-off transitions will occur as in the case when monitoring the position and initial positions of the Detection Unit. Because mechanical switches entail the physical "making" and "breaking" of metal alloy contacts the life span of mechanical switches are lower than that of non-contact switches (inductive and capacitive types) due to the wear of the metal contacts. Non-contact switches however, are much more expensive than traditional mechanical switches. It is for these two reasons that mechanical switches were used to monitor events or conditions that should not occur, and if they do, these occurrences will be very seldom thereby eliminating the contact wear as a factor. Another shortcoming that is associated with mechanical switches, and even mechanical relays for that matter, is contact bounce. When the metal contacts "make" or "break" there is a physical, high frequency bouncing action between the movable and stationary contact. See Figure 5-10 for and illustration of the above explanation.

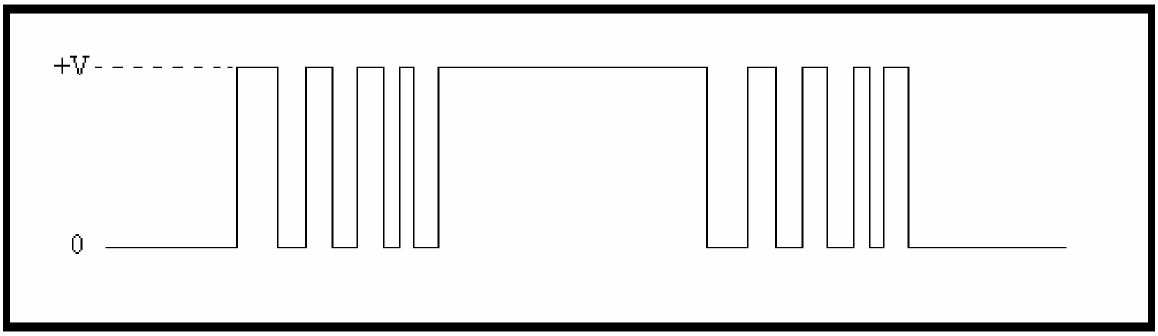


FIGURE 5-10: MECHANICAL CONTACT BOUNCE OSCILLATIONS

Bouncing contacts lead to undesirable high frequency oscillations when a switch or relay "makes" or "breaks". These oscillations cause immense problems to digital circuitry such as multiple switching, multiple interrupt edge triggering etc. De-bouncing refers to the elimination of these oscillations. There are two methods that can be implemented to achieve this. The first is de-bouncing using software. There various algorithms can be used to detect a change of state and thereafter verify the stability of the input line/signal, for example, allowing a delay after a change of state, pulse counting, pulse timing etc. The author has worked with many software de-bouncing techniques and in his experience has obtained the best results using a technique that involves the monitoring of the line after the first change of state. After the first change in state the line is read after a predefined delay, typically in the order of tens of microseconds.

If, when read, the line yields the same state for a predefined number of reading events typically twenty to fifty that state is accepted as an input. The delay time between readings, as well as the number of read events required to be stable before an input is accepted, are both variables that can be varied depending on the contact type, bounce oscillation frequency and the length of time that the oscillations are typically present for after the switch or relay "makes" or 'breaks". Software de-bouncing however, becomes more complicated when the input pin is an edge triggered microcontroller interrupt. Because there are a large number of oscillations, the interrupt will be triggered on each rising or falling edge. This means that the associated ISR needs to be disabled on the first raising or falling edge and the de-bouncing algorithm needs to be initiated within the ISR. This process entails taking control from the main program for the entire de-bouncing period plus the duration of the ISR executing time.

For this design the author has opted to use a hardware de-bouncing technique that overcomes the above inconvenience as well as frees the microcontroller to use its processing power on tasks more critical to the system than de-bouncing. With reference to Figure 5-11, a $\overline{S}$ - $\overline{R}$ latch is used to latch the line output to a stable state and keeping it stable regardless of any oscillations that may occur.

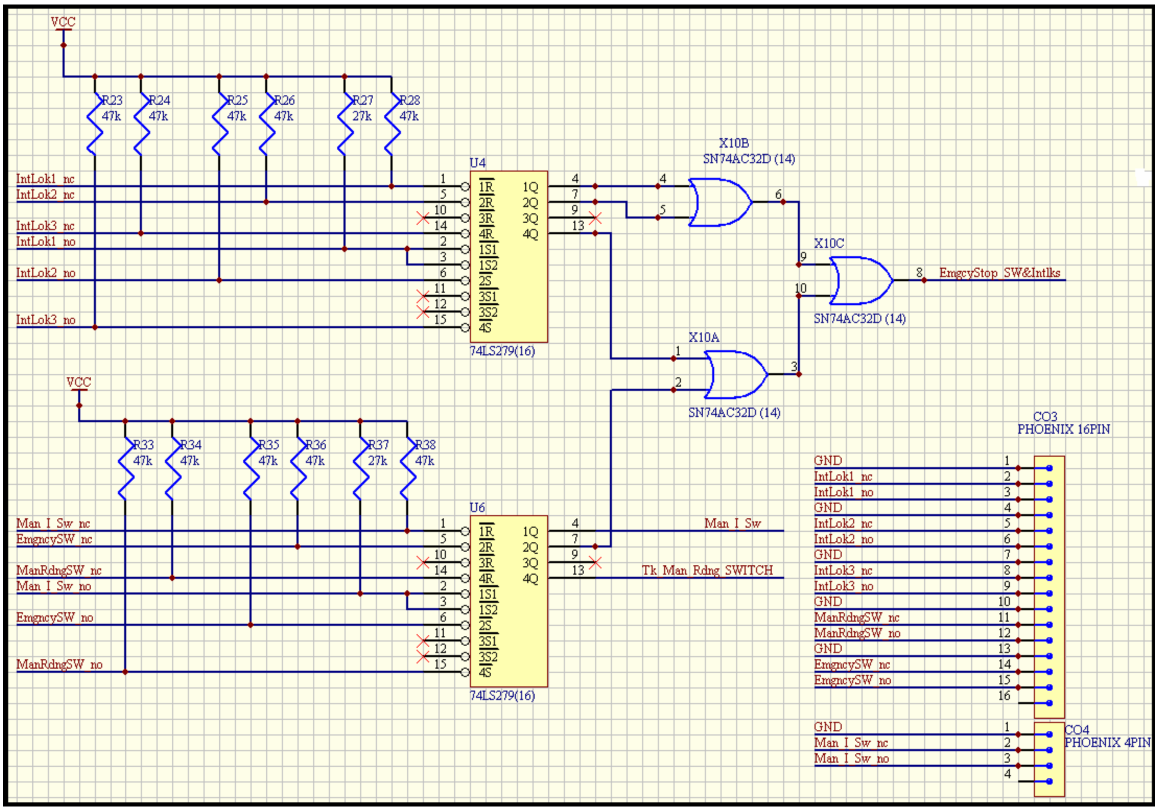


FIGURE 5-11: MECHANICAL SWITCH INPUT NETWORK

An illustration aiding the explanation of this network can be found in Figure 5-12.

