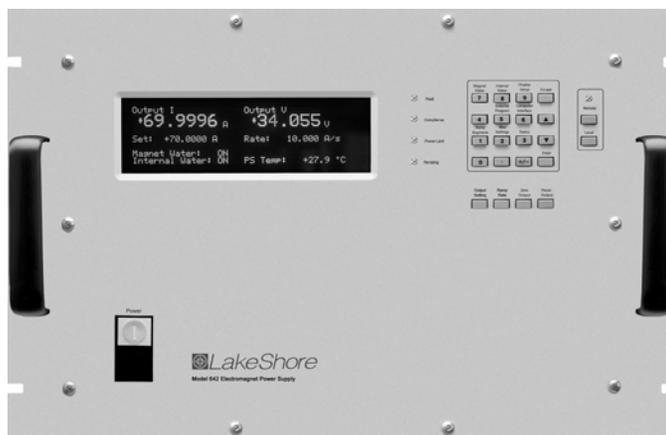




User's Manual

Model 642

Electromagnet Power Supply



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CE
DECLARATION OF CONFORMITY

We: **Lake Shore Cryotronics, Inc.**
575 McCorkle Blvd.
Westerville OH 43082-8888 USA

hereby declare that the equipment specified conforms to the following Directives and Standards:

Application of Council Directives:..... **73/23/EEC**
89/336/EEC

Standards to which Conformity is declared:..... **EN 61010-1:2001**
Overvoltage II
Pollution Degree 2
EN 61326 A2:2001
Class A
Annex B

Model Number: **642**

 **3/2/07**

Edward Maloof
Printed Name

Vice President of Engineering
Position

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TABLE OF CONTENTS

| <i>Chapter/Section</i> | <i>Title</i> | <i>Page</i> |
|------------------------|---|-------------|
| 1 | INTRODUCTION | 1-1 |
| 1.0 | GENERAL | 1-1 |
| 1.1 | DESCRIPTION..... | 1-1 |
| 1.2 | SPECIFICATIONS | 1-3 |
| 1.3 | SAFETY SUMMARY | 1-7 |
| 1.4 | SAFETY SYMBOLS..... | 1-9 |
| 2 | MAGNET SYSTEM DESIGN, INSTALLATION, AND OPERATION..... | 2-1 |
| 2.0 | GENERAL | 2-1 |
| 2.1 | INTRODUCTION..... | 2-1 |
| 2.2 | MAGNET CONSTRUCTION..... | 2-2 |
| 2.3 | CONNECTING THE MAGNET..... | 2-2 |
| 2.3.1 | Water Hose Connection | 2-2 |
| 2.3.2 | Magnet Coil Wiring | 2-2 |
| 2.3.3 | Temperature Switches and Flow Switches | 2-4 |
| 2.3.4 | Cooling Water and Water Valve | 2-4 |
| 2.3.5 | Grounding..... | 2-4 |
| 2.3.6 | Final Check-Out..... | 2-5 |
| 2.4 | ELECTROMAGNET OPERATION..... | 2-5 |
| 2.4.1 | Air Gap and Pole Caps..... | 2-5 |
| 2.4.2 | Maximum Power and Current..... | 2-5 |
| 2.4.3 | Operation Under Field Control..... | 2-7 |
| 2.4.4 | Avoiding Cooling Water Condensation | 2-8 |
| 3 | INSTALLATION..... | 3-1 |
| 3.0 | GENERAL | 3-1 |
| 3.1 | INSPECTION AND UNPACKING | 3-1 |
| 3.1.1 | Moving and Handling | 3-1 |
| 3.2 | REAR PANEL DEFINITION | 3-2 |
| 3.3 | POWER WIRING AND SET-UP..... | 3-3 |
| 3.3.1 | Line Voltage Selection..... | 3-3 |
| 3.3.2 | Circuit Breaker Setting..... | 3-4 |
| 3.3.3 | Start-Up Fuses | 3-5 |
| 3.3.4 | Cable Entry..... | 3-5 |
| 3.3.5 | Power Input Terminals..... | 3-5 |
| 3.3.6 | Wiring Cover..... | 3-6 |
| 3.3.7 | Mains Wiring..... | 3-7 |
| 3.4 | MAGNET CONNECTOR..... | 3-7 |
| 3.5 | AUXILIARY CONNECTOR | 3-7 |
| 3.6 | POWER SUPPLY CONNECTOR | 3-8 |
| 3.7 | COOLING WATER..... | 3-8 |
| 3.8 | MAGNET CABLE CONNECTIONS..... | 3-9 |
| 3.9 | ANALOG INPUT/OUTPUT CONNECTIONS | 3-11 |
| 3.9.1 | External Current Programming..... | 3-11 |
| 3.9.2 | Output Current and Voltage Monitors | 3-11 |
| 3.10 | COMPUTER INTERFACE | 3-11 |
| 3.10.1 | RS-232C Interface Connection..... | 3-11 |
| 3.10.2 | IEEE-488 Interface Connection | 3-11 |
| 3.11 | CHASSIS CONNECTION | 3-11 |
| 3.12 | DETACHABLE HANDLES | 3-12 |
| 3.13 | RACK MOUNTING..... | 3-12 |

TABLE OF CONTENTS (Continued)

| <i>Chapter/Section</i> | <i>Title</i> | <i>Page</i> |
|------------------------|---|-------------|
| 4 | OPERATION..... | 4-1 |
| 4.0 | GENERAL..... | 4-1 |
| 4.1 | TURNING POWER ON..... | 4-1 |
| 4.2 | DISPLAY DEFINITION..... | 4-2 |
| 4.3 | LED ANNUNCIATORS..... | 4-2 |
| 4.3.1 | Fault LED..... | 4-2 |
| 4.3.2 | Compliance LED..... | 4-2 |
| 4.3.3 | Power Limit LED..... | 4-2 |
| 4.3.4 | Ramping LED..... | 4-2 |
| 4.3.5 | Remote LED..... | 4-2 |
| 4.4 | KEYPAD DEFINITION..... | 4-3 |
| 4.4.1 | General Keypad Operation..... | 4-4 |
| 4.5 | DISPLAY SETUP..... | 4-4 |
| 4.6 | SETTING OUTPUT CURRENT..... | 4-4 |
| 4.7 | CURRENT RAMP RATE..... | 4-5 |
| 4.8 | RAMP SEGMENTS..... | 4-5 |
| 4.9 | PAUSE RAMP..... | 4-6 |
| 4.10 | ZERO OUTPUT..... | 4-6 |
| 4.11 | MAXIMUM SETTING LIMITS..... | 4-7 |
| 4.11.1 | Maximum Output Current..... | 4-7 |
| 4.11.2 | Maximum Current Ramp Rate..... | 4-7 |
| 4.12 | MAGNET WATER..... | 4-8 |
| 4.13 | INTERNAL WATER..... | 4-8 |
| 4.14 | ERROR STATUS DISPLAY..... | 4-8 |
| 4.15 | EXTERNAL CURRENT PROGRAMMING..... | 4-9 |
| 4.16 | LOCKING THE KEYPAD..... | 4-9 |
| 4.17 | COMPUTER INTERFACE..... | 4-10 |
| 4.17.1 | Changing Serial Baud Rate..... | 4-10 |
| 4.17.2 | Changing IEEE-488 Interface parameters..... | 4-11 |
| 4.18 | DEFAULT PARAMETER VALUES..... | 4-11 |
| 5 | COMPUTER INTERFACE OPERATION..... | 5-1 |
| 5.0 | GENERAL..... | 5-1 |
| 5.1 | IEEE-488 INTERFACE..... | 5-1 |
| 5.1.1 | Changing IEEE-488 Interface Parameters..... | 5-2 |
| 5.1.2 | Remote/Local Operation..... | 5-2 |
| 5.1.3 | IEEE-488 Command Structure..... | 5-2 |
| 5.1.3.1 | Bus Control Commands..... | 5-3 |
| 5.1.3.2 | Common Commands..... | 5-3 |
| 5.1.3.3 | Device Specific Commands..... | 5-3 |
| 5.1.3.4 | Message Strings..... | 5-3 |
| 5.1.4 | Status System..... | 5-4 |
| 5.1.4.1 | Overview..... | 5-4 |
| 5.1.4.1.1 | Condition Registers..... | 5-4 |
| 5.1.4.1.2 | Event Registers..... | 5-4 |
| 5.1.4.1.3 | Enable Registers..... | 5-4 |
| 5.1.4.1.4 | Status Byte Register..... | 5-4 |
| 5.1.4.1.5 | Service Request Enable Register..... | 5-4 |
| 5.1.4.1.6 | Reading Registers..... | 5-7 |
| 5.1.4.1.7 | Programming Registers..... | 5-7 |
| 5.1.4.1.8 | Clearing Registers..... | 5-7 |

TABLE OF CONTENTS (Continued)

| <i>Chapter/Section</i> | <i>Title</i> | <i>Page</i> |
|------------------------|---|-------------|
| 5.1.4.2 | Status Register Sets | 5-8 |
| 5.1.4.2.1 | Standard Event Status Register | 5-8 |
| 5.1.4.2.2 | Operation Event Register Set..... | 5-9 |
| 5.1.4.3 | Error Status Register Sets | 5-10 |
| 5.1.4.3.1 | Hardware Error Status Register Set | 5-10 |
| 5.1.4.3.2 | Operational Error Status Register Set | 5-11 |
| 5.1.4.4 | Status Byte and Service Request (SRQ) | 5-12 |
| 5.1.4.4.1 | Status Byte Register..... | 5-12 |
| 5.1.4.4.2 | Service Request Enable Register..... | 5-13 |
| 5.1.4.4.3 | Using Service Request (SRQ) and Serial Poll..... | 5-13 |
| 5.1.4.4.4 | Using Status Byte Query (*STB) | 5-13 |
| 5.1.4.4.5 | Using Message Available (MAV) Bit)..... | 5-13 |
| 5.1.4.4.6 | Using Operation Complete (*OPC) and Operation Complete Query (*OPC?)..... | 5-14 |
| 5.1.5 | IEEE-488 Interface Example Programs | 5-14 |
| 5.1.5.1 | IEEE-488 Interface Board Installation for Visual Basic Program | 5-14 |
| 5.1.5.2 | Visual Basic IEEE-488 Interface Program Setup | 5-16 |
| 5.1.5.3 | Program Operation | 5-20 |
| 5.1.6 | Troubleshooting..... | 5-20 |
| 5.2 | SERIAL INTERFACE OVERVIEW | 5-21 |
| 5.2.1 | Changing Baud Rate | 5-21 |
| 5.2.2 | Physical Connection | 5-21 |
| 5.2.3 | Hardware Support | 5-22 |
| 5.2.4 | Character Format | 5-22 |
| 5.2.5 | Message Strings..... | 5-22 |
| 5.2.6 | Message Flow Control..... | 5-23 |
| 5.2.7 | Serial Interface Example Programs..... | 5-23 |
| 5.2.7.1 | Visual Basic Serial Interface Program Setup | 5-24 |
| 5.2.7.2 | Program Operation | 5-27 |
| 5.2.8 | Troubleshooting..... | 5-27 |
| 5.3 | COMMAND SUMMARY | 5-28 |
| 5.3.1 | Interface Commands (Alphabetical Listing) | 5-29 |
| 6 | OPTIONS AND ACCESSORIES | 6-1 |
| 6.0 | GENERAL | 6-1 |
| 6.1 | ACCESSORIES INCLUDED | 6-1 |
| 6.2 | ACCESSORIES AVAILABLE | 6-1 |
| 7 | SERVICE | 7-1 |
| 7.0 | GENERAL | 7-1 |
| 7.1 | CONTACTING LAKE SHORE CRYOTRONICS | 7-1 |
| 7.2 | RETURNING PRODUCTS TO LAKE SHORE | 7-1 |
| 7.3 | LINE VOLTAGE SELECTION | 7-2 |
| 7.4 | CIRCUIT BREAKER SETTING | 7-3 |
| 7.5 | POWER LINE FUSE REPLACEMENT | 7-4 |
| 7.6 | ERROR MESSAGES | 7-5 |
| 7.7 | ELECTROSTATIC DISCHARGE | 7-6 |
| 7.7.1 | Identification of Electrostatic Discharge Sensitive Components | 7-6 |
| 7.7.2 | Handling Electrostatic Discharge Sensitive Components | 7-7 |
| 7.8 | ENCLOSURE BOTTOM REMOVAL AND REPLACEMENT | 7-7 |
| 7.8.1 | Removal | 7-7 |
| 7.8.2 | Installation | 7-7 |

TABLE OF CONTENTS (Continued)

| <i>Chapter/Section</i> | <i>Title</i> | <i>Page</i> |
|--|---|-------------|
| 7.9 | FIRMWARE REPLACEMENT | 7-7 |
| 7.10 | CONNECTOR AND CABLE DEFINITIONS | 7-11 |
| 7.10.1 | Analog I/O Connector | 7-11 |
| 7.10.2 | Magnet Connector | 7-11 |
| 7.10.3 | Auxiliary Connector..... | 7-12 |
| 7.10.4 | Power Supply Connector | 7-13 |
| 7.10.5 | RS-232C Serial Interface Connector | 7-13 |
| 7.10.6 | Serial Interface Cable Wiring | 7-14 |
| 7.10.7 | IEEE-488 Parallel Interface Connector | 7-14 |
| 7.11 | CALIBRATION | 7-16 |
| 7.11.1 | Calibration Interface..... | 7-16 |
| 7.11.2 | Calibration Equipment | 7-17 |
| 7.11.3 | Calibration Procedure..... | 7-17 |
| 7.11.3.1 | Calibrate Current Output Zero..... | 7-17 |
| 7.11.3.2 | Calibrate Current Reading Zero | 7-17 |
| 7.11.3.3 | Calibrate Output Voltage Reading Zero | 7-18 |
| 7.11.3.4 | Calibrate External Program Voltage Reading Zero | 7-18 |
| 7.11.3.5 | Calibrate Output Current Gain (Span)..... | 7-18 |
| 7.11.3.6 | Calibrate Current Reading Gain..... | 7-20 |
| 7.11.3.7 | Calibrate Voltage Reading Gain..... | 7-20 |
| 7.11.3.8 | Calibrate External Current Programming Voltage Reading Gain | 7-21 |
| 7.11.4 | Calibrate Specific Interface Commands..... | 7-21 |
| APPENDIX A – GLOSSARY OF TERMINOLOGY..... | | A-1 |
| APPENDIX B – UNITS FOR MAGNETIC PROPERTIES..... | | B-1 |

LIST OF ILLUSTRATIONS

| <i>Figure No.</i> | <i>Title</i> | <i>Page</i> |
|-------------------|---|-------------|
| 1-1 | Model 642 Front Panel | 1-2 |
| 2-1 | A Typical Electromagnet..... | 2-1 |
| 2-2 | Typical Magnet Water Hook-Up..... | 2-2 |
| 2-3 | Typical Magnet Coil Wiring Showing Series and Parallel Connections..... | 2-3 |
| 2-4 | Typical Thermal Switch, Flow Switch and Valve Wiring..... | 2-4 |
| 2-5 | Typical Curves of Field vs. Current for Various Air Gaps and Pole Cap Sizes | 2-5 |
| 3-1 | Model 642 Rear Panel | 3-3 |
| 3-2 | Voltage Change Detail..... | 3-4 |
| 3-3 | Circuit Breaker | 3-4 |
| 3-4 | Fuses..... | 3-5 |
| 3-5 | Typical Cable Entry with Bushing | 3-5 |
| 3-6 | Typical Power Input Wiring | 3-6 |
| 3-7 | Wiring Cover Installation..... | 3-6 |
| 3-8 | Typical Magnet Connector Wiring..... | 3-7 |
| 3-9 | Typical Auxiliary Connector Wiring | 3-7 |
| 3-10 | Typical Power Supply Connector Wiring..... | 3-8 |
| 3-11 | Typical Water Hose Connection | 3-8 |
| 3-12 | Water Valve Connection | 3-9 |
| 3-13 | Output Cable Connection | 3-10 |
| 3-14 | Output Lug Cover Installation | 3-10 |
| 3-15 | Analog Input/Output Connector | 3-11 |
| 3-16 | Mounting Hole Pattern | 3-12 |
| 4-1 | Model 642 Power Push Buttons | 4-1 |
| 4-2 | Model 642 Keypad and LED Layout | 4-3 |
| 5-1 | Model 642 Status System..... | 5-5 |
| 5-2 | Standard Event Status Register..... | 5-8 |
| 5-3 | Operation Event Register | 5-9 |
| 5-4 | Hardware Error Status Register..... | 5-10 |
| 5-5 | Operational Error Status Register..... | 5-11 |
| 5-6 | Status Byte Register and Service Request Enable Register | 5-12 |
| 5-7 | GPiB0 Setting Configuration..... | 5-15 |
| 5-8 | DEV 12 Device Template Configuration | 5-15 |
| 5-9 | Typical National Instruments GPiB Configuration from IBCONF.EXE | 5-19 |
| 7-1 | Model 642 Rear Panel | 7-2 |
| 7-2 | Voltage Change Detail..... | 7-3 |
| 7-3 | Circuit Breaker | 7-4 |
| 7-4 | Fuse Holder Detail..... | 7-5 |
| 7-5 | Board Locations..... | 7-9 |
| 7-6 | Digital Board Parts Locations | 7-10 |
| 7-7 | Analog I/O Connector Details | 7-11 |
| 7-8 | Magnet Connector Details | 7-11 |
| 7-9 | Auxiliary Connector Detail | 7-12 |
| 7-10 | Power Supply Connector Details | 7-13 |
| 7-11 | RS-232C (DTE) Connector Details..... | 7-13 |
| 7-12 | IEEE-488 Connector Details..... | 7-15 |

LIST OF TABLES

| <i>Table No.</i> | <i>Title</i> | <i>Page</i> |
|------------------|---|-------------|
| 3-1 | Rear Panel Connector Identification | 3-2 |
| 3-2 | Voltage and Current Selection | 3-3 |
| 3-3 | Current Capacity and Total Lead Lengths | 3-9 |
| 4-1 | Model 642 LED Descriptions | 4-2 |
| 4-2 | Model 642 Key Descriptions | 4-3 |
| 4-3 | Default Parameter Values | 4-12 |
| 5-1 | Binary Weighting of an 8-Bit Register | 5-7 |
| 5-2 | Register Clear Methods | 5-7 |
| 5-3 | Programming Example to Generate an SRQ | 5-13 |
| 5-4 | IEEE-488 Interface Program Control Properties | 5-17 |
| 5-5 | Visual Basic IEEE-488 Interface Program | 5-18 |
| 5-6 | Serial Interface Specifications | 5-22 |
| 5-7 | Serial Interface Program Control Properties | 5-25 |
| 5-8 | Visual Basic Serial Interface Program | 5-26 |
| 5-9 | Command Summary | 5-29 |
| 7-1 | Voltage and Current Selection | 7-3 |
| 7-2 | Instrument Hardware Errors | 7-5 |
| 7-3 | Operational Errors | 7-6 |
| B-1 | Conversion from CGS to SI Units | B-1 |
| B-2 | Recommended SI Values for Physical Constants | B-2 |

CHAPTER 1

INTRODUCTION

1.0 GENERAL

This chapter provides an introduction to the Model 642 Electromagnet Power Supply. The Model 642 was designed and manufactured in the United States of America by Lake Shore Cryotronics, Inc. The Model 642 features include the following.

- True 4-quadrant (bipolar) 70 A, 35 V output
- 0.1 mA output setting resolution
- Linear regulation minimizes noise and ripple to 0.007% of maximum current into a 0.50 Ω load
- 1.0 mA stability per hour, 5 mA per 24 hour
- CE compliance to *both* the low voltage directive *and* the electromagnetic compatibility (EMC) directive

1.1 DESCRIPTION

The Model 642 Electromagnet Power Supply is the ideal supply for small- to medium-sized magnets used in high-sensitivity materials research applications. The Model 642 is a practical alternative to both the larger one-size-fits-all magnet supplies and the endless adaptations of generic power supplies. By optimizing output power, Lake Shore was able to concentrate on the performance requirements of the most demanding magnet users. The resulting Model 642 provides high precision, low noise, safety, and convenience.

Precision in magnetic measurements is typically defined as smooth continuous operation with high setting resolution and low drift. Achieving these goals while driving an inductive load requires unique solutions. The Model 642 delivers up to 70 A at a nominal voltage of 35 V, with the supply acting as either a source or a sink in true 4-quadrant operation. Its current source output architecture with analog control enables both smooth operation and low drift. A careful blending of analog and digital circuits provides high setting resolution of 0.1 mA and flexible output programming.

Lake Shore chose linear input and output power stages for the nominal 2450 W output of the Model 642. Linear operation eliminates the radiated radio frequency (RF) noise associated with switching power supplies, allowing the Model 642 to reduce the overall noise in its output and the noise radiated into surrounding electronics.

Safety should never be an afterthought when driving an inductive load. The Model 642 incorporates a variety of hardware and firmware protection features to ensure the safety of the magnet and supply. For improved operator safety, the power supply was also designed for compliance with the safety requirements of the CE mark, including both the low voltage and the electromagnetic compatibility (EMC) directive.

Instrument users have come to rely on Lake Shore equipment for convenience and ease of use. The Model 642 includes features such as built-in current and power limits, internal cooling-water and magnet-water control to minimize condensation, current ramping and the capability to modulate the output current. Computer interfaces are also integrated for automation of the magnet system. The Model 642 is truly an excellent one-box solution for controlling an electromagnet.

Output Architecture

True 4-quadrant output capability of the Model 642 is ideal for the charge and discharge cycling of electromagnets for both positive and negative fields. Tightly integrated analog control of the 4-quadrant output provides smooth current change with very low overshoot on output change. The Model 642 has the ability to charge and discharge magnets up to a 50 A per second rate into a nominal 0.5 Ω , 0.5 H load.

True 4-quadrant operation eliminates the need for external switching or operator intervention to reverse the current polarity, significantly simplifying system operation. The transition through zero current is smooth and continuous, allowing the user to readily control the magnetic field as polarity changes.

At static fields, output current drift is also kept low by careful attention in the analog control circuits and layout. The high stability and low noise of the Model 642 provides a quiet and uniform magnetic field.

Output Architecture (Continued)

The Model 642 output architecture relies on low noise, linear input and output stages. The linear circuitry of the Model 642 permits operation with less electrical noise than switch-mode electromagnet power supplies. One key benefit of this architecture is CE compliance to the electromagnetic compatibility (EMC) directive, including the radiated emissions requirement.

Output Programming

The Model 642 output current is programmed internally via the keypad, externally by the computer interface, externally by the analog programming input, or by the sum of the external and internal settings. For internal programming, the Model 642 incorporates a proprietary digital-to-analog converter (DAC) that is monotonic over the entire output range and provides a resolution of 0.1 mA.

The Model 642 generates extremely smooth and continuous ramps with virtually no overshoot. The digitally generated constant current ramp rate is variable between 0.1 mA/s and 99.999 A/s. To ensure a smooth ramp rate, the power supply updates the high-resolution DAC 23.7 times per second. A low-pass filter on the DAC output smoothes the transitions at step changes during ramping.

Output Readings

The Model 642 provides high-resolution output readings. The output current reading has a resolution of 0.1 mA. The output voltage reading reports the voltage at the output terminals with a resolution of 0.1 mV. All output readings can be prominently displayed on the front panel and read over the computer interface.

Protection

The Model 642 continuously monitors the line voltage, load power, internal power, and load resistance as well as a variety of other internal circuit parameters for signs of trouble. Some fault conditions result in a warning message while others will provide a warning message and zero the output. When hazardous conditions exist, the Model 642 will shut itself off.

NOTE: The Model 642 is equipped with a high-line lockout circuit which will prevent the unit from being turned on if it is connected to a voltage source that is much higher than the voltage for which it is configured.

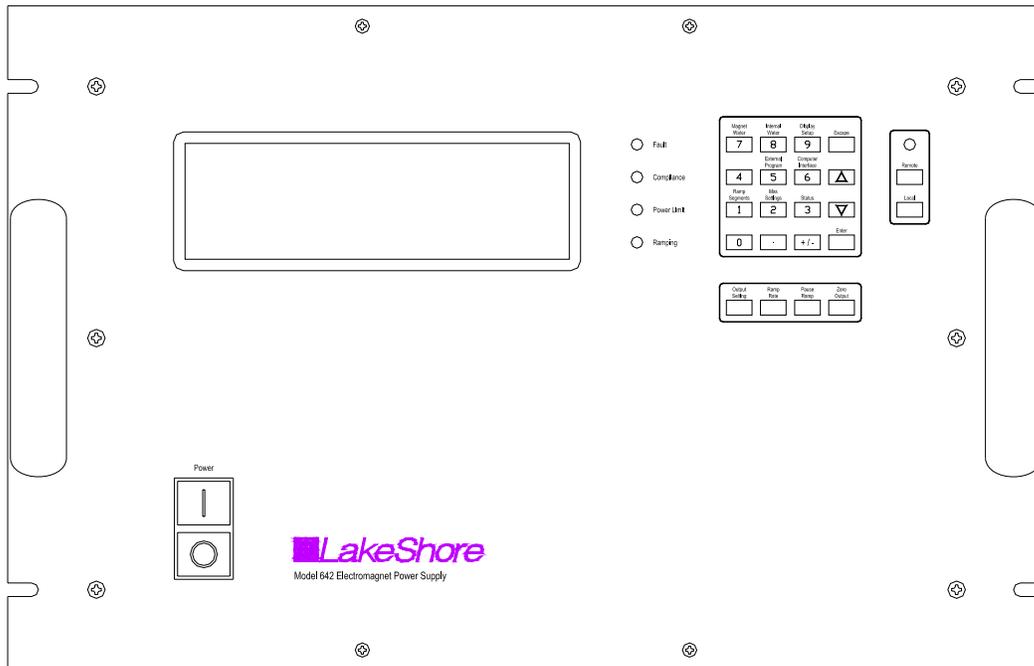


Figure 1-1. Model 642 Front Panel

Description (Continued)

Interfaces

The Model 642 includes IEEE-488 and RS-232C interfaces that provide access to operating data, stored parameters, and remote control of all front panel operated functions. A keypad lock-out feature is provided to prohibit any changes made from the front panel. The Model 642 can then be operated solely with the computer via the RS-232C or IEEE-488 interface.

The Model 642 provides two analog outputs to monitor the output current and voltage. Each output is a buffered, differential, analog voltage representation of the signal being monitored. The current monitor has a sensitivity of $7\text{ V} = 70\text{ A}$, while the voltage monitor has a sensitivity of $3.5\text{ V} = 35\text{ V}$.

Display and Keypad

The Model 642 incorporates a large 8-line by 40-character vacuum fluorescent display. Output current and output voltage readings are displayed simultaneously. Five LEDs on the front panel provide quick verification of instrument status, including ramping, power limit, compliance, fault, and computer interface mode. Error conditions are indicated on the main display along with an audible tone. Extended error descriptions are available in an error message screen by pressing the Status key.

The keypad is arranged logically to separate the different functions of the instrument. The most common functions of the power supply are accessed using a single key press. The keypad can be locked to either lock out all changes or to lock out just the instrument setup parameters allowing the output of the power supply to be changed.

1.2 SPECIFICATIONS

Output

| | |
|--------------------------|--|
| Type | Bipolar, 4-quadrant, DC current source |
| Current generation | Fully linear regulation with digital setting and analog control |
| Current range | $\pm 70\text{ A}$ |
| Compliance voltage (DC) | $\pm 35\text{ V}$ nominal |
| Power | 2450 W nominal |
| Nominal load | $0.5\ \Omega$, 0.5 H |
| Maximum load resistance | $0.6\ \Omega$ for $\pm 70\text{ A}$ DC operation at +10% to -5% line voltage |
| Minimum load resistance | $0.4\ \Omega$ for $\pm 70\text{ A}$ at +5% to -10% line voltage |
| Load inductance range | 0 H to 1 H |
| Current ripple | 5 mA RMS (0.007%) at 70 A into nominal load |
| Current ripple frequency | Dominated by the line frequency and its harmonics |
| Temperature coefficient | $\pm 15\text{ ppm}$ of full scale/ $^{\circ}\text{C}$ |
| Line regulation | $\pm 60\text{ ppm}$ of full scale/10% line change |
| Stability (1 h) | 1 mA/h (after warm-up) |
| >Stability (24 h) | 5 mA/24 h (typical, dominated by temperature coefficient and line regulation) |
| Isolation | Differential output is optically isolated from chassis to prevent ground loops |
| Slew rate | 50 A/s into nominal load 650 A/s maximum into a resistive load |
| Compliance voltage (AC) | $\pm 43\text{ V}$ at +10% to -5% line |
| Settling time | <1 s for 10% step to within 1 mA of output into nominal load |
| Modulation response | $\leq 0.17\text{ Hz}$ at $\pm 70\text{ A}$ sine wave into nominal load, <0.02% THD $\leq 10\text{ Hz}$ at $\pm 10\text{ A}$ sine wave into nominal load, <0.10% THD |
| Attenuation | -0.5 dB at 10 Hz |
| Protection | Short circuit, line loss, low line voltage, high line voltage, output over voltage, output over current, and over temperature |
| Connector | Two lugs with 6.4 mm (0.25 in) holes for M6 or 0.25 in bolts |

Specifications (Continued)

Output programming

Internal current setting

| | |
|---------------|---|
| Resolution | 0.1 mA (20 bit) |
| Settling time | 600 ms for 1% step to within 1 mA (of internal setting) |
| Accuracy | $\pm 10 \text{ mA} \pm 0.05\%$ of setting |
| Operation | Keypad, computer interface |
| Protection | Programmable current setting limit |

Internal current ramp

| | |
|---------------|---|
| Ramp rate | 0.1 mA/s to 99.999 A/s (compliance limited) |
| Update rate | 23.7 increments/s |
| Ramp segments | 5 |
| Operation | Keypad, computer interface |
| Protection | Programmable ramp rate limit |

External current programming

| | |
|------------------|---|
| Sensitivity | 10 V/70 A |
| Resolution | Analog |
| Accuracy | $\pm 10 \text{ mA} \pm 1\%$ of setting |
| Input resistance | 20 k Ω |
| Operation | Voltage program through rear panel, can be summed with internal current setting |
| Limits | Internally clamped at $\pm 10.1 \text{ V}$ and bandwidth limited at 40 Hz to protect output |
| Connector | Shared 15-pin D-sub |

Readings

Output current

| | |
|-------------|---------------------------------------|
| Resolution | 0.1 mA |
| Accuracy | $\pm 5 \text{ mA} \pm 0.05\%$ of rdg |
| Update rate | 2.5 rdg/s display, 10 rdg/s interface |

Output voltage (at supply terminals)

| | |
|-------------|--------------------------------------|
| Resolution | 1mV |
| Accuracy | $\pm 5 \text{ mV} \pm 0.05\%$ of rdg |
| Update rate | 2.5 rdg/s display, 5 rdg/s interface |

Front panel

| | |
|----------------------|--|
| Display type | 8-line by 40-character graphic vacuum fluorescent display module |
| Display readings | Output current, output voltage, and internal water temperature |
| Display settings | Output current and ramp rate |
| Display annunciators | Status and errors |
| LED annunciators | Fault, Compliance, Power Limit, Ramping, Remote |
| Audible annunciator | Errors and faults |
| Keypad type | 26 full travel keys |
| Keypad functions | Direct access to common operations, menu-driven setup |
| Power | White flush ON and black extended OFF push buttons |

Specifications (Continued)

Interface

IEEE-488.2 interface

| | |
|------------------|--|
| Features | SH1, AH1, T5, L4, SR1, RL1, PP0, DC1, DT0, C0, E1 |
| Reading rate | To 10 rdg/s |
| Software support | National Instruments LabVIEW™ driver (consult Lake Shore for availability) |

Serial interface

| | |
|-------------------|---------------------------|
| Electrical format | RS-232C |
| Baud rates | 9600, 19200, 38400, 57600 |
| Reading rate | To 10 rdg/s |
| Connector | 9-pin D-sub (DTE) |

Output current monitor

| | |
|------------------|---------------------|
| Sensitivity | 7 V/70 A |
| Accuracy | ±1% of full scale |
| Noise | 1 mV RMS |
| Source impedance | 20 Ω |
| Connector | Shared 15-pin D-sub |

Output voltage monitor

| | |
|------------------|---------------------|
| Sensitivity | 3.5 V/35 V |
| Accuracy | 1% of full scale |
| Noise | 1 mV RMS |
| Source impedance | 20 Ω |
| Connector | Shared 15-pin D-sub |

Power supply cooling water

| | |
|---------------------|--|
| Remote enable input | TTL low or contact closure to enable output; jumper required if unused |
| Valve power output | 24 VAC at 1 A maximum, automatic or manual control |
| Connector | Shared 4-pin detachable terminal block |

Flow switch and water valve optional

Magnet cooling water

| | |
|---------------------|--|
| Remote enable input | TTL low or contact closure to enable output; jumper required if unused |
| Valve power output | 24 VAC at 1 A maximum, automatic or manual control |
| Connector | Shared 4-pin detachable terminal block |

Flow switch, temperature switch, and water valve not included

Auxiliary

| | |
|----------------|---|
| Emergency stop | Requires 1 A, 24 VAC normally closed (NC) contact to enable power-up; jumper required if unused |
| Fault output | Relay with normally open (NO) or normally closed (NC) contact, 30 VDC at 1 A |
| Remote enable | TTL low or contact closure to enable output, jumper required if unused |
| Connector | Shared 8-pin detachable terminal block |

Emergency stop and enable switches not included

Specifications (Continued)

General

Line power

| | |
|---------------------|--|
| Power | 5500 VA max |
| Voltage and current | 200/208 VAC $\pm 10\%$, 13 A/phase 220/230 VAC $\pm 10\%$, 12 A/phase 380 VAC $\pm 10\%$, 7 A/phase 400/415 VAC $\pm 10\%$, 6.5 A/phase |
| Protection | Three phase thermal relay, with adjustable current setting Two class CC 1/4 A fuses Over-voltage lockout circuit |
| Frequency | 50 Hz or 60 Hz |
| Configuration | 3-phase delta |
| Connector | 4-pin terminal block |

Line voltage must be specified at time of order but is field reconfigurable

Cable from power supply to facility power not included

Cooling water

| | |
|----------------|--|
| Flow rate | 5.7 L (1.5 gal)/min minimum |
| Pressure range | 34 kPa (5 psi) to 552 kPa (80 psi) |
| Pressure drop | 10 kPa (1.5 psi) at 5.7 L (1.5 gal)/minute minimum for power supply only |
| Temperature | 15 °C to 30 °C (non condensing) |
| Connection | Two 10 mm (0.38 in) hose barbs |

CAUTION: Internal condensation can cause damage to the power supply

| | |
|----------------------|---|
| Enclosure type | 7 U high, 19 in rack mount with integral rack mount ears (25 mm (1 in) air space required on each side for ventilation) |
| Size | 483 mm W \times 310 mm H \times 572 mm D (19 in \times 12.2 in \times 22.5 in) with front handles removed |
| Weight | 74 kg (163 lb) |
| Shipping size | 635 mm W \times 559 mm H \times 736 mm D (25 in \times 22 in \times 29 in) |
| Shipping weight | 79.5 kg (175 lb) |
| Ambient temperature | 15 °C to 35 °C at rated accuracy, 5 °C to 40 °C at reduced accuracy |
| Humidity | Non condensing |
| Warm-up | 30 min at output current setting |
| Approvals | CE mark – low voltage compliance to EN61010-3, EMC compliance to EN55022-1 |
| Calibration schedule | 1 year |

Ordering Information

Part Number

Ordering Information

| | |
|---------|--|
| 642-204 | Model 642 ± 70 A ± 35 V, 2.5 kW, 204/208 VAC |
| 642-225 | Model 642 ± 70 A ± 35 V, 2.5 kW, 220/230 VAC |
| 642-380 | Model 642 ± 70 A ± 35 V, 2.5 kW, 380 VAC |
| 642-408 | Model 642 ± 70 A ± 35 V, 2.5 kW, 400/415 VAC |

Options

| | |
|------|--|
| 6041 | Water flow switch, 2 gallons/min |
| 6042 | 64X MPS water valve with mounting bracket and hose barb fittings |

Accessories included

| | |
|---------|---|
| MAN-642 | Model 642 user manual |
| 6031 | Two front handles |
| 6032 | Two rear handles |
| 6051 | Terminal block, 4 pin |
| 6052 | Terminal block, 8 pin |
| 6252 | 15-pin D-sub mating connector, analog I/O |
| 108-654 | Strain relief bushing kit |
| ---- | Calibration certificate |

Accessories available

| | |
|--------------|--|
| 6201 | 1 m (3.3 ft) long IEEE-488 (GPIB) computer interface cable |
| 6261 | 3 m (10 ft) magnet cable kit, AWG 4 |
| 6262 | 6 m (20 ft) magnet cable kit, AWG 4 |
| CAL-642-CERT | Instrument recalibration with certificate |
| CAL-642-DATA | Instrument recalibration with certificate and data |

1.3 SAFETY SUMMARY

Observe these safety precautions during all phases of instrument operation, service, and repair. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended instrument use. Lake Shore assumes no liability for Customer failure to comply with these requirements.

The Model 642 protects the operator and surrounding area from electric shock or burn, mechanical hazards, excessive temperature, and spread of fire from the instrument. Environmental conditions outside of the conditions below may pose a hazard to the operator and surrounding area.

- Indoor use.
- Altitude to 2000 meters.
- Temperature for safe operation: 5 °C to 40 °C.
- Over voltage category II.
- Pollution degree 2.
- Maximum relative humidity: 80% for temperature up to 31 °C decreasing linearly to 50% at 40 °C.
- Power supply voltage fluctuations not to exceed ±10% of the nominal voltage.

Power and Ground Connections

This instrument must be connected to a dedicated three-phase power circuit with proper size of circuit breaker. (Refer to Chapter 3 – Installation) Verify that the unit has been configured for the correct input voltage. The neutral line, if available, is not used. The unit may be hard-wired or connected with a flexible cable and plug. In all cases the correct size wire must be chosen for the current drawn and the length of cable used. To minimize shock hazard, the electrical ground (safety ground) lead must be connected. If a flexible cable and plug are used, plug the power cable into an approved electrical outlet. The power jack and mating plug of the power cable must meet Underwriters Laboratories (UL) and International Electromechanical Commission (IEC) safety standards. Power wiring must comply with electrical codes of the locality in which the unit is installed.

Ventilation

The instrument has ventilation holes in its side panels. Do not block these holes when the instrument is operating. Provide at least 25 mm (1 in) of air space on each side for ventilation.

Do Not Operate In An Explosive Atmosphere

Do not operate the instrument in the presence of flammable gases or fumes. Operation of any electrical instrument in such an environment constitutes a definite safety hazard.

Keep Away From Live Circuits

Operating personnel must not remove instrument covers. Refer component replacement and internal adjustments to qualified maintenance personnel. Do not replace components with power cable connected. To avoid injuries, always disconnect power and discharge circuits before touching them.

Safety Summary (Continued)

Do Not Substitute Parts Or Modify Instrument

Do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to an authorized Lake Shore representative for service to ensure that safety features are maintained.

Prevent Cooling Water Condensation

Do not operate the power supply when cooling water temperature is at or lower than the dew point for local atmospheric conditions. Condensation on cooling water lines inside the power supply can cause severe damage. Refer to Section 2.4.4 for additional details.

Cleaning

Do not submerge instrument. Clean only with a damp cloth and mild detergent on exterior surfaces only.

Moving and Handling

Four handles are provided for ease of moving and handling the Model 642. The handles can be used in place of lifting lugs when cloth straps are used. Always use all four handles when moving the unit. Because of its weight, the Model 642 should be handled by mechanical means. If for some reason it is necessary to move it by hand, a minimum of two people is required.

CAUTION: To avoid injury to personnel, always observe proper lifting techniques in accordance with OSHA and other regulatory agencies.