In the first state with the switch on the normally closed (NC) contact the reset pin ($\overline{R}$) of the latch is pulled down to ground hence resetting the latch and producing an output of 0V. Next, the switch is to be switched on by breaking contact with the NC contact and making contact with the normally open (NO) contact. As soon as this transition is initiated, the instant contact with the NC contact is broken and the $\overline{R}$ pin is pulled high to Vcc via pull up resistor, R2.

The instant contact is made with the NO contact (i.e. the $\overline{S}$ pin), it is pulled down to ground initially before the bouncing oscillations begin. This first low pulse duration is sufficient to latch the output in a stable High (1) state before the oscillation have any effect on the line being read. With $\overline{R}$ held to Vcc the oscillations have no bearing on the output. See the truth table provided in Table 5-1. When $\overline{S}$ goes High (1) with $\overline{R}$ held High (1), the output remains unchanged i.e. latched High (1). And when $\overline{S}$ goes Low (0) with $\overline{R}$ held High(1), the output is Set (1) leaving it unchanged i.e. latched High (1). The same latching principal will apply when the switch is switched off.

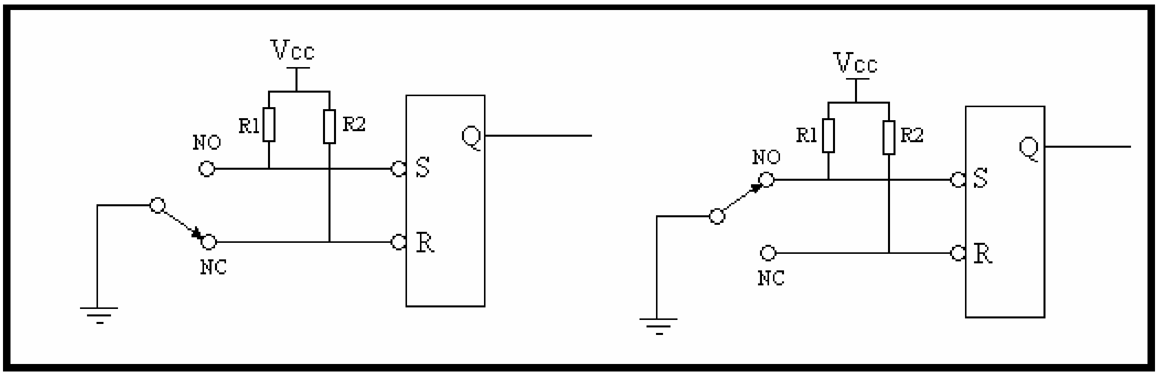


FIGURE 5-12: THE $\overline{S}$ - $\overline{R}$ LATCH USED FOR DE-BOUNCING

$\overline{S}$ - $\overline{R}$ **Latch Truth Table**			
Inputs		**Output**	**Comment**
$\overline{S}$	$\overline{R}$	**Q**	
1	1	NC	No Change in State
0	1	1	Latch Set
1	0	0	Latch Reset
0	0	1	Invalid Condition

TABLE 5-1: $\overline{S}$ - $\overline{R}$ LATCH TRUTH TABLE

As shown in Figure 5-11, hardware de-bouncing is used for all mechanical switches that provided input signals to the system. These include the Safety Interlock switches, Emergency Stop switch, Take Manual Reading switch, Manual Test Current switch etc. An OR gate network is used to output a High (1) via signal "*EmgcyStop_SW&Intlks*" if any of the safety interlocks or the Emergency Stop Switch is activated. And the "*Tk_Man_Rdng_SWITCH*" signal alerts the controller that a manual reading is about to be taken.

5.1.5 The Inductive Proximity Switch Module

The Inductive Proximity Switch module is responsible for triggering External Interrupt 0 on the Automation Microcontroller when the Detection Unit has reached either its initial position, i.e. the point from which it was lowered, or when the spring loaded test probe has reached the surface of the armature under test. A single inductive proximity switch is used to monitor the position of the Detection Unit when it is being raised to its initial position and two inductive proximity switches, one on each spring loaded probe, are used to monitor when the probes have reached the surface of the bars. See Figure 5-12. The AND gate ensures that the interrupt is only triggered when both test probes are on the surface of the commutator. The OR gate facilitates the triggering of the interrupt (by signal "*Detect_Unit_Switches*") when either raising or lowering the Detection unit. The outputs of the inductive switches are open collector PNP, an example of which is depicted in Figure 5-7.

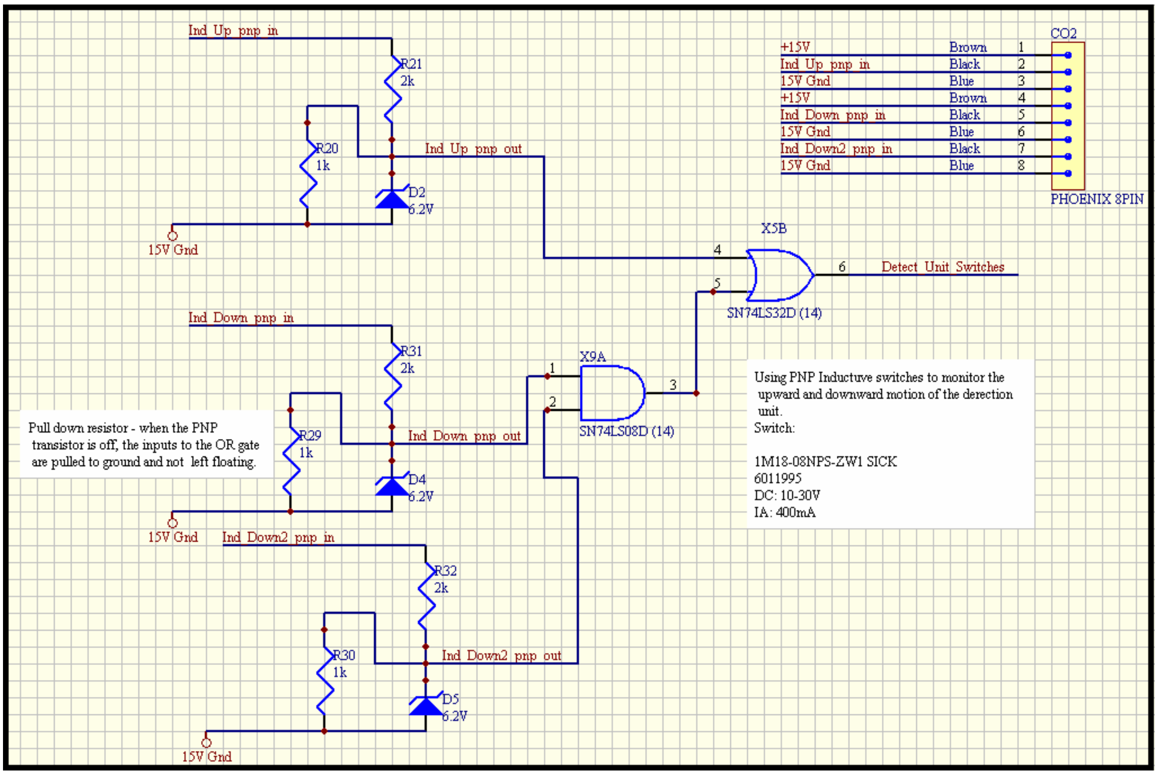


FIGURE 5-12: INDUCTIVE PROXIMITY SWITCH NETWORK

When switched on, the PNP transistor connects the load, in this case the resistor-zener network, to the supply. When switched off, the PNP transistor is also turned off and is ideally seen as an open circuit. When the inductive proximity switch is switched on the inputs to the interfacing ICs are High (1), i.e. 5V. When the inductive proximity switch is off the PNP transistor is also off. This is where the 1kΩ resistor serves a second purpose – it is also a pull-down resistor, pulling the TTL input Low (0) i.e. 0V when the inductive proximity switch is off. If there was no 1kΩ resistor present when the transistor is switched off, the input to the TTL circuitry will essentially be floating. The introduction of the 1kΩ resistor provides a path down to ground pulling the TTL input to ground when the Inductive switch and hence, the transistor is switched off. The 1kΩ resistor together with the 2kΩ resistor forms a voltage divider network and with a 6.2V zener diode or Tranzorb in parallel with the 1kΩ resistor for protection. This network operates exactly the same as the network described in the Bar Detection module.

5.1.6 Test Current On-Time Timing Module

This module is used to monitor the amount of time the Test Current is applied to the armature under test. Under normal test conditions the Test Current should not be required to be applied for a period longer than twenty seconds. If for any reason there is a system fault or an oversight on the part of the test technician (when taking a manual reading) that may cause the Test Current to be applied to the armature for excessive amounts of time, the system needs to be shut down in order to prevent any damage to the armature under test, the test system or any potentially dangerous situations for the test technician or any personnel in the vicinity. A 555 timer set to operate in monostable mode is preset with a period (using a 300kΩ resistor, a 500kΩ variable resistor, and a 100 µF capacitor) that the Test Current On-Time should not exceed. Using the equation

$$T = 1.1 \text{ x } (R+V_r)C$$

with the 500kΩ variable resistor set to zero ohms, the allowable on-time is set to,

$$T = 1.1 \text{ x } (300k + 0)\ (100uF) = 33s$$

and setting the variable resistor to its full resistance value the allowable on-time is set to

$$T = 1.1 \text{ x } (300k + 500k)\ (100uF) = 88s$$

The allowable Test Current On-Time can be preset to any value within the above range. The 555 timer is triggered by the same microcontroller output that switches the Test Current on, "*Test_Current*", via a NOT gate as the 555 timer is a negative edge triggered device. The 555 timer's output is then set High (1) for the period preset by the aforementioned capacitor and resistors. When this period has expired the output returns to a Low (0) state. The Automation Microcontroller continually monitors the output of the 555 timer, "*I_On_T_Exceded*", during a Volt-Drop reading procedure. If this output goes Low (0) before the reading has been completed, Error 3 is signalled and the system enters shutdown by initiating an Emergency Stop. When the Test current is switched off under normal conditions (i.e. before the allowable time is exceeded) the 555 timer is reset for triggering on the next reading cycle. See Figure 5-13 below, for an illustration of this module.