Safety Summary (Continued)

1.4 SAFETY SYMBOLS

| Number | Symbol | Publication | Description |
|--------|---|--|---|
| 1 |  | IEC 417, No. 5031 | Direct current |
| 2 |  | IEC 417, NO. 5032 | Alternating current |
| 3 |  | IEC 417, No. 5033 | Both direct and alternating current |
| 4 |  | IEC 617-2, No. 02-02-06 | Three-phase alternating current |
| 5 |  | IEC 417, No. 5017 | Earth (ground) TERMINAL |
| 6 |  | IEC 417, No. 5019 | PROTECTIVE CONDUCTOR TERMINAL |
| 7 |  | IEC 417, No. 5020 | Frame or chassis ground |
| 8 |  | IEC 417, No. 5021 | Equipotentiality |
| 9 |  | IEC 417, No. 5007 | On (supply) |
| 10 |  | IEC 417, No. 5008 | Off (supply) |
| 11 |  | IEC 417, No. 5172 | Equipment protected by DOUBLE INSULATION OR REINFORCED INSULATION |
| 12 |  | ISO 3864, No. B.3.6 Bcakground color-yellow Symbol and outline-black | Caution, risk of electric shock |
| 13 |  | IEC 417, No. 5041 Background color-yellow Symbol and outline-black | Caution, hot surface |
| 14 |  | ISO 3864, No. B.3.1 Background color-yellow Symbol and outline-black | Caution (refer to accompanying documents) |
| 15 |  | IEC 417, No. 5268-a | In-position of bistable push control |
| 16 |  | IEC 417, No. 5269-a | Out-position of bistable push control |
| None |  | IEC 1010-1 | Fuse |

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CHAPTER 2

MAGNET SYSTEM DESIGN, INSTALLATION, AND OPERATION

2.0 GENERAL

This chapter provides the user insight into the design, installation, and operation of a typical electromagnet. For information on how to install the Model 642 please refer to Chapter 3. For Model 642 operation information, refer to Chapter 4.

2.1 INTRODUCTION

A magnet used with the Model 642 Power Supply is typically an iron pole, twin coil, 4-inch pole diameter, variable air gap, water cooled electromagnet. Larger magnets can be used depending on their electrical parameters and the magnetic field requirements. The electromagnet provides a uniform magnetic field in the air gap between two adjustable poles. The samples, which are to be tested for their magnetic properties, are placed in the air gap with appropriate monitoring equipment attached. By varying the polarity and intensity of the field, useful data can be collected. A typical electromagnet is shown in Figure 2-1.

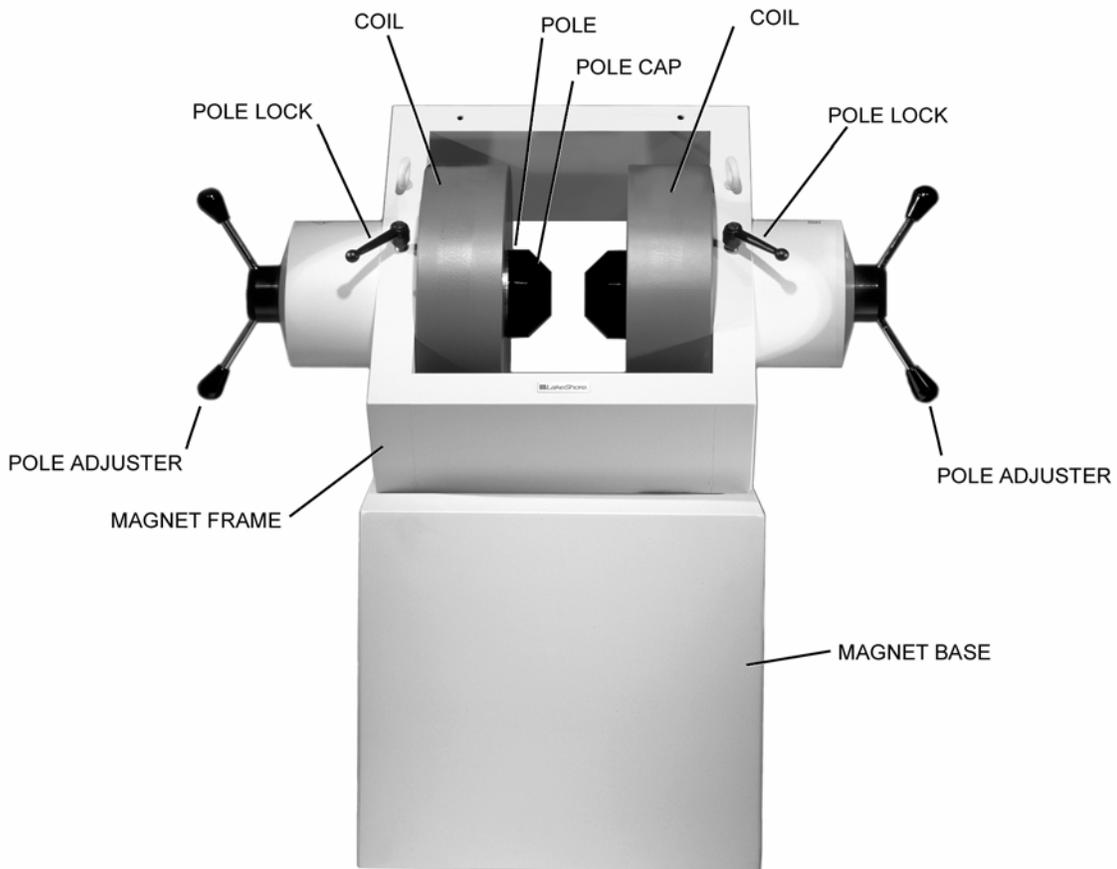


Figure 2-1. A Typical Electromagnet

2.2 MAGNET CONSTRUCTION

The magnet consists of two water-cooled coils surrounding adjustable iron poles, which are fitted into an iron frame. The frame supports the poles and coils, and improves the magnet's efficiency. The iron poles are fitted with adjusting mechanisms so that the air gap width can be set. Lock mechanisms are provided to hold the poles in place after adjustment is made. The pole faces have pole caps attached, which provide the desired magnetic focus. The size and shape of the pole caps are chosen according to the size of sample being tested and the magnetic field requirement.

2.3 CONNECTING THE MAGNET

Connecting the magnet to the power supply requires three separate circuits: the cooling water hoses, the main high current power lines, and the safety switches which may include any combination of temperature and flow switches. These connections are shown below.

2.3.1 Water Hose Connection

Water-cooling is essential for these magnets. The power dissipated can raise the temperature of the coils to the point where they will be destroyed. In addition, the samples being tested may exhibit changes in their magnetic performance with changes in temperature causing errors in the collected data. Typical water connection is shown in Figure 2-2. The magnets may be supplied with hose barbs or standard hose fittings. The coils are connected in parallel so that the water temperature rise is the same for both. Every effort should be made to insure that the flow rate in both coils is the same. The minimum flow required is usually specified by the magnet vendor.

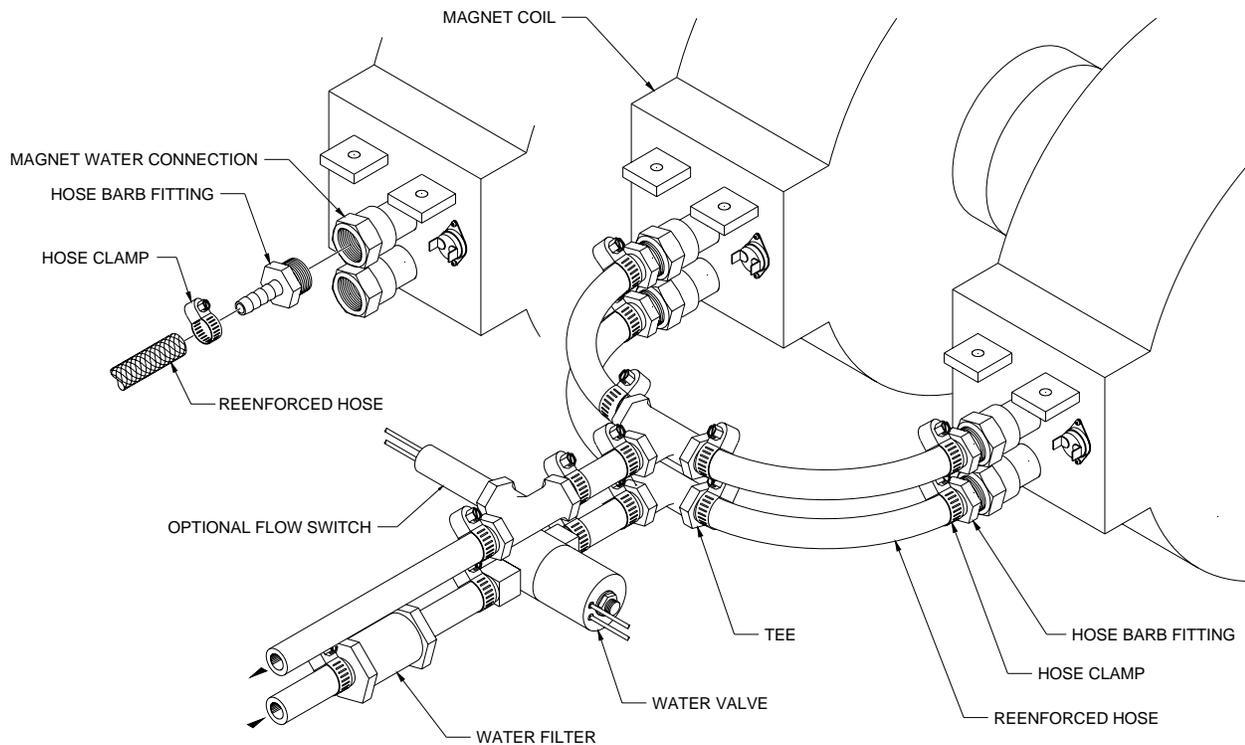


Figure 2-2. Typical Magnet Water Hook-Up

2.3.2 Magnet Coil Wiring

Typical magnet coil wiring is shown in Figure 2-3. The connecting cable used should be of sufficient gage to prevent excessive voltage drop and heat rise in the cable. The cables should be as short as possible to minimize the voltage drop. Current carrying capacities for various sizes of cables and cable lengths are shown in Table 3-3. The connections must be made with the correct size of hardware for the magnet terminal. We recommend the use of a spring or Belleville washer for cable terminations. When the parts of a connection expand and contract with changes in temperature, they tend to loosen. A spring washer will reduce this tendency.

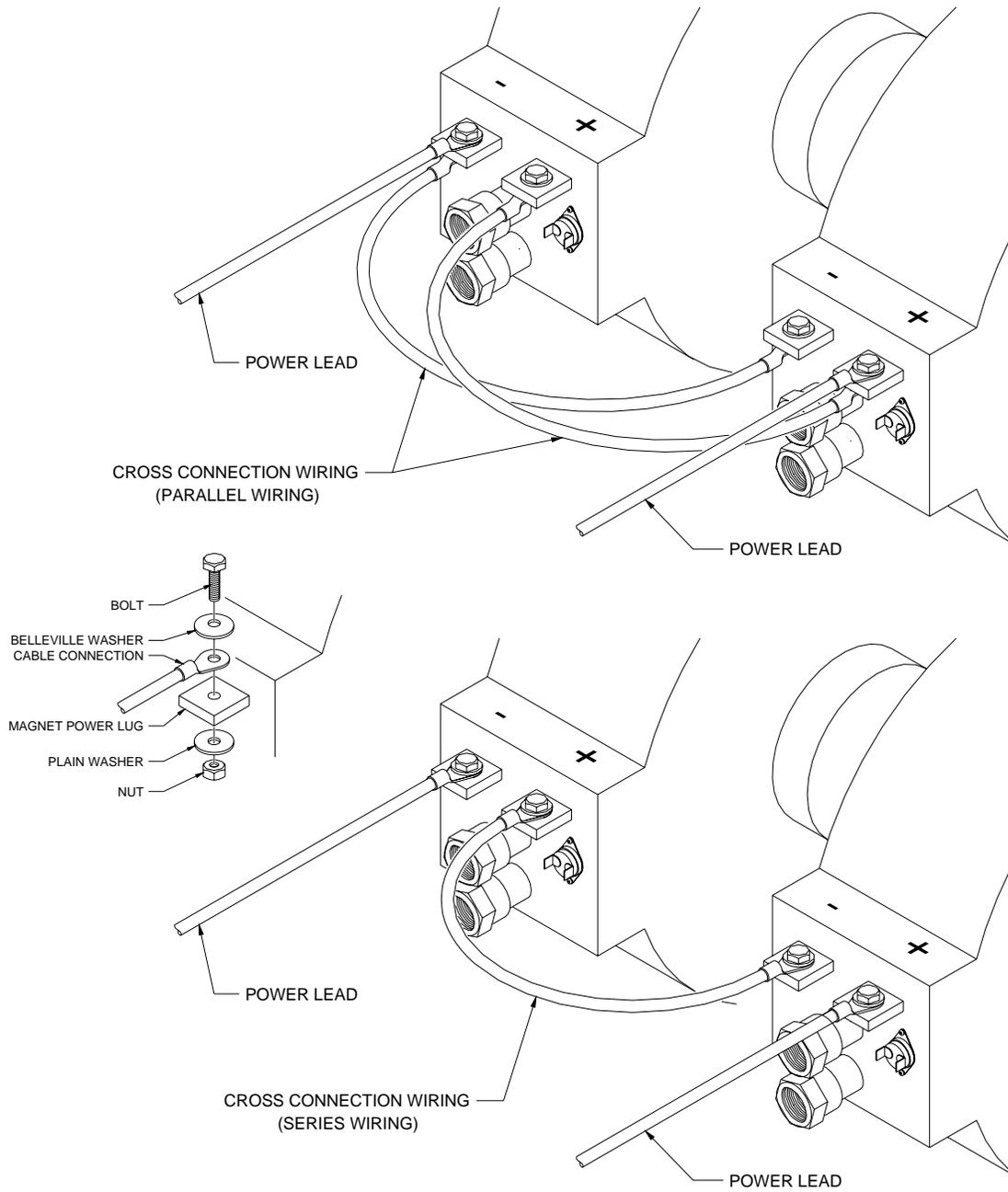


Figure 2-3. Typical Magnet Coil Wiring Showing Series and Parallel Connections

2.3.3 Temperature Switches and Flow Switches

As discussed in Section 2.3.1, water-cooling for the magnet is essential. To protect the magnet from damage resulting from an interruption in cooling water, a flow switch, temperature switches or both should be installed. The switches must have a normally closed contact, and if multiple switches are used, they must be connected in series. The switches are then connected to the Flow Switch terminals of the Magnet Connector on the Model 642. The Model 642 monitors the switches and if an open is detected, the output current is ramped to zero. (Flow switch monitoring depends on water valve mode setting. See sections 4.12 and 4.13 for details.) Given the cost of the magnet, it is prudent to use both temperature and flow switches. Some installations use two flow switches, one in the exhaust line of each coil so that if a clog occurs in only one coil, it can be detected. Figure 2-4 shows the typical flow and temperature switch connection.

CAUTION: Care must be used in the selection of the flow switch. Some switches use a sensitive reed switch, which can be overpowered by stray flux from the magnet and will not open when the magnet is operating at high field. The flow switch must be tested by turning off the water while the magnet is operating at full current.

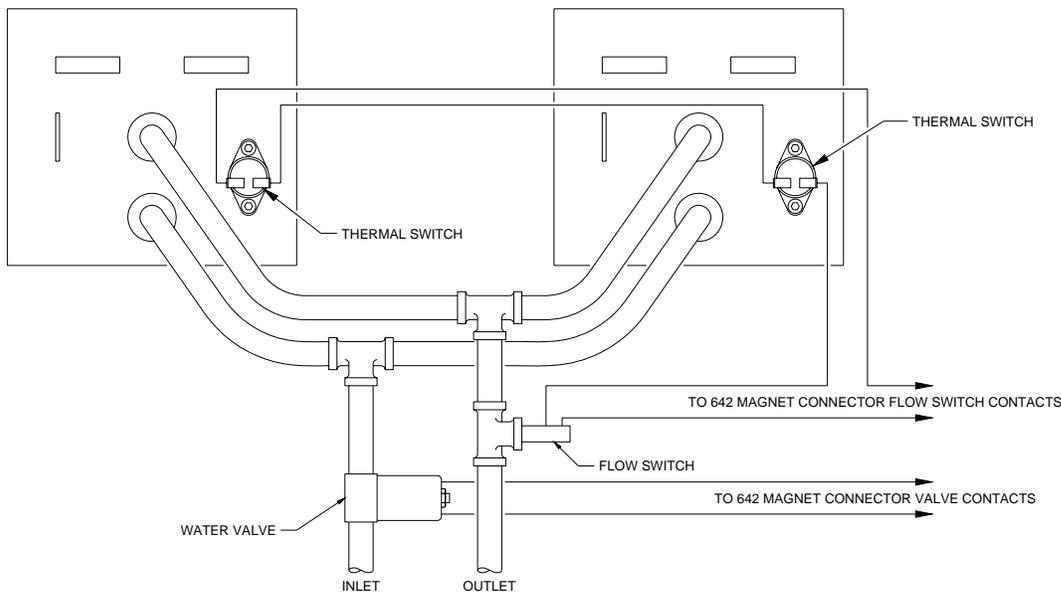


Figure 2-4. Typical Thermal Switch, Flow Switch and Valve Wiring

2.3.4 Cooling Water and Water Valve

The cooling water for the magnet can be drawn from the municipal water facility or from a dedicated re-circulating water chiller designed for this purpose. When water is drawn from the municipal water facility, the water should be turned on only when it is required to reduce consumption and reduce the likelihood of scale build-up in the magnet. The water can be turned on and off manually when the magnet is used, or automatically with a solenoid valve. The Model 642 provides automatic control and a 24 VAC at 1 A output for this purpose. The optional water valve is shown in Figure 2-2. The water inlet line should also be fitted with a sediment filter (not shown) to reduce scale build-up in the magnet coils and connecting lines.

2.3.5 Grounding

A ground connection (tapped hole) is usually available at the rear of the electromagnet frame. This ground point is provided for customers who would like to use the electromagnet frame as a signal ground or will be bringing hazardous live voltages near the electromagnet and would like to make it an electrical safety ground. Please verify suitability for such a function and compatibility with local and national electrical codes before making ground connections. Scrape off excess paint near the connecting screw to ensure a good electrical contact with the bare steel of the electromagnet frame.

2.3.6 Final Check-Out

When all of the connections have been made the system should be tested to be sure it is operating correctly. The settings for the magnet water should be checked to verify that they are correct for the configuration which has been installed (Refer to Section 4.12 – Magnet Water). The maximum current setting for the magnet should be set also (Refer to Section 2.4.2 and Section 4.11.1.)

2.4 ELECTROMAGNET OPERATION

This section provides a brief description of the typical operation of an electromagnet. For operation of the Model 642, refer to Chapter 4.

2.4.1 Air Gap and Pole Caps

The first step in setting up a magnet for operation is to select the proper pole caps and adjust the air gap. These parameters are determined by the size and shape of the sample, and the connections that must be made to the sample. Generally, a smaller pole face provides a higher field within the air gap. A smaller air gap also provides a higher field. The pole faces must be selected to accommodate the size of the sample being tested. The air gap is selected based on the size of the sample and the other equipment being used. The curves for Field versus Current for various air gaps and pole cap sizes for the Lake Shore Model EM4-HVA are shown in Figure 2-5. It also shows that these parameters are not linear. This must be taken into account when operating an electromagnet. To obtain linearity, it is necessary to operate the magnet and power supply under field control. (Refer to Section 2.4.4)

2.4.2 Maximum Current and Power

The Model 642 was designed to operate with a magnet load resistance of 0.50 Ω, but will work with a resistance range of 0.40 Ω to 0.60 Ω. The resistance of a magnet will rise with a rise in temperature and this should be taken into account. The power dissipated in the magnet is given by: $P=I^2R$. If the current remains constant, the power dissipated will rise proportionately with the rise in resistance. The Model 642 allows the user to set a maximum current limit to prevent damage to the magnet. (Refer to Section 4.11.1.)

EM4-HVA 2.5 cm (1 in) Pole Face Field Plot

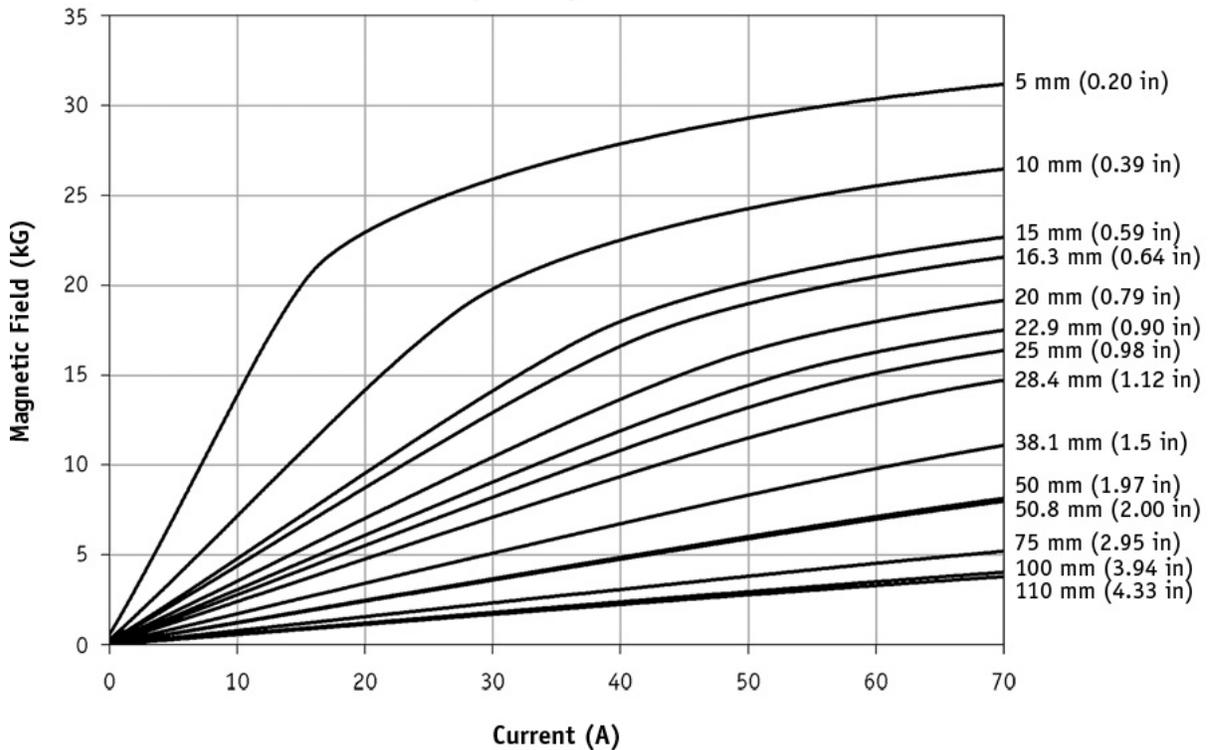
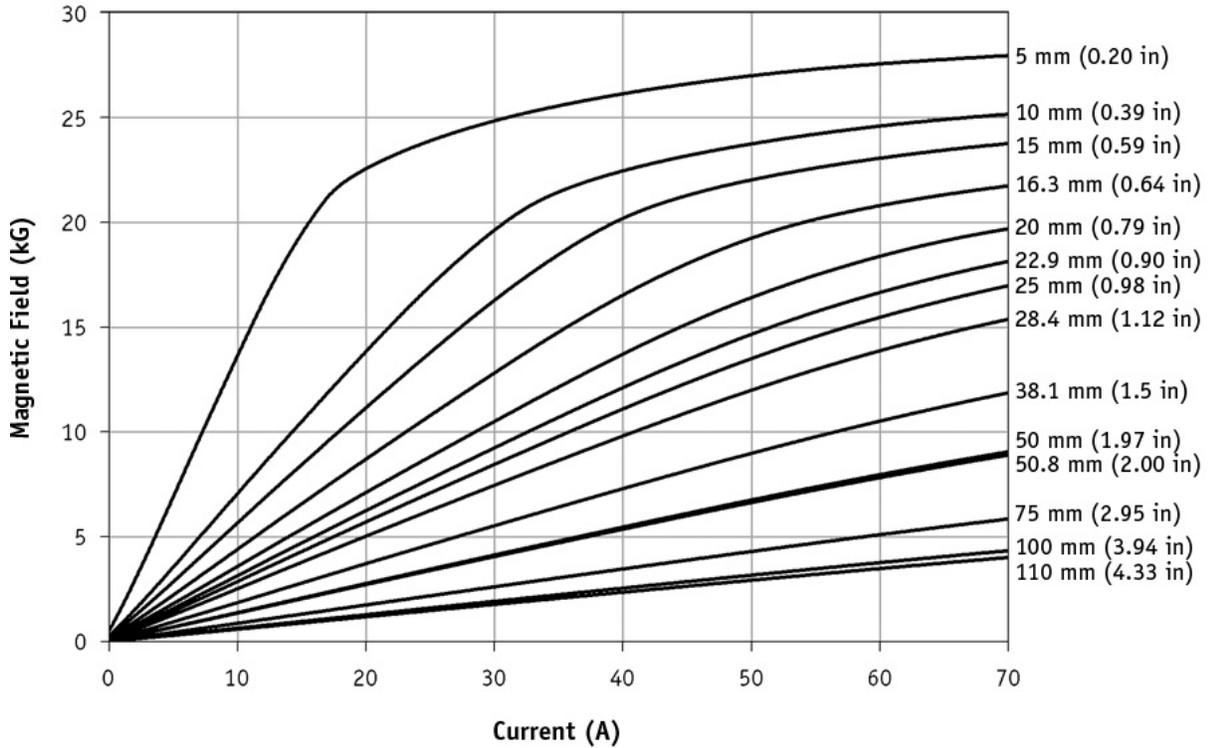


Figure 2-5. Typical Curves of Field vs. Current for Various Air Gaps and Pole Cap Sizes (Sheet 1 of 3)

EM4-HVA 5.1 cm (2 in) Pole Face Field Plot



EM4-HVA 7.6 cm (3 in) Pole Face Field Plot

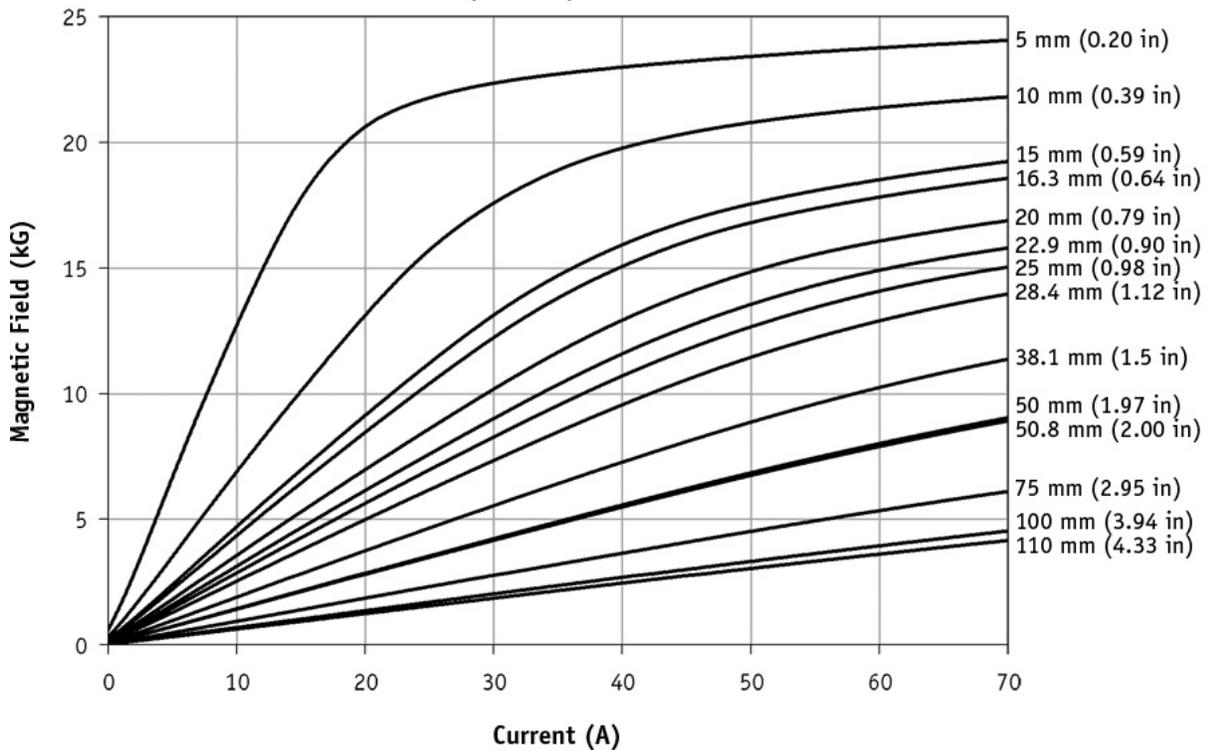


Figure 2-5. Typical Curves of Field vs. Current for Various Air Gaps and Pole Cap Sizes (Sheet 2 of 3)

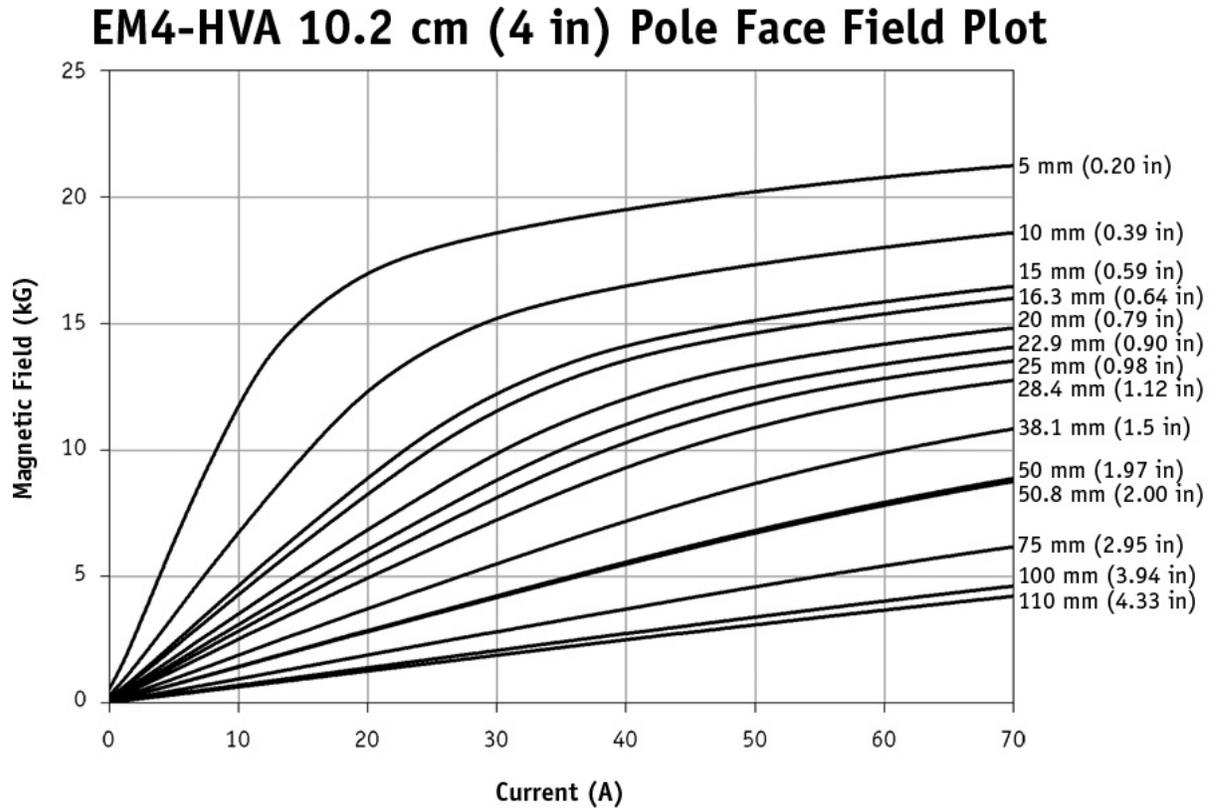


Figure 2-5. Typical Curves of Field vs. Current for Various Air Gaps and Pole Cap Sizes (Sheet 3 of 3)

2.4.3 Operation Under Field Control

To obtain a linear field ramp, a magnetic sensor such as a Hall probe is placed in the air gap along with the sample being tested. The sensor is connected to a Gaussmeter. The output of the Gaussmeter is used to correct the programming input to the power supply. In this way non-linearity can be corrected. Lakeshore manufactures probes and Gaussmeters for this purpose.

2.4.4 Avoiding Cooling Water Condensation

If the temperature of the cooling water is too cool relative to the air temperature and humidity, condensation can occur. Condensation inside the power supply can cause severe damage. To avoid condensation, the power supply operator must remain cognizant of the ambient air temperature, cooling water temperature, and the relative humidity. Lake Shore defines the limits of these conditions as follows: ambient temperature = 18–28 °C (64–82 °F), cooling water temperature = 15–25 °C (59–77 °F), and humidity = 20–80% (non-condensing). Knowing the actual state of these conditions, the operator can calculate the dew point, or temperature at which condensation will occur. Tables 2-1 and 2-2 are included to aid in dew point calculation.

Table 2-1. Dew Point Calculation Table (In Degrees Celsius)

| °C | % Relative Humidity | | | | | | | | | | | | | | | | | | |
|----|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| | 100 | 95 | 90 | 85 | 80 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 |
| 32 | 32 | 31 | 31 | 29 | 28 | 27 | 26 | 24 | 23 | 22 | 20 | 18 | 17 | 15 | 12 | 9 | 6 | 2 | 0 |
| 29 | 29 | 28 | 27 | 27 | 26 | 24 | 23 | 22 | 21 | 19 | 18 | 16 | 14 | 12 | 10 | 7 | 3 | 0 | – |
| 27 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 19 | 18 | 17 | 15 | 13 | 12 | 10 | 7 | 4 | 2 | 0 | – |
| 24 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 14 | 13 | 11 | 9 | 7 | 5 | 2 | 0 | – | – |
| 21 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 10 | 8 | 7 | 4 | 3 | 0 | – | – | – |
| 18 | 18 | 17 | 17 | 16 | 15 | 14 | 13 | 12 | 10 | 9 | 7 | 6 | 4 | 2 | 0 | – | – | – | – |
| 16 | 16 | 14 | 14 | 13 | 12 | 11 | 10 | 9 | 7 | 6 | 5 | 3 | 2 | 0 | – | – | – | – | – |

Table 2-2. Dew Point Calculation Table (In Degrees Fahrenheit)

| °F | % Relative Humidity | | | | | | | | | | | | | | | | | | |
|----|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| | 100 | 95 | 90 | 85 | 80 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 |
| 90 | 90 | 88 | 87 | 85 | 83 | 81 | 79 | 76 | 74 | 71 | 68 | 65 | 52 | 59 | 54 | 49 | 43 | 36 | 32 |
| 85 | 85 | 83 | 81 | 80 | 78 | 76 | 74 | 72 | 69 | 67 | 64 | 61 | 58 | 54 | 50 | 45 | 38 | 32 | – |
| 80 | 80 | 78 | 77 | 75 | 73 | 71 | 69 | 67 | 65 | 62 | 59 | 56 | 53 | 50 | 45 | 40 | 35 | 32 | – |
| 75 | 75 | 73 | 72 | 70 | 68 | 66 | 64 | 62 | 60 | 58 | 55 | 52 | 49 | 45 | 41 | 36 | 32 | – | – |
| 70 | 70 | 68 | 67 | 65 | 63 | 61 | 59 | 57 | 55 | 53 | 50 | 47 | 44 | 40 | 37 | 32 | – | – | – |
| 65 | 65 | 63 | 62 | 60 | 59 | 57 | 55 | 53 | 50 | 48 | 45 | 42 | 40 | 36 | 32 | – | – | – | – |
| 60 | 60 | 58 | 57 | 55 | 53 | 52 | 50 | 48 | 45 | 43 | 41 | 38 | 35 | 32 | – | – | – | – | – |

Example: Determine the actual air temperature and relative humidity. Find the closest air temperature in the left-hand column and the closest relative humidity across the top. If the air temperature is 24 °C (75 °F) and the relative humidity is 35%, the intersection of the two shows a dew point of 7 °C (45 °F). Therefore, for the given conditions, the cooling water must remain above 7 °C (45 °F) to prevent condensation.

CHAPTER 3

INSTALLATION

3.0 GENERAL

This chapter provides general installation instructions for the Model 642 Electromagnet Power Supply. **CAUTION:** To ensure the best possible performance and maintain operator safety, read this entire chapter before installing the instrument and applying power. Serious hazards can exist when an instrument of this power capacity is used incorrectly. If you do not understand any section of this manual, consult Lake Shore for clarification. Lake Shore Cryotronics assumes no responsibility for damage or injuries incurred due to improper installation, defeat of any of the safety features or misuse of this power supply.

3.1 INSPECTION AND UNPACKING

Inspect shipping containers for external damage before opening them. Photograph any container that has significant damage before opening it. If there is visible damage to the contents of the container, contact the shipping company and Lake Shore immediately, preferably within 5 days of receipt of goods. Keep all damaged shipping materials and contents until instructed to either return or discard them.

Open the shipping container and keep the container and shipping materials until all contents have been accounted for. Check off each item on the packing list as it is unpacked. Instruments themselves may be shipped as several parts. The items included with the Model 642 are listed below. Contact Lake Shore immediately if there is a shortage of parts or accessories. Lake Shore is not responsible for any missing items if not notified within 60 days of shipment.

Inspect all items for both visible and hidden damage that occurred during shipment. If damage is found, contact Lake Shore immediately for instructions on how to file a proper insurance claim. Lake Shore products are insured against damage during shipment but a timely claim must be filed before Lake Shore will take further action. Procedures vary slightly with shipping companies. Keep all shipping materials and damaged contents until instructed to either return or discard them.

If the instrument must be returned for recalibration, replacement or repair, a returned goods authorization (RA) number must be obtained from a factory representative prior to return. The Lake Shore RA procedure is given in Paragraph 7.2.

Items Included with Model 642 Electromagnet Power Supply:

- 1 – Model 642 Instrument
- 1 – Model 642 User's Manual
- 2 – Front Handles (shipped attached)
- 2 – Rear Handles (shipped attached)
- 1 – Analog I/O Mating Connector
- 1 – Output Terminal Fasteners (set)
- 1 – Wiring Cover Plate and Screws
- 2 – 4 Pin Detachable Terminal Blocks
- 1 – 8 Pin Detachable Terminal Block
- 2 – Hose Clamps
- 1 – Output Lug Cover and Screws

3.1.1 Moving and Handling

Four handles are provided for ease of moving and handling the Model 642. The handles can be used in place of lifting lugs when cloth straps are used. Always use all four handles when moving the Model 642. Because of its weight, the Model 642 should be handled by mechanical means. If for some reason it is necessary to move it by hand, a minimum of two people is required.

CAUTION: To avoid injury to personnel, always observe proper lifting techniques in accordance with OSHA and other regulatory agencies.

3.2 REAR PANEL DEFINITION

This paragraph defines the rear panel of the Model 642. Refer to Table 3-1. Readers are referred to paragraphs that contain installation instructions and connector pin-outs for each feature.

CAUTION: Verify that the Model 642 has been set up for the proper line voltages.

CAUTION: Make rear panel connections with the instrument power off.

Table 3-1 below highlights the connections to be made on the rear panel. Figure 3-1 shows the rear panel and identifies the connectors.

Table 3-1. Rear Panel Connector Identification

| | | |
|----|-------------------------------|---|
| 1 | VOLTAGE SELECTION | 16 DIN terminals are provided behind a wiring cover to facilitate setting the correct input voltage. |
| 2 | CIRCUIT BREAKER | An adjustable current auto-resetting circuit breaker is provided behind a wiring cover to protect main power circuits. |
| 3 | FUSES | ¼ A Class CC fuses (2) are provided behind a wiring cover to protect the start-up circuit. |
| 4 | CABLE ENTRY | A 34 mm (1.3 inch) hole is provided for power cable entry and strain relief bushing. |
| 5 | POWER TERMINALS | Four DIN terminals are provided behind a wiring cover for connection of power wiring. |
| 6 | MAGNET CONNECTOR | A 4-pin detachable screw terminal block is provided to connect the optional magnet water valve power and temperature and/or flow switch. |
| 7 | AUXILIARY CONNECTOR | An 8-pin detachable screw terminal block is provided to connect the optional Emergency Stop, Remote Fault Indicator, Remote Enable and Chassis Ground. |
| 8 | POWER SUPPLY CONNECTOR | A 4-pin detachable screw terminal block is provided to connect the optional power supply water valve power and/or flow switch. |
| 9 | COOLING WATER | Two 10 mm (3/8") hose barbs are provided for input and output of cooling water. |
| 10 | OUTPUT TERMINALS | Two output lugs are provided for the magnet cable connections. Refer to Paragraph 3.8 and Figures 3-13 and 3-14 for connecting the magnet cables to the instrument. |
| 11 | ANALOG I/O | A 15-pin D subminiature connector provides output for current and voltage monitoring, as well as analog programming input. Refer to Paragraph 3.9 and see Figure 7-7. |
| 12 | RS-232C (DTE) | A 9-pin D subminiature plug wired in DTE configuration is provided for use with RS-232C serial computer interface. Refer to Paragraph 5.2.2 and see Figure 7-11. |
| 13 | IEEE-488 INTERFACE | An IEEE-488 compliant interface connector is provided for use with IEEE-488 parallel computer interface. Refer to Paragraph 5.1 and Figure 7-12. |
| 14 | CHASSIS CONNECTION | An earth safety chassis connection is provided to facilitate connection to the magnet frame if noise problems exist. |
| 15 | DETACHABLE HANDLES | Two high-strength detachable handles are provided to aid in handling and lifting. |

Line Voltage Selection (Continued)

Changing line voltage is accomplished by moving four wires to the required voltage terminals. The required location is shown in Figure 3-2. To change the voltage setting, loosen the four terminal screws in the voltage-change terminal block to which the wires are connected and move the wires to the required voltage position. The wires are held in place in a locator card to maintain their spacing and prevent mis-wiring. The screws in the new terminal location must be loosened four full turns to allow the entry of the wires. Move all four wires at once by lifting the locator card to extract the wires from the terminals. Move the card and wires to the correct location and insert the wires completely so that the card rests against the terminals. While holding the locator card in place to keep the wires fully inserted, tighten the terminal screws. The recommended torque requirement is 0.5 Nm. Also, tighten the four terminals where the wires were previously.