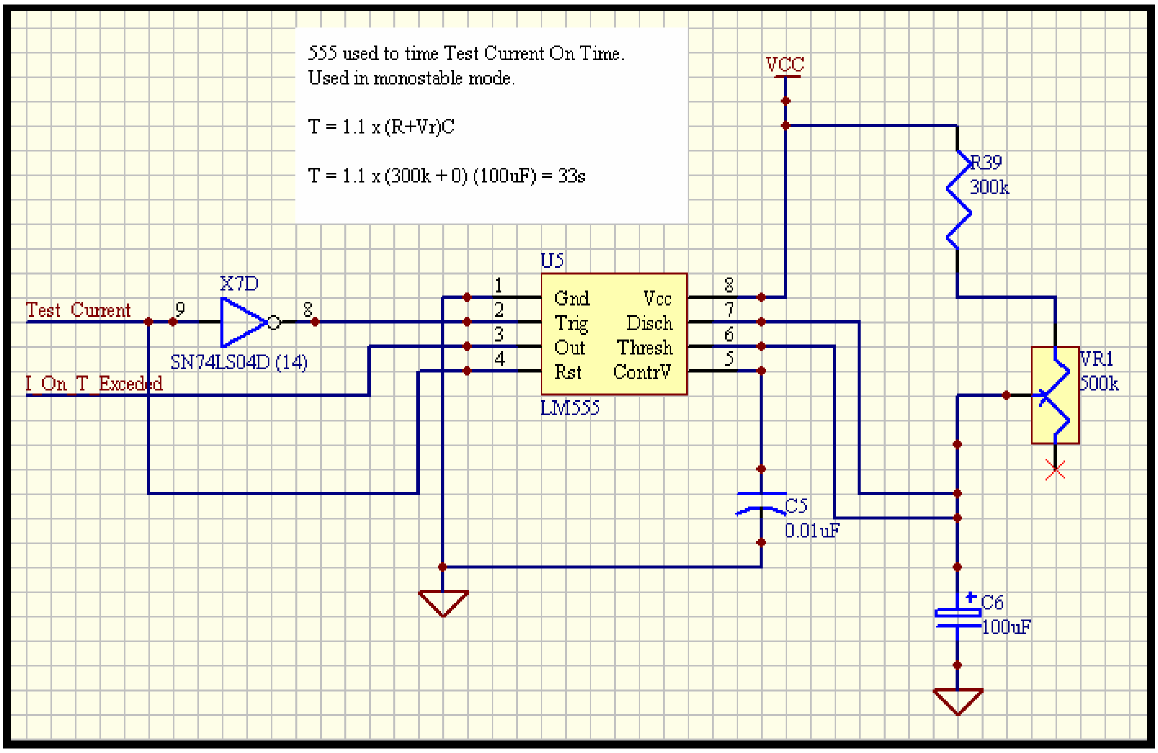


FIGURE 5-13: TEST CURRENT ON-TIME TIMING NETWORK

5.1.7 The Test Current Pulse Module

Recall that this system was designed to operate in two modes, namely, Automated Mode and Manual Mode. In Automated Mode the test current is pulsed/switched on and off via an IGBT by the controller (the Automation Microcontroller to be specific) using P2.7 ("*Test_Current*" signal). When operating in Manual Mode the test technician is required to pulse/switch the test current on and off manually via a push button or foot switch. This implies the IGBT driver must have two triggering sources, one for manual operation and one for automated operation. The Test Current Pulse module fulfils this purpose. With reference to Figure 5-14, the first input signal, "*Test_Current*" to the OR gate is provided during operation in automated mode. The second input signal to the OR gate, "*Man_I*", is provided during manual operation. It is clear that the IGBT that switches the test current can be triggered either during manual or automatic operation (via the "*TestCuttent_Sw_Out*" signal).

However for completeness and safety reasons it is required that any pulses from the push button or foot switch be ignored during automatic operation. This is accomplished using the AND and NOT gates as follows. The input signal to the NOT gate ("*Auto-Man_Togl*") is the same signal that the Communications Microcontroller uses to inform the Automation Microcontroller in which mode the test is to be run. For automated mode, a High (1) is signalled and for manual mode, a Low (0) is signalled. So in manual mode this signal is always Low (0) and due to the NOT gate the input to the AND gate is High (1).

The second input to this AND gate, "*Man_I_Sw*", is provided by the push button or foot switch that is used for the manual pulsing of the IGBT. During automated operation the signal, "*Auto-Man_Togl* ", is always High (1). Due to the NOT gate, a Low (0) is input to the AND gate while operating in this mode. Hence, it is only during manual operation that the pulses from the manual reading, push button or foot switch, are recognised. Note that during manual operation, the Automation Microcontroller is forced to enter Power-down with all its output ports cleared (i.e. 0). This implies that the "*Test_Current*" input will always be Low (0) and will therefore have no influence on the triggering of the IGBT during manual operation.

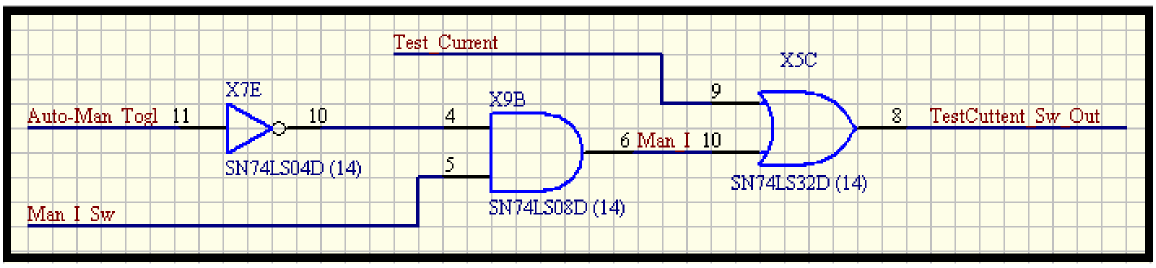


FIGURE 5-14: TEST CURRENT PULSE NETWORK

5.1.8 The Serial Port Driver/Receiver Module

This module facilitates serial communication between the on-board serial port on the Communication Microcontroller and the serial port on the PC or Laptop that is running the GUI. The MAX 232 is an industry standard level shifter that was designed for this purpose. As shown in Figure 5-15, the interconnection of this device is simple and straight-forward with only capacitors being used as additional components, as prescribed in the MAX 232 datasheet (see Appendix J).