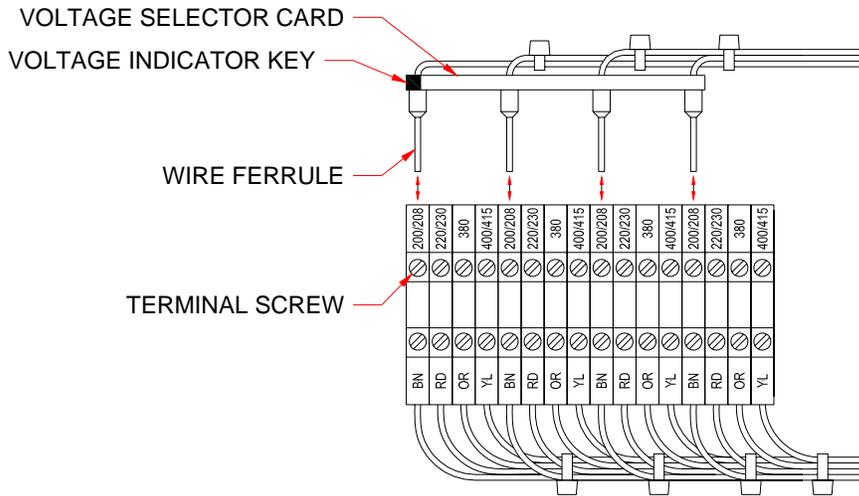


Figure 3-2. Voltage Change Detail

3.3.2 Circuit Breaker Setting

The circuit breaker is an important safety feature of the Model 642. The required current setting depends on the voltage for which the unit is wired. (Refer to Table 3-2.) Verify that the circuit breaker is set correctly for the line voltage being applied to the unit. To set the breaker trip current, open the access cover on the circuit breaker and adjust the current setting dial to the correct value. (See Figure 3-3.)

NOTE: The circuit breaker has an automatic reset feature. If the breaker trips, it will reset within a few minutes and the unit can be restarted. If the units trips again after a short time, the trip current may be set incorrectly.

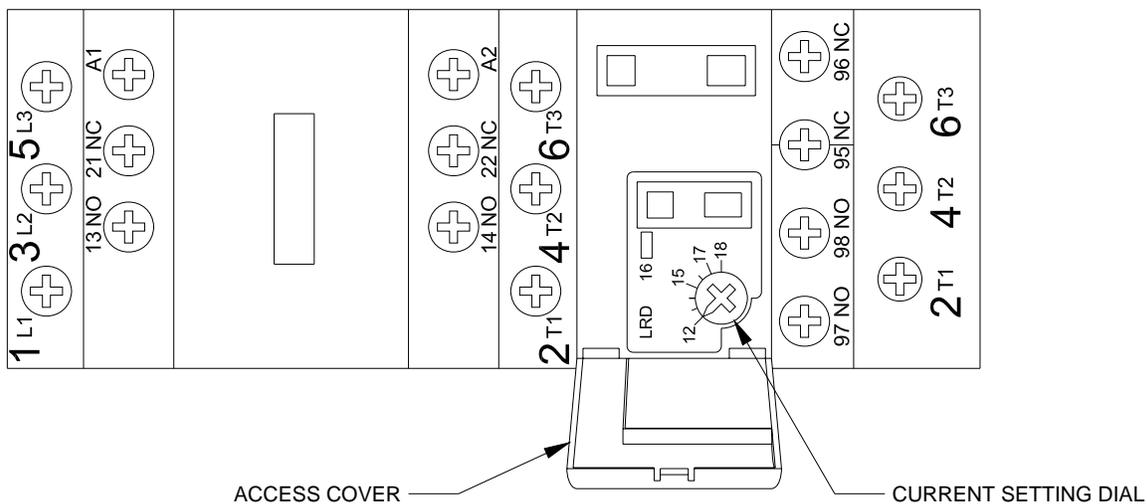


Figure 3-3. Circuit Breaker

3.3.3 Start-up Fuses

The start-up transformer and associated circuitry are energized whenever the power is connected. To protect this circuitry, two ¼ A, class CC fuses are provided. A fuse is accessed by pulling open the access door on the fuse holder as shown in Figure 3-4. The fuses are inserted small-end first as shown.

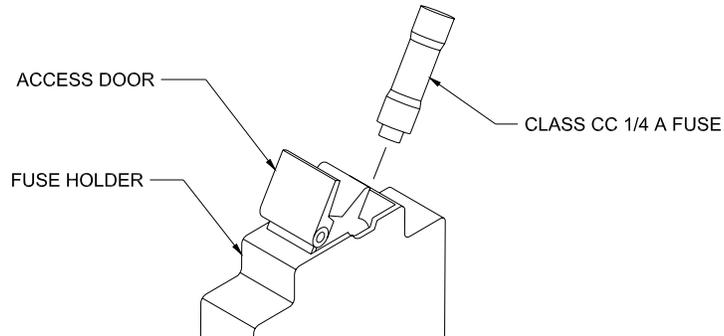


Figure 3-4. Fuses

3.3.4 Cable Entry

A 34 mm (1.3 inch) diameter hole is provided for the power cable to enter the unit. A bushing is provided which will accommodate a 16-19 mm (0.62-0.75 in) round neoprene jacketed cable (See Chapter 6). If a different cable is used, a strain relief of the appropriate type and size must be provided by the installing agency.

CAUTION: Failure to install a strain-relief bushing is a hazard and could cause injury or death to operating personnel in the event of a fault. Lake Shore reserves the right to void the warranty of any instrument not properly installed.

A typical cable entry with bushing is shown in Figure 3-5.

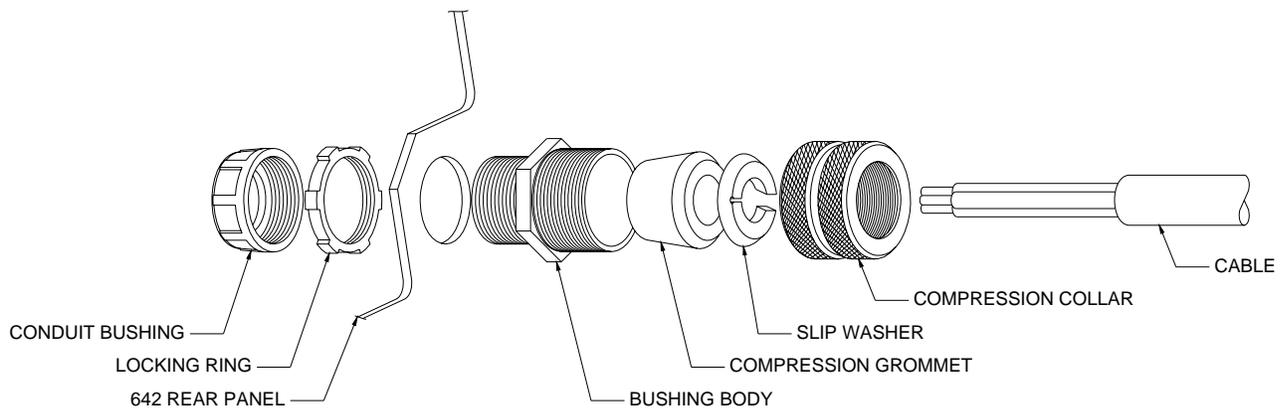


Figure 3-5. Typical Cable Entry with Bushing

3.3.5 Power Input Terminals

The Model 642 requires a 4 conductor power cord (not included). The input to the Model 642 is wired in a delta configuration, but will operate from a delta or wye source. If operating from a wye source, the neutral line (N) is not used. The ground (the green/yellow ground terminal) connects the instrument chassis to the electrical ground (safety ground), and is required to prevent fault conditions which may be hazardous to operating personnel. In no case should the safety ground line be omitted. In no case should a neutral line be used as a safety ground. If a detachable cord is used, always plug the power cord into a properly grounded receptacle to ensure safe operation of the instrument. All wiring must comply with the code requirements of the locality in which the instrument is installed. Figure 3-6 shows typical input wiring. The wire ferrules shown are not required, but are recommended to prevent stray strands from shorting to adjacent terminals.

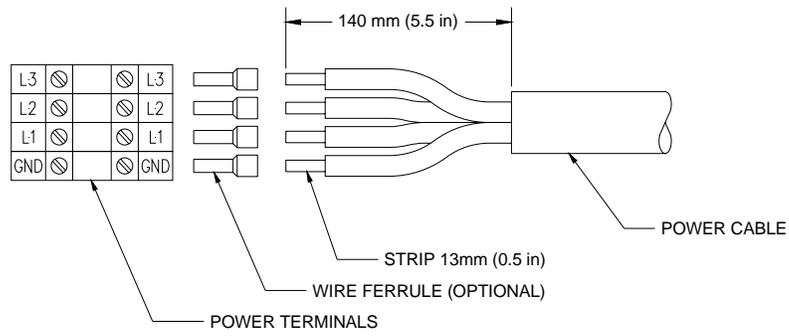


Figure 3-6. Typical Power Input Wiring

3.3.6 Wiring Cover

When the power wiring, voltage setting and current setting are complete, install the wiring cover with the six (6) 6-32 \times 3/8 screws provided. The wiring cover installation is shown in Figure 3.7. Be sure that the voltage indicator tab of the voltage locator card (Figure 3.2) shows through the correct indicator slot in the wiring cover.

WARNING: Do not connect power or attempt to operate the unit with this cover removed. Lethal voltage and currents exist inside. There is a risk of injury or death if an operator or technician comes in contact with these potentials.

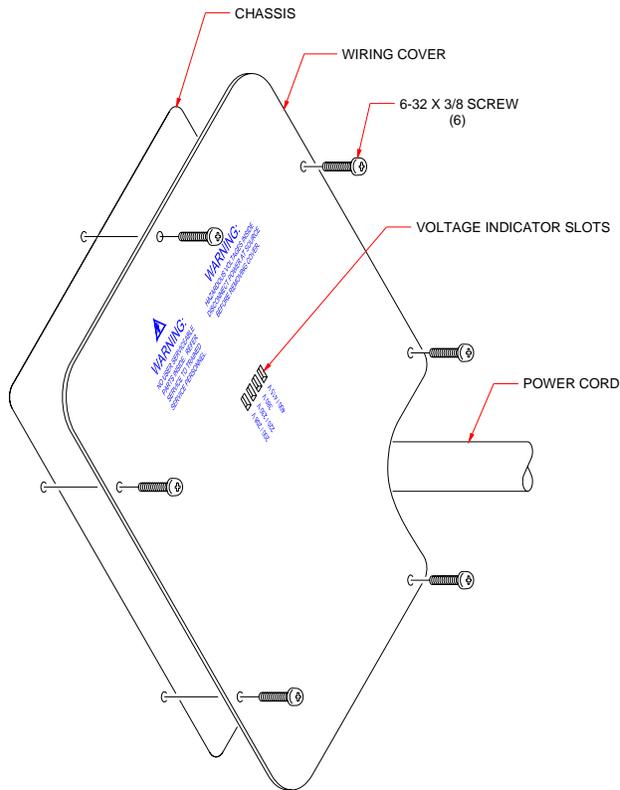


Figure 3-7. Wiring Cover Installation

3.3.7 Mains Wiring

No cord or disconnecting plug is provided with the unit. In all cases, the field connection of the mains wiring shall comply with all local wiring codes where the Model 642 is installed. The power source shall be protected with a dedicated circuit breaker or fuse. The rating of the protection device shall be a value equal to that of the internal breaker or the next higher commercially available value (See Table 3-2). If the Model 642 is connected with permanent wiring, a disconnect switch shall be installed. The disconnect switch shall be located within 3 meters (10 feet) of the Model 642, be clearly marked in layman's language and be easily accessible.

3.4 MAGNET CONNECTOR

The magnet connector provides terminals for an optional magnet temperature switch or magnet water flow switch and an optional magnet water control solenoid valve. The flow or temperature switch must have a normally closed contact rated at 5 V at 10 mA. A contact closure is required to enable the Model 642 output. If a switch is not used, a jumper is required. 24 VAC at 1 A is provided to operate a solenoid water valve for the magnet. This output is controlled by the power supply, either automatically via software, or manually through the Magnet Water menu.

Water control is desirable to reduce water consumption when the water comes from a municipal facility. Turning the water off when it is not required also reduces the probability of condensation on the magnet or connecting hoses. If the cooling water comes from a facility chiller system, condensation is not usually a problem and a control valve is not required. In this case, it is appropriate to install a flow switch (optional) or temperature switch (optional) to monitor the water flow and protect the magnet in the event of a water flow interruption. Figure 3-8 shows examples of typical magnet connector wiring.

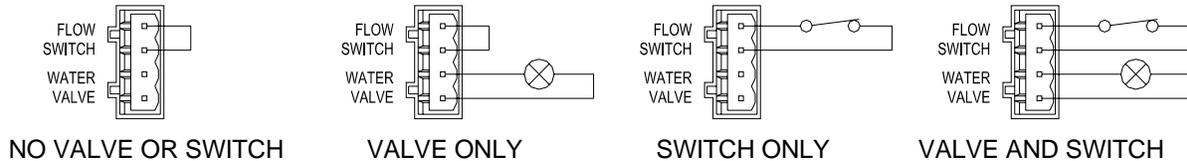


Figure 3-8. Typical Magnet Connector Wiring

3.5 AUXILIARY CONNECTOR

The Auxiliary connector provides terminals for an emergency stop, contacts for a remote alarm, remote enable and a chassis connection. The Emergency Stop must have a normally closed contact rated at 24 V at 1 A. When the contact is opened, it turns off the Model 642. If an Emergency Stop switch is not used, a jumper is required. A normally closed or normally open contact is provided to control a remote alarm annunciator. This set of contacts is rated at 30 V, 1 A. If it is desirable to have a remotely located alarm to echo the internal alarm, these contacts can be used with an external power source and external alarm. The Remote Enable switch must have a normally closed contact rated at 5 V at 10 mA. A contact closure is required to enable the Model 642 output. If a remote enable switch is not used, a jumper is required. Figure 3-8 shows some typical auxiliary connector wiring. A chassis terminal is provided in the event that any of the wires require a shield to minimize noise. Figure 3-9 shows some typical Auxiliary Connector wiring.

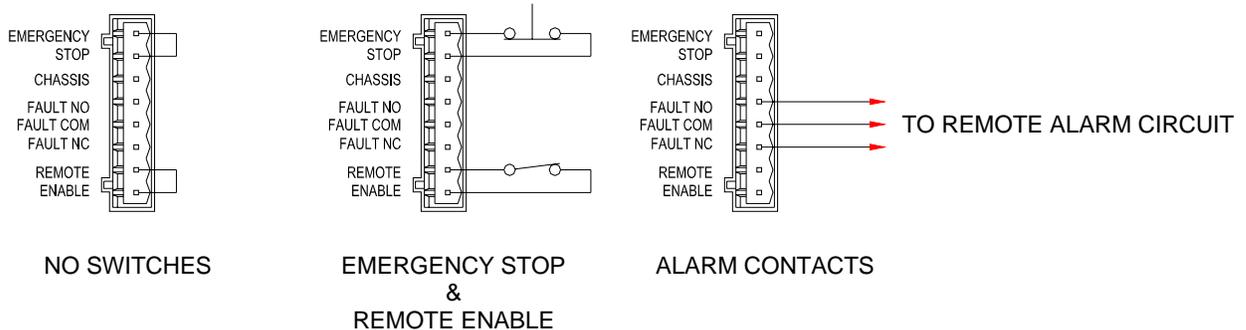


Figure 3-9. Typical Auxiliary Connector Wiring

3.6 POWER SUPPLY CONNECTOR

The Power Supply connector provides terminals for an optional water flow switch and an optional cooling water control solenoid valve. The flow switch must have a normally closed contact rated at 5 V at 10 mA contact closure is required to enable the Model 642 output. If a switch is not used, a jumper is required. 24 VAC at 1 A is provided to operate a water control solenoid valve for the power supply cooling water. This output is controlled by the power supply, either automatically via software, or manually through the Internal Water menu.

Water control is desirable to reduce water consumption when the water comes from a municipal facility. Turning the water off when it is not required also reduces the probability of condensation within the power supply and connecting tubing. If the cooling water comes from a facility chiller system, condensation is not usually a problem and a control valve is not required. Figure 3-10 shows some typical Power Supply Connector wiring.

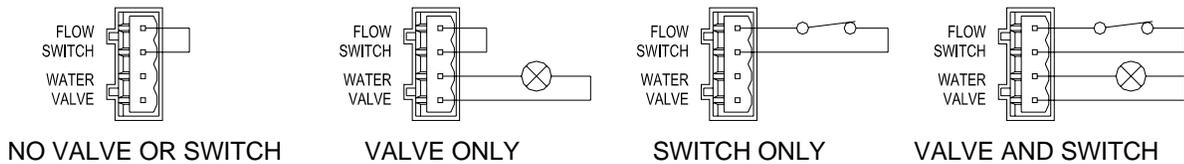


Figure 3-10. Typical Power Supply Connector Wiring

3.7 COOLING WATER

Two 10 mm (0.38 in) hose barbs are provided to connect to cooling water. The connection to the cooling water source should be made with two 10mm (3/8 in) I.D. fiberglass reinforced hoses and two 20mm (25/32 in) adjustable hose clamps. In addition, we recommend the installation of a sediment filter in the input line. A typical water hose connection is shown in Figure 3-11.

The cooling water must be clean and free from sediment, salt and other contaminants, which might clog or erode the water fittings. A minimum flow rate of 5.7 L (1.5 gal) per minute is required with a minimum pressure of 34 kPa (5 psi) and a maximum pressure of 552kPa (80 psi). The temperature must be kept above 15°C to avoid condensation and below 30°C to ensure adequate system cooling. If water is drawn from a local municipal water source, the optional water valve should be installed for economy and to prevent condensation (See 3.6 Power Supply Connector). If water is supplied by a facility chiller, a valve can still be used but is not required.

CAUTION: Do not use de-ionized water because it is corrosive to the water fittings inside the Model 642.

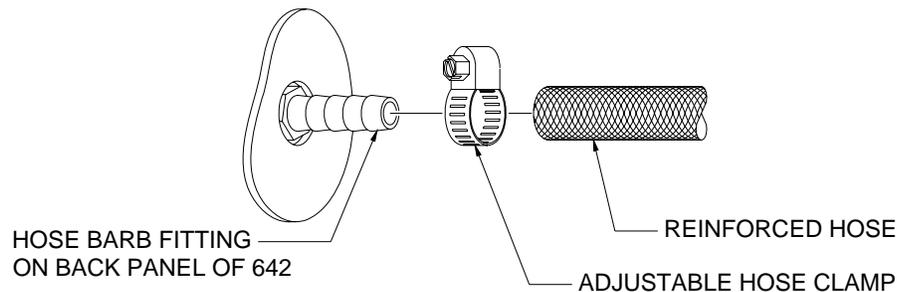


Figure 3-11. Typical Water Hose Connection

Figure 3-12 shows the connections required when a water valve is used. The optional solenoid water valve is supplied mounted to a bracket which mounts to the rear of the Model 642 as shown in Figure 3-12. Hose connections are made as shown in Figure 3-11.

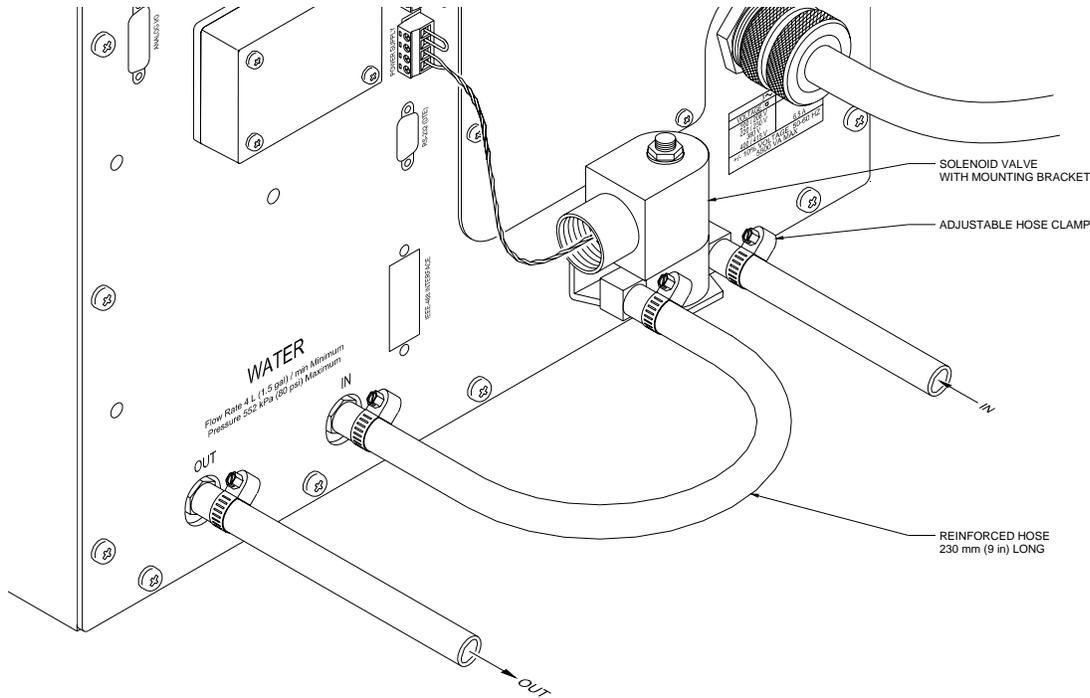


Figure 3-12. Water Valve Connection

3.8 MAGNET CABLE CONNECTIONS

Magnet cable connections are made at the OUTPUT + and – terminals on the rear panel. These plated copper bus bars accommodate M6 (¼ inch) mounting hardware. Two ¼-20 bolts, nuts, and Belleville washers are provided. Use load wires heavy enough to limit the voltage drop to less than 0.5 volts per lead. This ensures proper regulation and keeps the cables from overheating while carrying the required output current. Table 3-3 lists the current capacity and lead lengths for load connections. Lake Shore sells magnet cables in 10 and 20 foot lengths. Refer to Paragraph 6.2 for ordering accessories.

Figure 3-13 shows how the output cables are connected to the Model 642. A plain washer and a spring or Belleville washer are provided. The Belleville washer is required to maintain contact pressure through varying material thickness due to heating. The magnet leads should be dressed straight down to allow the installation of the protective lug cover. Lug cover installation is shown in Figure 3-14.

Table 3-3. Current Capacity and Total Lead Lengths

| AWG | Area (mm ²) | Capacity (A) | Resistivity Ω/1000 feet | Distance to Magnet |
|-----|-------------------------|--------------|-------------------------|--------------------|
| | | | | Max Output of 70 A |
| 0 | 53.5 | 245 | 0.09827 | 22 M (72 ft) |
| 2 | 33.6 | 180 | 0.1563 | 14 M (45ft) |
| 4 | 21.2 | 135 | 0.2485 | 8.5 M (28 ft) |
| 6 | 13.3 | 100 | 0.3951 | 5.5 M (18 ft) |
| 8 | 8.4 | 75 | 0.6282 | 3.4 M (11 ft) |

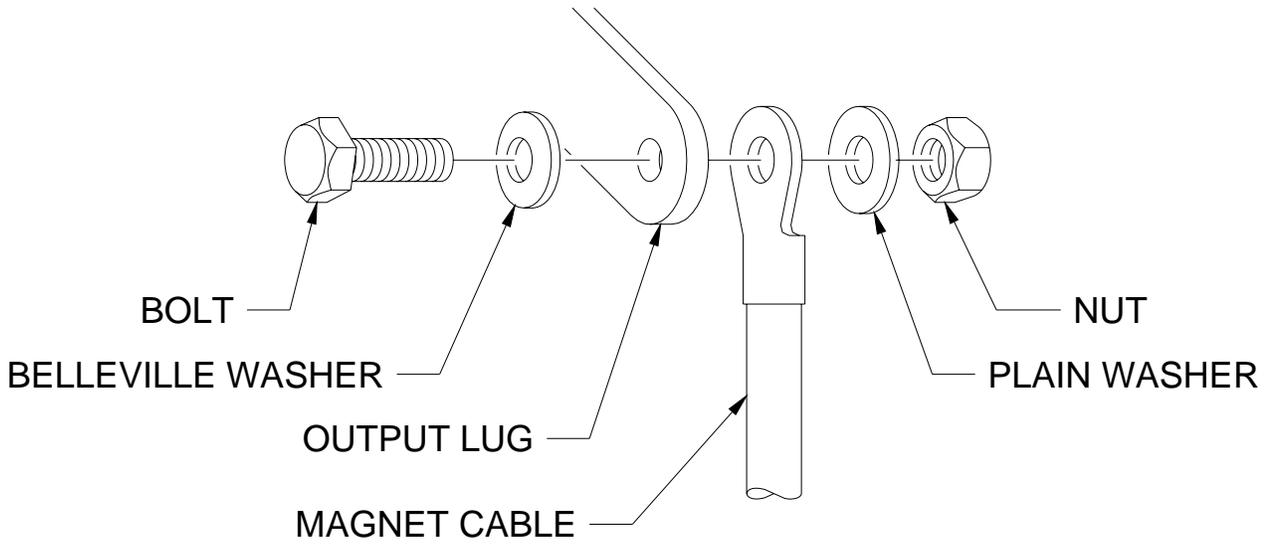


Figure 3-13. Output Cable Connection

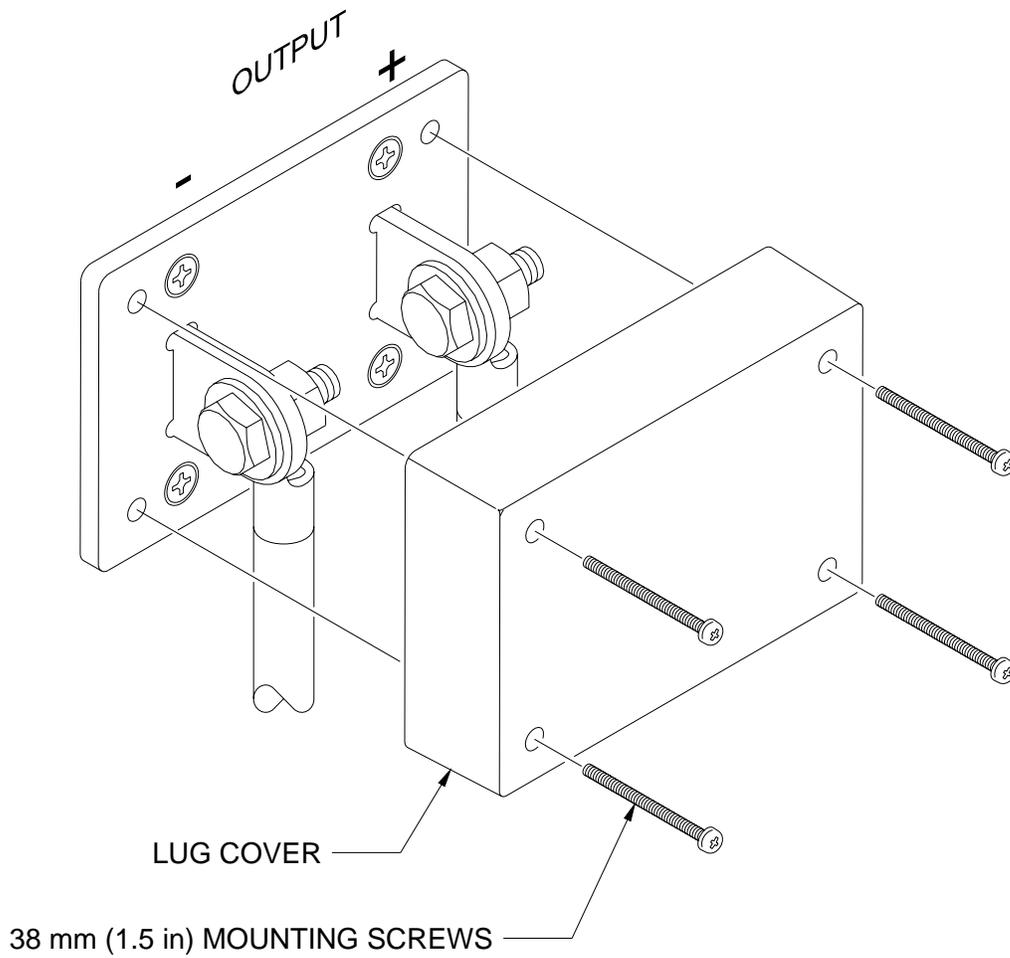
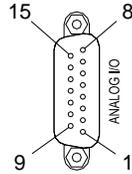


Figure 3-14. Output Lug Cover Installation

3.9 ANALOG INPUT/OUTPUT CONNECTIONS

The Analog I/O connector provides connections to analog signals used to monitor or control the power supply. A Current Program input is provided to control the current output. Two outputs are also provided to monitor the output current and the output voltage. The connector and pin-out table is shown in figure 3-15. Specific information on each function is provided in paragraphs 3.9.1 and 3.9.2.



| <i>Pin</i> | <i>Name</i> | <i>Pin</i> | <i>Name</i> |
|------------|-------------------|------------|-------------------|
| 1 | NC | 9 | NC |
| 2 | Chassis | 10 | Chassis |
| 3 | Current Program – | 11 | Current Program + |
| 4 | Chassis | 12 | Chassis |
| 5 | Voltage Monitor – | 13 | Voltage Monitor + |
| 6 | Chassis | 14 | Chassis |
| 7 | Current Monitor – | 15 | Current Monitor + |
| 8 | Chassis | | |

Figure 3-15. Model 642 Analog Input/Output Connector

3.9.1 External Current Programming

The output current can be programmed externally using an AC or DC voltage. This programming voltage can also be summed with the internal current setting or ramp. Refer to Paragraph 4.15 to change the external current program mode. The external current programming input is a differential input with a sensitivity of 10 V = 70 A and an input impedance of > 50 kΩ. The programming voltage is limited internally to approximately ±10.1 V (Category 1) but care must be taken to insure that maximum current capability of the magnet is never exceeded.

3.9.2 Output Current and Voltage Monitors

The output current and output voltage of the power supply can be monitored externally using the monitor output connections on the Analog I/O connector. Each output is a buffered, differential, analog voltage representation of the signal being monitored. The current monitor has a sensitivity of 7 V = 70 A and the voltage monitor has a sensitivity of 3.5 V = 35V. Both outputs have a source impedance of 20 Ω.

3.10 COMPUTER INTERFACE

The Model 642 can be programmed externally with a computer. Both RS-232C and IEEE-488 ports are provided.

3.10.1 RS-232C Interface Connection

An RS-232C port has been provided to allow remote computer control of the power supply. (Refer to Chapter 5, Computer Interface Operation)

3.10.2 IEEE-488 Interface Connection

An IEEE-488 port has been provided to allow remote computer control of the power supply. (Refer to Chapter 5, Computer Interface Operation)

3.11 CHASSIS CONNECTION

A 6-32 screw has been provided for attaching an optional chassis ground connection. This connection is normally not required. However, occasionally there are noise problems associated with a floating magnet or other ancillary equipment.

3.12 DETACHABLE HANDLES

The Model 642 is supplied with 4 detachable handles to enable handling. The handles should normally remain attached to the unit. However, in some cases it may be necessary to remove the handles to enable mounting in an equipment rack. In this case, handles may be removed but they should be stored in the rack with the power supply so that they may be reattached if the unit must be returned for service. Heavy duty handles have been installed to carry the weight of the power supply. No substitutions should be made. Light duty handles may fail when moving the supply causing the risk of injury to personnel and damage to equipment.

3.13 RACK MOUNTING

The Model 642 can be installed in a standard 19-inch rack mount cabinet and requires 311 mm (12.25 in) (7U) in height. At least 25 mm (1 in) of space should be provided on each side for cross ventilation. No ventilation panels are required above or below the unit. Due to the weight of the power supply, it is recommended that the supply be located at the bottom of the rack and that it rest on the bottom panel of the rack. If the rack does not have a bottom panel, a shelf, capable of supporting 74 kg (163 lb) must be provided. Light duty support rails, which bolt to the sides of the front and rear mounting rails of the rack are not strong enough to support this unit.

In addition, if the equipment rack which houses the Model 642 is to be shipped, the Model 642 must be anchored to the shelf. Threaded inserts are provided in the bottom of the Model 642 for this purpose. Four (4) 1/4-20 x 1/2 in bolts (not included) are required. The hole pattern for mounting is shown in Figure 3.16.

CAUTION: The front panel rack mount is to be used only to secure the power supply to the front of the rack. The bottom of the rack or the equipment shelf must support the entire weight of the supply. **Do NOT attempt to support the supply from the front mounting holes alone.**

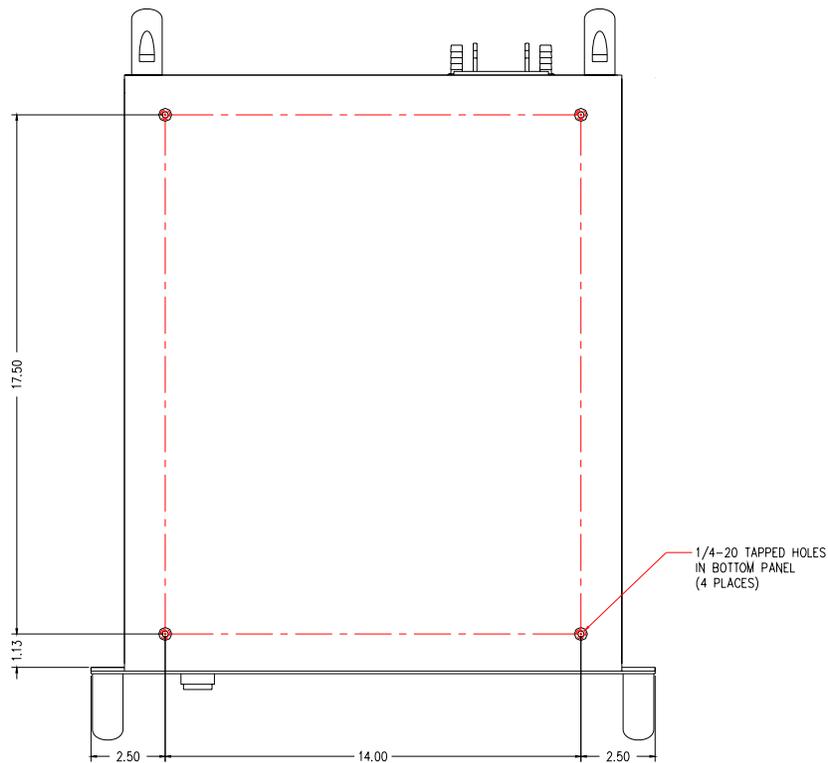


Figure 3-16. Mounting Hole Pattern

CHAPTER 4

OPERATION

4.0 GENERAL

This chapter provides operating instructions for the features of the Model 642 Electromagnet Power Supply. Computer interface instructions are in Chapter 5.

4.1 TURNING POWER ON

Verify that the AC line voltage indicator on the rear panel of the unit shows the appropriate AC line voltage before turning the instrument on. The instrument may be damaged if it is turned on with the incorrect voltage selected. Instructions for checking line voltage selection are given in Paragraph 3.3.1.

CAUTION: Be sure the unit is connected to an appropriate load before applying power.

Note: The Model 642 will not turn on if an Emergency Stop Switch is not connected or a jumper is not put in its place on the “Auxiliary” connector at the rear of the unit. The unit will not turn on if it is connected to a voltage source more than 10% greater than the voltage for which it is configured.

The power ON and OFF buttons are located in the lower left corner of the front panel. Press the ON button to energize the Model 642. The Model 642 can be de-energized by pressing the OFF button, by pressing an optional remote Emergency Stop button, or by the Model 642 software when a hazardous fault condition is detected. The ON and OFF buttons are illustrated in Figure 4-1.

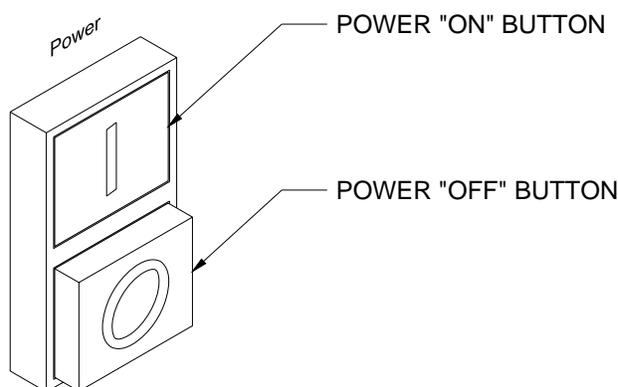


Figure 4-1. Model 642 Power Push Buttons

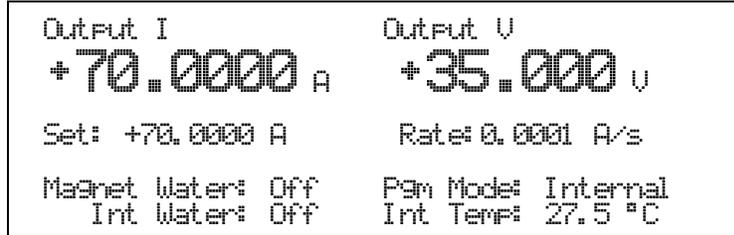
When the Model 642 is turned on, the display shows the Lake Shore logo and the alarm beeper sounds briefly. After a few seconds, a “Checking Hardware” message will appear in the center of the logo display while the instrument does an internal diagnostic and makes sure everything is working. Most of the instrument setup parameter values are retained when power is off with a few exceptions. The output current will always be set to 0 A anytime the instrument is powered up. When the instrument is powered on for the first time, parameter values are set to their defaults, as listed in Table 4-3.

When initialization is complete, the instrument will begin its normal reading cycle. Current and voltage readings should appear on the display. Any error messages will appear in the center of the display. Messages listed in Table 7-2, Instrument Hardware Errors, are related to the instrument hardware and may require help from Lake Shore service. The messages listed in Table 7-3, Operational Errors, are related to instrument operation and may be corrected with user intervention.

The Model 642 should be allowed to warm up for a minimum of 30 minutes to achieve rated accuracy.

4.2 DISPLAY DEFINITION

The Model 642 has an 8 line by 40 character vacuum fluorescent (VF) display capable of showing both text and graphic images. The features displayed during normal operation include current measurement, voltage measurement, current programming, ramp rate, magnet water status, internal water status, program mode, and internal temperature. Other display configurations appear during parameter setting and data entry operations. These displays are illustrated in their individual operation paragraphs. A typical display is shown below.



4.3 LED ANNUNCIATORS

There are five LED annunciators on the front panel that are used to indicate the status of the instrument. These provide easy verification of the operation of the instrument. See Figure 4-2 for LED locations.

Table 4-1. Model 642 LED Descriptions

| | |
|--------------------|---|
| Fault | On when a hardware fault condition exists, blinking when a soft fault condition exists. |
| Compliance | On when maximum compliance voltage is reached. |
| Power Limit | On when power in internal devices reaches the maximum limit. |
| Ramping | On when output current is ramping, blinking when ramp is paused. |
| Remote | On when instrument is in remote computer interface mode. |

4.3.1 Fault LED

The Fault LED will light whenever an error condition is encountered. It may also be accompanied by an alarm depending on the fault. (Refer to Table 7-2 Instrument Hardware Errors, and Table 7-3 Operational Errors.)

4.3.2 Compliance LED

The Compliance LED lights whenever the maximum output voltage is reached. This can happen when attempting to rapidly ramp a magnet with higher than usual voltage required to overcome the magnet's inductance. The led will go out when the condition clears.