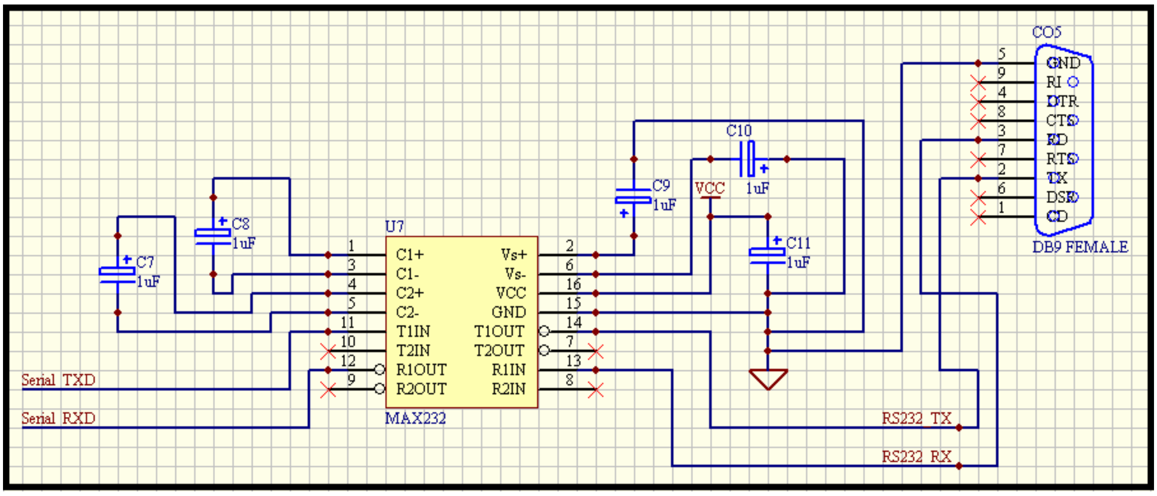


FIGURE 5-15: SERIAL PORT DRIVER/RECEIVER MODULE

5.2 Supply Regulation

The controller will be powered by a $\pm$ 24V Switch Mode, off-the-shelf, power supply. The controller circuitry requirements include a + 5V supply for the digital circuitry, $\pm$ 15V supply to power up the Op-Amps, Comparators, Optical Sensors and Inductive Proximity Switches, and a +24V supply for any interfacing power circuitry that may be needed. The 78xx and 79xx series of voltage regulators along with stabilisation and filtering capacitors were used to provide the required regulated supply voltages. See Sheet 3 of the circuit schematic in Appendix M. Note that the string of 0.1µF capacitors found at the bottom of this sheet are bypass capacitors that were distributed to the appropriate locations on the PCB when the PCB layout was being finalised.

5.3 The Data Acquisition Module

The Data Acquisition module is responsible for measuring the difference in potential between two successive bars, signal conditioning to rejecting any inputs outside the expected input range and converting the input analogue signal to a sixteen-bit word that is to be transmitted to the Graphic User Interface (GUI) via the Communications Microcontroller. See Figure 5-16A and Figure 5-16B for the block diagram describing this module.

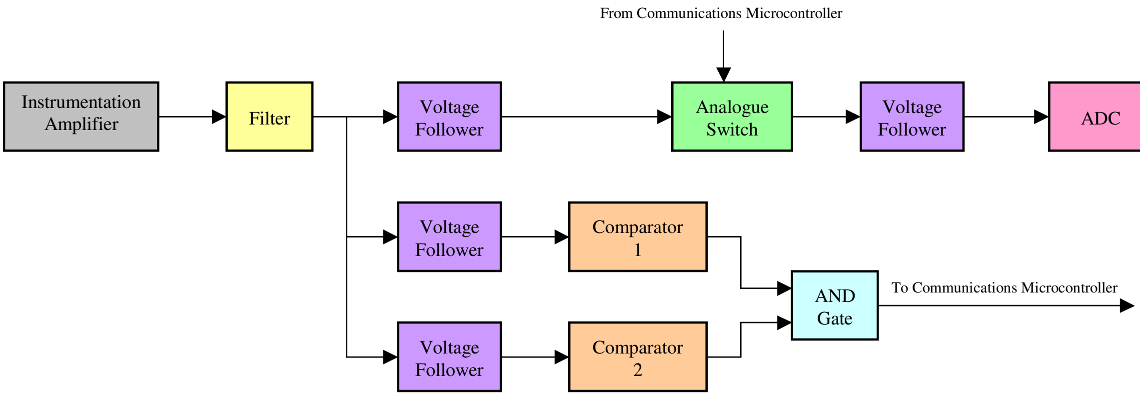


FIGURE 5-16A: BLOCK DIAGRAM FOR THE DATA ACQUISITION MODULE

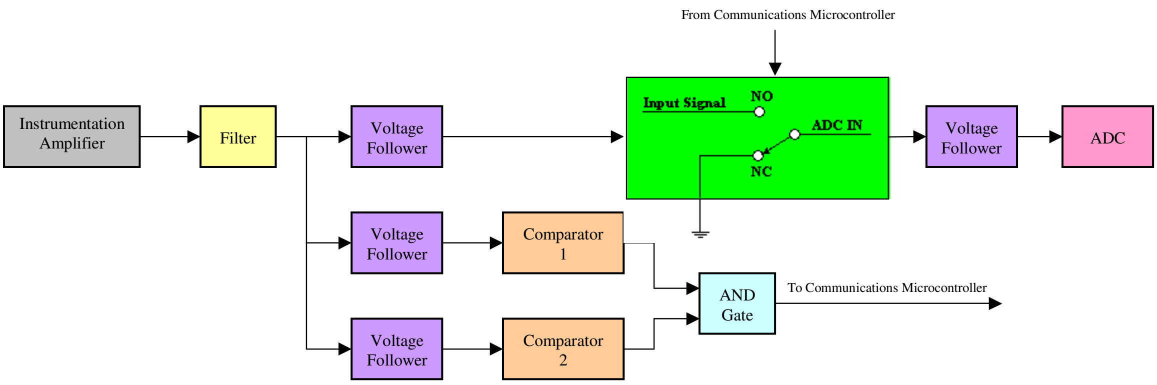


FIGURE 5-16B: DETAILED BLOCK DIAGRAM FOR THE DATA ACQUISITION MODULE

Before discussing this module any further it is important for the reader to know the type and magnitude of the input signal that is to be measured. The test supply is a maximum of +15V / 400A. The typical potential difference (or volt drop) expected to be measured between a pair of successive bars, on any armature that is to be tested, is in the range of between 100mV and 350mV for a healthy winding. Before the test begins the test technician will verify that readings within this range are produced by measuring the volt drop across the first pair of bars and, if need be, varying the magnitude of the test supply or varying the arc length of the test supply probes or both to ensure that the reading produced is within the stipulated range.

The technician will thereafter measure the volt drop across at least five other successive pairs of bars that lie within the arc length of the test supply probes in order to verify the range. If the readings on these bars fall outside the range that was set on the first pair of bars the implication is that the windings of first pair of bars are unhealthy or damaged. In this case the input range must be set and verified on one of the other five measured pairs of bars.

The expected input range discussed above only applies to healthy windings, i.e. windings that are not open circuited, shot circuited or damaged. If a winding is open circuited the volt drop across the connected pair of bars will be equal to the supply potential. If a winding is short circuited the volt drop across the pair of connected bars will be zero volts. If a winding is damaged the volt-drop across the connected pair of bars will fall outside the preset variance (or tolerance) from the reference reading specified at the beginning of the test. The input signals are DC with no expected AC components. Any AC components encountered are regarded as noise and will be rejected and/or filtered.