4.3.3 Power Limit LED

The Model 642 has a hardware power limit to protect the internal power MOSFETs. If the power supply is driving a load which has a resistance lower than the supply's rated minimum, the power required may be higher than the devices can safely handle. If this happens, the power in the devices is prevented from exceeding the safe limit and the Power Limit LED will light to alert the operator to the condition. The led will go out when the condition clears.

4.3.4 Ramping LED

The Ramping LED lights whenever the internal control circuitry is changing the output current. When the ramp is completed and the current is at the desired point, the LED goes out. The LED does not light when the output current is being controlled by an external source.

4.3.5 Remote LED

The Remote LED is lit when the Remote key has been pressed to accept remote computer programming input, or upon receiving the first command over the IEEE bus. When the LED is lit, the main keypad is locked out. Pressing the Local key will return the unit to the local mode and reestablish keypad functions.

4.4 KEYPAD DEFINITION

The Model 642 has 22 keys separated into 3 groups on the instrument front panel. The sixteen keys in the center of the grouping combines instrument setup and data entry. The keys below control the output current and ramping. The keys to the right control the computer interface mode of the instrument. See Figure 4-2 for key locations. Refer to Table 4-2 for keypad descriptions.

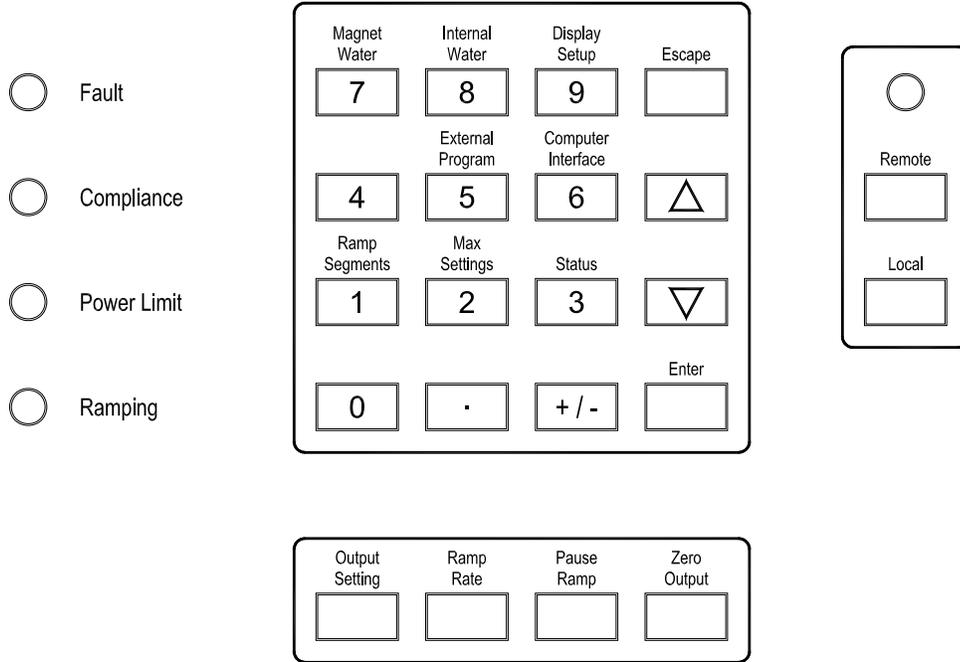


Figure 4-2. Model 642 Keypad and LED Layout

Table 4-2. Model 642 Key Descriptions

| | |
|---------------------------|--|
| Magnet Water | Selects the magnet water setup menu. Refer to Paragraph 4.12. |
| Internal Water | Selects the internal water setup menu. Refer to Paragraph 4.13. |
| Display Setup | Sets the display brightness. Refer to Paragraph 4.5. |
| Escape | Exits from parameter setting sequence without changing the parameter value. Press and hold to reset parameters to default values. Refer to Paragraph 4.18. |
| External Program | Setup the external current programming mode. Refer to Paragraph 4.15. |
| Computer Interface | Setup RS-232C and IEEE-488 computer interfaces. Refer to Paragraph 4.17. |
| Ramp Segments | Setup ramp segment values. Refer to Paragraph 4.8. |
| Max Settings | Setup maximum setting limits for output current, and ramp rate. Refer to Paragraph 4.11. |
| Status | Displays a summary of the instrument status. Refer to Paragraph 4.14. |
| Enter | Accepts a new parameter value. Press and hold to lock keypad. Refer to Paragraph 4.16. |
| 0-9, ±, . | Numeric data entry within a setting sequence. |
| ↶ (Up) | Increments a parameter selection or value. |
| ↷ (Down) | Decrements a parameter selection or value. |
| Output Setting | Sets the output current. Refer to Paragraph 4.6. |
| Ramp Rate | Sets the output current ramp rate. Refer to Paragraph 4.7. |
| Pause Ramp | Pauses the output ramp and holds the current where it was pause pressed. Press again to continue ramp. Refer to Paragraph 4.9. |
| Zero Output | Ramps the current to 0 A at the programmed ramp rate. Refer to Paragraph 4.10. |
| Remote | Places the instrument to Remote mode. Refer to Paragraph 5.1.2. |
| Local | Returns the instrument to Local mode if in Remote. Refer to Paragraph 5.1.2. |

4.4.1 General Keypad Operation

The Model 642 uses three basic keypad operations, direct operation, setting selection, and data entry, for the majority of operator interface. A few specialized keypad operations, such as ramp segment entry, are described in the individual operation paragraphs.

Direct Operation: Key functions occur immediately when the key is pressed. **Pause Ramp** and **Zero Output** are examples of keys that operate this way.

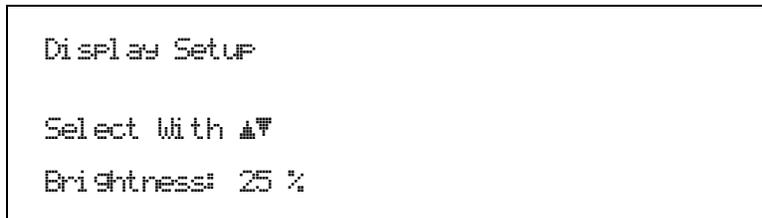
Setting Selection: Allows the user to select from a finite list of parameter values. During setting selection the \leftarrow and \rightarrow keys are used to select a parameter value. **Enter** is used to accept the change and advance to the next parameter. **Escape** will cancel the change to that parameter and return to the normal display. Setting selection screens always include the message: "Select with \leftarrow ".

Data Entry: Allows the user to enter numeric parameter values using the data entry keys that are printed on the key tops. Data entry keys include numbers from 0 to 9, \pm sign, and decimal point. The labels printed above the keys describe the key function during normal operation. When one of the keys is pressed and a data entry sequence is started, the keys follow the data entry functions printed on the key tops. Once the correct parameter value is entered, press **Enter** to accept the change and advance to next parameter. Pressing **Escape** once will clear the new value and restart the setting sequence. Pressing **Escape** again will return to the normal display. Data entry screens always include the message: "Enter a value for".

Related setting selection and data entry sequences are often chained together under a single key. To skip over a parameter without changing its value, press **Enter** before pressing an arrow or number key. To return to the normal display in the middle of a setting sequence, press **Escape** before pressing an arrow or number key. Changes entered before **Escape** is pressed are kept.

4.5 DISPLAY SETUP

The Display Setup allows the user to set the display brightness. The vacuum fluorescent (VF) display on the Model 642 has four brightness settings between 25% and 100% that can be changed from the front panel. The brightness setting changes the entire VF display but does not affect the LED annunciators to the right of the display. Continuous use of the instrument at 100% brightness will reduce the operating life of the display and brightness of 25%, the default setting, is recommended for most applications. To change the display brightness, press **Display Setup** and the brightness setup will appear.



```
Display Setup
Select With ▲▼
Brightness: 25%
```

Use the \blacktriangle or \blacktriangledown key to select brightness, 25%, 50%, 75%, or 100%. Press **Enter** to accept the new selection and return to the normal display. Press **Escape** to cancel the new selection and return to the normal display.

4.6 SETTING OUTPUT CURRENT

The main purpose of the Model 642 Electromagnet Power Supply is to supply a very precise and stable current to a magnet load. Before setting output current, **make sure that the instrument is properly setup for the magnet system that is being used.** This includes setting up the maximum output current and maximum ramp rate. When a new output current setting is entered, the supply will ramp to the new setting at the current ramp rate, unless limited by the fixed compliance voltage. The Ramping LED will be lit while the output current is ramping. When the output current setting is entered, it will be limited in magnitude by the maximum current setting. Refer to Paragraph 4.11 to setup the maximum settings.

Setting Output Current (Continued)

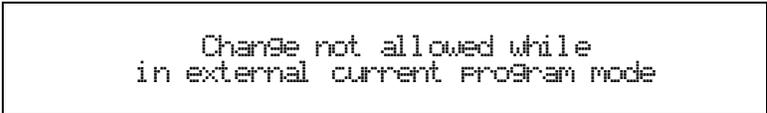
To change the output current setting, press the **Output Setting** key. The output current setting value on the normal display will be highlighted to prompt for the new output current setting value.



Use the data entry keys to enter an output current setting value between -70.0000 and $+70.0000$. Press **Enter** to accept the new value. Press **Escape** to restart the setting sequence and enter a different value. Press **Escape** again to leave the setting sequence.

NOTE: The output current setting value can be set as high as ± 70.1000 A. This can be used to compensate for variances in calibration. The output current is guaranteed to reach a minimum of 70 A into a 0.5 ohm load but may not be able to reach 70.1 A in all circumstances.

The output current setting is not allowed to change if the instrument is setup so that the output current is programmed solely by an external voltage. Refer to Paragraph 4.15 to setup the external current program mode.



4.7 CURRENT RAMP RATE

The output current of the Model 642 will always ramp from one current setting to another. There is no way to turn off the current ramping function, but if a very fast ramp rate is desired, a ramp rate as high as 99.999 A/s can be entered.

To change the current ramp rate press the **Ramp Rate** key. The ramp rate value on the normal display will be highlighted to prompt for the new ramp rate value.



Use the data entry keys to enter the ramp rate value between 0.0001 and 99.999 A/s. Press **Enter** to accept the new value. Press **Escape** to restart the setting sequence and enter a different value. Press **Escape** again to leave the setting sequence.

4.8 RAMP SEGMENTS

The magnetic field produced by electromagnets is not linear with current setting. The best way to compensate for this is to use closed loop field control but if absolute accuracy is not necessary than some of this nonlinearity can be corrected by the use of the ramp segments feature. The ramp segments feature can be used to increase the current ramp rate as the magnet saturates in an attempt to maintain the same field ramp rate. This feature can change the output current ramp rate based on the output current setting. As the output setting ramps through the segment boundary, the new ramp rate will be used although it will still be limited by the maximum ramp rate setting. Refer to Paragraph 4.11.2 to set the maximum ramp rate.

To use the ramp segment feature, the ramp segments must be enabled and the ramp segment table must be setup to specify which ramp rate to use for each current setting. The table should be setup in order of increasing current. A current entry of 0 A indicates the end of the table and the instrument will not search any higher in the table.

Ramp Segments (Continued)

To configure the ramp segments press **Ramp Segments**. The first ramp segments setup screen appears as a prompt for the ramp segments mode.

```
Ramp Segments
Select With ▲▼
Ramp Segments: Enable
```

Use the ▲ or ▼ key to select the ramp segments mode, either Enable or Disable. Press **Enter** to accept the new selection and continue to the next setting screen. Press **Escape** to cancel the new selection and return to the normal display.

If the ramp segments are enabled, the next ramp segments screen that appears is for entering or editing the ramp segments table. All five of the ramp segments are shown on the display at the same time. The segments should be entered in order of increasing current. An entry of 0 A will indicate the end of the table and the instrument will not search beyond that segment.

```
Ramp Segments
Current      Ramp Rate
1: 10.0000 A  1.0000 A/s
2: 15.0000 A  0.8000 A/s
3: 20.0000 A  0.7000 A/s
4: 30.0000 A  0.6000 A/s
5: 40.0000 A  0.5000 A/s
```

When the segment number is highlighted, use the ▲ or ▼ key to scroll through the ramp segments. Press the **Enter** key when the desired segment number is highlighted and continue to the current field.

When the current field is highlighted, use the numerical keypad to enter the upper current setting for that ramp segment in amps. Press **Enter** to accept the new selection and continue to the ramp rate field. Press **Escape** to restart the setting sequence and enter a new value. Press **Escape** again to highlight the segment number.

When the ramp rate field is highlighted, use numerical keypad to enter the applicable ramp rate in A/s. Press **Enter** to accept the new selection and continue to the next segment. Press **Escape** to restart the setting sequence and enter a new value. Press **Escape** again to highlight the segment number.

Similarly enter or edit all ramp segments. When complete, press the **Escape** key while the segment number field is highlighted to exit the ramp segment edit screen and return to the normal display. When output current is called for using the Output Setting key, the output will ramp to the desired current using the ramp segment set points.

4.9 PAUSE RAMP

The **Pause Ramp** key will pause the output current ramp within two seconds after the key is pressed. While the output current ramp is paused, the Ramping LED will blink. Pressing the **Pause Ramp** key again will continue the ramping. Pressing the **Enter** key while the ramp is paused will set the current at the paused setting and exit the **Pause Ramp** mode.

4.10 ZERO OUTPUT

The **Zero Output** key on the front panel can be used to set the output current to 0 A. When the **Zero Output** key is pressed, the current output will begin to ramp down using the current ramp rate. This key is equivalent to using the **Output Setting** key and entering 0 A except that it works even when the Model 642 is being programmed externally. Refer to Paragraph 4.6 to set the output current.

NOTE: The current ramp rate applies only to the internal current output setting. When the Model 642 is programmed externally, the drop to zero output (when the **Zero Output** key is pressed) will be quite rapid (~1 second) and limited primarily by the magnet reactance and the Model 642 voltage compliance limit. The voltage compliance LED may light during the change.

4.11 MAXIMUM SETTING LIMITS

The Model 642 offers a maximum setting limit for output current and ramp rate. Typical properties of the magnet will dictate these parameters. These maximum parameters should be entered before the magnet system is used to prevent damage.

4.11.1 Maximum Output Current

Maximum Output Current limits the output current that can be entered. This setting will only limit the internal output current setting. If the output current is being programmed by an external voltage, then some external provision must be made to insure that the programming voltage will never exceed the desired output current. See Paragraph 4.15 to setup the External Current Programming mode.

To set the maximum output current limit press **Max Settings**. The first maximum setting screen appears as a prompt for the maximum output current limit.

```
Maximum Settings
Enter a Value For
Max Current: 60.0000 A
```

Use the data entry keys to enter the maximum output current limit value between 0.0000 and 70.0000 A. Press **Enter** to accept the new value. Press **Escape** to restart the setting sequence and enter a different value. Press **Escape** again to leave the setting sequence.

NOTE: The maximum output current limit value can be set as high as 70.1000 A. This can be used to compensate for variances in calibration. The output current is guaranteed to reach a minimum of 70 A into a 0.5-ohm load but may not be able to reach 70.1 A in all circumstances.

4.11.2 Maximum Current Ramp Rate

Maximum Current Ramp Rate limits the maximum current ramp rate that can be entered. This setting will only limit the internal output current ramp setting. If ramp segments are being used, this setting will also limit the ramp rate that can be set by a ramp segment. Refer to Paragraph 4.8 to setup Ramp Segments.

To enter a value for the maximum current ramp rate limit, continue from the maximum current screen or press **Max Settings** then **Enter** until the following display setup screen appears as a prompt for the maximum current ramp rate limit.

Use the data entry keys to enter the maximum current ramp rate limit value between 0.0001 and 99.999 A/s. Press **Enter** to accept the new value. Press **Escape** to restart the setting sequence and enter a different value. Press **Escape** again to leave the setting sequence.

```
Maximum Settings
Enter a Value For
Max Ramp Rate: 1.0000 A/s
```

4.12 MAGNET WATER

The Model 642 provides power to control an external magnet water solenoid control valve. The setup of the valve control is available in the **Magnet Water** menu. The four menu selections are **Auto, On, Off, and Disabled**, with **Auto** being the default setting.

In the **Auto** mode, the water valve will be energized when the power in the magnet exceeds 100 W. When the power drops below 100 W, the valve will remain energized for an additional minute to remove any residual heat build-up.

In the **On** mode, the valve will be energized whenever the power supply is on. This feature can be used when the system is first installed to purge air from the water lines and magnet. It can also be used to turn on the water in advance of a test to bring the magnet temperature to equilibrium. The **Off** menu selection can be used to turn it off.

In the **Disabled** mode, the Model 642 assumes that no valve is installed and the line for Magnet Water status will not be displayed.

The magnet water flow switch is monitored whenever the water valve is energized. It is also monitored continuously when in Disabled mode to allow the use of a flow switch even when no water valve is used. If no flow switch or water valve is present, then a jumper must be installed across the flow switch contacts for proper operation.

4.13 INTERNAL WATER

The Model 642 provides power to control an external water solenoid control valve to control the cooling water for the power supply. The setup of the valve control is available in the **Internal Water** menu. The four menu selections are **Auto, On, Off, and Disabled**, with **Disabled** being the default setting.

In the **Auto** mode, the water valve will be energized when the power in the internal power devices exceeds 100 W. When the power drops below 100 W, the valve will remain energized for an additional minute to remove any residual heat build-up.

In the **On** mode, the valve will be energized whenever the power supply is on. This feature can also be used when the Model 642 is first installed to purge air from the lines. The **Off** menu selection can be used to turn it off.

In the **Disabled** mode, the Model 642 assumes that no valve is installed and the line for Internal Water status will not be displayed.

The internal water flow switch is monitored whenever the water valve is energized. It is also monitored continuously when in Disabled mode to allow the use of a flow switch even when no water valve is used. If no flow switch or water valve is present, then a jumper must be installed across the flow switch contacts for proper operation.

4.14 ERROR STATUS DISPLAY

Error messages appear in the center of the instrument display when a problem is identified during operation. The Fault LED will also light to indicate error conditions, blinking for operational errors, on continuously for instrument hardware errors. Refer to Paragraph 7.6 for a listing of all the error conditions. When an error condition occurs, the name of the error is shown in the display alternately with "Press Status Key for More Info." Pressing the **Status** key will bring up a screen that will show an extended description of the error.

To enter the error status display press **Status** while in the main display. A screen similar to the one shown below appears. This screen will differ depending on the error that is being displayed. If there are no errors to report, the display will show "No errors reported." The following example shows the description for "External Current Program Error".

```
Cannot set external current program mode.  
Set programming voltage to 0 V or change to  
internal program mode.
```

4.15 EXTERNAL CURRENT PROGRAMMING

The output current of the Model 642 can be set internally, externally, or by the sum of the external and internal settings. Normally, the current is controlled internally by entering a setting from the front panel using the **Output Setting** key. Refer to Paragraph 4.6 to set the output current. When the external program mode is set to External, the front panel setting is fixed at 0 A and the output current is set using an external voltage where 10 V = 70 A. When the external program mode is set to Sum, the internal and external settings are summed together to set the output current. When using the External or Sum modes, care must be taken to insure that the output current does not exceed the maximum current for the magnet. The software maximum setting limits cannot limit the output current or ramp rate that is set when using the External or Sum modes. A -3 dB, 40 Hz, two-pole, low-pass filter limits the bandwidth of the external current programming input. The bandwidth of the output is also limited by the compliance voltage and the inductance of the magnet. To configure the external current program mode press **External Program**. The following setup screen appears as a prompt for the external current program mode.

```

External Program Mode

Select With ▲▼

External Program Mode: Internal
    
```

Use the ▲ or ▼ key to select the external current program mode, Internal, External, or Sum. Press **Enter** to accept the new selection and return to the normal display. Press **Escape** to cancel the new selection and return to the normal display.

To avoid discontinuities in the output current, the external current programming mode cannot be changed if the programming voltage is not zero or the front panel current setting is not zero. If the external current program mode is going to be kept from changing, an error box will pop up explaining why the new setting is being ignored. This error box is shown below.

```

Change not allowed while
programming voltage is not zero.
    
```

4.16 LOCKING THE KEYPAD

The keypad lock feature prevents accidental changes to parameter values. When the keypad is locked, parameter values may be viewed but cannot be changed from the front panel. The Model 642 has two keypad lock modes. The lock all mode locks out changes to all parameters. The lock limits mode locks out changes to all of the parameters except Output Setting, Ramp Rate, Zero Output and Pause Ramp. This allows the power supply to be operated without allowing any changes to the power supply setup.

A 3-digit code must be used to lock and unlock the keypad. The factory default code is **123** and it can only be changed using a computer interface. If the instrument parameters are reset to default values (See Default Parameter Values 4.18), the code is reset to the factory default. The instrument parameters cannot be reset to default values from the front panel when the keypad is locked.

The following message box appears on the display if the user attempts to change a parameter while the keypad is locked.

```

Change not allowed while
keypad is locked.
    
```

NOTE: The computer interface has a remote operation mode that may be mistaken for a locked keypad. If the front panel Remote LED is lit, press the **Local** key to change to local control of the instrument.

Locking the Keypad (Continued)

To lock or unlock the instrument keypad press and hold the **Enter** key for 5 seconds. The following setup screen appears as a prompt for the keypad lock mode.

```
Keypad Lock

Select With ▲▼
Keypad Lock: Unlock
```

Use the ▲ or ▼ key to select the keypad lock mode, Unlock, Lock All, or Lock Limits. Press **Enter** to choose the new selection and continue to the keypad lock code verification. The change to the keypad lock mode is not made until the correct keypad lock code has been entered. Press **Escape** to cancel the new selection and return to the normal display.

Once the keypad lock mode has been selected, the keypad lock code must be entered to accept the change. The following screen appears as a prompt for the keypad lock code.

```
Keypad Lock

Enter A Value For
Keypad Lock Code:
```

Use the data entry keys to enter the 3-digit lock code (default 123). An asterisk will appear on the display for each number entered. If the code entered matches the lock code, the display will show "Change Accepted" and the keypad lock mode will be updated. If the code entered does not match the lock code, the display will show "Invalid Lock Code" and the keypad lock mode will not change.

4.17 COMPUTER INTERFACE

There are two computer interfaces on the Model 642, a serial RS-232C interface and an IEEE-488 interface. These interfaces are used to connect the instrument to a computer for automated control or data taking. Refer to Chapter 5.

4.17.1 Changing Serial Baud Rate

To select the Serial Interface Baud Rate press the **Computer Interface** key. The first computer interface screen appears as a prompt for Baud.

```
Computer Interface

Select With ▲▼
Baud: 9600
```

Use the ▲ or ▼ key to select 9600, 19200, 38400, or 57600 Baud. Default is 9600 Baud. Press **Enter** to accept the new selection and continue to the next screen. Press **Escape** to cancel the new selection and return to the normal display.

4.17.2 Changing IEEE-488 Interface Parameters

Two interface parameters, address and terminators, must be set from the front panel before IEEE-488 communication with the instrument can be established. Other interface parameters can be set via the interface using the device specific commands provided in Paragraph 5.3.

To set the IEEE-488 parameters, press the **Computer Interface** key and press **Enter** to skip past Serial Interface Baud Rate. The following computer interface screen appears as a prompt for the IEEE-488 address.

```

Computer Interface

Select With ▲▼

IEEE Address: 12

```

Use the **▲** or **▼** key to select an address between 1 and 30. The default is twelve. Press **Enter** to accept the new selection and continue to the next setting screen. Press **Escape** to cancel the new selection and return to the normal display. The next computer interface screen appears as a prompt for the IEEE-488 terminators.

```

Computer Interface

Select With ▲▼

IEEE Term: Cr Lf

```

Use the **▲** or **▼** key to select one of the following terminators: CR/LF, LF/CR, LF, and EOI. The default is CR/LF. Press **Enter** to accept the new selection and continue to the next setting screen. Press **Escape** to cancel the new selection and return to the normal display.

4.18 DEFAULT PARAMETER VALUES

It is sometimes desirable to reset instrument parameters to their default values. This data is stored in nonvolatile memory called EEPROM. Instrument calibration is not affected by this operation. Firmware version information for the main firmware and the DAC firmware is also displayed during this sequence.

To clear EEPROM memory or view the firmware versions press and hold the **Escape** key for 5 seconds. The following screen appears to show the main firmware version, the DAC processor firmware version, and as a prompt for returning the instrument parameters to default values. Default parameter values are listed in Table 4-3.

```

Main Code Version: 1.0
DAC Code Version: 1.0

Select With ▲▼

Default Values: No

```

Use the **▲** or **▼** key to select Yes for default values and No to continue without changing the parameter values. Press **Enter** to accept the new selection and return to the normal display. Press **Escape** to cancel the new selection and return to the normal display.

Table 4-3. Default Parameter Values

| | |
|--|--|
| <p>Output Settings Output Current* 0 A Current Ramp Rate..... 99.999 A/s</p> <p>Maximum Settings Max Output Current..... 70.1 A Max Ramp Rate 99.999 A/s</p> <p>External Program Mode External Program Mode Internal</p> <p>Ramp Segments Ramp Segments Disabled Ramp Segments Current 0 A Ramp Segments Rate 1.0000 A/s</p> <p>Display Brightness 25%</p> | <p>Keypad Locking State..... Unlocked Lock Code 123</p> <p>Computer Interface Baud..... 9600 IEEE-488 Address 12 IEEE-488 Terminators CR/LF Mode* Local</p> <p>Water Settings Magnet Water..... Disabled Internal Water Disabled</p> <p>* Indicates value is also initialized on power up</p> |
|--|--|

CHAPTER 5

COMPUTER INTERFACE OPERATION

5.0 GENERAL

This chapter provides operational instructions for the computer interface for the Lake Shore Model 642 Electromagnet Power Supply. Either of the two computer interfaces provided with the Model 642 permit remote operation. The first is the IEEE-488 Interface described in Paragraph 5.1. The second is the Serial Interface described in Paragraph 5.2. The two interfaces share a common set of commands detailed in Paragraph 5.3. Only one interface can be used at a time.

5.1 IEEE-488 INTERFACE

The IEEE-488 Interface is an instrumentation bus with hardware and programming standards that simplify instrument interfacing. The Model 642 IEEE-488 Interface complies with the IEEE-488.2-1987 standard and incorporates its functional, electrical, and mechanical specifications unless otherwise specified in this manual.

All instruments on the interface bus perform one or more of the interface functions of TALKER, LISTENER, or BUS CONTROLLER. A TALKER transmits data onto the bus to other devices. A LISTENER receives data from other devices through the bus. The BUS CONTROLLER designates to the devices on the bus which function to perform. The Model 642 performs the functions of TALKER and LISTENER but cannot be a BUS CONTROLLER. The BUS CONTROLLER is the digital computer which tells the Model 642 which functions to perform.

Below are Model 642 IEEE-488 interface capabilities:

- **SH1:** Source handshake capability.
- **RL1:** Complete remote/local capability.
- **DC1:** Full device clear capability.
- **DT0:** No device trigger capability.
- **C0:** No system controller capability.
- **T5:** Basic TALKER, serial poll capability, talk only, unaddressed to talk if addressed to listen.
- **L4:** Basic LISTENER, unaddressed to listen if addressed to talk.
- **SR1:** Service request capability.
- **AH1:** Acceptor handshake capability.
- **PP0:** No parallel poll capability.
- **E1:** Open collector electronics.

Instruments are connected to the IEEE-488 bus by a 24-conductor connector cable as specified by the standard. Refer to Paragraph 7.12.2. Cables can be purchased from Lake Shore or other electronic suppliers.

Cable lengths are limited to 2 meters for each device and 20 meters for the entire bus. The Model 642 can drive a bus with up to 10 loads. If more instruments or cable length is required, a bus expander must be used.

5.1.1 Changing IEEE-488 Interface Parameters

Two interface parameters, address and terminators, must be set from the front panel before communication with the instrument can be established. Other interface parameters can be set via the interface using the device specific commands provided in Paragraph 5.3.

To set the IEEE-488 parameters, press the **Computer Interface** key and press **Enter** to skip past Serial Interface Baud Rate. The following computer interface screen appears as a prompt for the IEEE-488 address.

```

Computer Interface

Select With ▲▼

IEEE Address: 12
    
```

Use the ▲ or ▼ key to select an address between 1 and 30. The default is twelve. Press **Enter** to accept the new selection and continue to the next setting screen. Press **Escape** to cancel the new selection and return to the normal display. The next computer interface screen appears as a prompt for the IEEE-488 terminators.

```

Computer Interface

Select With ▲▼

IEEE Term: Cr Lf
    
```

Use the ▲ or ▼ key to select one of the following terminators: CR/LF, LF/CR, LF, and EOI. The default is Cr/Lf. Press **Enter** to accept the new selection and continue to the next setting screen. Press **Escape** to cancel the new selection and return to the normal display.

5.1.2 Remote/Local Operation

Normal operations from the keypad are referred to as 'Local' operations. The Model 642 can also be configured for 'Remote' operations via the IEEE-488 interface or the **Remote** key. The **Local** key will take the instrument out of 'Remote' operation and place it in 'Local' operation. During 'Remote' operations, the Remote LED annunciator will be illuminated and operations from the keypad will be disabled.

5.1.3 IEEE-488 Command Structure

The Model 642 supports several command types. These commands are divided into three groups.

1. **Bus Control** – Refer to Paragraph 5.1.3.1.
 - a. Universal
 - (1) Uniline
 - (2) Multiline
 - b. Addressed Bus Control
2. **Common** – Refer to Paragraph 5.1.3.2.
3. **Device Specific** – Refer to Paragraph 5.1.3.3.
4. **Message Strings** – Refer to Paragraph 5.1.3.4.

5.1.3.1 Bus Control Commands

A Universal Command addresses all devices on the bus. Universal Commands include Uniline and Multiline Commands. A Uniline Command (Message) asserts only a single signal line. The Model 642 recognizes two of these messages from the BUS CONTROLLER: **Remote (REN)** and **Interface Clear (IFC)**. The Model 642 sends one Uniline Command: **Service Request (SRQ)**.

REN (Remote) – Puts the Model 642 into remote mode.

IFC (Interface Clear) – Stops current operation on the bus.

SRQ (Service Request) – Tells the bus controller that the Model 642 needs interface service.

A Multiline Command asserts a group of signal lines. All devices equipped to implement such commands do so simultaneously upon command transmission. These commands transmit with the Attention (ATN) line asserted low. The Model 642 recognizes two Multiline commands:

LLO (Local Lockout) – Prevents the use of instrument front panel controls.

DCL (Device Clear) – Clears Model 642 interface activity and puts it into a bus idle state.

Finally, Addressed Bus Control Commands are Multiline commands that must include the Model 642 listen address before the instrument responds. Only the addressed device responds to these commands. The Model 642 recognizes four of the Addressed Bus Control Commands:

SDC (Selective Device Clear) – The SDC command performs essentially the same function as the DCL command except that only the addressed device responds.

GTL (Go To Local) – The GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

SPE (Serial Poll Enable) and **SPD (Serial Poll Disable)** – Serial polling accesses the Service Request Status Byte Register. This status register contains important operational information from the unit requesting service. The SPD command ends the polling sequence.

5.1.3.2 Common Commands

Common Commands are addressed commands which create commonality between instruments on the bus. All instruments that comply with the IEEE-488 1987 standard share these commands and their format. Common commands all begin with an asterisk. They generally relate to “bus” and “instrument” status and identification. Common query commands end with a question mark (?). Model 642 common commands are detailed in Paragraph 5.3 and summarized in Table 5-8.

5.1.3.3 Device Specific Commands

Device specific commands are addressed commands. The Model 642 supports a variety of device specific commands to program instruments remotely from a digital computer and to transfer measurements to the computer. Most device specific commands perform functions also performed from the front panel. Model 642 device specific commands are detailed in Paragraph 5.3 and summarized in Table 5-8.

5.1.3.4 Message Strings

A message string is a group of characters assembled to perform an interface function. There are three types of message strings: commands, queries and responses. The computer issues command and query strings through user programs, the instrument issues responses. Two or more command strings or queries can be chained together in one communication but they must be separated by a semi-colon (;). The total communication string must not exceed 255 characters in length.

A command string is issued by the computer and instructs the instrument to either perform a function or change a parameter setting. When a command is issued, the computer is acting as ‘talker’ and the instrument as ‘listener’. The format is:

<command mnemonic><space><parameter data><terminators>.

Command mnemonics and parameter data necessary for each one is described in Paragraph 5.3. Terminators must be sent with every message string.

Message Strings (Continued)

A query string is issued by the computer and instructs the instrument which response to send. Queries are issued similar to commands with the computer acting as 'talker' and the instrument as 'listener'. The query format is:

`<query mnemonic><?><space><parameter data><terminators>.`

Query mnemonics are often the same as commands with the addition of a question mark. Parameter data is often unnecessary when sending queries. Query mnemonics and parameter data if necessary is described in Paragraph 5.3. Terminators must be sent with every message string. Issuing a query does not initiate a response from the instrument.

A response string is sent by the instrument only when it is addressed as a 'talker' and the computer becomes the 'listener'. The instrument will respond only to the last query it receives. The response can be a reading value, status report or the present value of a parameter. Response data formats are listed along with the associated queries in Paragraph 5.3.

5.1.4 Status System**5.1.4.1 Overview**

The Model 642 implements a status system compliant to the IEEE 488.2 – 1992 standard. The status system provides a method of recording and reporting instrument information and is typically used to control the Service Request (SRQ) interrupt line. A diagram of the status system is shown in Figure 5-1. The status system is made up of register sets, the Status Byte register and the Service Request Enable register. Each register set consists of three types of registers, condition, event, and enable,

5.1.4.1.1 Condition Registers

Each register set (except the Standard Event Register set) includes a condition register as shown in Figure 5-1. The condition register constantly monitors the instrument status. The data bits are real-time and are not latched or buffered. The register is read-only.

5.1.4.1.2 Event Registers

Each register set includes an event register as shown in Figure 5-1. Bits in the event register correspond to various system events and latch when the event occurs. When an event bit is set, subsequent events corresponding to that bit are ignored. Set bits remain latched until the register is cleared by a query command (such as *ESR?) or a *CLS command. The register is read-only.

5.1.4.1.3 Enable Registers

Each register set includes an enable register as shown in Figure 5-1. An enable register determines which bits in the corresponding event register will set the summary bit for the register set in the Status Byte. The user may write to or read from an enable register. Each event register bit is logically ANDed to the corresponding enable bit of the enable register. When an enable register bit is set by the user, and the corresponding bit is set in the event register, the output (summary) of the register will be set, which in turn sets the summary bit of the Status Byte register.

5.1.4.1.4 Status Byte Register

The Status Byte register, typically referred to as simply the Status Byte, is a non-latching, read-only register that contains all of the summary bits from the register sets. The status of the summary bits are controlled from the register sets as explained above. The Status Byte also contains the Request for Service (RQS)/Master Summary Status (MSS) bit. This bit is used to control the Service Request hardware line on the bus and to report if any of the summary bits are set via the *STB? command. The status of the RQS/MSS bit is controlled by the summary bits and the Service Request Enable Register.

5.1.4.1.5 Service Request Enable Register

The Service Request Enable Register determines which summary bits in the Status Byte will set the RQS/MSS bit of the Status Byte. The user may write to or read from the Service Request Enable Register. Each Status Byte summary bit is logically ANDed to the corresponding enable bit of the Service Request Enable Register. When a Service Request Enable Register bit is set by the user, and the corresponding summary bit is set in the Status Byte, the RQS/MSS bit of the Status Byte will be set, which in turn sets the Service Request hardware line on the bus.

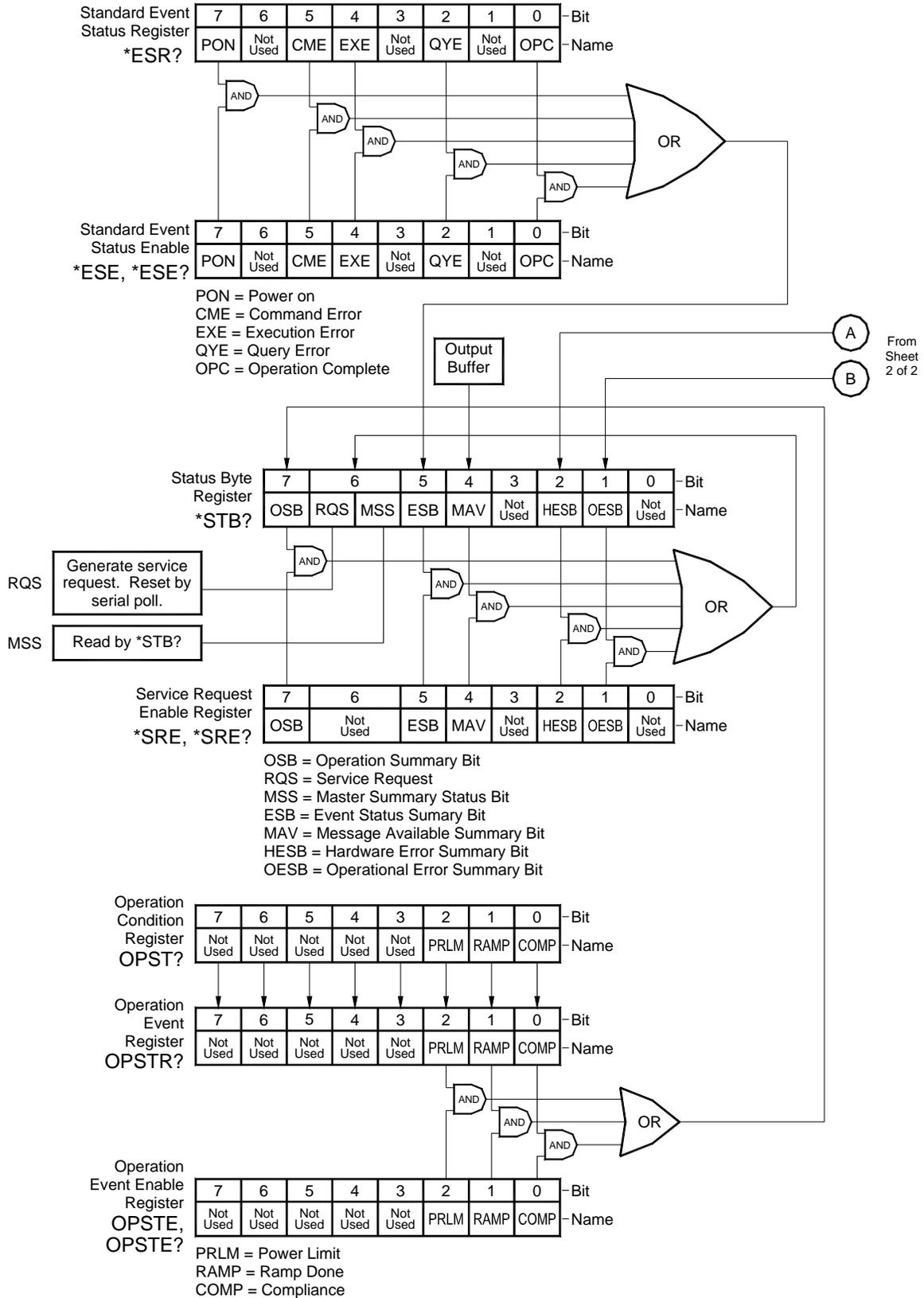


Figure 5-1. Model 642 Status System (Sheet 1 of 2)

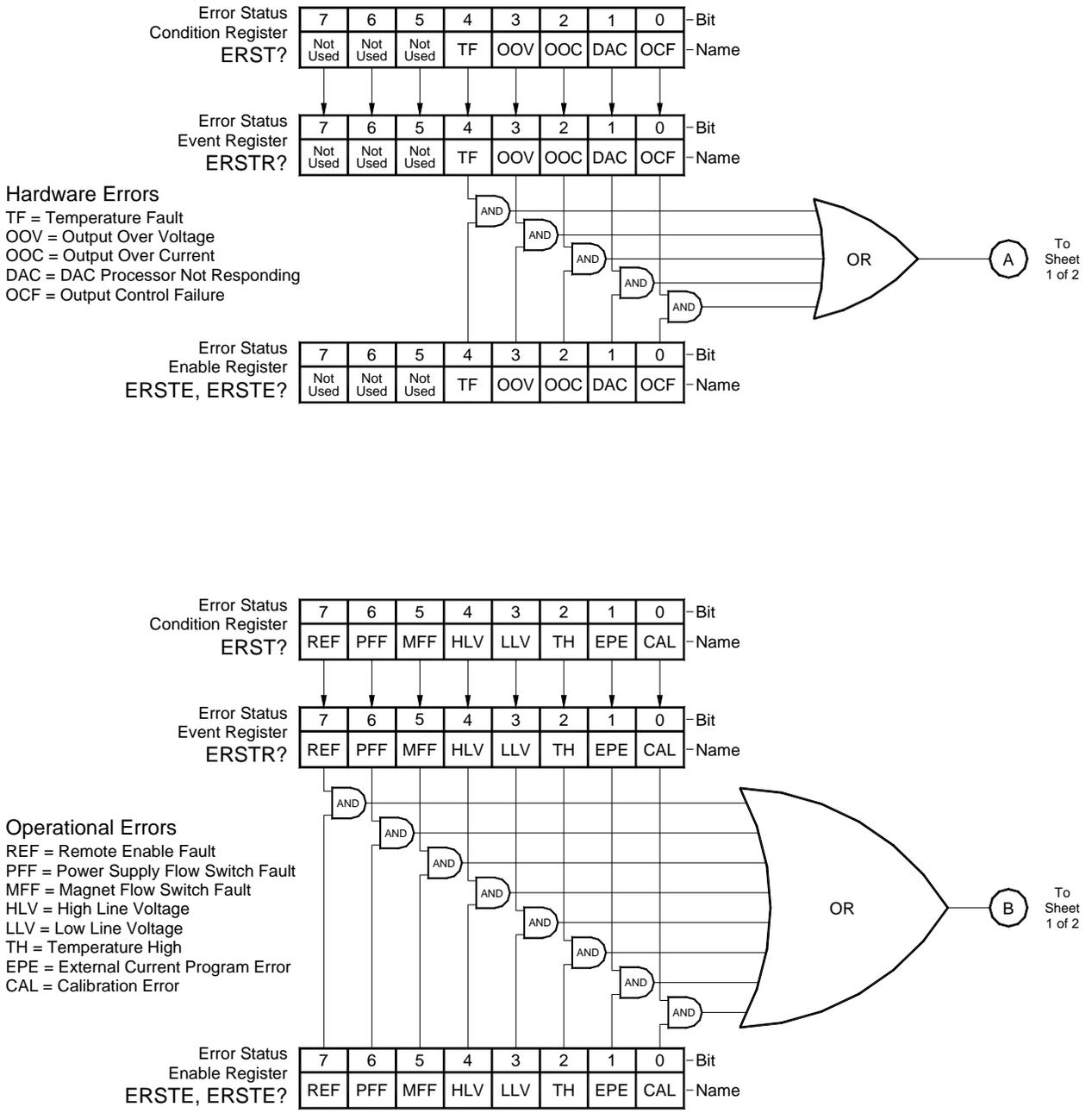


Figure 5-1. Model 642 Status System (Sheet 2 of 2)

5.1.4.1.6 Reading Registers

Any register in the status system may be read using the appropriate query command. Some registers clear when read, others do not. Refer to Paragraph 5.1.4.1.7. The response to a query will be a decimal value that corresponds to the binary-weighted sum of all bits in the register, Refer to Table 5-1. The actual query commands are described later in this section.

Table 5-1. Binary Weighting of an 8-Bit Register

| Position | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|-----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Decimal | 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
| Weighting | 2 ⁷ | 2 ⁶ | 2 ⁵ | 2 ⁴ | 2 ³ | 2 ² | 2 ¹ | 2 ⁰ |

Example: If bits 0, 2, and 4 are set, a query of the register will return a decimal value of 21 (1+4+16).

5.1.4.1.7 Programming Registers

The only registers that may be programmed by the user are the enable registers. All other registers in the status system are read-only registers. To program an enable register send a decimal value which corresponds to the desired binary-weighted sum of all bits in the register, Refer to Table 5-1. The actual commands are described later in this section.

5.1.4.1.8 Clearing Registers

The methods to clear each register are detailed in Table 5-2.

Table 5-2. Register Clear Methods

| <i>Register</i> | <i>Method</i> | <i>Example</i> |
|---------------------------------------|---|---|
| Condition Registers | None – registers are not latched | — |
| Event Registers: | | *ESR? (clears Standard Event Status register) |
| Standard Event Status Register | Query the event register. | |
| Operation Event Register | Send *CLS | *CLS (clears all three registers) |
| Error Status Event Register | Power on instrument | — |
| Enable Registers: | | *ESE 0 (clears Standard Event Status Enable register) |
| Standard Event Status Enable Register | Write 0 to the enable register. | |
| Operation Event Enable Register | Power on instrument | — |
| Error Status Enable Register | | |
| Service Request Enable Register | | |
| Status Byte | There are no commands that directly clear the Status Byte as the bits are non-latching. To clear individual summary bits, clear the event register that corresponds to the summary bit. Sending *CLS will clear all event registers which in turn clears the status byte. | If bit 5 (ESB) of the Status Byte is set, send *ESR? to read the Standard Event Status Register and bit 5 will clear. |
| | Power on instrument | — |

5.1.4.2 Status Register Sets

As shown in Figure 5-1, there are five register sets in the status system of the Model 642; Standard Event Status Register, Operation Event Register, Hardware Error Status Register, Operational Error Status Register, and the Persistent Switch Error Register.

5.1.4.2.1 Standard Event Status Register Set

The Standard Event Status Register reports the following interface related instrument events: power on detected, command syntax errors, command execution errors, query errors, operation complete. Any or all of these events may be reported in the standard event summary bit through the enable register, see Figure 5-2. The Standard Event Status Enable command (*ESE) programs the enable register and the query command (*ESE?) reads it. *ESR? reads and clears the Standard Event Status Register. The used bits of the Standard Event Register are described as follows:

Power On (PON), Bit (7) – This bit is set to indicate an instrument off-on transition.

Command Error (CME), Bit (5) – This bit is set if a command error has been detected since the last reading. This means that the instrument could not interpret the command due to a syntax error, an unrecognized header, unrecognized terminators, or an unsupported command.

Execution Error (EXE), Bit (4) – This bit is set if an execution error has been detected. This occurs when the instrument is instructed to do something not within its capabilities.

Query Error (QYE), Bit (2) – This bit indicated a query error. It occurs rarely and involves loss of data because the output queue is full.

Operation Complete (OPC), Bit (0) – When *OPC is sent, this bit will be set when the instrument has completed all pending operations. The operation of this bit is not related to the *OPC? command which is a separate interface feature. Refer to Paragraph 5.1.4.4.6 for more information.

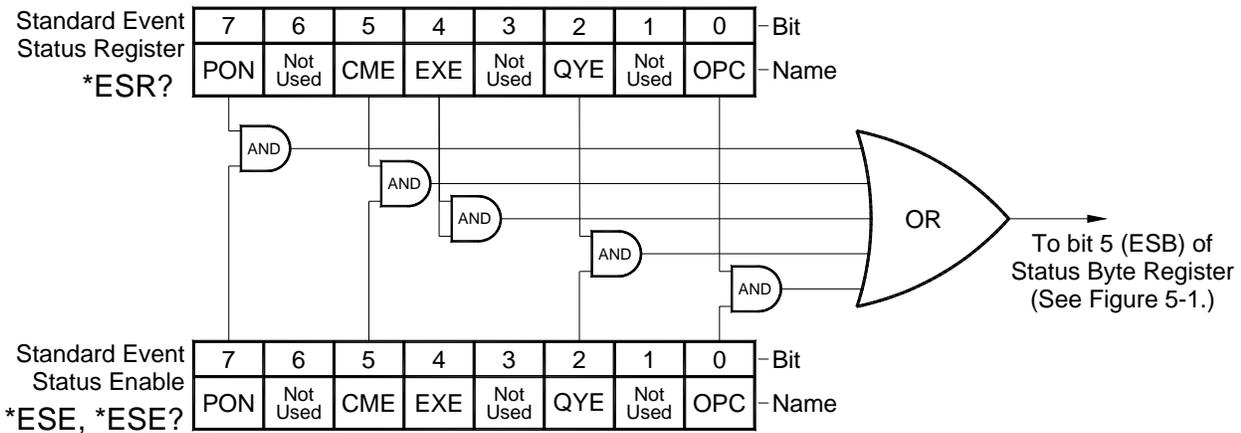


Figure 5-2. Standard Event Status Register

5.1.4.2.2 Operation Event Register Set

The Operation Event Register reports the following instrument events: ramp done, compliance. Any or all of these events may be reported in the operation event summary bit through the enable register, see Figure 5-3. The Operation Event Enable command (OPSTE) programs the enable register and the query command (OPSTE?) reads it. OPSTR? reads the Operation Event Register. OPST? reads and clears the Operation Condition register. The used bits of the Operation Event Register are described as follows:

Power Limit, Bit (2) – This bit is set if the output is in power limit.

Ramp Done, Bit (1) – This bit is set when the output current ramp is completed.

Compliance, Bit (0) – This bit is set if the output is in compliance limit.

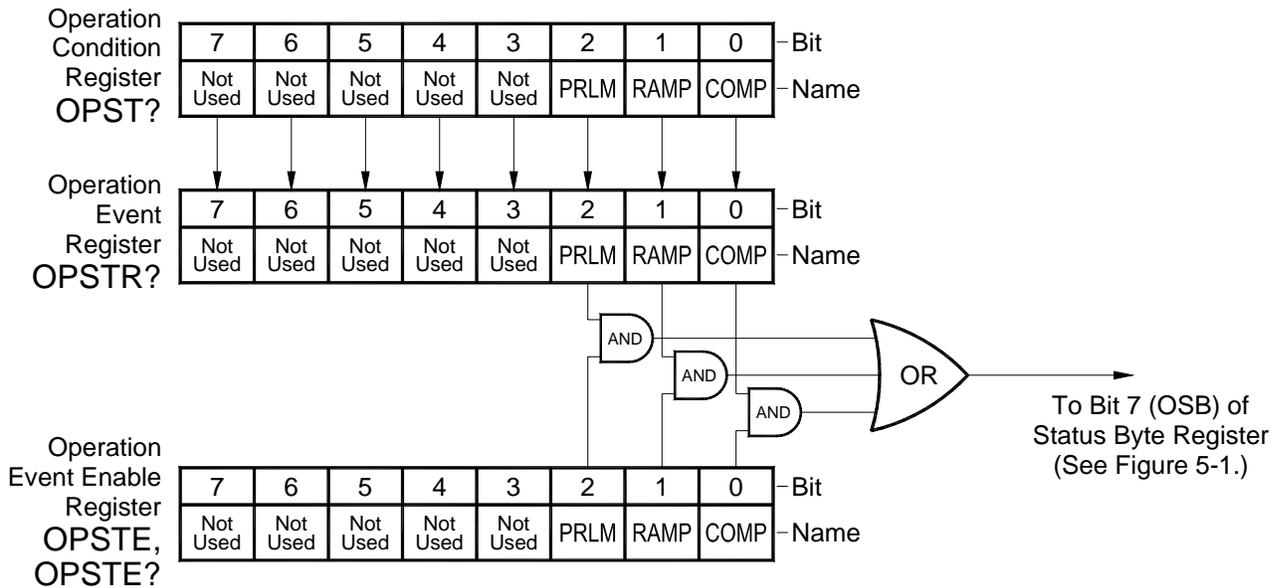


Figure 5-3. Operation Event Register

5.1.4.3 Error Status Register Sets

As shown in Figure 5-1, there are two register sets in the error status system of the Model 642; Hardware Error Status Register, and Operational Error Status Register.

5.1.4.3.1 Hardware Error Status Register Set

The Hardware Error Status Register reports the following instrument hardware error events: temperature fault, output over voltage, output over current, DAC processor not responding and output control failure. Any or all of these events may be reported in the standard event summary bit through the enable register, see Figure 5-4. The Hardware Error Status Register is the first value of the two values associated with the Error Status Registers. The Error Status Enable command (ERSTE) programs the enable register and the query command (ERSTE?) reads it. ERSTR? reads and clears the Error Status Register. The used bits of the Error Status Event Register are described as follows:

Temperature Fault (TF), Bit (4) – This bit is set if the internal temperature of the instrument exceeded the maximum safe value of 45 °C. The instrument will shut down within 10 seconds of detecting this fault.

Output Over Voltage (OOV), Bit (3) – This bit is set if the output voltage exceeded the compliance voltage limit setting.

Output Over Current (OOC), Bit (2) – This bit is set if the output current is above 62 A exceeding the maximum output current of the instrument.

DAC Processor Not Responding (DAC), Bit (1) – This bit is set to indicate that communication to the DAC processor has failed.

Output Control Failure (OCF), Bit (0) – This bit is set if there is a failure on the output control board.

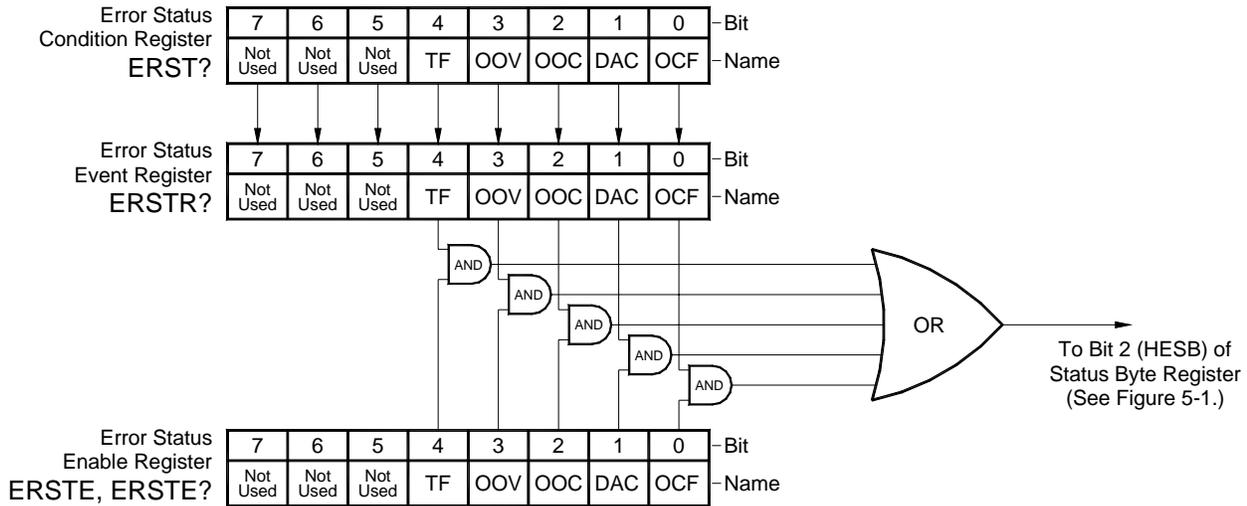


Figure 5-4. Hardware Error Status Register

5.1.4.3.2 Operational Error Status Register Set

The Operational Error Status Register reports the following instrument operational error events: remote enable fault detected, power supply flow switch fault detected, magnet flow switch fault detected, high line voltage, low line voltage, temperature high, external current program error, calibration error. Any or all of these events may be reported in the standard event summary bit through the enable register, see Figure 5-5. The Operational Error Status Register is the second value of the two values associated with the Error Status Registers. The Error Status Enable command (ERSTE) programs the enable register and the query command (ERSTE?) reads it. ERSTR? reads and clears the Error Status Register. The used bits of the Error Status Event Register are described as follows:

Remote Enable Fault Detected (REF), Bit (7) – This bit is set if a fault condition is detected on the remote enable interlock.

Power Supply Flow Switch Fault Detected (PFF), Bit (6) – This bit is set if a fault condition is detected on the power supply flow switch interlock.

Magnet Flow Switch Fault Detected (MFF), Bit (5) – This bit is set if a fault condition is detected on the magnet flow switch interlock.

High Line Voltage (HLV), Bit (4) – This bit is set if the power line voltage exceeds an acceptable amplitude. Operation can continue but additional heat may be dissipated by the instrument.

Low Line Voltage (LLV), Bit (3) – This bit is set if the power line voltage drops below an acceptable amplitude. Operation can continue but output voltage may not reach maximum specification.

Temperature High (OOV), Bit (2) – This bit is set if the internal temperature of the instrument exceeded 40 °C. The output current will be set to zero and will not be settable until the fault is cleared.

External Current Program Error (EPE), Bit (1) – This bit is set if the instrument cannot go into external or sum current programming modes because the programming voltage is too high. The output current will be set to zero and will not be settable until the fault is cleared.

Calibration Error (CAL), Bit (0) – This bit is set if the instrument is not calibrated or the calibration data has been corrupted.

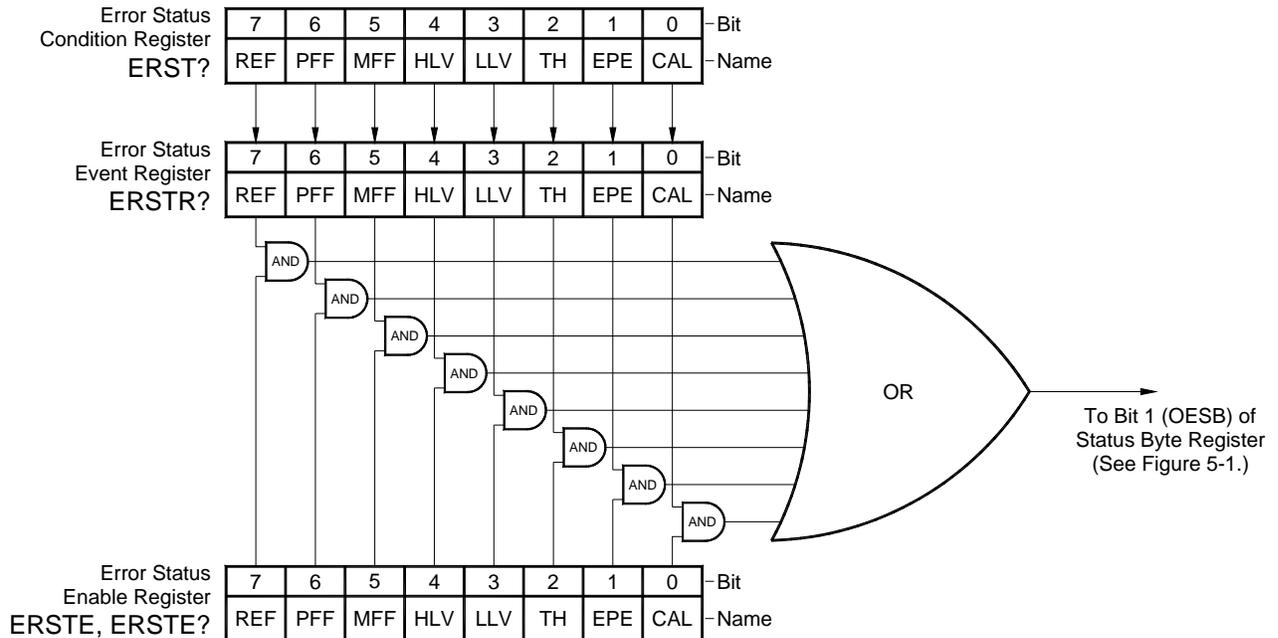


Figure 5-5. Operational Error Status Register

5.1.4.4 Status Byte and Service Request (SRQ)

As shown in Figure 5-1, the Status Byte Register receives the summary bits from the two status register sets and the message available summary bit from the output buffer. The status byte is used to generate a service request (SRQ). The selection of summary bits that will generate an SRQ is controlled by the Service Request Enable Register.

5.1.4.4.1 Status Byte Register

The summary messages from the event registers and output buffer set or clear the summary bits of the Status Byte Register, see Figure 5-5. These summary bits are not latched. Clearing an event register will clear the corresponding summary bit in the Status Byte Register. Reading all messages in the output buffer, including any pending queries, will clear the message available bit. The bits of the Status Byte Register are described as follows:

Operation Summary (OSB), Bit (7) – Set summary bit indicates that an enabled operation event has occurred.

Request Service (RQS)/Master Summary Status (MSS), Bit (6) – This bit is set when a summary bit and the summary bits corresponding enable bit in the Service Request Enable Register are set. Once set, the user may read and clear the bit in two different ways, which is why it is referred to as both the RQS and the MSS bit. When this bit goes from low to high, the Service Request hardware line on the bus is set, this is the RQS function of the bit. See Paragraph 5.1.4.4.3. In addition, the status of the bit may be read with the *STB? query which returns the binary weighted sum of all bits in the Status Byte, this is the MSS function of the bit.

Performing a serial poll will automatically clear the RQS function but not the MSS function. A *STB? will read the status of the MSS bit (along with all of the summary bits), but also will not clear it. To clear the MSS bit, either clear the event register that set the summary bit or disable the summary bit in the Service Request Enable Register.

Event Summary (ESB), Bit (5) – Set summary bit indicates that an enabled standard event has occurred.

Message Available (MAV), Bit (4) – Set summary bit indicates that a message is available in the output buffer.

Bit (3) – Not used.

Hardware Errors Summary (HESB), Bit (2) – Set summary bit indicates that an enabled hardware error event has occurred.

Operational Errors Summary (OESB), Bit (1) – Set summary bit indicates that an enabled operational error event has occurred.

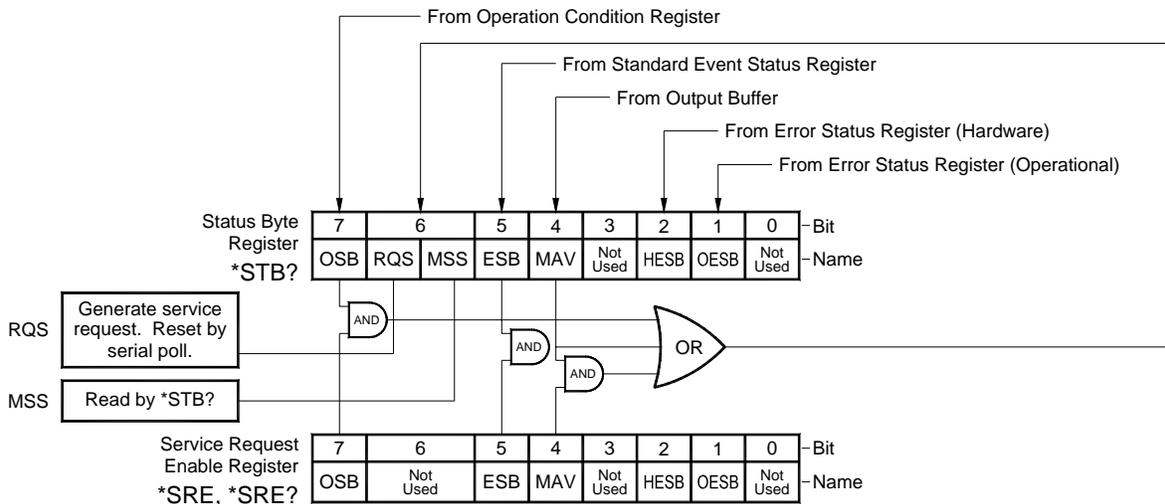


Figure 5-6. Status Byte Register and Service Request Enable Register

5.1.4.4.2 Service Request Enable Register

The Service Request Enable Register is programmed by the user and determines which summary bits of the Status Byte may set bit 6 (RQS/MSS) to generate a Service Request. Enable bits are logically ANDed with the corresponding summary bits, see Figure 5-6. Whenever a summary bit is set by an event register and its corresponding enable bit is set by the user, bit 6 will set to generate a service request. The Service Request Enable command (*SRE) programs the Service Request Enable Register and the query command (*SRE?) reads it. Reading the Service Request Enable Register will not clear it. The register may be cleared by the user by sending *SRE 0.

5.1.4.4.3 Using Service Request (SRQ) and Serial Poll

When a Status Byte summary bit (or MAV bit) is enabled by the Service Request Enable Register and goes from 0 to 1, bit 6 (RQS/MSS) of the status byte will be set. This will send a service request (SRQ) interrupt message to the bus controller. The user program may then direct the bus controller to serial Poll the instruments on the bus to identify which one requested service (the one with bit 6 set in its status byte).

Serial polling will automatically clear RQS of the Status Byte Register. This allows subsequent serial polls to monitor bit 6 for an SRQ occurrence generated by other event types. After a serial poll, the same event or any event that uses the same Status Byte summary bit, will not cause another SRQ unless the event register that caused the first SRQ has been cleared, typically by a query of the event register.

The serial poll does not clear MSS. The MSS bit stays set until all enabled Status Byte summary bits are cleared, typically by a query of the associated event register, refer to Paragraph 5.1.4.4.4.

The programming example in Table 5-3 initiates an SRQ when a command error is detected by the instrument.

Table 5-3. Programming Example to Generate an SRQ

| <i>Command or Operation</i> | <i>Description</i> |
|-----------------------------|--|
| *ESR? | Read and clear the Standard Event Status Register. |
| *ESE 32 | Enable the Command Error (CME) bit in the Standard Event Status Register |
| *SRE 32 | Enable the Event Summary Bit (ESB) to set the RQS |
| *ABC | Send improper command to instrument to generate a command error |
| Monitor bus | Monitor the bus until the Service Request interrupt (SRQ) is sent. |
| Initiate Serial Poll | Serial Poll the bus to determine which instrument sent the interrupt and clear the RQS bit in the Status Byte. |
| *ESR? | Read and clear the Standard Event Status Register allowing an SRQ to be generated on another command error. |

5.1.4.4.4 Using Status Byte Query (*STB?)

The Status Byte Query (*STB?) command is similar to a Serial Poll except it is processed like any other instrument command. The *STB? command returns the same result as a Serial Poll except that the Status Byte bit 6 (RQS/MSS) is not cleared. In this case bit 6 is considered the MSS bit. Using the *STB? command does not clear any bits in the Status Byte Register.

5.1.4.4.5 Using Message Available (MAV) Bit

Status Byte summary bit 4 (MAV) indicates that data is available to read into your bus controller. This message may be used to synchronize information exchange with the bus controller. The bus controller can, for example, send a query command to the Model 642 and then wait for MAV to set. If the MAV bit has been enabled to initiate an SRQ, the user's program can direct the bus controller to look for the SRQ leaving the bus available for other use. The MAV bit will be clear whenever the output buffer is empty.

5.1.4.4.6 **Using Operation Complete (*OPC) and Operation Complete Query (*OPC?)**

The Operation Complete (*OPC) and Operation Complete Query (*OPC?) are both used to indicate when pending device operations complete. However, the commands operate with two distinct methods.

The *OPC command is used in conjunction with bit 0 (OPC) of the Standard Event Status Register. If *OPC is sent as the last command in a command sequence, bit 0 will be set when the instrument completes the operation that was initiated by the command sequence. Additional commands may be sent between the instrument and the bus controller while waiting for the initial pending operation to complete. A typical use of this function would be to enable the OPC bit to generate an SRQ and include the *OPC command when programming the instrument. The bus controller could then be instructed to look for an SRQ allowing additional communication with the instrument while the initial process executes.

The *OPC? query has no interaction with bit 0 (OPC) of the Standard Event Status Register. If the *OPC? query is sent at the end of a command sequence, the bus will be held until the instrument completes the operation that was initiated by the command sequence. Additional commands (except *RST) should not be sent until the operation is complete as erratic operation will occur. Once the sequence is complete a 1 will be placed in the output buffer. This function is typically used to signal a completed operation without monitoring the SRQ. It is also used when it is important to prevent any additional communication on the bus during a pending operation.

5.1.5 **IEEE-488 Interface Example Programs**

A Visual Basic program is included to illustrate the IEEE-488 communication functions of the instrument. Instructions for setting up the IEEE-488 Board is included in Section 5.1.5.1. Refer to Section 5.1.5.2 for instructions on how to setup the program. The Visual Basic code is provided in Table 5-5. A description of program operation is provided in Section 5.1.5.3. While the hardware and software required to produce and implement these programs not included with the instrument, the concepts illustrated apply to most applications.

5.1.5.1 **IEEE-488 Interface Board Installation for Visual Basic Program**

This procedure works for Plug and Play GPIB Hardware and Software for Windows 98/95. This example uses the AT-GPIB/TNT GPIB card.

1. Install the GPIB Plug and Play Software and Hardware using National Instruments instructions.
2. Verify that the following files have been installed to the Windows System folder:
 - a. gpib-32.dll
 - b. gpib.dll
 - c. gpib32ft.dllFiles b and c support any 16-bit Windows GPIB applications being used.
3. Locate the following files and make note of their location. These files will be used during the development process of a Visual Basic program.
 - a. Niglobal.bas
 - b. Vbib-32.bas

NOTE: If the files in Steps 2 and 3 are not installed on your computer, they may be copied from your National Instruments setup disks or they may be downloaded from www.ni.com.

4. Configure the GPIB by selecting the System icon in the Windows Control Panel located under Settings on the Start Menu. Configure the GPIB Settings as shown in Figure 5-7. Configure the DEV12 Device Template as shown in Figure 5-8. Be sure to check the Readdress box.

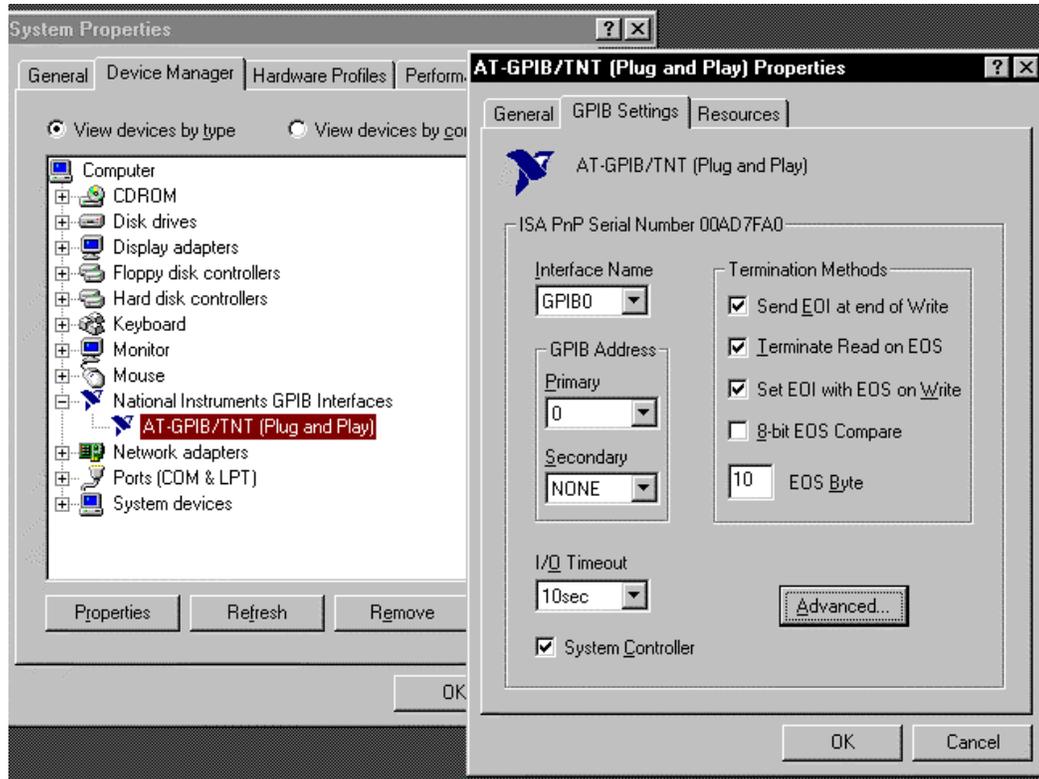


Figure 5-7. GPIB0 Setting Configuration

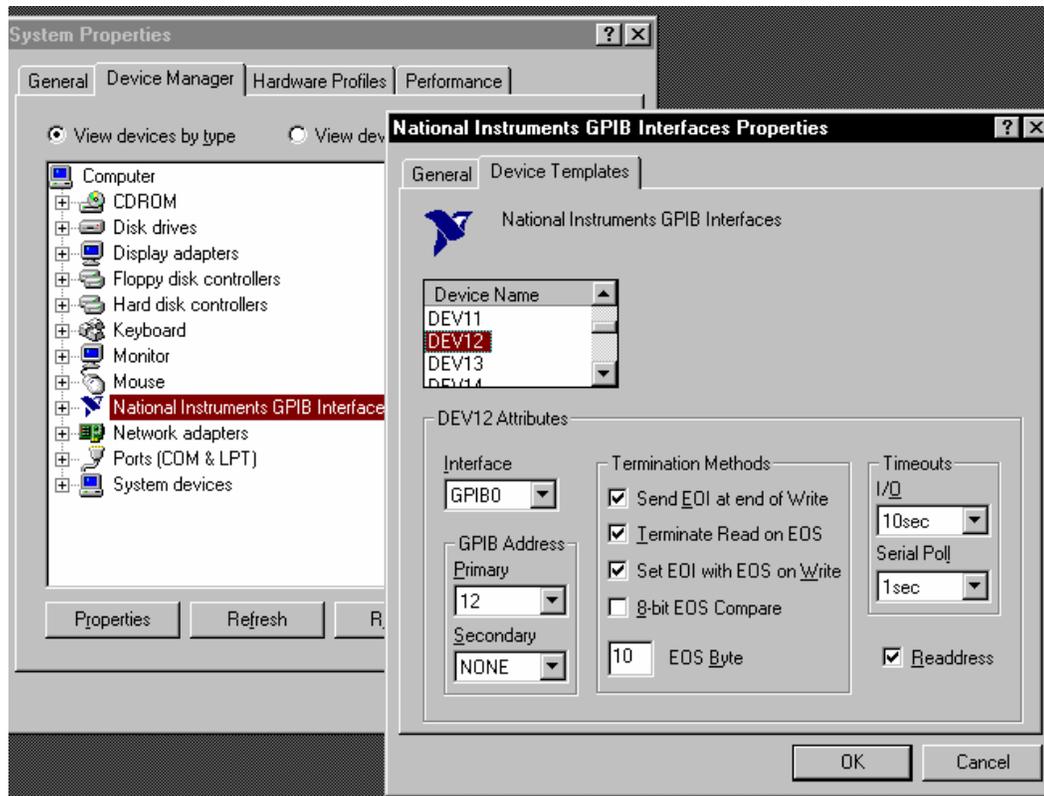
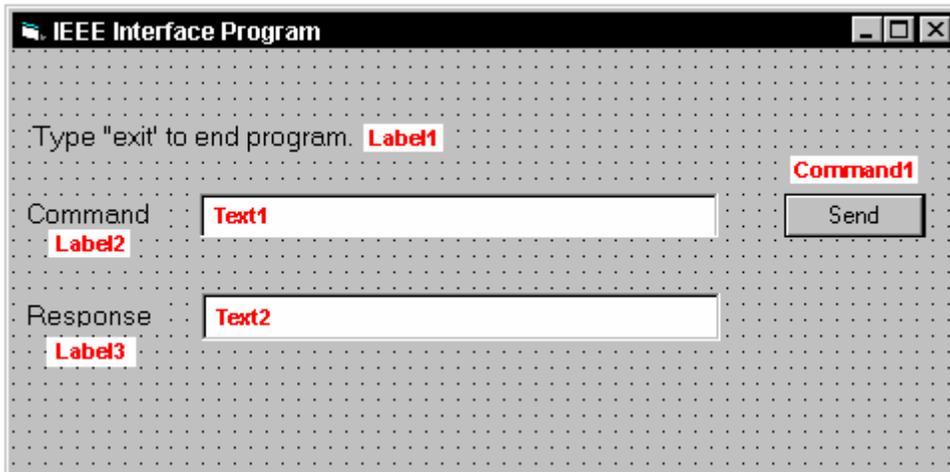


Figure 5-8. DEV 12 Device Template Configuration

5.1.5.2 Visual Basic IEEE-488 Interface Program Setup

This IEEE-488 interface program works with Visual Basic 6.0 (VB6) on an IBM PC (or compatible) with a Pentium-class processor. A Pentium 90 or higher is recommended, running Windows 95 or better. It assumes your IEEE-488 (GPIB) card is installed and operating correctly (refer to Paragraph 5.1.5.1). Use the following procedure to develop the IEEE-488 Interface Program in Visual Basic.

1. Start VB6.
2. Choose Standard EXE and select Open.
3. Resize form window to desired size.
4. On the Project Menu, select Add Module, select the Existing tab, then navigate to the location on your computer to add the following files: Niglobal.bas and Vbib-32.bas.
5. Add controls to form:
 - a. Add three Label controls to the form.
 - b. Add two TextBox controls to the form.
 - c. Add one CommandButton control to the form.
6. On the View Menu, select Properties Window.
7. In the Properties window, use the dropdown list to select between the different controls of the current project.

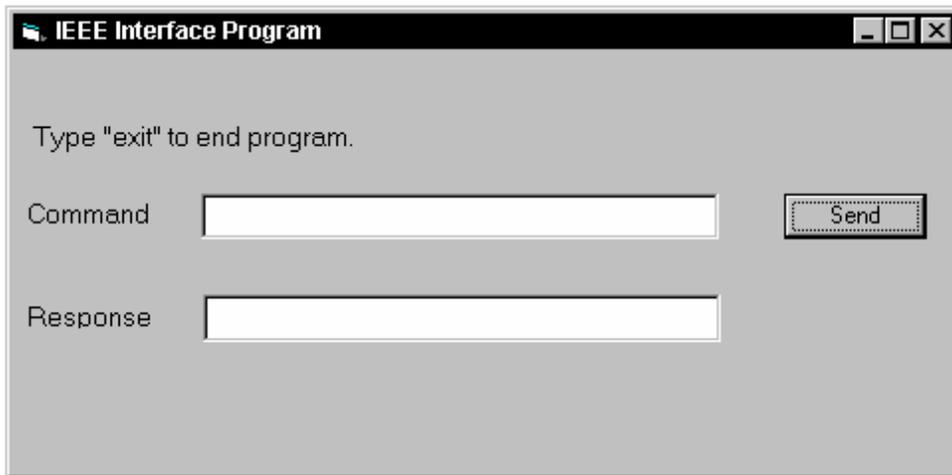


10. Set the properties of the controls as defined in Table 5-4.
11. Save the program.

Table 5-4. IEEE-488 Interface Program Control Properties

| <i>Current Name</i> | <i>Property</i> | <i>New Value</i> |
|---------------------|----------------------------|---|
| Label1 | Name Caption | lblExitProgram Type "exit" to end program. |
| Label2 | Name Caption | lblCommand Command |
| Label3 | Name Caption | lblResponse Response |
| Text1 | Name Text | txtCommand <blank> |
| Text2 | Name Text | txtResponse <blank> |
| Command1 | Name Caption Default | cmdSend Send True |
| Form1 | Name Caption | From IEEE-488 IEEE-488 Interface Program |

12. Add code (provided in Table 5-5).
 - a. In the Code Editor window, under the Object dropdown list, select (General). Add the statement: Public gSend as Boolean
 - b. Double Click on cmdSend. Add code segment under Private Sub cmdSend_Click() as shown in Table 5-5.
 - c. In the Code Editor window, under the Object dropdown list, select Form. Make sure the Procedure dropdown list is set at Load. The Code window should have written the segment of code: Private Sub Form_Load(). Add the code to this subroutine as shown in Table 5-5.
13. Save the program.
14. Run the program. The program should resemble the following.



15. Type in a command or query in the Command box as described in Paragraph 5.1.5.5.
16. Press Enter or select the Send button with the mouse to send command.
17. Type Exit and press Enter to quit.