A precision Instrumentation Amplifier, the INA 118 is used to acquire the potential difference (or volt drop) between two successive bars. See Appendix J for the complete datasheet for the INA 118. This amplifier features, amongst other things, a high Common Mode Rejection (CMR) of 110dB (at a gain of 10) and input protection up to $\pm$ 40V. It also offers a non-linearity of typically $\pm$ 0.0005% of the full-scale range (at a gain of 10). Some of the specifications mentioned above are stipulated at a gain of 10. This is because a gain of 10 is set (using the external resistor, R_G – see datasheet) to amplify the input signal from the hundreds of millivolts to the volt range. Hence, an input of 350mV will be amplified to 3.5V. This is done in order to utilise the full input range of the sixteen-bit Analogue-to-Digital Converter hence maximising the 16-bit resolution and reducing the effects of any conversion errors should they occur.

A sixteen-bit, successive approximation, Analogue-to-Digital Converter, the MAX 1166, with an input range of between –0.3V and V_{Ref} (4.096V) is used to convert the input signal to a sixteen-bit word (2 eight-bit wide, parallel output words). See Appendix J for the complete datasheet for the MAX 1166. The operation of the ADC was discussed in detail in Chapter 4, under the section entitled ADC Control. The ADC was set-up to make use of the internal reference voltage as prescribed in the datasheet and shown in Figure 5-17.

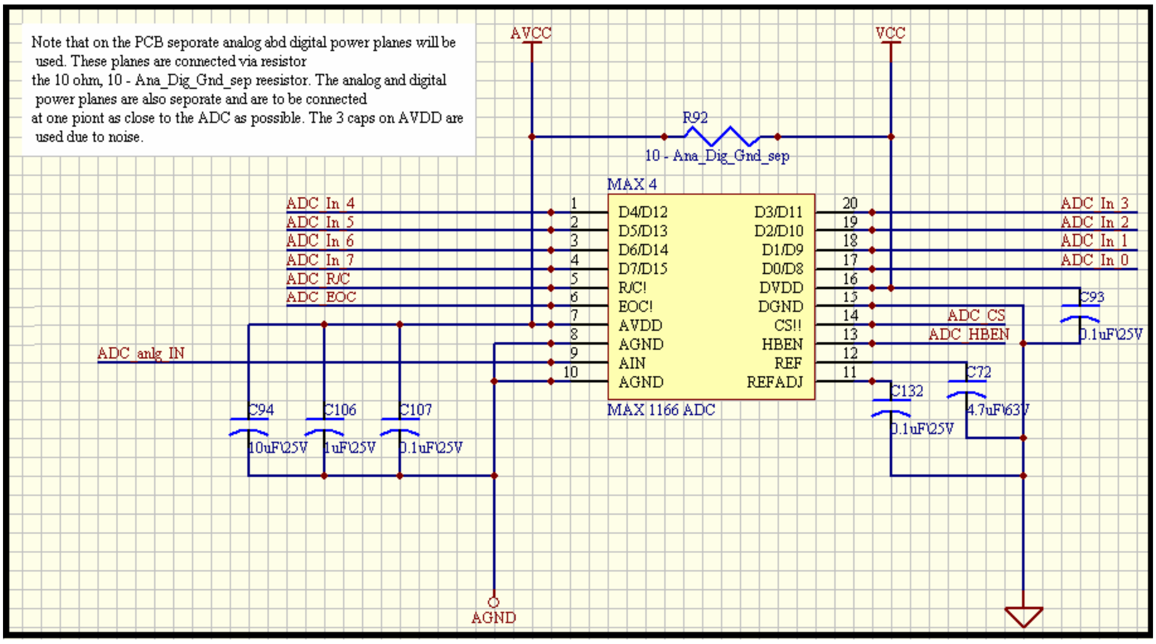


FIGURE 5-17: ANALOGUE-TO-DIGITAL CONVERTER NETWORK

The ADC features, amongst other things, sixteen-bit resolution, a high speed sampling rate, an eight-bit wide parallel output and an accuracy of $\pm$ 2 LSB (Least Significant Bit). With an internal V_{Ref} of 4.096V and sixteen bit resolution, the smallest voltage increment that the input signal can broken down into is:

$$\text{Resolution in Volts} = 4.096 / 65536 = 62.5\mu V$$

i.e. each digital bit is equal to an analogue step of 62.5µV.

Recalling that the input signal is amplified by a factor of 10 the true analogue step size (after being scaled down in software) is 6.25µV. Similarly, the true input voltage range after being scaled down by software will be 0 to 350mV.

This implies that a variance of

$$\text{Variance (\%)} = \frac{6.25\,\mu\text{V}}{350\text{mV}} \text{ x } 100 = 1.786 \text{ x } 10^{-3}\%$$

can theoretically/ideally be detected by the system. This value has two important connotations, the first being the fact that the smallest input change that can be detected is well below 1% hence, the percentage variance from the reference reading can be calculated with a great degree of accuracy and the second connotation is that the ADC error of $\pm$ 2 LSB will be almost negligible when considering the percentage variance from the reference value.

Recalling that the input range for the ADC is between –0.3V and V_{Ref} (4.096V), the ADC has to be protected from any inputs outside this range as they will potentially damage the ADC. Out of range input signals can be produced in two ways, the first being due to an open circuit. In this case, the potential difference across the pair of bars that are connected to an open circuited winding will equal to potential of the test supply current (which may be as high as 15V). The second way an out of range reading can be produced is by the reversal of the orientation of the test probes with respect to the test supply probes.

This means that when the test current positive probe is to the right of the negative probe and the positive test probe is to the left of the negative test probe (or versa-visa) a negative reading of equal magnitude to the positive reading will be produced. This situation can arise when the test technician setting up the test reverses the polarity of the test supply or when the test technician is taking a manual reading and uses an independent (unauthorised) set of test probes to take a manual reading and unknowingly reverses the orientation of the polarity of the inputs with respect to the potential of the test supply probes. Although this situation should not occur protection has to be designed into the system to prevent any hardware damage that may occur. The reader may ask why an ADC with an equal positive and negative input range (e.g. $\pm$ 5V) is not used.