Table 5-5. Visual Basic IEEE-488 Interface Program

| | |
|--|---|
| Public gSend As Boolean | 'Global used for Send button state |
| Private Sub cmdSend_Click() gSend = True End Sub | 'Routine to handle Send button press 'Set Flag to True |
| Private Sub Form_Load() Dim strReturn As String Dim term As String Dim strCommand As String Dim intDevice As Integer frmIEEE.Show term = Chr(13) & Chr(10) strReturn = "" Call ibdev(0, 12, 0, T10s, 1, &H140A, intDevice) Call ibconfig(intDevice, ibcREADDR,1) Do Do DoEvents Loop Until gSend = True gSend = False strCommand = frmIEEE.txtCommand.Text strReturn = "" strCommand = UCase(strCommand) If strCommand = "EXIT" Then End End If Call ibwrt(intDevice, strCommand & term) If (ibsta And EERR) Then do error handling if needed End If If InStr(strCommand, "?") <> 0 Then strReturn = Space(100) Call ibrd(intDevice, strReturn) If (ibsta And EERR) Then do error handling if needed End If If strReturn <> "" Then strReturn = RTrim(strReturn) Do While Right(strReturn, 1) = Chr(10) Or Right(strReturn, 1) = Chr(13) strReturn = Left(strReturn, Len(strReturn) - 1) Loop Else strReturn = "No Response" End If frmIEEE.txtResponse.Text = strReturn End If Loop End Sub | 'Main code section 'Used to return response 'Terminators 'Data string sent to instrument 'Device number used with IEEE 'Show main window 'Terminators are <CR><LF> 'Clear return string 'Initialize the IEEE device 'Setup Repeat Addressing 'Wait loop 'Give up processor to other events 'Loop until Send button pressed 'Set Flag as False 'Get Command 'Clear response display 'Set all characters to upper case 'Get out on EXIT 'Send command to instrument 'Check for IEEE errors 'Handle errors here 'Check to see if query 'Build empty return buffer 'Read back response 'Check for IEEE errors 'Handle errors here 'Check if empty string 'Remove extra spaces and Terminators 'Send No Response 'Put response in text on main form |

| National Instruments | GPIB0 Configuration | GPIB-PC2/2A Ver 2.1 |
|---|---------------------|--|
| Primary GPIB Address →0 | ↑ █ ↓ | Select the primary GPIB address by using the left and right arrow keys. |
| Secondary GPIB Address NONE | | This address is used to compute the talk and listen addresses which identify the board or device on the GPIB. Valid primary addresses range from 0 to 30 (00H to 1EH). |
| Timeout setting 10sec | | * Adding 32 to the primary address forms the Listen Address (LA). |
| Terminate Read on EOS Yes | | * Adding 64 to the primary address forms the Talk Address (TA). |
| Set EOI with EOS on Writes .. Yes | | EXAMPLE: Selecting a primary address of 10 yields the following: |
| Type of compare on EOS 7-Bit | | 10 + 32 = 42 (Listen address) |
| EOS byte 0Ah | | 10 + 64 = 74 (Talk address) |
| Send EOI at end of Write Yes | | |
| System Controller Yes | | |
| Assert REN when SC No | | |
| Enable Auto Serial Polling .. No | | |
| Enable CIC Protocol No | | |
| Bus Timing 500nsec | | |
| Parallel Poll Duration Default | | |
| Use this GPIB board Yes | | |
| Board Type PCII | | |
| Base I/O Address 02B8h | | |
| F1: Help F6: Reset Value F9/Esc: Return to Map Ctl PgUp/PgDn: Next/Prev Board | | |

| National Instruments | DEV12 Configuration | GPIB-PC2/2A Ver 2.1 |
|---|---------------------|--|
| Primary GPIB Address →12 | ↑ █ ↓ | Select the primary GPIB address by using the left and right arrow keys. |
| Secondary GPIB Address NONE | | This address is used to compute the talk and listen addresses which identify the board or device on the GPIB. Valid primary addresses range from 0 to 30 (00H to 1EH). |
| Timeout setting 10sec | | * Adding 32 to the primary address forms the Listen Address (LA). |
| Serial Poll Timeout 1sec | | * Adding 64 to the primary address forms the Talk Address (TA). |
| Terminate Read on EOS Yes | | EXAMPLE: Selecting a primary address of 10 yields the following: |
| Set EOI with EOS on Writes .. Yes | | 10 + 32 = 42 (Listen address) |
| Type of compare on EOS 7-Bit | | 10 + 64 = 74 (Talk address) |
| EOS byte 0Ah | | |
| Send EOI at end of Write Yes | | |
| Enable Repeat Addressing Yes | | |
| F1: Help F6: Reset Value F9/Esc: Return to Map Ctl PgUp/PgDn: Next/Prev Board | | |

IBCONF.EXE.eps

Figure 5-9. Typical National Instruments GPIB Configuration from IBCONF.EXE

5.1.5.3 Program Operation

Once the running, try the following commands and observe the response of the instrument. Input from the user is shown in **bold** and terminators are added by the program. The word [term] indicates the required terminators included with the response.

| | |
|--|---|
| <p>ENTER COMMAND? *IDN? RESPONSE: LSCI,MODELModel 642,1234567,06122006 [term]</p> | <p>Identification query. Instrument will return a string identifying itself.</p> |
| <p>ENTER COMMAND? SETI? RESPONSE: +20.0545 [term]</p> | <p>Output current setting query. Instrument will return a string with the present output current setting.</p> |
| <p>ENTER COMMAND? XPGM 0 ENTER COMMAND? XPGM? RESPONSE: 0 [term]</p> | <p>External program mode command. Instrument will set program mode to internal. No response will be sent. External program mode query. Instrument will return a string with the present external program mode setting.</p> |
| <p>ENTER COMMAND? XPGM 1;XPGM? RESPONSE: 1 [term]</p> | <p>External program mode command followed by a query. Instrument will change to external programming mode, then return a string with the present setting.</p> |

The following are additional notes on using either IEEE-488 Interface program.

- If you enter a correctly spelled query without a “?”, nothing will be returned. Incorrectly spelled commands and queries are ignored. Commands and queries should have a space separating the command and associated parameters.
- Leading zeros and zeros following a decimal point are not needed in a command string, but are sent in response to a query. A leading “+” is not required but a leading “-” is required.

5.1.6 Troubleshooting

New Installation

1. Check instrument address.
2. Always send terminators.
3. Send entire message string at one time including terminators.
4. Send only one simple command at a time until communication is established.
5. Be sure to spell commands correctly and use proper syntax.
6. Attempt both ‘Talk’ and ‘Listen’ functions. If one works but not the other, the hardware connection is working, so look at syntax, terminators, and command format.
7. If only one message is received after resetting the interface, check the “repeat addressing” setting. It should be enabled.

Old Installation No Longer Working

8. Power instrument off then on again to see if it is a soft failure.
9. Power computer off then on again to see if the IEEE-488 card is locked up.
10. Verify that the address has not been changed on the instrument during a memory reset.
11. Check all cable connections.

Intermittent Lockups

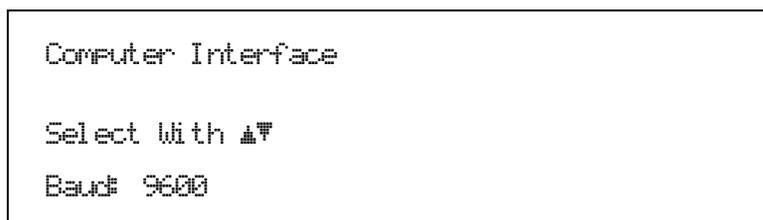
12. Check cable connections and length.
13. Increase delay between all commands to 50 ms to make sure instrument is not being over loaded.

5.2 SERIAL INTERFACE OVERVIEW

The serial interface used in the Model 642 is commonly referred to as an RS-232C interface. RS-232C is a standard of the Electronics Industries Association (EIA) that describes one of the most common interfaces between computers and electronic equipment. The RS-232C standard is quite flexible and allows many different configurations. However, any two devices claiming RS-232C compatibility cannot necessarily be plugged together without interface setup. The remainder of this paragraph briefly describes the key features of a serial interface that are supported by the instrument. A customer supplied computer with similarly configured interface port is required to enable communication.

5.2.1 Changing Baud Rate

To select the Serial Interface Baud Rate press the **Computer Interface** key. The first computer interface screen appears as a prompt for Baud.



Use the ▲ or ▼ key to select 9600, 19200, 38400, or 57600 Baud. The default is 9600 Baud. Press **Enter** to accept the new selection and continue to the next setting screen. Press **Escape** to cancel the new selection and return to the normal display.

5.2.2 Physical Connection

The Model 642 has a 9 pin D-Subminiature plug on the rear panel for serial communication. The original RS-232C standard specifies 25 pins but both 9- and 25-pin connectors are commonly used in the computer industry. Many third party cables exist for connecting the instrument to computers with either 9- or 25-pin connectors. Paragraph 7.10.5 gives the most common pin assignments for 9- and 25-pin connectors. Please note that not all pins or functions are supported by the Model 642.

The instrument serial connector is the plug half of a mating pair and must be matched with a socket on the cable. If a cable has the correct wiring configuration but also has a plug end, a “gender changer” can be used to mate two plug ends together.

The letters DTE near the interface connector stand for Data Terminal Equipment and indicate the pin connection of the directional pins such as transmit data (TD) and receive data (RD). Equipment with Data Communications Equipment (DCE) wiring can be connected to the instrument with a straight through cable. As an example, Pin 3 of the DTE connector holds the transmit line and Pin 3 of the DCE connector holds the receive line so the functions complement.

It is likely both pieces of equipment are wired in the DTE configuration. In this case Pin 3 on one DTE connector (used for transmit) must be wired to Pin 2 on the other (used for receive). Cables that swap the complementing lines are called null modem cables and must be used between two DTE wired devices. Null modem adapters are also available for use with straight through cables. Paragraph 7.10.5 illustrates suggested cables that can be used between the instrument and common computers.

The instrument uses drivers to generate the transmission voltage levels required by the RS-232C standard. These voltages are considered safe under normal operating conditions because of their relatively low voltage and current limits. The drivers are designed to work with cables up to 50 feet in length.

5.2.3 Hardware Support

The Model 642 interface hardware supports the following features. Asynchronous timing is used for the individual bit data within a character. This timing requires start and stop bits as part of each character so the transmitter and receiver can be resynchronized between each character. Half duplex transmission allows the instrument to be either a transmitter or a receiver of data but not at the same time. Communication speeds of 9600, 19200, 38400, or 57600 Baud are supported. The Baud rate is the only interface parameter that can be changed by the user.

Hardware handshaking is not supported by the instrument. Handshaking is often used to guarantee that data message strings do not collide and that no data is transmitted before the receiver is ready. In this instrument appropriate software timing substitutes for hardware handshaking. User programs must take full responsibility for flow control and timing as described in Paragraph 5.2.6.

5.2.4 Character Format

A character is the smallest piece of information that can be transmitted by the interface. Each character is 10 bits long and contains data bits, bits for character timing and an error detection bit. The instrument uses 7 bits for data in the ASCII format. One start bit and one stop bit are necessary to synchronize consecutive characters. Parity is a method of error detection. One parity bit configured for odd parity is included in each character.

ASCII letter and number characters are used most often as character data. Punctuation characters are used as delimiters to separate different commands or pieces of data. Two special ASCII characters, carriage return (CR 0DH) and line feed (LF 0AH), are used to indicate the end of a message string.

Table 5-6. Serial Interface Specifications

| | |
|------------------------|-----------------------------------|
| Connector Type: | 9-pin D-style connector plug |
| Connector Wiring: | DTE |
| Voltage Levels: | EIA RS-232C Specified |
| Transmission Distance: | 50 feet maximum |
| Timing Format: | Asynchronous |
| Transmission Mode: | Half Duplex |
| Baud Rate: | 9600, 19200, 38400, 57600 |
| Handshake: | Software timing |
| Character Bits: | 1 Start, 7 Data, 1 Parity, 1 Stop |
| Parity: | Odd |
| Terminators: | CR(0DH) LF(0AH) |
| Command Rate: | 20 commands per second maximum |

5.2.5 Message Strings

A message string is a group of characters assembled to perform an interface function. There are three types of message strings commands, queries and responses. The computer issues command and query strings through user programs, the instrument issues responses. Two or more command or query strings can be chained together in one communication but they must be separated by a semi-colon (;). The total communication string must not exceed 255 characters in length.

A command string is issued by the computer and instructs the instrument to perform a function or change a parameter setting. The format is:

<command mnemonic><space><parameter data><terminators>.

Command mnemonics and parameter data necessary for each one is described in Paragraph 5.3. Terminators must be sent with every message string.

Message Strings (Continued)

A query string is issued by the computer and instructs the instrument to send a response. The query format is:

<query mnemonic><?><space><parameter data><terminators>.

Query mnemonics are often the same as commands with the addition of a question mark. Parameter data is often unnecessary when sending queries. Query mnemonics and parameter data if necessary is described in Paragraph 5.3. Terminators must be sent with every message string. The computer should expect a response very soon after a query is sent.

A response string is the instruments response or answer to a query string. The instrument will respond to the last query or queries it receives. The response can be a reading value, status report or the present value of a parameter. Response data formats are listed along with the associated queries in Paragraph 5.3. The response is sent as soon as possible after the instrument receives the query. Typically it takes 10 ms for the instrument to begin the response. Some responses take longer.

5.2.6 Message Flow Control

It is important to remember that the user program is in charge of the serial communication at all times. The instrument cannot initiate communication, determine which device should be transmitting at a given time or guarantee timing between messages. All of this is the responsibility of the user program.

When issuing commands only the user program should:

- Properly format and transmit the command including terminators as one string.
- Guarantee that no other communication is started for 50 ms after the last character is transmitted.
- Not initiate communication more than 20 times per second.

When issuing queries or queries and commands together the user program should:

- Properly format and transmit the query including terminators as one string.
- Prepare to receive a response immediately.
- Receive the entire response from the instrument including the terminators.
- Guarantee that no other communication is started during the response or for 50 ms after it completes.
- Not initiate communication more than 20 times per second.

Failure to follow these simple rules will result in inability to establish communication with the instrument or intermittent failures in communication.

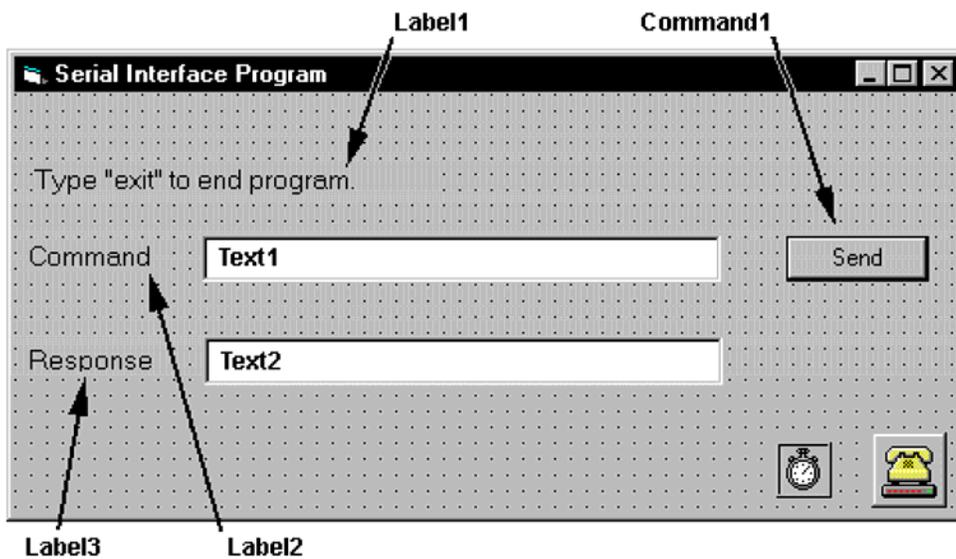
5.2.7 Serial Interface Example Programs

A Visual BASIC program is included to illustrate the serial communication functions of the instrument. Refer to Paragraph 5.2.7.1 for instructions on how to setup the program. The Visual Basic code is provided in Table 5-8. Refer to Paragraph 5.2.7.2 for instructions on how to setup the program. A description of operation is provided in Paragraph 5.2.7.2. While the hardware and software required to produce and implement these programs not included with the instrument, the concepts illustrated apply to almost any application where these tools are available.

5.2.7.1 Visual Basic Serial Interface Program Setup

The serial interface program works with Visual Basic 6.0 (VB6) on an IBM PC (or compatible) with a Pentium-class processor. A Pentium 90 or higher is recommended, running Windows 95 or better, with a serial interface. It uses the COM1 communications port at 9600 Baud. Use the following procedure to develop the Serial Interface Program in Visual Basic.

1. Start VB6.
2. Choose Standard EXE and select Open.
3. Resize form window to desired size.
4. On the Project Menu, click Components to bring up a list of additional controls available in VB6.
5. Scroll through the controls and select Microsoft Comm Control 6.0. Select OK. In the toolbar at the left of the screen, the Comm Control will have appeared as a telephone icon.
6. Select the Comm control and add it to the form.
7. Add controls to form:
 - a. Add three Label controls to the form.
 - b. Add two TextBox controls to the form.
 - c. Add one CommandButton control to the form.
 - d. Add one Timer control to the form.
8. On the View Menu, select Properties Window.
9. In the Properties window, use the dropdown list to select between the different controls of the current project.

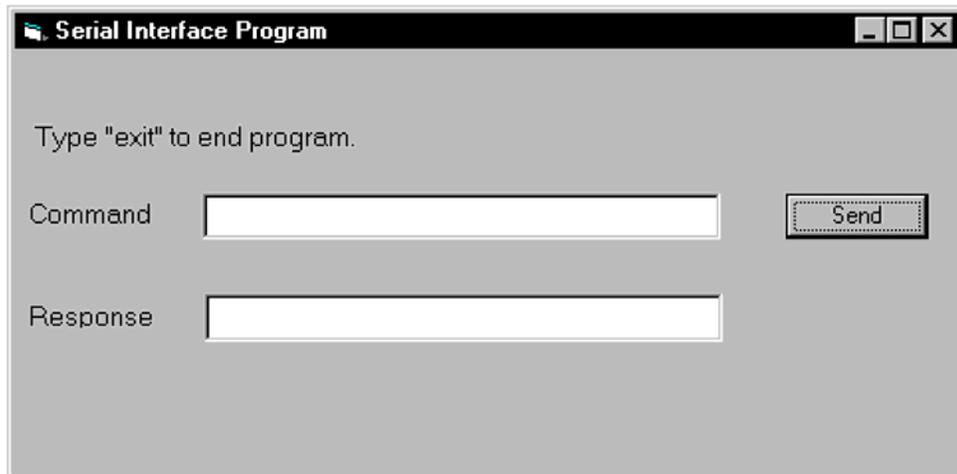


10. Set the properties of the controls as defined in Table 5-7.
11. Save the program.

Table 5-7 Serial Interface Program Control Properties

| <i>Current Name</i> | <i>Property</i> | <i>New Value</i> |
|---------------------|----------------------------|---|
| Label1 | Name Caption | lblExitProgram Type "exit" to end program. |
| Label2 | Name Caption | lblCommand Command |
| Label3 | Name Caption | lblResponse Response |
| Text1 | Name Text | txtCommand <blank> |
| Text2 | Name Text | txtResponse <blank> |
| Command1 | Name Caption Default | cmdSend Send True |
| Form1 | Name Caption | frmSerial Serial Interface Program |
| Timer1 | Enabled Interval | False 10 |

12. Add code (provided in Table 5-8).
 - a. In the Code Editor window, under the Object dropdown list, select (General). Add the statement: Public gSend as Boolean
 - b. Double Click on cmdSend. Add code segment under Private Sub cmdSend_Click() as shown in Table 5-8.
 - c. In the Code Editor window, under the Object dropdown list, select Form. Make sure the Procedure dropdown list is set at Load. The Code window should have written the segment of code: Private Sub Form_Load(). Add the code to this subroutine as shown in Table 5-8.
 - d. Double Click on the Timer control. Add code segment under Private Sub Timer1_Timer() as shown in Table 5-8.
 - e. Make adjustments to code if different Com port settings are being used.
13. Save the program.
14. Run the program. The program should resemble the following.



15. Type in a command or query in the Command box as described in Paragraph 5.2.7.2.
16. Press Enter or select the Send button with the mouse to send command.
17. Type Exit and press Enter to quit.

Table 5-8. Visual Basic Serial Interface Program

| | |
|---|--|
| Public gSend As Boolean | 'Global used for Send button state |
| Private Sub cmdSend_Click() gSend = True End Sub | 'Routine to handle Send button press 'Set Flag to True |
| Private Sub Form_Load() Dim strReturn As String Dim strHold As String Dim Term As String Dim ZeroCount As Integer Dim strCommand As String frmSerial.Show Term = Chr(13) & Chr(10) ZeroCount = 0 strReturn = "" strHold = "" If frmSerial.MSComm1.PortOpen = True Then frmSerial.MSComm1.PortOpen = False End If frmSerial.MSComm1.CommPort = 1 frmSerial.MSComm1.Settings = "9600,o,7,1" frmSerial.MSComm1.InputLen = 1 frmSerial.MSComm1.PortOpen = True Do Do DoEvents Loop Until gSend = True gSend = False strCommand = frmSerial.txtCommand.Text strReturn = "" strCommand = UCase(strCommand) If strCommand = "EXIT" Then End End If frmSerial.MSComm1.Output = strCommand & Term If InStr(strCommand, "?") <> 0 Then While (ZeroCount < 20) And (strHold <> Chr\$(10)) If frmSerial.MSComm1.InBufferCount = 0 Then frmSerial.Timer1.Enabled = True Do DoEvents Loop Until frmSerial.Timer1.Enabled = False ZeroCount = ZeroCount + 1 Else ZeroCount = 0 strHold = frmSerial.MSComm1.Input strReturn = strReturn + strHold End If Wend If strReturn <> "" Then strReturn = Mid(strReturn, 1, InStr(strReturn, Term) - 1) Else strReturn = "No Response" End If frmSerial.txtResponse.Text = strReturn strHold = "" ZeroCount = 0 End If Loop End Sub | 'Main code section 'Used to return response 'Temporary character space 'Terminators 'Counter used for Timing out 'Data string sent to instrument 'Show main window 'Terminators are <CR><LF> 'Initialize counter 'Clear return string 'Clear holding string 'Close serial port to change settings 'Example of Comm 1 'Example of 9600 Baud, Parity, Data, Stop 'Read one character at a time 'Open port 'Wait loop 'Give up processor to other events 'Loop until Send button pressed 'Set Flag as false 'Get Command 'Clear response display 'Set all characters to upper case 'Get out on EXIT 'Send command to instrument 'Check to see if query 'Wait for response 'Add 1 to timeout if no character 'Wait for 10 millisecond timer 'Timeout at 2 seconds 'Reset timeout for each character 'Read in one character 'Add next character to string 'Get characters until terminators 'Check if string empty 'Strip terminators 'Send No Response 'Put response in textbox on main form 'Reset holding string 'Reset timeout counter |
| Private Sub Timer1_Timer() frmSerial.Timer1.Enabled = False End Sub | 'Routine to handle Timer interrupt 'Turn off timer |

5.2.7.2 Program Operation

Once the example program is running, try the following commands and observe the response of the instrument. Input from the user is shown in **bold** and terminators are added by the program. The word [term] indicates the required terminators included with the response.

| | |
|---|--|
| ENTER COMMAND? *IDN? | Identification query. Instrument will return a string identifying itself. |
| RESPONSE: LSCI,MODELModel 642,1234567,06122006 [term] | |
| ENTER COMMAND? SETI? | Output current setting query. Instrument will return a string with the present output current setting. |
| RESPONSE: +20.0545 [term] | |
| ENTER COMMAND? XPGM 0 | External program mode command. Instrument will set program mode to internal. No response will be sent. |
| ENTER COMMAND? XPGM? | External program mode query. Instrument will return a string with the present external program mode setting. |
| RESPONSE: 0 [term] | |
| ENTER COMMAND? XPGM 1;XPGM? | External program mode command followed by a query. Instrument will change to external programming mode, then return a string with the present setting. |
| RESPONSE: 1 [term] | |

The following are additional notes on using either IEEE-488 Interface program.

- If you enter a correctly spelled query without a “?”, nothing will be returned. Incorrectly spelled commands and queries are ignored. Commands and queries should have a space separating the command and associated parameters.
- Leading zeros and zeros following a decimal point are not needed in a command string, but are sent in response to a query. A leading “+” is not required but a leading “-” is required.

5.2.8 Troubleshooting

New Installation

1. Check instrument Baud rate.
2. Make sure transmit (TD) signal line from the instrument is routed to receive (RD) on the computer and vice versa. (Use a null modem adapter if not).
3. Always send terminators.
4. Send entire message string at one time including terminators. (Many terminal emulation programs do not.)
5. Send only one simple command at a time until communication is established.
6. Be sure to spell commands correctly and use proper syntax.

Old Installation No Longer Working

7. Power instrument off then on again to see if it is a soft failure.
8. Power computer off then on again to see if communication port is locked up.
9. Verify that Baud rate has not been changed on the instrument during a memory reset.
10. Check all cable connections.

Intermittent Lockups

11. Check cable connections and length.
12. Increase delay between all commands to 100 ms to make sure instrument is not being over loaded.

5.3 COMMAND SUMMARY

This paragraph provides a listing of the IEEE-488 and Serial Interface Commands. A summary of all the commands is provided in Table 5-9. All the commands are detailed in Paragraph 5.3.1, which is presented in alphabetical order.

Sample Command Format

SETI Output Current Setting Command

Input: **SETI** <current> [term]

Format: ±nn.nnnn
 <current> Specifies the output current setting: 0.0000 – ±70.1000A.

Remarks: Sets the current value that the output will ramp to at the present ramp rate. Setting value is limited by LIMIT.

Sample Query Format

SETI? Output Current Setting Query

Input: **SETI?** [term]

Returned: <current> [term]

Format: ±nn.nnnn (Refer to command for description)

Key

- * Begins common interface command.
- ? Required to identify queries.
- aa... String of alpha numeric characters.
- ±nn... String of number characters that may include a decimal point.
- [term] Terminator characters.
- <...> Indicated a parameter field, many are command specific.
- <state> Parameter field with only On/Off states.

Table 5-9. Command Summary

| <u>Command</u> | <u>Function</u> | <u>Page</u> | <u>Command</u> | <u>Function</u> | <u>Page</u> |
|----------------|---|-------------|----------------|--|-------------|
| *CLS | Clear Interface Cmd | 29 | INTWR? | Internal Water Mode Query | 33 |
| *ESE | Event Status Enable Cmd..... | 29 | KEYST? | Keypad Status Query | 33 |
| *ESE? | Event Status Enable Query..... | 30 | LIMIT | Limit Output Settings Cmd..... | 34 |
| *ESR? | Event Status Register Query | 30 | LIMIT? | Limit Output Settings Query..... | 33 |
| *IDN? | Identification Query | 30 | LOCK | Keypad Lock Cmd | 34 |
| *OPC | Operation Complete Cmd | 30 | LOCK? | Keypad Lock Query..... | 34 |
| *OPC? | Operation Complete Query | 30 | MAGWTR | Magnet Water Mode Command..... | 34 |
| *RST | Reset Instrument Cmd..... | 30 | MAGWTR? | Magnet Water Mode Query | 34 |
| *SRE | Service Request Enable Cmd..... | 31 | MODE | IEEE Interface Mode Cmd..... | 34 |
| *SRE? | Service Request Enable Query..... | 31 | MODE? | IEEE Interface Mode Query | 34 |
| *STB? | Status Byte Query | 31 | OPST? | Operational Status Query..... | 35 |
| *TST? | Self-Test Query | 31 | OPSTE | Operational Status Enable Cmd | 35 |
| *WAI | Wait-To-Continue Cmd | 31 | OPSTE? | Operational Status Enable Query | 35 |
| BAUD | RS-232C Baud Rate Cmd | 31 | OPSTR? | Operational Status Register Query..... | 35 |
| BAUD? | RS-232C Baud Rate Query | 31 | RATE | Current Ramp Rate Setting Cmd | 35 |
| DFLT | Factory Defaults Cmd | 32 | RATE? | Current Ramp Rate Setting Query | 35 |
| DISP | Display Parameter Cmd | 32 | RDGI? | Current Output Reading Query..... | 35 |
| DISP? | Display Parameter Query | 32 | RDGV? | Output Voltage Reading Query..... | 36 |
| ERCL | Error Clear Cmd..... | 32 | RSEG | Ramp Segments Enable Cmd..... | 36 |
| ERST? | Error Status Query | 32 | RSEG? | Ramp Segments Enable Query | 36 |
| ERSTE | Error Status Enable Cmd..... | 32 | RSEGS | Ramp Segments Parameters Cmd..... | 36 |
| ERSTE? | Error Status Enable Query | 32 | RSEGS? | Ramp Segments Parameters Query..... | 36 |
| ERSTR? | Error Status Register Query | 33 | SETI | Output Current Setting Cmd | 36 |
| IEEE | IEEE-488 Interface Parameter Cmd..... | 33 | SETI? | Output Current Setting Query | 36 |
| IEEE? | IEEE-488 Interface Parameter Query..... | 33 | STOP | Stop Output Current Ramp Cmd..... | 37 |
| INTWR | Internal Water Mode Command | 33 | XPGM | External Program Mode Cmd | 37 |
| | | | XPGM? | External Program Mode Query..... | 37 |

5.3.1 Interface Commands (Alphabetical Listing)

***CLS** Clear Interface Command
Input: *CLS[term]
Remarks: Clears the bits in the Status Byte Register and Standard Event Status Register and terminates all pending operations. Clears the interface, but *not* the instrument. The related instrument command is *RST.

***ESE** Standard Event Status Enable Register Command
Input: *ESE <bit weighting>[term]
Format: nnn
Remarks: The Standard Event Status Enable Register determines which bits in the Standard Event Status Register will set the summary bit in the Status Byte. This command programs the enable register using a decimal value that corresponds to the binary-weighted sum of all bits in the register. Refer to Paragraph 5.1.4.2.1.

***ESE?** Standard Event Status Enable Register Query
Input: *ESE?[term]
Returned: <bit weighting>[term]
Format: nnn (Refer to command for description)

***ESR?** Standard Event Status Register Query
Input: *ESR?[term]
Returned: <bit weighting>
Format: nnn
Remarks: Bits in this register correspond to various system events and latch when the event occurs. When an event bit is set, subsequent events corresponding to that bit are ignored. Set bits remain latched until the register is reset by this query or a *CLS command. Refer to Paragraph 5.1.4.2.1.

***IDN?** Identification Query
Input: *IDN?[term]
Returned: <manufacturer>,<model>,<serial>,<firmware version>[term]
Format: aaaa,aaaaaaaa,aaaaaaaa,n.n/n.n
 <manufacture> Manufacturer ID
 <model> Instrument model number
 <serial> Serial number
 <firmware version> Instrument firmware version, main firmware/DAC firmware.
Example: **LSCI,MODEL642,1234567,1.0/1.0**

***OPC** Operation Complete Command
Input: *OPC[term]
Remarks: Used in conjunction with bit 0 (OPC of the Standard Event Status Register. If sent as the last command in a command sequence, bit 0 will be set when the instrument completes the operation that was initiated by the command sequence. Refer to Paragraph 5.1.4.4.6 for more information.

***OPC?** Operation Complete Query
Input: *OPC?[term]
Returned: 1[term]
Remarks: Has *no* interaction with bit 0 (OPC) of the Standard Event Status Register. If sent at the end of a command sequence, the bus will be held until the instrument completes the operation that was initiated by the command sequence. Once the sequence is complete a 1 will be placed in the output buffer. Refer to Paragraph 5.1.4.4.6 for more information.

***RST** Reset Instrument Command
Input: *RST[term]
Remarks: Sets controller parameters to power-up settings. Use the **DFLT** command to set factory defaults.

***SRE** Service Request Enable Register Command

Input: *SRE <bit weighting>[term]

Format: nnn

Remarks: The Service Request Enable Register determines which summary bits of the Status Byte may set bit 6 (RQS/MSS) of the Status Byte to generate a Service Request. This command programs the enable register using a decimal value that corresponds to the binary-weighted sum of all bits in the register. Refer to Paragraph 5.1.4.4.

***SRE?** Service Request Enable Register Query

Input: *SRE?[term]

Returned: <bit weighting>[term]

Format: nnn (Refer to command for description)

***STB?** Status Byte Query

Input: *STB?[term]

Returned: <bit weighting>[term]

Format: nnn

Remarks: This command is similar to a Serial Poll except it is processed like any other instrument command. It returns the same result as a Serial Poll except that the Status Byte bit 6 (RQS/MSS) is not cleared. Refer to paragraph 5.1.4.4.4

***TST?** Self-Test Query

Input: *TST?[term]

Returned: <status>[term]

Format: n
<status> 0 = No errors found, 1 = Errors found

Remarks: The Model 642 reports status based on test done at power up.

***WAI** Wait-to-Continue Command

Input: *WAI[term]

Remarks: This command is not supported in the Model 642.

BAUD RS-232C Baud Rate Command

Input: BAUD <bps>[term]

Format: n
<bps> Specifies Baud rate: 0 = 9600 Baud, 1 = 19200 Baud, 2 = 38400 Baud, 3 = 57600 Baud.

BAUD? RS-232C Baud Rate Query

Input: BAUD?[term]

Returned: <bps>[term]

Format: n (Refer to command for description)

DFLT Factory Defaults Command
Input: **DFLT 99[term]**
Remarks: Sets all configuration values to factory defaults and resets the instrument. The instrument must be at zero amps for this command to work. The "99" is included to prevent accidentally setting the unit to defaults.

DISP Display Parameter Command
Input: **DISP <brightness> [term]**
Format: n
 <brightness> Specifies display brightness: 0 = 25%, 1 = 50%, 2 = 75%, 3 = 100%.

DISP? Display Parameter Query
Input: **DISP? [term]**
Returned: <brightness> [term]
Format: n (Refer to command for definition).

ERCL Error Clear Command
Input: **ERCL [term]**
Remarks: This command will clear the operational errors. The errors will only be cleared if the error conditions have been removed. Hardware errors can never be cleared. Refer to Paragraph 5.1.4.3 for a list of error bits.

ERST? Error Status Query
Input: **ERST? [term]**
Returned: <hardware errors>, <operational errors> [term]
Format: nnn,nnn
Remarks: The integers returned represent the sum of the bit weighting of the error bits. Refer to Paragraph 5.1.4.3 for a list of error bits. Use the **ERCL** command to clear the operational errors. Hardware errors cannot be cleared.

ERSTE Error Status Enable Command
Input: **ERSTE <hardware errors>, <operational errors> [term]**
Format: nnn,nnn
Remarks: Each bit has a bit weighting and represents the enable/disable mask of the corresponding error bits in the Error Status Register. This determines which status bits can set the corresponding summary bits in the Status Byte Register. To enable an error bit, send the command **ERSTE** with the sum of the bit weighting for each desired bit. Refer to Paragraph 5.1.4.3 for a list of error bits.

ERSTE? Error Status Enable Query
Input: **ERSTE?[term]**
Returned: <hardware errors>, <operational errors> [term]
Format: nnn,nnn Refer to Paragraph 5.1.4.3 for a list of error bits.

ERSTR? Error Status Register Query

Input: **ERSTR? [term]**

Returned: <hardware errors>, <operational errors> [term]

Format: nnn,nnn

Remarks: The integers returned represent the sum of the bit weighting of the error bits. These error bits are latched when an error condition is detected. This register is cleared when it is read. Refer to Paragraph 5.1.4.3 for a list of error bits. Use the **ERRCL** command to clear the operational errors. Hardware errors cannot be cleared.

IEEE IEEE-488 Interface Parameter Command

Input: **IEEE <terminator>, <EOI enable>, <address>[term]**

Format: n,n,nn

<terminator> Specifies the terminator. Valid entries: 0 = <CR><LF>, 1 = <LF><CR>, 2 = <LF>, 3 = No terminator (must have EOI enabled).

<EOI enable> Sets EOI mode: 0 = Enabled, 1 = Disabled.

<address> Specifies the IEEE address: 1 – 30. (Address 0 and 31 are reserved.)

Example: **IEEE 0,0,4[term]** – After receipt of the current terminator, the instrument uses <CR><LF> as the new terminator, uses EOI mode, and responds to address 4.

IEEE? IEEE-488 Interface Parameter Query

Input: **IEEE?[term]**

Returned: <terminator>, <EOI enable>, <address>[term]

Format: n,n,nn (Refer to command for description)

<mode> 0 = Manual Off, 1 = Manual On, 2 = Auto, 3 = Disabled

INTWTR Internal Water Mode Command

Input: **INTWTR <mode> [term]**

Format: n

<mode> 0 = Manual Off, 1 = Manual On, 2 = Auto, 3 = Disabled

Example: **INTWTR 2[term]** – Places the internal water mode to Auto, which will automatically control the power supply water valve based on the internal power dissipation and temperature.

INTWTR? Internal Water Mode Query

Input: **INTWTR? [term]**

Returned: <mode>[term]

Format: n (Refer to command for description)

KEYST? Keypad Status Query

Input: **KEYST? [term]**

Returned: <code>[term]

Format: nn

Remarks: Returns a number descriptor of the last key pressed since the last KEYST?. Returns “01” after initial power-up. Returns “00” if no key pressed since last query.

LIMIT Limit Output Settings Command

Input: **LIMIT <current>, <rate> [term]**

Format: +nn.nnnn, +nn.nnnn
 <current> Specifies the maximum output current setting allowed: 0 – 70.1000 A.
 <rate> Specifies the maximum output current ramp rate setting allowed: 0.0001 – 99.999 A/s.

Remarks: Sets the upper setting limits for output current, compliance voltage, and output current ramp rate. This is a software limit that will limit the settings to these maximum values.

LIMIT? Limit Output Settings Query

Input: **LIMIT? [term]**

Returned: <current>, <rate> [term]

Format: +nn.nnnn, +nn.nnnn (Refer to command for description)

LOCK Keypad Lock Command

Input: **LOCK <state>, <code>[term]**

Format: n,nnn
 <state> 0 = Unlock, 1 = Lock All, 2 = Lock Limits.
 <code> Specifies lock-out code. Valid entries are 000–999.

Remarks: Locks out all front panel entries operations.

Example: **LOCK 1,123[term]** – Enables keypad lock and sets the code to 123.

LOCK? Keypad Lock Query

Input: **LOCK?[term]**

Returned: <state>, <code>[term]

Format: n,nnn (Refer to command for description)

MAGWTR Magnet Water Mode Command

Input: **MAGWTR <mode>[term]**

Format: n
 <mode> 0 = Manual Off, 1 = Manual On, 2 = Auto, 3 = Disabled.

Example: **MAGWTR 2[term]** – Places the magnet water mode to Auto, which will automatically control the magnet water valve based on the calculated output power.

MAGWTR? Magnet Water Mode Query

Input: **MAGWTR?[term]**

Returned: <mode>[term]

Format: n (Refer to command for description)

MODE IEEE Interface Mode Command

Input: **MODE <mode>[term]**

Format: n
 <mode> 0 = Local, 1 = Remote, 2 = Remote with local lockout.

Example: **MODE 2[term]** – Places the Model 642 into remote mode with local lockout.

MODE? IEEE Interface Mode Query

Input: **MODE?[term]**

Returned: <mode>[term]

Format: n (Refer to command for description)

OPST? Operational Status Query
Input: **OPST? [term]**
Returned: <bit weighting> [term]
Format: nnn
Remarks: The integer returned represents the sum of the bit weighting of the operational status bits. Refer to Paragraph 5.1.4.2.2 for a list of operational status bits.

OPSTE Operational Status Enable Command
Input: **OPSTE <bit weighting> [term]**
Format: nnn
Remarks: Each bit has a bit weighting and represents the enable/disable mask of the corresponding operational status bit in the Operational Status Register. This determines which status bits can set the corresponding summary bit in the Status Byte Register. To enable a status bit, send the command **OPSTE** with the sum of the bit weighting for each desired bit. Refer to Paragraph 5.1.4.2.2 for a list of operational status bits.

OPSTE? Operational Status Enable Query
Input: **OPSTE?[term]**
Returned: <bit weighting> [term]
Format: nnn Refer to Paragraph 5.1.4.2.2 for a list of operational status bits.

OPSTR? Operational Status Register Query
Input: **OPSTR? [term]**
Returned: <bit weighting> [term]
Format: nnn
Remarks: The integers returned represent the sum of the bit weighting of the operational status bits. These status bits are latched when the condition is detected. This register is cleared when it is read. Refer to Paragraph 5.1.4.2.2 for a list of operational status bits.

RATE Output Current Ramp Rate Setting Command
Input: **RATE <rate> [term]**
Format: +n.nnnn
 <rate> Specifies the rate at which the current will ramp at when a new output current setting is entered: 0.0001 – 99.999 A/s.
Remarks: Sets the output current ramp rate. This value will be used in both the positive and negative directions. Setting value is limited by LIMIT.

RATE? Output Current Ramp Rate Setting Query
Input: **RATE? [term]**
Returned: <rate> [term]
Format: +n.nnnn (Refer to command for description)

RDGI? Current Output Reading Query
Input: **RDGI? [term]**
Returned: <current> [term]
Format: ±nn.nnnn
 <current> Actual measured output current.

RDGV? Output Voltage Reading Query
Input: **RDGV? [term]**
Returned: <voltage> [term]
Format: ±n.nnnn
 <voltage> Actual output voltage measured at the power supply terminals.

RSEG Ramp Segments Enable Command
Input: **RSEG <enable> [term]**
Format: n [term]
 <enable> Specifies if ramp segments are to be used: 0 = Disabled, 1 = Enabled.
Remarks: Ramp segments are used to change the output current ramp rate based on the output current. Ramp segments need to be setup first using the RSEGS command.

RSEG? Ramp Segments Enable Query
Input: **RSEG? [term]**
Returned: <enable> [term]
Format: n (Refer to command for description)

RSEGS Ramp Segments Parameters Command
Input: **RSEGS <segment>, <current>, <rate> [term]**
Format: n, +nn.nnnn, +n.nnnn [term]
 <segment> Specifies the ramp segment to be modified: 1 – 5.
 <current> Specifies the upper output current setting that will use this segment:
 0.0000 – +70.1000A.
 <rate> Specifies the rate at which the current will ramp at when the output current is in this
 segment: 0.0001 – 99.999 A/s.
Remarks: Ramp segments are used to change the output current ramp rate based on the output current. The ramp segment feature needs to be turned on using the RSEG command.