The answer to this is – the expected input range is between 0 and 3.5V (after amplification). And with a sixteen-bit ADC that has a positive input range (eg. +5V), all sixteen bits are dedicated to conversions within this positive range. If a sixteen-bit ADC with an equal positive and negative range was to be used, eight bits will be dedicated to the positive range, 0 to +5V, and the other eight bits will be dedicated to the negative range, 0 to –5V. Hence only an eight bit resolution can be expected for the readings of importance i.e. those within the 0 to 5V range. The eight bits dedicated to the conversion of negative values will only be used in events of unwanted or undesirable readings that are produced by an incorrect system set up or use. In the author's opinion, the eight bit resolution used for the negative range of inputs is wasted. The author has hence elected to use a sixteen-bit ADC with only a positive input range and has devised a method of rejecting all unwanted and potentially damaging input signals. This method will be discussed in the paragraphs that follow.

With reference to Sheet 4 of the circuit schematic found in Appendix M, the first stage of the data acquisition module is the INA 118 instrumentation amplifier. This stage is followed by a filtering stage that comprises capacitors of various values which facilitates more efficient filtering over a range of frequencies. Seeing as the output of the instrumentation amplifier is expected (and required) to be purely DC in nature, any AC components found on this signal must be filtered before the signal progresses to the next phase of the system. It is for this reason that capacitors were used as low-pass filters instead of low-pass high order passive or active filters with a cut-off frequencies set very low (almost zero Hertz, in this case).

In the phase that follows, three Voltage Followers (or Buffers) makes three identical copies of the original signal. A Voltage Follower is simply an Op-Amp (LM 741 in this case) with its output fed directly into its inverting input. The non-inverting input is the input pin for the signal. This network produces an output with zero gain, i.e. an output that is equal to the input. A fourth Voltage Follower is placed at the input to the ADC.

Note that all the Op-Amp and Comparator ICs that are used make provision for a potentiometer that is used to nullify the output offset voltage. These potentiometers are also used for "tuning" purposes to ensure that the signal which is the input to the

ADC is equal to the signal at the input end of the data acquisition module provided that the magnitude of signal is within the allowable ADC input range.

Three identical copies of the input signal are made purely to maintain the integrity of the input signal to the ADC. Two comparator stages are required to determine whether the input signal is outside the ADC input range. These two stages are in parallel implying that they each require a perfect copy of the original input signal. The third copy of the input signal flows directly to the ADC input via an analogue switch. If only one signal was used in each of the comparison stages before being input to the ADC, the integrity of that one signal would be compromised, i.e. the ADC input signal will vary from the original input signal to the data acquisition module.

Recalling that the input of the ADC must be within the –0.3V to 4.096V range, a comparison must be done in order to reject all inputs outside this range. This comparison is done in two parallel stages. The first stage determines if the input signal is less than the ADC reference voltage, V_{Ref} , which is equal to 4.096V. In order to do this a comparator (the LM 311) is used with the input signal connected to the comparator's inverting input and a reference voltage connected to the non-inverting input pin. The reference voltage is set up using a voltage divider network that comprises of a 2kΩ and a 9kΩ resistor both with a 1% tolerance. With these values the expected reference at zero percent variance is:

$$V_{Ref} = \frac{9k\Omega}{9k\Omega + 2k\Omega} \text{ x } 5V = 4.091V$$

with a $\pm$ 1% V_{Ref} variance of the range between 4.076V and 4.105V.

The output of LM 311 is open-collector, with pin 7 being the collector end and pin 1 being the emitter end of the output transistor. Connecting the collector (pin 7) via a pull-up resistor to the +5V supply and connecting the emitter (pin 1) to ground, the comparator outputs a High (1), i.e. +5V, when the non-inverting input is greater than the inverting input and a Low (0), 0V (or V_{ce}) when the inverting input is greater than the non-inverting input. The output of this comparison stage is connected to the first of two inputs of an AND gate.

The second comparison stage is tasked to ensure that all negative input signals are rejected. Here the input signal is connected to the non-inverting input pin of the comparator (LM 311) and the reference is connected to the inverting input. The reverence voltage, $V_{Ref,}$ is set to 0V by connecting the inverting input directly to ground. However, the reader should note that a voltage divider network that is set up between –15V and ground (Gnd) is provided in the event that a slightly negative reference is required due to the operating environment. To set a 0V reference using this network the resistor to ground is replaced with a physical jumper and the resistor to the negative supply is not inserted. The output of this comparison stage is connected to the second of the two inputs to the AND gate.

When the input signal is within range the first comparator stage will produce a High input signal to the AND gate because the potential at the inverting pin will be greater than that at the non-inverting pin. The second comparator stage will also produce a High input signal to the AND gate for the same reason. The output of the AND gate is hence High. The output of the AND gate ("*V_RangeDetect*") provides the input to the Communication Microcontroller's P0.2. Before a reading can be taken this input port (i.e. P0.2) is tested to verify if it is High (1).

If this is the case, the Analogue Switch (MAX 4622) is switched on by the Communication Microcontroller port pin P0.0, allowing the signal to pass through to the ADC input pin. See Appendix J for a complete datasheet for the MAX 4622. If this port pin is Low, the analogue switch is left off, connecting the ADC input pin to ground. The MAX 4622 analogue switch has a low on-resistance, with a normally open, normally closed and a common pin. It can be operated from a bipolar supply of $\pm$18V, although in this case the operating supply is $\pm$15V. This allows the analogue switch to control any input within this range without any damage which makes it perfect for this application. When the input pin of this device is low, as in the case where the input signal is found to be outside the allowable range, the common pin is "connected" to the normally closed pin which in this case is connected to ground. When the input pin of this device is High, as in the case where the input signal is found to be within the allowable range, the common pin is "connected" to the normally open pin which in this case is connected to output pin of the first voltage follower stage which represents the input signal to the data acquisition unit.

For completeness, if the input signal is higher than the preset reference, V_{Ref}, of the first comparison stage as in the case where an open circuit is detected on a winding connected to the pair of bars under test, the output of the comparison stage will be Low. This is because the inverting input will be at a higher potential than the non-inverting input. The output of the AND gate will therefore be Low hence ensuring that the Communication Microcontroller keeps the analogue switch off. This in turn ensures that the ADC input remains connected to ground, i.e. 0V, and not to the out-of-range input signal.

If the input signal is lower than preset reference, 0V, of the second comparison stage, as in the case where the orientation of the test probes is reversed with respect to that of the Test Supply probes, the output of the comparison stage will be Low. This is because the inverting input will be at a higher potential than the non-inverting input. The output of the AND gate will be Low ensuring that the Communication Microcontroller keeps the analogue switch off. This in turn ensures that the ADC input remains connected to ground, i.e. 0V, and not to the out-of-range input signal. It is in this way that all out-of-range inputs are rejected by the data acquisition module.

This method was not the first approach that was tried. After researching and experimenting with adaptive (variable) gain Op-Amp networks, arithmetic using a number of Op-Amp stages, scaling and using various switching devices such as relays, BJTs and FETs, this approach was found to be the simplest, most effective and most accurate method of rejecting out-of-range input signals while still maintaining the integrity of the original input signal.

5.4 Automation Output Module

This relatively simple module provides the signals that control the actuators in the automated system via the respective electronic control drives such as inverters in the case of motors and IGBT drivers in the case if IGBTs. The controller is just one module of the entire Automated Test Station. Other modules that interact with this module are the two electronic motor drives (one for the rotation of the armature under test and the other for lowering and raising the detection unit), the IGBT driver and the GUI. With this in mind, the author provided two types of control outputs.

The first being simple 5V TTL control signals. These can be used to pulse any type of drive or drivers via a second output module that will have to be designed depending on the input requirements of the drivers that are being used. This second output module can be considered as a level shifter or adapter that will make it possible for the controller to be more versatile and to be seen as a "plug and play" module that can be used with an array of different transducers, drivers and drives, provided that the adaptor is designed for those transducers, drivers and drives that are being used.

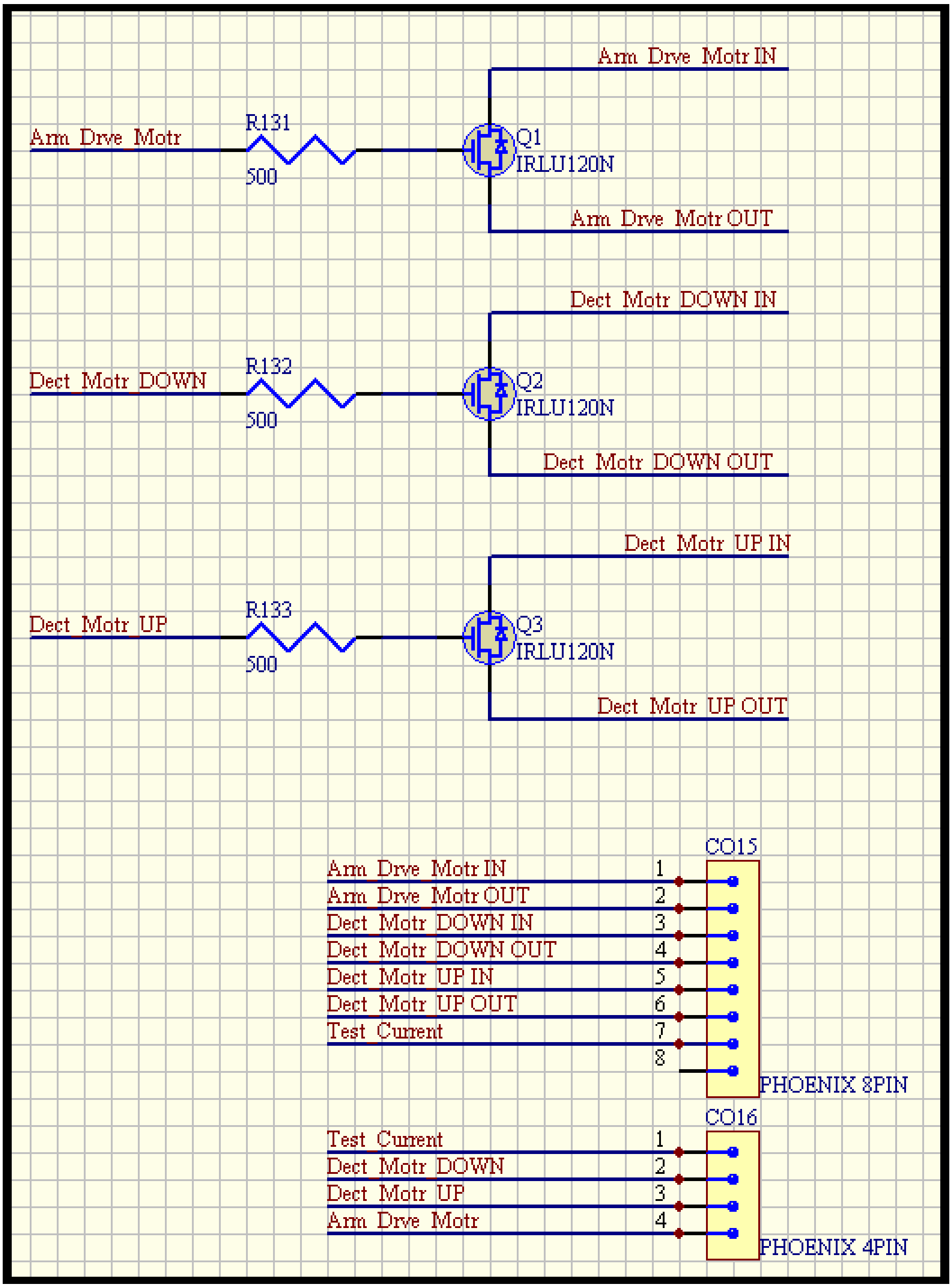


FIGURE 5-18: CONTROLLER OUTPUT MODULE

The other outputs that are provided are specifically designed for the drives and drivers being used for this project. As per the contractor's requirements, three switching devices that can 'make' and 'break' a 24V/20mA input must be provided for the drives that control the motors. The drive itself has a 24V/20mA source that will be the input to the switching device with the output of the switching device providing an input to the input pins of electronic drive. Hence the electronic motor drive is controlled by controlling the switching device. As has been the pattern throughout this design process, the author has opted to use semiconductor switches rather than mechanical switching devices such as mechanical relays, for the reasons explained earlier. In this case, a gate logic level power MOSFET was used. See Appendix J for a complete datasheet for the IRLU120N. The IRLU120N is a power MOSFET with a gate that is activated and deactivated by 5V and 0V logic level pulses respectively, hence avoiding the need for gate drivers. Off the shelf IGBT drivers are today available with inputs that operate on 5V and 0V logic level pulses. It is for this reason that one TTL output is provided for IGBT switching.