RSEGS? Ramp Segments Parameters Query
Input: **RSEGS? <segment>[term]**
Returned: <current>, <rate> [term]
Format: +nn.nnnn, +n.nnnn (Refer to command for description)

SETI Output Current Setting Command
Input: **SETI <current> [term]**
Format: ±nn.nnnn
 <current> Specifies the output current setting: 0.0000 – ±70.1000A.
Remarks: Sets the current value that the output will ramp to at the present ramp rate. Setting value is limited by LIMIT.

SETI? Output Current Setting Query
Input: **SETI? [term]**
Returned: <current> [term]
Format: ±nn.nnnn (Refer to command for description)

STOP Stop Output Current Ramp Command

Input: **STOP [term]**

Remarks: This command will stop the output current ramp within two seconds of sending the command. To restart the ramp, use the **SETI** command to set a new output current setpoint.

XPGM External Program Mode Command

Input: **XPGM <mode>[term]**

Format: n
<mode> 0 = Internal, 1 = External, 2 = Sum.

Example: **XPGM 1[term]** – Places the Model 642 into external program mode where the output current is set by an external voltage.

XPGM? External Program Mode Query

Input: **XPGM?[term]**

Returned: <mode>[term]

Format: n (Refer to command for description)

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CHAPTER 6

OPTIONS AND ACCESSORIES

6.0 GENERAL

This chapter provides information on accessories available for the Model 642 Electromagnet Power Supply.

6.1 ACCESSORIES INCLUDED

| <i>Part Number</i> | <i>Description</i> |
|----------------------|--|
| MAN-Model 642 | Model 642 Electromagnet Power Supply User's Manual. |
| 6031 | Two front handles. |
| 6032 | Two rear handles. |
| 6051 | Terminal Block, 4 Pin |
| 6052 | Terminal Block, 8 Pin |
| 6252 | 15-pin D-sub mating connector, analog I/O. |
| 108-654 | Strain Relief Bushing Kit |
| – | Calibration Certificate. |

6.2 ACCESSORIES AVAILABLE

| <i>Part Number</i> | <i>Description</i> |
|---------------------|--|
| 6201 | IEEE-488 Cable Kit, 1 meter (3 foot) IEEE-488 (GPIB) computer interface cable assembly. |
| 6261 | Magnet Cable Kit, 3 meters (10 feet), 60 A, AWG 4. |
| 6262 | Magnet Cable Kit, 6 meters (20 feet), 60 A, AWG 4. |
| 6041 | Flow Switch. |
| 6042 | Solenoid Water Valve with Bracket. |
| CAL-642-CERT | Instrument recalibration with certificate. |
| CAL-642-DATA | Instrument recalibration with certificate and data. |

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CHAPTER 7

SERVICE

7.0 GENERAL

This chapter provides basic service information for the Model 642 Superconducting Magnet Power Supply. Customer service of the product is limited to the information presented in this chapter. Factory trained service personnel should be consulted if the instrument requires repair.

7.1 CONTACTING LAKE SHORE CRYOTRONICS

If a Lake Shore product was purchased through a dealer or representative, please use that resource for prompt sales or service information. When contacting Lake Shore directly, please specify the name of a department if do not know the name of an individual. Questions regarding product applications, price, availability and shipments should be directed to sales. Questions regarding instrument calibration or repair should be directed to instrument service. **Do not return a product to Lake Shore without a Return Authorization number.** Refer to Paragraph 7.2. Current contact information can always be found on the Lake Shore web site: www.lakeshore.com.

| | | |
|------------------|---|-----------------------------|
| Mailing Address: | Lake Shore Cryotronics, Inc. Instrument Service Department 575 McCorkle Blvd. Westerville, OH USA 43082-8888 | |
| E-mail Address: | sales@lakeshore.com service@lakeshore.com | Sales Instrument Service |
| Telephone: | 614-891-2244 614-891-2243 ext. 131 | Sales Instrument Service |
| Fax: | 614-818-1600 614-818-1609 | Sales Instrument Service |

When contacting Lake Shore please provide your name and complete contact information including e-mail address if possible. It is often helpful to include the instrument model number and serial number (located on the rear panel of the instrument) as well as the firmware revision information as described in Paragraph 4.21.

7.2 RETURNING PRODUCTS TO LAKE SHORE

If it is necessary to return the Model 642 for recalibration, repair or replacement, a Return Authorization (**RA**) number must be obtained from a factory representative or from the Lake Shore web site. **Do not return a product to Lake Shore without an RA number.** The following information must be provided to Lake Shore in order to obtain an RA number.

1. Instrument model and serial number.
2. User name, company, address, phone number, and e-mail address.
3. Malfunction symptoms.
4. Description of the system in which the product is used.

If possible, the original packing material should be retained for reshipment. If not available, a minimum of three inches of shock adsorbent packing material should be placed snugly on all sides of the instrument placed in a sturdy corrugated cardboard box. The RA number should be included in the mailing label or written prominently on the outside of the box. A copy of the customer contact information and RA number should be included inside the box. Consult Lake Shore with questions regarding shipping and packing instructions.

7.3 LINE VOLTAGE SELECTION

The Model 642 may be configured for four basic AC power configurations: 208 VAC, 230 VAC, 380 VAC and 415 VAC. Proper voltage selection must be made before connection to the power mains. Each configuration requires the appropriate wiring within the power wiring access panel on the rear of the instrument. Nominal line voltages and appropriate selections are shown in Table 7-1. See Section 3.3.1 for further details. See Figure 7-1 for general locations.

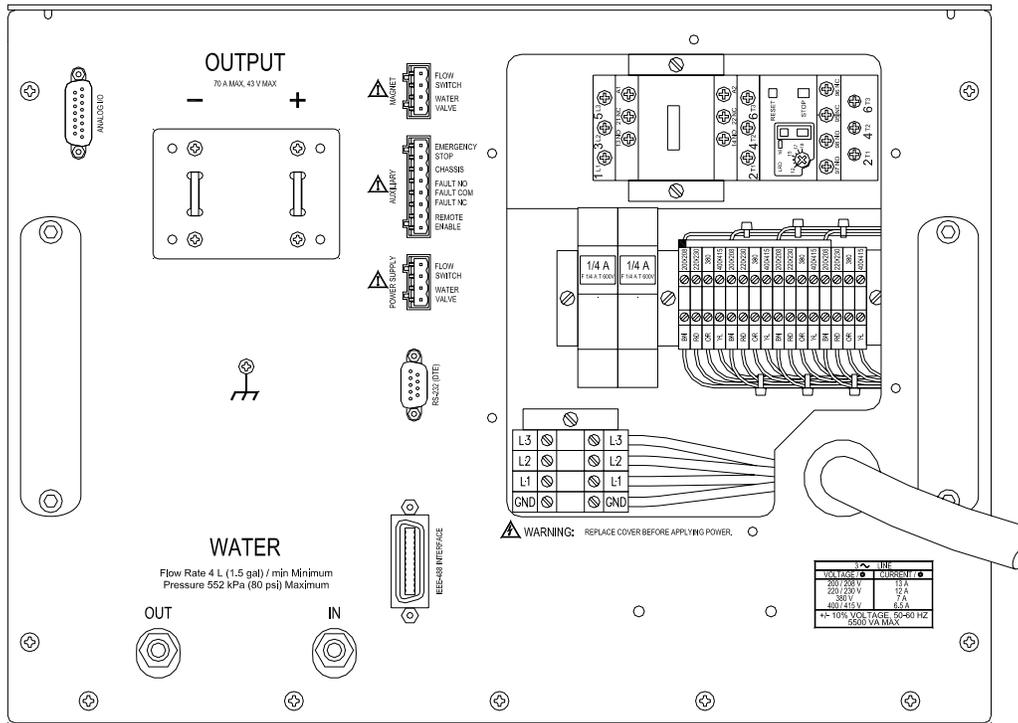


Figure 7-1. Model 642 Rear Panel (shown with wiring cover removed)

Use the following procedure to change the instrument line voltage.

WARNING: To avoid potentially lethal shocks, turn off the power supply and disconnect it from AC power before performing this procedure.

1. Identify the power wiring access panel on the rear of the Model 642.
2. Turn the front panel line power switch OFF (O).
3. Disconnect the power cable at the plug end for safety.
4. Remove the perimeter screws holding the power wiring access panel.
5. Observe the 4 voltage-selection wires held by the clear plastic wiring guide. See Figure 7-2.
6. Loosen the screw terminals presently holding the four wires.
7. Relocate the 4 wires (using the wiring guide) to the desired voltage position. Refer to Table 7-1.
8. Place the wires into the appropriate screw terminals and tighten.
9. Verify solid, tight screw connections to these four wires.
10. Replace the power wiring access panel using all perimeter screws.
11. Verify the voltage indicator in the window of the power wiring access panel.

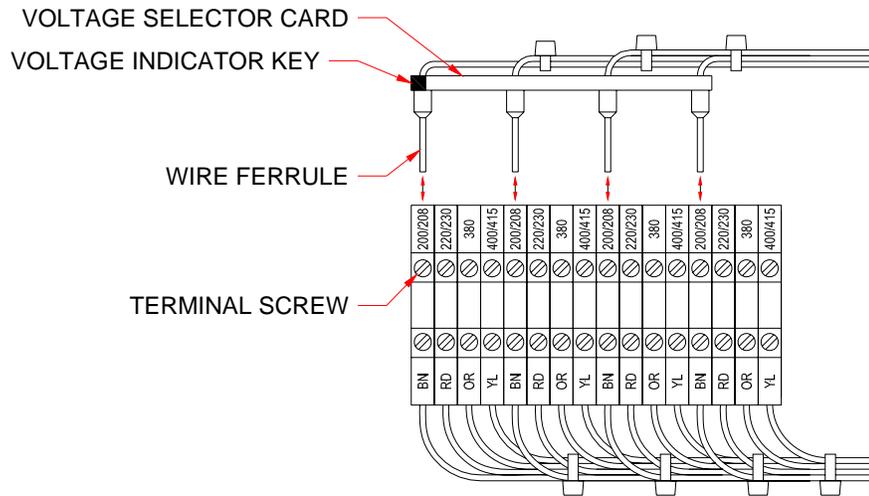


Figure 7-2. Voltage Change Detail

7.4 CIRCUIT BREAKER SETTING

The main three-phase input power is protected by an automatic-reset circuit breaker within the instrument. A smaller, start-up power supply is fused separately and discussed in Section 7.5. If the breaker trips, it will reset within a few minutes and the unit can be restarted. If the unit trips again after a short time, the circuit breaker trip current may be set incorrectly. Table 7-1 shows required voltage and current settings.

Table 7-1. Voltage and Current Selection

| <i>Nominal Voltage</i> | <i>Voltage Tap</i> | <i>Circuit Breaker</i> |
|------------------------|--------------------|------------------------|
| 200 V | 204 V | 18 A |
| 208 V | 204 V | 18 A |
| 220 V | 225 V | 17 A |
| 230 V | 225 V | 17 A |
| 380 V | 380 V | 12 A |
| 400 V | 408 V | 12 A |
| 415 V | 408 V | 12 A |

WARNING: To avoid potentially lethal shocks, turn off the power supply and disconnect it from AC power before performing this procedure.

CAUTION: For continued protection against fire hazard, use only the recommended current setting for the line voltage selected.

Use the following procedure to verify or change the circuit breaker current setting.

1. Identify the power wiring access panel on the rear of the Model 642.
2. Turn the front panel line power switch OFF (●).
3. Disconnect the power cable at the plug end for safety.
4. Remove the perimeter screws holding the power wiring access panel.
5. Refer to Figure 7-1 to locate the circuit breaker detailed in Figure 7-3.
6. Lift the circuit breaker setting access door and visually confirm the setting as shown in Figure 7-3.

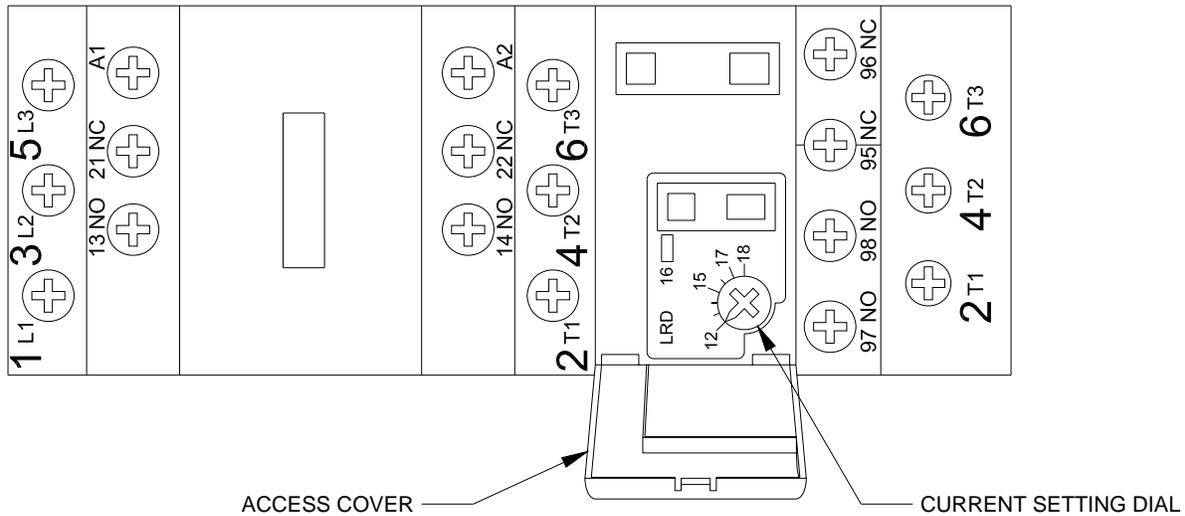


Figure 7-3. Circuit Breaker

7. If incorrect, use a small straight blade screwdriver to reset according to Table 7-1.
8. Close the circuit breaker access door.
9. Replace the power wiring access panel using all perimeter screws.

7.5 POWER LINE FUSE REPLACEMENT

The Model 642 uses a low-power, start-up power supply to provide power to the main contactor coil through multiple thermal safety switches. The start-up supply is energized any time the three-phase power input voltage is connected to the Model 642. This section deals with the fuses for this supply. If the power line fuses for this supply are open, the Model 642 internal three-phase contactor will not close and normal operation will not be possible. If the Model 642 is connected to an input voltage that is higher than the selected voltage of the Model 642, these fuses are expected to clear and prevent operation of the Model 642. Proper voltage selection must be made before connection to the power mains. Access to these fuses is through the power wiring access panel.

WARNING: To avoid potentially lethal shocks, turn off the power supply and disconnect it from AC power before performing this procedure.

CAUTION: For continued protection against fire hazard, replace only with same fuse type and rating specified for the line voltage selected.

Use the following procedure to change the power line fuses.

1. Identify the power wiring access panel on the rear of the Model 642.
2. Turn the front panel line power switch OFF (●).
3. Disconnect the power cable at the plug end for safety.
4. Remove the perimeter screws holding the power wiring access panel.
5. Locate the two fuse holder assemblies as shown in Figure 7-1 and detailed in Figure 7-4
6. Pull open the access door to remove a fuse.
7. Check the fuse for continuity. Replace fuse(s) if necessary. Fuses should be replaced in pairs. Fuses are inserted small-end first as shown.
8. Close the fuse access door(s).
9. Replace the wiring access panel using all perimeter screws.

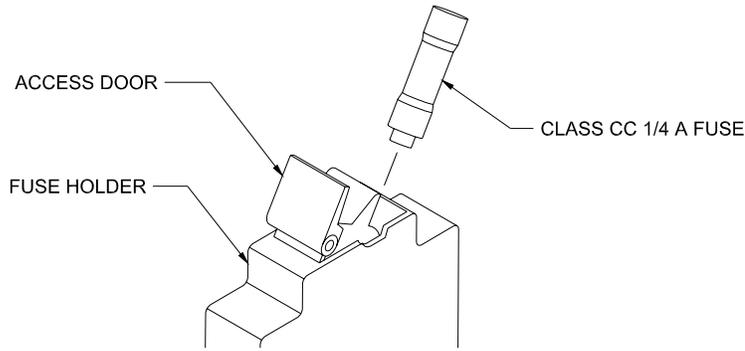


Figure 7-4. Fuse Holder Detail

7.6 ERROR MESSAGES

The following messages appear on the lower part of the instrument display when it identifies a problem during operation. The Fault LED will light in conjunction with the error message. A more extensive description of the error message can shown by pressing the **Status** key. If the error condition can be immediately cleared, it can be done by pressing the **Status** key while in the error status display. Refer to Paragraph 4.14 for a description of the error status display.

Error messages are divided into three groups:

Instrument Hardware Errors are related to internal instrument circuitry. When one of these errors occurs, the Fault LED is solidly lit, the output setting is set to 0 A, current entry will not be allowed and there is no way to clear the error unless power is cycled. If one of these error messages persists after power is cycled, the instrument requires repair. Instrument Hardware Errors are listed in Table 7-2.

Operational Errors are related to instrument operation and do not necessarily indicate a hardware problem. When one of these errors occurs, the Fault LED will be blinking and the error condition can be cleared once the fault condition has been removed. Operational Errors are listed in Table 7-3.

User Errors are related to user requests that cannot be processed. These errors generate responses that immediately explain the cause of the error. These are usually simple order-of-operation issues and are easily resolved. The fault LED is not used for these simpler errors. User Errors are self-explanatory and are therefore not listed.

Table 7-2. Instrument Hardware Errors

| | |
|------------------------------|--|
| Internal Temperature Fault | Cold Plate temperature is over 45° C. The output setting is set to 0 A and no current entry will be allowed. The error message will flash for 10 seconds then the Model 642 will turn itself off. |
| Output Over Voltage | The output voltage is greater than the 44 V compliance voltage limit indicating a problem with the compliance voltage circuitry. The output setting is set to 0 A and no current entry will be allowed. The error message will flash for 10 seconds then the Model 642 will turn itself off. |
| Output Over Current | The measured output current exceeded 73 A. The output setting is set to 0 A and no current entry will be allowed. The error message will flash for 10 seconds then the Model 642 will turn itself off. |
| DAC Processor not Responding | The processor that controls the output DAC is not responding or is responding incorrectly. The output setting is set to 0 A and no current entry will be allowed. Cycle power to attempt to clear. |
| Output Control Failure | One of the internally monitored voltages is beyond an acceptable range on power up. The output setting is set to 0 A and no current entry will be allowed. Cycle power to clear attempt to clear. |

Table 7-3. Operational Errors

| | |
|---|--|
| Remote Enable Fault Detected | The Remote Enable connection loop is not closed. The output setting is set to 0 A and no current entry will be allowed. Once the loop is closed, the error is cleared by pressing the STATUS key or sending "ERCL" over computer interface. |
| Power Supply Flow Switch Fault Detected | The Power Supply Flow Switch connection loop is not closed. The output setting is set to 0 A and no current entry will be allowed. Once the loop is closed, the error is cleared by pressing the STATUS key or sending "ERCL" over computer interface. |
| Magnet Flow Switch Fault Detected | The Magnet Flow Switch connection loop is not closed. The output setting is set to 0 A and no current entry will be allowed. Once the loop is closed, the error is cleared by pressing the STATUS key or sending "ERCL" over computer interface. |
| High Line Voltage Detected | The Output Stage Voltage (Out Stg V) is greater than 66 V. The most likely cause is a power mains voltage that is too high. This error will clear when the power mains voltage is within specified tolerances. Continued operation is allowed but may not be optimal. |
| Low Line Voltage Detected | The Output Stage Voltage (Out Stg V) is less than 44 V. The most likely cause is a power mains voltage that is too low. This error will clear when the power mains voltage is within specified tolerances. Continued operation is allowed but may not be optimal. |
| Internal Temperature High | Cold Plate temperature is over 40° C. The output setting is set to 0 A and no current entry will be allowed. The error will clear when the Cold Plate temperature falls below 40° C. This may be indicative of low cooling water flow or high water temperature. |
| External Current Program Error | The instrument was not allowed to change to external or sum current programming modes (including power-up) because the programming voltage was greater than 0.025 V. This error can be cleared when the programming voltage is less than 0.025 V or the instrument is changed to internal current programming mode. |
| Calibration Invalid | The instrument has either not been calibrated or calibration data has been corrupted. This error can be cleared at any time by pressing both ESC and ENTER keys on the keypad simultaneously. The instrument can still be used in this state but there is no guarantee that it is operating within specifications. The instrument must be recalibrated to properly correct this error condition. |

7.7 ELECTROSTATIC DISCHARGE

Electrostatic Discharge (ESD) may damage electronic parts, assemblies, and equipment. ESD is a transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field. The low-energy source that most commonly destroys Electrostatic Discharge Sensitive (ESDS) devices is the human body, which generates and retains static electricity. Simply walking across a carpet in low humidity may generate up to 35,000 volts of static electricity.

Current technology trends toward greater complexity, increased packaging density, and thinner dielectrics between active elements, which results in electronic devices with even more ESD sensitivity. Some electronic parts are more ESDS than others. ESD levels of only a few hundred volts may damage electronic components such as semiconductors, thick and thin film resistors, and piezoelectric crystals during testing, handling, repair, or assembly. Discharge voltages below 4000 volts cannot be seen, felt, or heard.

7.7.1 Identification of Electrostatic Discharge Sensitive Components

The following are various industry symbols used to label components as ESDS.



7.7.2 Handling Electrostatic Discharge Sensitive Components

Observe all precautions necessary to prevent damage to ESDS components before attempting installation. Bring the device and everything that contacts it to ground potential by providing a conductive surface and discharge paths. As a minimum, observe these precautions:

1. De-energize or disconnect all power and signal sources and loads used with unit.
2. Place unit on a grounded conductive work surface.
3. Ground the technician through a conductive wrist strap (or other device) using 1 M Ω series resistor to protect operator.
4. Ground any tools, such as soldering equipment, that will contact unit. Contact with operator's hands provides a sufficient ground for tools that are otherwise electrically isolated.
5. Place ESDS devices and assemblies removed from a unit on a conductive work surface or in a conductive container. An operator inserting or removing a device or assembly from a container must maintain contact with a conductive portion of the container. Use only plastic bags approved for storage of ESD material.
6. Do not handle ESDS devices unnecessarily or remove from the packages until actually used or tested.

7.8 ENCLOSURE TOP PANEL REMOVAL AND REPLACEMENT

WARNING: To avoid potentially lethal shocks, set current output to 0 A, turn off the power supply, and disconnect it from AC power line before performing this procedure. Only qualified personnel should perform this procedure.

7.8.1 Removal

1. Set power switch to Off (O) and disconnect power cord from the power outlet.
2. Remove the Model 642 from rack (if necessary) to gain easy access to the top panel.
3. Remove and retain the 17 flat-head Phillips screws securing the top panel of the Model 642.
4. Remove and retain the two truss-head Phillips screws and nylon washers from the top edge of the front panel that secure the top panel to the front panel.
5. Carefully remove the top panel from the unit.

7.8.2 Installation

1. Replace the top panel on the Model 642 with the folded lip of the panel toward the front of the unit.
2. Replace and secure the 17 flat-headed Phillips screws. Do not use excessive torque.
3. Replace the two Phillips head screws securing the top panel lip to the top edge of the front panel.
4. Replace the Model 642 in the rack (if used)
5. Reconnect the Model 642 to the power outlet. Apply power via the front panel button (I).

7.9 FIRMWARE REPLACEMENT

There are two integrated circuits (IC) that may potentially require replacement. See Figure 7-6 for respective locations.

- Main Firmware Erasable Programmable Read Only Memory (EPROM) (U35) – Contains the user interface software. Has a sticker on top labeled “MModel 642F.HEX” and a date.
- DAC Microcontroller (U51) – Contains software that controls the output DAC. Has a sticker on top labeled “MModel 642DACF.HEX” and a date.

Use the following procedure to replace either or both of these ICs.

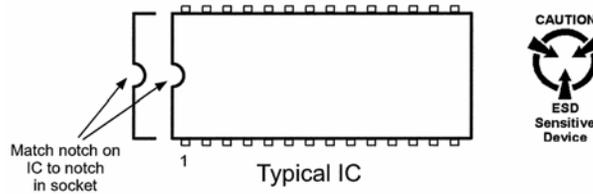
1. Follow the top of enclosure removal procedure of Section 7.8.1.
2. Refer to Figure 7-5 and locate the Digital Board assembly.
3. Disconnect the housekeeping transformer connector from J-1.

Firmware Replacement (Continued)

4. Disconnect the ribbon cable to the Analog Board assembly from J-2.
5. Disconnect the cable to the fan from J-3.
6. Disconnect the ribbon cable to the Keypad Board assembly from J-4.
7. Disconnect the main transformer connector from J-7.
8. Remove all connections from the IEEE-488, RS232C, Power Supply, Auxiliary, and Magnet Water connectors on the back of the Model 642.
9. Remove and retain the hexagonal mounting standoffs from the IEEE-488 and RS232C connectors on the back of the Model 642.
10. Locate, remove and retain the two 6-32 pan-head machine screws holding the Digital Board in place. See Figure 7-6.
11. Remove the Digital Board by pulling it toward the front to clear the rear connectors from their back panel holes and then carefully lifting the Board assembly out of the unit.
12. Locate the appropriate IC(s) on the main circuit board. See Figure 7-6. Note orientation of existing IC.

CAUTION: The ICs are Electrostatic Discharge Sensitive (ESDS) devices. Wear shock-proof wrist straps (resistor limited to <5 mA) to prevent injury to service personnel and to avoid inducing an Electrostatic Discharge (ESD) into the device.

13. Use IC puller to remove existing IC(s) from the socket.
14. Noting orientation of new IC(s), use an IC insertion tool to place new device(s) into socket(s). Ensure that no pins are allowed to bend.



15. Reinstall the Digital Board into the unit taking care to properly locate the bottom edge of the board between the four locator pins on the bottom of the instrument. Push the Digital Board carefully rearward taking care to locate the rear connectors through the rear panel of the unit.
16. Attach the Digital Board using the two 6-32 pan-head Phillips screws removed earlier.
17. Remount the IEEE-488 and RS232C connectors using the hexagonal mounting standoffs removed earlier.
18. Reinstall all appropriate rear panel connections that were removed earlier. Take care NOT to interchange the "Magnet" and "Power Supply" connectors.
19. Reinstall all Digital Board connections removed earlier. See Figure 7-6
20. Recheck that all connectors have been reinstalled and confirm proper locations and orientations of each.
21. Follow the top of enclosure installation procedure of Section 7.8.2.

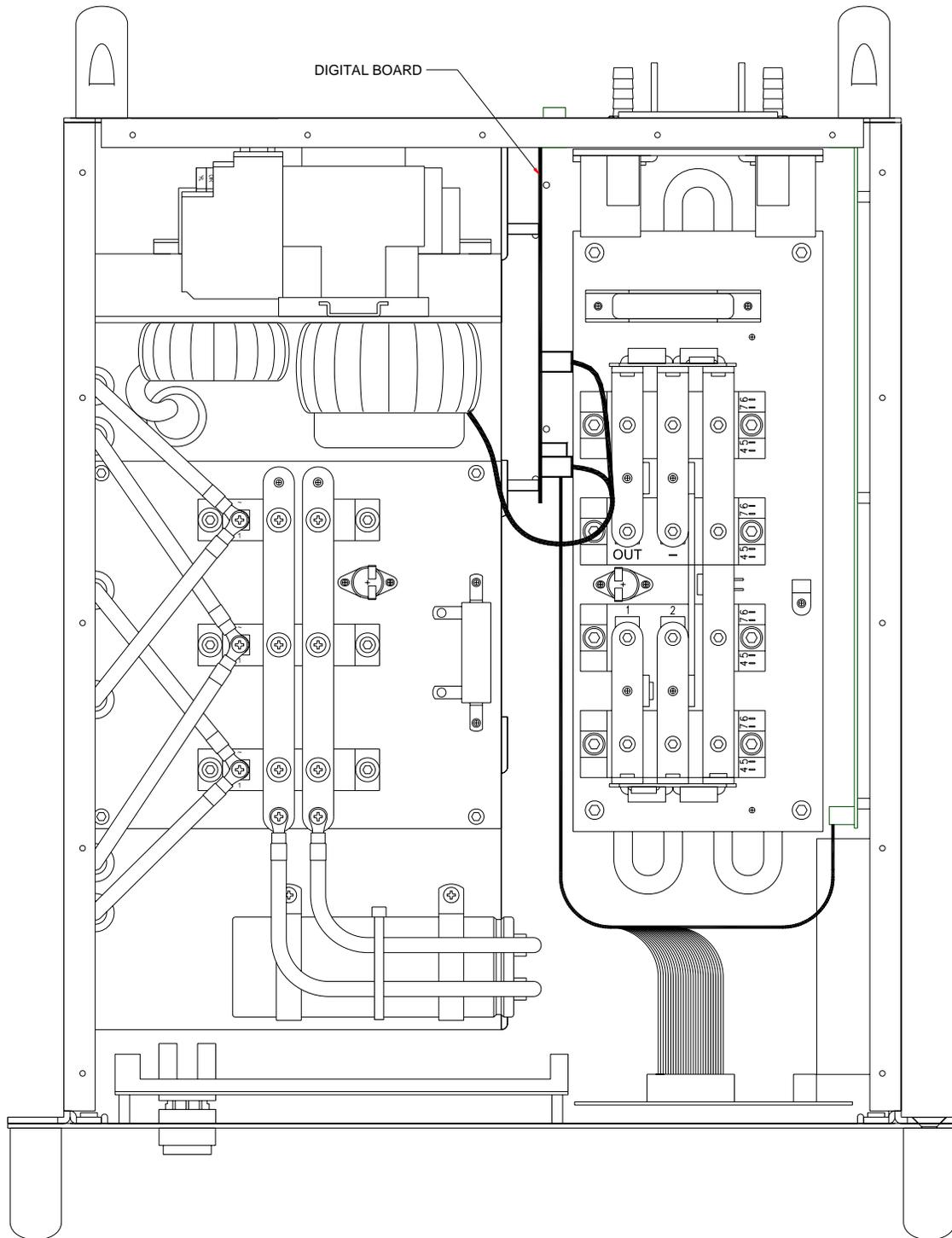
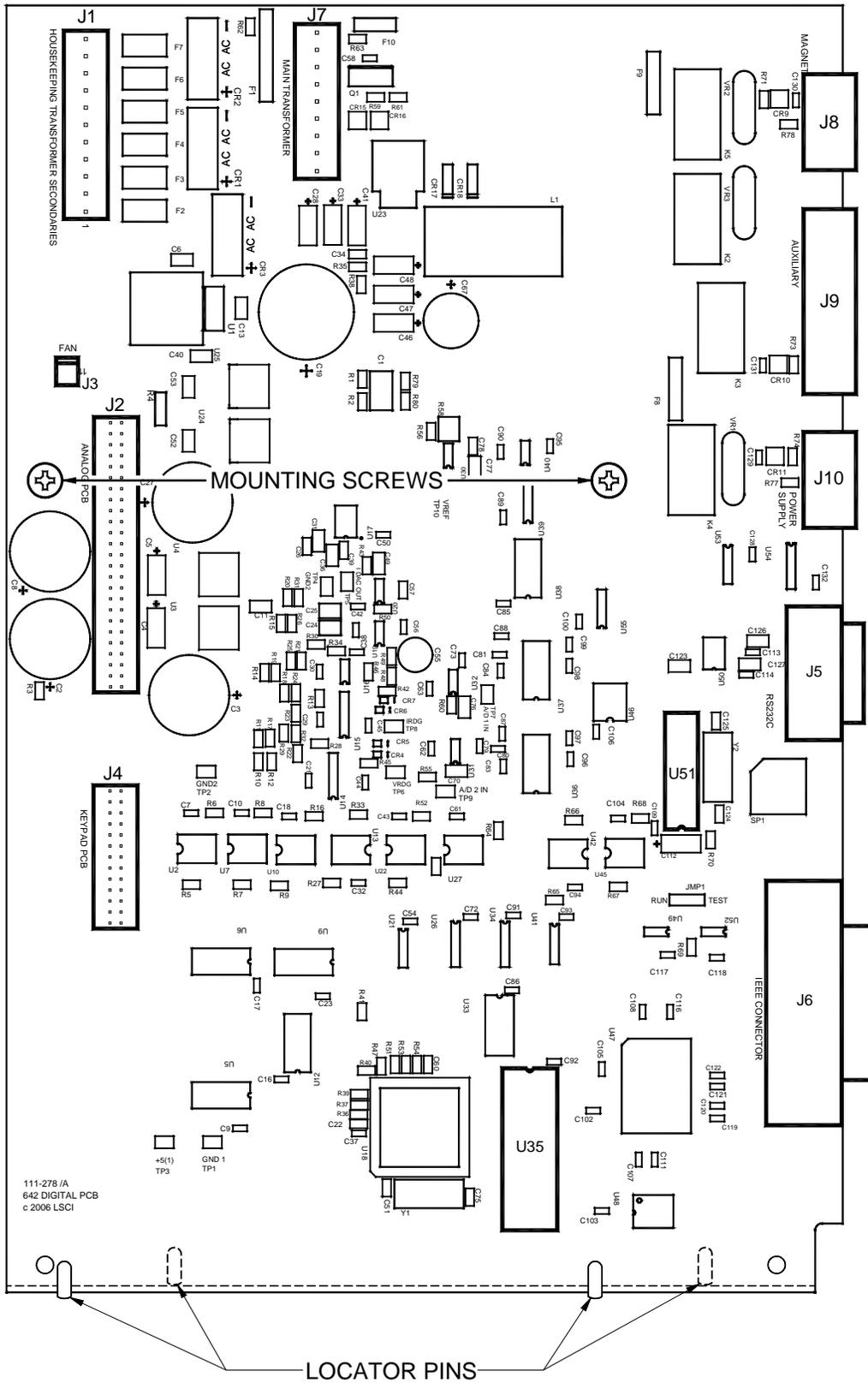


Figure 7-5. Board Locations (top view)

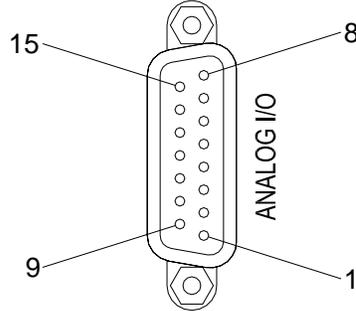


7.10 CONNECTOR AND CABLE DEFINITIONS

All non-power electrical connections to the rear of the Model 642 are detailed in this section.

7.10.1 Analog I/O Connector

The Analog I/O connector provides the connections for the External Programming voltage as well as Analog representations of the current and voltage output levels. Although these inputs/outputs are electronically balanced to minimize ground loops, the common-mode voltage should not exceed 5 V on the outputs and 2 V on the input.

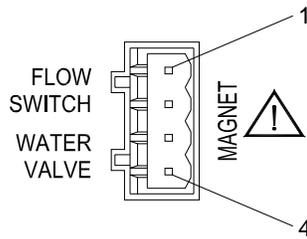


| <i>Pin</i> | <i>Name</i> | <i>Pin</i> | <i>Name</i> |
|------------|-------------------|------------|-------------------|
| 1 | NC | 9 | NC |
| 2 | Chassis-common | 10 | Chassis-common |
| 3 | Current Program – | 11 | Current Program + |
| 4 | Chassis-common | 12 | Chassis-common |
| 5 | Voltage Monitor – | 13 | Voltage Monitor + |
| 6 | Chassis-common | 14 | Chassis-common |
| 7 | Current Monitor – | 15 | Current Monitor + |
| 8 | Chassis-common | | |

Figure 7-7. ANALOG I/O Connector Details

7.10.2 Magnet Connector

The Magnet Water connector provides the means to connect a water control valve (24 VAC) and an associated water flow switch (closed during flow) to protect the magnet from loss of water flow. Pins 1 & 2 must be closed for normal operation. Pins 3 & 4 supply 24 VAC at 1 A for operation of a water control valve.



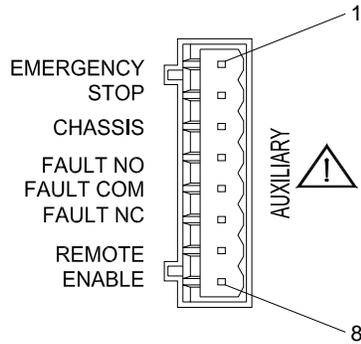
| <i>Pin</i> | <i>Name</i> |
|------------|----------------------|
| 1 | Flow Switch (Com) |
| 2 | Flow Switch |
| 3 | Magnet Water Valve A |
| 4 | Magnet Water Valve B |

Figure 7-8. Magnet Connector Details

7.10.3 Auxiliary Connector

The Auxiliary Connector provides connections for three functions:

1. **Emergency Stop** – This normally-closed circuit turns off power to the Model 642 just as if the OFF (O) button was pressed on the front panel when opened. Normal operation requires a closed connection between the pins.
2. **Fault Relay** – The fault relay can be used to communicate the presence of a Model 642 fault to external equipment. The relay follows the operation of the Fault light on the front panel. Both normally-open and normally-closed configurations are provided. The contacts are electrically isolated from the Model 642 chassis.
3. **Remote Enable** – These contacts are similar in function to the flow switch inputs. Normal (enabled) operation requires a closed connection between the pins.

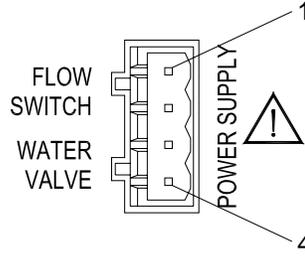


| <i>Pin</i> | <i>Name</i> |
|------------|------------------|
| 1 | Emergency Stop A |
| 2 | Emergency Stop B |
| 3 | Chassis-common |
| 4 | Fault-NO |
| 5 | Fault-Com |
| 6 | Fault-NC |
| 7 | Chassis-common |
| 8 | Remote Enable |

Figure 7-9. Auxiliary Connector Details

7.10.4 Power Supply Connector

The Power Supply connector provides the means to connect a water control valve (24 VAC) and an associated water flow switch (closed during flow) to protect the Model 642 from loss of water flow. Pins 1 & 2 must be closed for normal operation. Pins 3 & 4 supply 24 VAC at 1 A for operation of a water control valve.

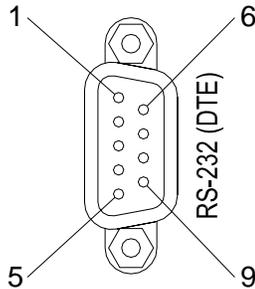


| <i>Pin</i> | <i>Name</i> |
|------------|----------------------------|
| 1 | Flow Switch (Com) |
| 2 | Flow Switch |
| 3 | Power Supply Water Valve A |
| 4 | Power Supply Water Valve B |

Figure 7-10. Power Supply Connector Details

7.10.5 RS-232C Serial Interface Connector

This connector provides one of two means of computer interface. Command descriptions are found in Section 5.

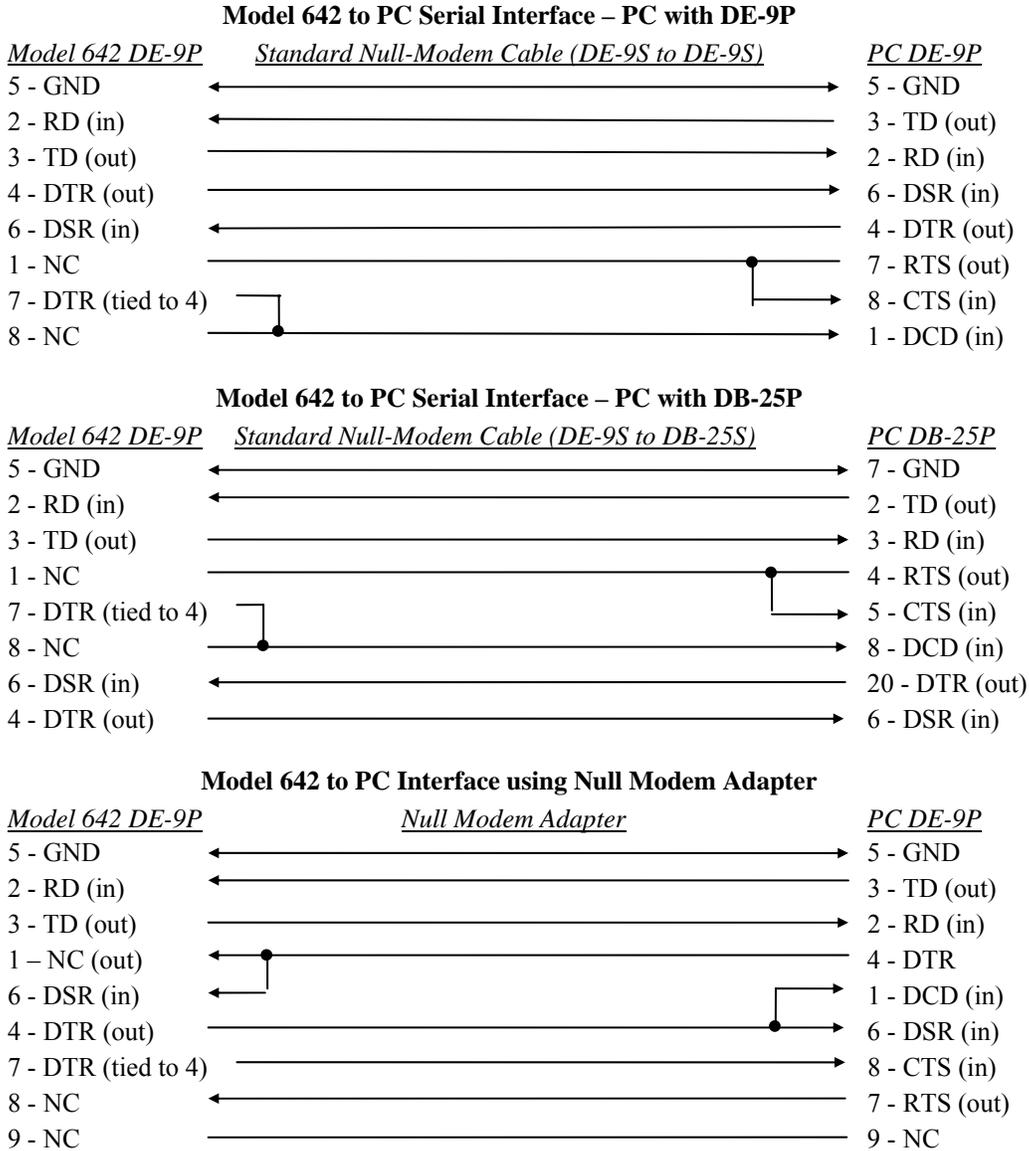


| <i>Model 642 Electromagnet Power Supply</i> | | <i>Typical Computers</i> | | | |
|---|---|--------------------------|--------------------|--------------------|--------------------|
| <i>DE-9P (DTE)</i> | | <i>DB-25P (DTE)</i> | | <i>DE-9P (DTE)</i> | |
| <i>Pin</i> | <i>Description</i> | <i>Pin</i> | <i>Description</i> | <i>Pin</i> | <i>Description</i> |
| 1 | NC | 2 | TD (out) | 1 | DCD (in) |
| 2 | Receive Data (RD in) | 3 | RD (in) | 2 | RD (in) |
| 3 | Transmit Data (TD out) | 4 | RTS (out) | 3 | TD (out) |
| 4 | Data Terminal Ready (DTR out) | 5 | CTS (in) | 4 | DTR (out) |
| 5 | Chassis-common | 6 | DSR (in) | 5 | GND |
| 6 | Data Set Ready (DSR in) | 7 | GND | 6 | DSR (in) |
| 7 | Data Terminal Ready (DTR out) (tied to 4) | 8 | DCD (in) | 7 | RTS (out) |
| 8 | NC | 20 | DTR (out) | 8 | CTS (in) |
| 9 | NC | 22 | Ring in (in) | 9 | Ring in (in) |

Figure 7-11. RS232C (DTE) Connector Details

7.10.6 Serial Interface Cable Wiring

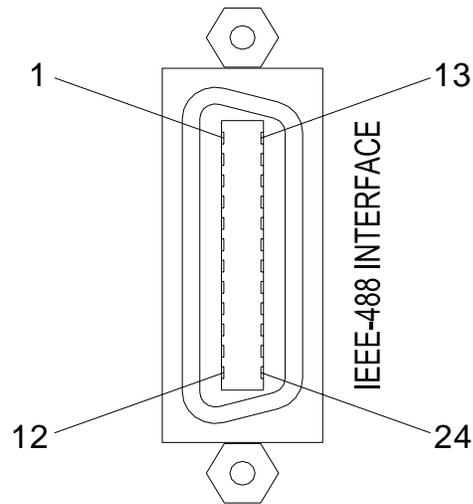
The following are suggested cable wiring diagrams for connecting the Model 642 Serial Interface to various Customer Personal Computers (PCs).



NOTE: Same as null modem cable design except PC CTS is provided from the Model 642 on DTR.

7.10.7 IEEE-488 Parallel Interface Connector

Connect to the IEEE-488 Interface connector on the Model 642 rear with cables specified in the IEEE-488-1978 standard document. The cable has 24 conductors with an outer shield. The connectors are 24-way Amphenol 57 Series (or equivalent) with piggyback receptacles to allow daisy-chaining in multiple device systems. The connectors are secured in the receptacles by two captive locking screws with metric threads. The total length of cable allowed in a system is 2 meters for each device on the bus, or 20 meters maximum. The Model 642 can drive a bus of up to 10 devices. A connector extender is required to use the IEEE-488 Interface and Relay Terminal Block at the same time. Figure 7-12 shows the IEEE-488 Interface connector pin and signal names as viewed from the Model 642 rear panel.



| <i>Pin</i> | <i>Symbol</i> | <i>Description</i> |
|------------|---------------|--------------------------------------|
| 1 | DIO 1 | Data Input/Output Line 1 |
| 2 | DIO 2 | Data Input/Output Line 2 |
| 3 | DIO 3 | Data Input/Output Line 3 |
| 4 | DIO 4 | Data Input/Output Line 4 |
| 5 | EOI | End Or Identify |
| 6 | DAV | Data Valid |
| 7 | NRFD | Not Ready For Data |
| 8 | NDAC | Not Data Accepted |
| 9 | IFC | Interface Clear |
| 10 | SRQ | Service Request |
| 11 | ATN | Attention |
| 12 | SHIELD | Cable Shield |
| 13 | DIO 5 | Data Input/Output Line 5 |
| 14 | DIO 6 | Data Input/Output Line 6 |
| 15 | DIO 7 | Data Input/Output Line 7 |
| 16 | DIO 8 | Data Input/Output Line 8 |
| 17 | REN | Remote Enable |
| 18 | GND 6 | Ground Wire – Twisted pair with DAV |
| 19 | GND 7 | Ground Wire – Twisted pair with NRFD |
| 20 | GND 8 | Ground Wire – Twisted pair with NDAC |
| 21 | GND 9 | Ground Wire – Twisted pair with IFC |
| 22 | GND 10 | Ground Wire – Twisted pair with SRQ |
| 23 | GND 11 | Ground Wire – Twisted pair with ATN |
| 24 | GND | Logic Ground |

Figure 7-12. IEEE-488 Connector Details

7.11 CALIBRATION

Lake Shore maintains a fully automated calibration fixture for the Model 642 that measures existing performance of the unit and then recalibrates the using NIST traceable resistance and voltage standards. In addition, non-calibration features are verified for proper operation by a full battery of extensive tests. Although this testing is very complete, it requires the return of the Model 642 to Lake Shore to perform the recalibration. In some instances, however, it may be necessary to recalibrate the Model 642 in the field. Calibration information for the following operating parameters is provided:

- Output Current.
- Output Current Reading
- Output Voltage Reading
- External Programming Voltage Reading

These calibrations are done through the computer interface and the calibration constants are stored in the non-volatile memory in the instrument. The cover does not have to be removed to calibrate the instrument. The remaining features of the Model 642 do not require calibration to operate within their specified tolerances.

Uncalibrated (default) values for gains are 1 while offsets are 0. Operation with these values is possible but the accuracy will be reduced to as much as $\pm 2\%$ of full scale, generally. If the Model 642 is used in closed loop operation and programmed through the external input, regular calibration may not be required.

7.11.1 Calibration Interface

Computer interface commands are included in the Model 642 specifically for calibration. These commands work with either the IEEE-488 or RS-232C interface. Refer to Section 7.13.4 for a complete description of each calibration command.

It is always recommended to read out old calibration coefficients using the CALZ? and CALG? interface queries before attempting to calibrate. This will give the operator experience with the interface command, data formatting, and typical values. If the old values are saved, they can be reloaded in the case of accidental loss of data during calibration. New calculated calibration coefficients should be very similar to the old values. Discrepancy between the old and new values of more than 0.1% of gain calibration coefficients or 0.1% of range for zero coefficients could indicate an error in the calibration procedure or a hardware failure. Do not attempt to recalibrate a damaged instrument.

The instrument will use the new calibration coefficients as soon as they are sent with the either the CALZ or CALG interface command but they are not saved permanently until the CALSAVE command is issued. If a mistake is made in the calibration process, turn the instrument power off and on again *before* CALSAVE is issued to restore the old calibration constants. Once CALSAVE is issued, old values cannot be retrieved from the instrument.

If calibration coefficients are left at default or are outside of the normal calibration range, the following error message will appear in the instrument display when the instrument is turned on: "Calibration Invalid". This error message must be bypassed to allow calibration of the instrument. Press both **Enter** and **Escape** keys simultaneously to bypass the error message. Operation in this state is possible but at least one calibration is known to be out of proper range and measurement is likely to be erroneous.

Simple communications program examples are shown in Sections 5.1.5.2 and 5.2.7.1. Some time should be spent becoming familiar with the calibration commands before beginning a calibration. Although the calibration factors are sent to the Model 642 over the computer interface, this procedure is written to obtain the Model 642 readings solely by visual observation of the front panel.

7.11.2 Calibration Equipment

1. **Calibration Shunt Resistor** – The output current of the Model 642 must be measured externally as the primary reference for calibration. When current is measured, it is the result of the current through the known resistance of the calibration resistor. This resistor must be accurately measured and its actual value (R_{shunt}) used to determine the actual current flow. For example, if the resistor is measured at $0.99661\text{ m}\Omega$, the actual current flowing is calculated by the following equation.

$$I_{shunt} = V_{shunt}/0.99661 \times 10^{-3} \quad \text{or} \quad I_{shunt} = 1000 \times V_{shunt}/0.99661$$

This resistor must withstand the full current of the Model 642 and do so with a minimum of heating that can easily change the resistance and therefore the current measurement. At 70 A, this resistor only dissipates 4.9 W. Even so, it is highly recommended to mount the resistor on a heat sink with forced air-cooling to minimize temperature rise and related value changes during calibration. (Alpha PSBWR0010F is suggested)

2. **Magnet Load** – The Model 642 is designed for a nominal magnet load of 0.5-ohms and 0.5 H. For calibration purposes, the magnet can easily be used as the calibration load. The calibration shunt resistor is wired in series with the positive output terminal using a cable of similar current handling capability as the normal magnet lines. An alternative to this is the use of a resistor bank with total resistance of 0.5-ohms capable of safely dissipating 2,450 W of heat (the equivalent of a medium sized space heater). This procedure assumes the use of the water-cooled magnet as a calibration load.
3. **DC Voltmeter (DVM)** – The voltmeter must measure VDC accurately to 10's of μV if resolution to 10's of mA (from the Model 642). The Agilent Model 34401 DMM or better is suggested.

7.11.3 Calibration Procedure

The following calibration steps should be performed exactly in the order provided. Pay close attention to the use of "CALZ" vs "CALG" commands. They can easily be confused and will certainly create unexpected results if accidentally interchanged. Zeroing calibrations use "CALZ" commands while Gain (Span) calibrations use "CALG" commands.

7.11.3.1 Calibrate Current Output Zero

The $1\text{ m}\Omega$ shunt resistor is wired in series with the calibration load from the positive output terminals with #4 AWG wire. Cable length is relatively unimportant but should be less than 5 feet to the shunt resistor. Voltage across the shunt resistor is to be monitored by the DVM. The DVM input connections must both be isolated from earth (power line) ground.

1. Send "CALZ 10, 0" to set the output offset constant to 0.
2. Set the Model 642 output current to 0 A.
3. Measure the actual voltage across the shunt and record (V_{shunt}).
4. Calculate the zero offset constant: $-(V_{shunt}/R_{shunt})$.
5. Send "CALZ 10, zero offset constant".
6. Reset the Model 642 output current to 0 A (loads the new offset setting).
7. Verify the actual output current to be less than $\pm 1\text{ mA}$.
8. Send "CALSAVE" to write this calibration to non-volatile memory.

7.11.3.2 Calibrate Current Reading Zero

1. Send "CALZ 0, 0" to set the current reading offset constant to 0.
2. Measure the actual voltage across the shunt and record (V_{shunt}).
3. Get the Model 642 output current reading (by front panel or interface) and record (I reading).
4. Calculate the zero offset constant: $-(I_{reading} - (V_{shunt}/R_{shunt}))$.
5. Send "CALZ 0, zero offset constant".
6. Verify the Model 642 output current reading to match the actual output current within $\pm 0.0005\text{ mA}$.
7. Send "CALSAVE" to write this calibration to non-volatile memory.

7.13.3.3 Calibrate Output Voltage Reading Zero

This step assumes that the previous two steps are successful and the current through the shunt resistor is quite low resulting in virtually no voltage across the Model 642 output terminals.

1. Send "CALZ 5, 0" to set the current reading offset constant to 0.
2. Get the Model 642 output voltage reading (by front panel or interface).
3. Calculate zero offset constant: $-(\text{output voltage reading})$.
4. Send "CALZ 5, zero offset constant".
5. Verify the Model 642 output voltage reading to be 0 ± 0.001 V.
6. Send "CALSAVE" to write this calibration to non-volatile memory.

7.11.3.4 Calibrate External Programming Voltage Reading Zero

1. Short the external current programming input lines (pins 3 and 11 of the Analog I/O connector).
2. Send "CALZ 7, 0". To set the external programming voltage reading constant to 0.
3. Get the Model 642 external programming voltage reading.

NOTE: To get this reading from the Model 642, press and hold the **Status** key on the front panel until the display goes dark (≈ 3 seconds). When the key is then released, a diagnostics display will be seen. The upper right reading, "EXT PROG", is the reading needed for this step.

4. Calculate zero offset constant: $-(\text{external programming voltage reading})$.
5. Send "CALZ 7, zero offset constant".
6. Verify the Model 642 external programming voltage reading to be 0 ± 0.0001 V.
7. Send "CALSAVE" to write this calibration to non-volatile memory.

7.11.3.5 Calibrate Output Current Gain (Span)

This calibration is the most difficult and most important of the procedure. It first requires measuring the span of the *trim range* (which changes from unit to unit within 1 – 2%) to determine the trim adjustment range that corresponds to a 100% calibration trim change. In other words, we adjust the calibration in % from -100% to $+100\%$ but the size of the calibration trim range changes slightly for each unit. We first measure the span of the calibration trim range and then measure the full span of the instrument with the calibration trim set to 0%. We have adopted the use of % as the unit name for the trim calibration since it corresponds to only the percent of *trim range* and **not** the full span of the instrument.

The 65 A set point for calibration is chosen because the maximum trim range at 70 A forces the current past the 70.1 A internal analog limit and therefore creates significant error. The shunt resistor remains connected in series with the magnet load for this procedure.

1. Send "CALG 10, 0". To set the output current gain trim constant to 0.
2. Set the Model 642 output current to +65 A (ramp rate 30 A/s nominal).
3. Wait 30 seconds for settling.
4. Measure the actual voltage across the shunt and record (V_{shunt}).
5. Calculate and record (I_{max}): $V_{\text{shunt}}/R_{\text{shunt}}$.
6. Send "CALG 10, -100 ". To set the output current gain trim constant to maximum.
7. Wait 10 seconds.
8. Measure the actual voltage across the shunt and record (V_{shunt}).
9. Calculate and record ($I_{\text{maxpostrim}}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
10. Send "CALG 10, $+100$ ". To set the output current gain trim constant to minimum.
11. Wait 10 seconds.

Calibrate Output Current Gain (Continued)

12. Measure the actual voltage across the shunt and record (V_{shunt}).
13. Calculate and record ($I_{minpostrim}$): V_{shunt}/R_{shunt} .
14. Send "CALG 10, 0". To set the output current gain trim constant to 0.
15. Set the Model 642 to -65A V (ramp rate 30 A/s nominal).
16. Wait 30 seconds for settling.
17. Measure the actual voltage across the shunt and record (V_{shunt}).
18. Calculate and record (I_{min}): V_{shunt}/R_{shunt} .
19. Send "CALG 10, -100". To set the output current gain trim constant to maximum.
20. Wait 10 Seconds.
21. Measure the actual voltage across the shunt and record (V_{shunt}).
22. Calculate and record ($I_{maxnegtrim}$): V_{shunt}/R_{shunt} .
23. Send "CALG 10, +100". To set the output current gain trim constant to minimum.
24. Wait 10 seconds.
25. Measure the actual voltage across the shunt and record (V_{shunt}).
26. Calculate and record ($I_{minnegtrim}$): V_{shunt}/R_{shunt} .
27. Send "CALG 10, 0". To return the output current gain trim constant to 0.
28. Set the Model 642 output current to 0 A.
29. Calculate the gain constant per the following equation:

$$\text{Current Output Gain Constant} = 200((I_{max} - I_{min}) - 130)/((I_{maxpostrim} - I_{minpostrim}) - (I_{maxnegtrim} - I_{minnegtrim}))$$

30. Send "CALG 10, gain constant".

This method, while somewhat lengthy, averages the trim spans between negative and positive settings to split the error between positive and negative operation.

This gain calibration may shift the initial zero calibration for the Current Output DAC slightly. It is best to repeat the current zero calibrations at this point.

31. Recalibrate Current Output Zero (refer to Section 7.13.3.1).
32. Recalibrate Current Reading Zero (refer to Section 7.13.3.2).
33. Set the Model 642 output current to 65 A (ramp rate 30 A/s nominal).
34. Wait 30 seconds.
35. Measure the actual voltage across the shunt and record (V_{shunt}).
36. Calculate and record (I_{out+}): V_{shunt}/R_{shunt} .
37. Verify $I_{out} = 65 \text{ A} \pm 0.010 \text{ A}$ (0.015%).
39. Set the Model 642 output current to -65 A (ramp rate 30 A/s nominal).
40. Wait 30 seconds.
41. Calculate and record (I_{out-}): V_{shunt}/R_{shunt} .
42. Verify $I_{out} = -65 \text{ A} \pm 0.010 \text{ A}$ (0.015%).
43. Set the Model 642 output current to 0 A.
44. Send "CALSAVE" to write this calibration to non-volatile memory.

7.13.3.6 Calibrate Current Reading Gain

1. Send "CALG 0, 1". To set the output current reading gain constant to 1.
2. Set the Model 642 output current to -70 A. (Ramp rate 30 A/s nominal).
3. Wait 30 seconds.
4. Measure the actual voltage across the shunt and record (V_{shunt}).
5. Calculate and record ($I_{measuredneg}$): V_{shunt}/R_{shunt} .
6. Get the Model 642 output current reading (by front panel or interface) and record ($I_{readingneg}$).
7. Set the Model 642 output current to +70 A (Ramp rate 30 A/s nominal).
8. Wait 30 seconds.
9. Measure the actual voltage across the shunt and record (V_{shunt}).
10. Calculate and record ($I_{measuredpos}$): V_{shunt}/R_{shunt} .
11. Get the Model 642 output current reading (by front panel or interface) and record ($I_{readingpos}$).
12. Calculate gain constant per the following equation:

$$\text{Current Reading Gain Constant} = (I_{measuredpos} - I_{measuredneg}) / (I_{readingpos} - I_{readingneg})$$

13. Verify gain factor to be 1, ± 0.02 .
14. Send "CALG 0, gain constant".
15. Verify the Model 642 output current reading to equal $I_{measuredpos}$, ± 0.010 A.
16. Set the Model 642 output current to 0 A.
17. Send "CALSAVE" to write this calibration to non-volatile memory.

This method is somewhat lengthy, but averages the differences between positive (+) and negative (-) excursions.

7.11.3.7 Calibrate Voltage Reading Gain

1. Send "CALG 5, 1". To set the output voltage reading gain constant to 1.
2. Set the Model 642 output current to 65 A.
3. Wait 30 seconds.
4. Measure the Model 642 actual output voltage at the output terminals and record ($V_{measuredpos}$).
5. Get the Model 642 output voltage reading (by front panel or interface) and record ($V_{readingpos}$).
6. Set the Model 642 output current to -65 A.
7. Wait 30 seconds.
8. Measure the Model 642 actual output voltage at the output terminals and record ($V_{measuredneg}$).
9. Get the Model 642 output voltage reading (by front panel or interface) and record ($V_{readingneg}$).
10. Calculate gain constant per the following equation:

$$\text{Voltage Reading Gain Constant} = (V_{measuredpos} - V_{measuredneg}) / (V_{readingpos} - V_{readingneg})$$

11. Verify the gain factor to be 1, ± 0.02 .
12. Send "CALG 5, gain constant".
13. Verify the Model 642 output voltage reading to match the actual output voltage within, ± 0.001 V.
14. Set the Model 642 output current to 0 A.
15. Send "CALSAVE" to write this calibration to non-volatile memory.

7.11.3.8 Calibrate External Current Programming Voltage Reading Gain

This procedure calibrates only the input voltage reading of the External Programming Input. The actual current output from this input is specified to a 1% tolerance and is not adjustable. It is NOT necessary to engage the External Programming feature of the Model 642 for this calibration.

1. Connect a new 9 V alkaline battery to the external current programming input lines (positive to positive input).
2. Send "CALG 7, 1". To set the external programming voltage reading gain constant to 1.
3. Get the Model 642 external programming voltage reading and record (V_{reading}).

NOTE: To get this reading from the Model 642, press and hold the **Status** key on the front panel until the display goes dark (~3 seconds). When the key is then released, a diagnostics display will be seen. The upper right reading, "Ext Prog", is the reading needed for this step.

4. Measure the voltage directly across the 9 V battery and record (V_{measured})
5. Calculate the gain constant per the following equation:

$$\text{Programming Voltage Reading Gain Constant} = V_{\text{measured}}/V_{\text{reading}}$$

6. Verify the gain constant to be 1, ± 0.05 .
7. Send "CALG 7, constant".
8. Verify the Model 642 external programming voltage reading to match the measured 9 V battery voltage within, ± 0.0005 V.
9. Send "CALSAVE" to write this calibration to non-volatile memory.

7.11.4 Calibration-Specific Interface Commands

The following interface commands are only used during calibration and are in addition to those listed in Chapter 5.

CALG Gain Calibration Constant Command

Input: CALG <type>, <value> [term]

Format: nn, ±nnnnnnn

<input> Specifies the item to calibrate. Valid entries are:

- 0 = Output I Reading
- 1 = Bias A Reading *
- 2 = Bias B Reading *
- 3 = Gnd Diff Reading *
- 4 = Out Con Reading *
- 5 = Output V Reading
- 6 = Boost V Reading*
- 7 = Ext Prog Input Reading
- 8 = Temp Reading*
- 9 = Out Stg V Reading *
- 10 = Actual Output Current

<value> Gain calibration constant value.

Remarks: Items marked with a * are for internal diagnostic use only and should always be set to a value of 1 (default).

CALG? Gain Calibration Constant Query
Input: **CALG?** <type> [term]
Format: nn
 <type> 0 – 10.
Returned: <value>[term]
Format: ±nnnnnnn (Refer to command for description)

CALSAVE Calibration Save Command
Input: **CALSAVE** [term]
Remarks: Saves all CALZ and CALG calibration constants in non-volatile memory.

CALZ Zero Offset Calibration Constant Command
Input: **CALZ** <type>, <value> [term]
Format: nn, ±nnnnnnn
 <type> Specifies the item to calibrate. Valid entries are:
 0 = Output I Reading
 1 = Bias A Reading *
 2 = Bias B Reading *
 3 = Gnd Diff Reading *
 4 = Out Con Reading *
 5 = Output V Reading
 6 = Boost V Reading*
 7 = Ext Prog Input Reading
 8 = Temp Reading*
 9 = Out Stg V Reading *
 10 = Actual Output Current
 <value> Zero offset calibration constant value.
Remarks: Items marked with a * are for internal diagnostic use only and should always be set to a value of 0 (default).

CALZ? Zero Offset Calibration Constant Query
Input: **CALZ?** <type> [term]
Format: nn
 <type> 0 – 10.
Returned: <value>[term]
Format:±nnnnnnn (Refer to command for description)

APPENDIX A

GLOSSARY OF TERMINOLOGY

accuracy. The degree of correctness with which a measured value agrees with the true value.²

electronic accuracy. The accuracy of an instrument independent of the sensor.

sensor accuracy. The accuracy of a temperature sensor and its associated calibration or its ability to match a standard curve.

American Standard Code for Information Interchange (ASCII). A standard code used in data transmission, in which 128 numerals, letters, symbols, and special control codes are represented by a 7-bit binary number as follows:

| Bits | | Col. | | | | | | | | | | | | |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----|------|-----|----|---|---|----|-----|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | | |
| b ₇ | b ₆ | b ₅ | b ₄ | b ₃ | b ₂ | b ₁ | Row | Col. | | | | | | |
| | | | | | | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NUL | DLE | SP | ' | P | @ | p |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | SOH | DC1 | ! | 1 | A | Q | q |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | STX | DC2 | " | 2 | B | R | r |
| 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | ETX | DC3 | # | 3 | C | S | s |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | EOT | DC4 | \$ | 4 | D | T | t |
| 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | ENG | NAK | % | 5 | E | U | u |
| 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | ACK | SYN | & | 6 | F | V | v |
| 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | BEL | ETB | ' | 7 | G | W | w |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | BS | CAN | (| 8 | H | X | x |
| 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | HT | EM |) | 9 | I | Y | y |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | LF | SS | * | : | J | Z | z |
| 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | VT | ESC | + | ; | K | [| k |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | FF | FS | , | < | L | ~ | l |
| 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | CR | GS | - | = | M |]m |) |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | SO | RS | . | > | N | ^ | n |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | SI | US | / | ? | O | _ | o |
| | | | | | | | | | | | | | | DEL |

American Wire Gage (AWG). Wiring sizes are defined as diameters in inches and millimeters as follows:

| AWG | Dia. In. | Dia. mm |
|-----|----------|---------|-----|----------|---------|-----|----------|---------|-----|----------|---------|
| 1 | 0.2893 | 7.348 | 11 | 0.0907 | 2.304 | 21 | 0.0285 | 0.7230 | 31 | 0.0089 | 0.2268 |
| 2 | 0.2576 | 6.544 | 12 | 0.0808 | 2.053 | 22 | 0.0253 | 0.6438 | 32 | 0.0080 | 0.2019 |
| 3 | 0.2294 | 5.827 | 13 | 0.0720 | 1.829 | 23 | 0.0226 | 0.5733 | 33 | 0.00708 | 0.178 |
| 4 | 0.2043 | 5.189 | 14 | 0.0641 | 1.628 | 24 | 0.0207 | 0.5106 | 34 | 0.00630 | 0.152 |
| 5 | 0.1819 | 4.621 | 15 | 0.0571 | 1.450 | 25 | 0.0179 | 0.4547 | 35 | 0.00561 | 0.138 |
| 6 | 0.1620 | 4.115 | 16 | 0.0508 | 1.291 | 26 | 0.0159 | 0.4049 | 36 | 0.00500 | 0.127 |
| 7 | 0.1443 | 3.665 | 17 | 0.0453 | 1.150 | 27 | 0.0142 | 0.3606 | 37 | 0.00445 | 0.1131 |
| 8 | 0.1285 | 3.264 | 18 | 0.0403 | 1.024 | 28 | 0.0126 | 0.3211 | 38 | 0.00397 | 0.1007 |
| 9 | 0.1144 | 2.906 | 19 | 0.0359 | 0.9116 | 29 | 0.0113 | 0.2859 | 39 | 0.00353 | 0.08969 |
| 10 | 0.1019 | 2.588 | 20 | 0.0338 | 0.8118 | 30 | 0.0100 | 0.2546 | 40 | 0.00314 | 0.07987 |

ambient temperature. The temperature of the surrounding medium, such as gas or liquid, which comes into contact with the apparatus.¹

ampere. The constant current that, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed one meter apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.² This is one of the base units of the SI.

ampere-turn. A MKS unit of magnetomotive force equal to the magnetomotive force around a path linking one turn of a conducting loop carrying a current of one ampere; or 1.26 gilberts.

ampere/meter (A/m). The SI unit for magnetic field strength (H). 1 ampere/meter = $4\pi/1000$ oersted ≈ 0.01257 oersted.

analog controller. A feedback control system where there is an unbroken path of analog processing between the feedback device (sensor) and control actuator (heater).

analog data. Data represented in a continuous form, as contrasted with digital data having discrete values.¹

analog output. A voltage output from an instrument that is proportional to its input. For example, from a digital voltmeter, the output voltage is generated by a digital-to-analog converter so it has a discrete number of voltage levels.

autotuning. In Lake Shore instruments, the Autotuning algorithm automatically determines the proper settings for Gain (Proportional), Reset (Integral), and Rate (Derivative) by observing the time response of the system upon changes in setpoint.

B. Symbol for magnetic flux density. See Magnetic Flux Density.

bar. Unit of pressure equal to 10^5 pascal, or 0.98697 standard atmosphere.

Baud. A unit of signaling speed equal to the number of discrete conditions or signal events per second, or the reciprocal of the time of the shortest signal element in a character.²

bit. A contraction of the term "binary digit"; a unit of information represented by either a zero or a one.²

BNC. Bayonet Nut Connector.

- boiling point.** The temperature at which a substance in the liquid phase transforms to the gaseous phase; commonly refers to the boiling point at sea level and standard atmospheric pressure.
- calibrate.** To determine, by measurement or comparison with a standard, the correct value of each scale reading on a meter or other device, or the correct value for each setting of a control knob.¹
- Carbon-Glass™.** A temperature sensing material fabricated from a carbon-impregnated glass matrix used to make the Lake Shore Carbon Glass Resistor (CGR) family of sensors.
- Celsius (°C) Scale.** A temperature scale that registers the freezing point of water as 0 °C and the boiling point as 100 °C under normal atmospheric pressure. Celsius degrees are purely derived units, calculated from the Kelvin Thermodynamic Scale. Formerly known as “centigrade.” *See* Temperature for conversions.
- Cernox™.** A Lake Shore resistance temperature detector based on a ceramic-oxy-nitride resistance material.
- cgs system of units.** A system in which the basic units are the centimeter, gram, and second.²
- Chebyshev polynomials.** A family of orthogonal polynomials which solve Chebyshev's differential equation.¹
- Chebyshev differential equation.** A special case of Gauss' hypergeometric second-order differential equation:
 $(1 - x^2) f''(x) - xf'(x) + n^2 f(x) = 0.$ ¹
- closed-loop.** *See* feedback control system.
- coercive force (coercive field).** The magnetic field strength (H) required to reduce the magnetic induction (B) in a magnetic material to zero.
- coercivity.** generally used to designate the magnetic field strength (H) required to reduce the magnetic induction (B) in a magnetic material to zero from saturation. The coercivity would be the upper limit to the coercive force.
- cryotronics.** The branch of electronics that deals with the design, construction, and use of cryogenic devices.¹
- Curie temperature (T_c).** Temperature at which a magnetized sample is completely demagnetized due to thermal agitation. Named for Pierre Curie (1859 – 1906), a French chemist.
- current source.** A type of power supply that supplies a constant current through a variable load resistance by automatically varying its compliance voltage. A single specification given as “compliance voltage” means the output current is within specification when the compliance voltage is between zero and the specified voltage.
- curve.** A set of data that defines the temperature response of a temperature sensor. It is used to convert the signal from the sensor to temperature.
- demagnetization.** when a sample is exposed to an applied field (H_a), poles are induced on the surface of the sample. Some of the returned flux from these poles is inside of the sample. This returned flux tends to decrease the net magnetic field strength internal to the sample yielding a true internal field (H_{int}) given by: $H_{int} = H_a - DM$, where M is the volume magnetization and D is the demagnetization factor. D is dependent on the sample geometry and orientation with respect to the field.
- deviation.** The difference between the actual value of a controlled variable and the desired value corresponding to the setpoint.¹
- differential permeability.** The slope of a B versus H curve: $\mu_d = dB/dH.$
- differential susceptibility.** The slope of a M versus H curve: $\chi_d = dM/dH.$
- digital controller.** A feedback control system where the feedback device (sensor) and control actuator (heater) are joined by a digital processor. In Lake Shore controllers the heater output is maintained as a variable DC current source.
- digital data.** Pertaining to data in the form of digits or interval quantities. Contrast with analog data.²
- dimensionless sensitivity.** Sensitivity of a physical quantity to a stimulus, expressed in dimensionless terms. The dimensionless temperature sensitivity of a resistance temperature sensor is expressed as $S_d = (T/R)(dR/dT)$ which is also equal to the slope of R versus T on a log-log plot, that is $S_d = d \ln R / d \ln T.$ Note that the absolute temperature (in Kelvin) must be used in these expressions.
- drift, instrument.** An undesired but relatively slow change in output over a period of time, with a fixed reference input. *Note:* Drift is usually expressed in percent of the maximum rated value of the variable being measured.²
- electromagnet.** A device in which a magnetic field is generated as the result of electrical current passing through a helical conducting coil. It can be configured as an iron-free solenoid in which the field is produced along the axis of the coil, or an iron-cored structure in which the field is produced in an air gap between pole faces. The coil can be water cooled copper or aluminum, or superconductive.
- electrostatic discharge (ESD).** A transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field.
- error.** Any discrepancy between a computed, observed, or measured quantity and the true, specified, or theoretically correct value or condition.²
- excitation.** Either an AC or DC input to a sensor used to produce an output signal. Common excitations include: constant current, constant voltage, or constant power.
- Fahrenheit (°F) Scale.** A temperature scale that registers the freezing point of water as 32 °F and the boiling point as 212 °F under normal atmospheric pressure. *See* Temperature for conversions.
- feedback control system.** A system in which the value of some output quantity is controlled by feeding back the value of the controlled quantity and using it to manipulate an input quantity so as to bring the value of the controlled quantity closer to a desired value. Also known as closed-loop control system.¹

four-lead. measurement technique where one pair of excitation leads and an independent pair of measurement leads are used to measure a sensor. This method reduces the effect of lead resistance on the measurement.

gamma. A cgs unit of low-level flux density, where 100,000 gamma equals one oersted, or 1 gamma equals 10^{-5} oersted.

gauss (G). The cgs unit for magnetic flux density (B). 1 gauss = 10^{-4} tesla. Named for Karl Fredrich Gauss (1777–1855) a German mathematician, astronomer, and physicist.

gaussian system (units). A system in which centimeter-gram-second units are used for electric and magnetic qualities.

general purpose interface bus (GPIB). Another term for the IEEE-488 bus.

germanium (Ge). A common temperature sensing material fabricated from doped germanium to make the Lake Shore GR family of resistance temperature sensor elements.

gilbert (Gb). A cgs electromagnetic unit of the magnetomotive force required to produce one maxwell of magnetic flux in a magnetic circuit of unit reluctance. One gilbert is equal to $10/4\pi$ ampere-turn. Named for William Gilbert (1540–1603), an English physicist; hypothesized that the Earth is a magnet.

gilbert per centimeter. Practical cgs unit of magnet intensity. Gilberts per cm are the same as oersteds.

Greek alphabet. The Greek alphabet is defined as follows:

| | | | | | | | | |
|---------|------------|----------|---------|------------|-----------|---------|------------|----------|
| Alpha | α | A | Iota | ι | I | Rho | ρ | P |
| Beta | β | B | Kappa | κ | K | Sigma | σ | Σ |
| Gamma | γ | Γ | Lambda | λ | Λ | Tau | τ | T |
| Delta | δ | Δ | Mu | μ | M | Upsilon | υ | Y |
| Epsilon | ϵ | E | Nu | ν | N | Phi | ϕ | Φ |
| Zeta | ζ | Z | Xi | ξ | Ξ | Chi | χ | X |
| Eta | η | H | Omicron | \omicron | O | Psi | ψ | Ψ |
| Theta | θ | Θ | Pi | π | Π | Omega | ω | Ω |

ground. A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the Earth, or to some conducting body of relatively large extent that serves in place of the Earth.

Note: It is used for establishing and maintaining the potential of the Earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting ground current to and from the Earth (or of the conducting body).²

H. Symbol for magnetic field strength. *See* Magnetic Field Strength.

Hall effect. The generation of an electric potential perpendicular to both an electric current flowing along a thin conducting material and an external magnetic field applied at right angles to the current. Named for Edwin H. Hall (1855–1938), an American physicist.

hertz (Hz). A unit of frequency equal to one cycle per second.

hysteresis. The dependence of the state of a system on its previous history, generally in the form of a lagging of a physical effect behind its cause.¹ Also *see* magnetic hysteresis.

IEC. International Electrotechnical Commission.

IEEE. Institute of Electrical and Electronics Engineers.

IEEE-488. An instrumentation bus with hardware and programming standards designed to simplify instrument interfacing. The addressable, parallel bus specification is defined by the IEEE.

initial permeability. The permeability determined at $H = 0$ and $B = 0$.

initial susceptibility. The susceptibility determined at $H = 0$ and $M = 0$.

infrared (IR). For practical purposes any radiant energy within the wavelength range 770 to 10^6 nanometers is considered infrared energy.² The full range is usually divided into three sub-ranges: near IR, far IR, and sub-millimeter.

interchangeability. Ability to exchange one sensor or device with another of the same type without a significant change in output or response.

international system of units (SI). A universal coherent system of units in which the following seven units are considered basic: meter, kilogram, second, ampere, Kelvin, mole, and candela. The International System of Units, or *Système International d'Unités* (SI), was promulgated in 1960 by the Eleventh General Conference on Weights and Measures. For definition, spelling, and protocols, *see* Reference 3 for a short, convenient guide.

interpolation table. A table listing the output and sensitivity of a sensor at regular or defined points which may be different from the points at which calibration data was taken.

intrinsic coercivity. The magnetic field strength (H) required to reduce the magnetization (M) or intrinsic induction in a magnetic material to zero.

intrinsic induction. The contribution of the magnetic material (B_i) to the total magnetic induction (B).

$$B_i = B - \mu_0 H \quad (\text{SI}) \qquad B_i = B - H \quad (\text{cgs})$$

isolated (neutral system). A system that has no intentional connection to ground except through indicating, measuring, or protective devices of very-high impedance.²

Kelvin (K). The unit of temperature on the Kelvin Scale. It is one of the base units of SI. The word “degree” and its symbol ($^\circ$) are omitted from this unit. *See* Temperature Scale for conversions.

- Kelvin Scale.** The Kelvin Thermodynamic Temperature Scale is the basis for all international scales, including the ITS-90. It is fixed at two points: the absolute zero of temperature (0 K), and the triple point of water (273.16 K), the equilibrium temperature that pure water reaches in the presence of ice and its own vapor.
- line regulation.** The maximum steady-state amount that the output voltage or current changes as result of a specified change in input line voltage (usually for a step change between 105–125 or 210–250 volts, unless otherwise specified).
- line voltage.** The RMS voltage of the primary power source to an instrument.
- load regulation.** A steady-state decrease of the value of the specified variable resulting from a specified increase in load, generally from no-load to full-load unless otherwise specified.
- lock-in amplifier.** An amplifier that uses some form of automatic synchronization with an external reference signal to detect and measure very weak electromagnetic radiation at radio or optical wavelengths in the presence of very high noise levels.¹
- M.** Symbol for magnetization. *See* magnetization.
- magnetic air gap.** The air space, or non-magnetic portion, of a magnetic circuit.
- magnetic field strength (H).** The magnetizing force generated by currents and magnetic poles. For most applications, the magnetic field strength can be thought of as the applied field generated, for example, by a Electromagnet. The magnetic field strength is not a property of materials. Measure in SI units of A/m or cgs units of oersted.
- magnetic flux density (B).** Also referred to as magnetic induction. This is the net magnetic response of a medium to an applied field, H. The relationship is given by the following equation: $B = \mu_0(H + M)$ for SI, and $B = H + 4\pi M$ for cgs, where H = magnetic field strength, M = magnetization, and $\mu_0 =$ permeability of free space = $4\pi \times 10^{-7}$ H/m.
- magnetic hysteresis.** The property of a magnetic material where the magnetic induction (B) for a given magnetic field strength (H) depends upon the past history of the samples magnetization.
- magnetic induction (B).** *See* magnetic flux density.
- magnetic moment (m).** This is the fundamental magnetic property measured with dc magnetic measurements systems such as a vibrating sample magnetometer, extraction magnetometer, SQUID magnetometer, etc. The exact technical definition relates to the torque exerted on a magnetized sample when placed in a magnetic field. Note that the moment is a total attribute of a sample and alone does not necessarily supply sufficient information in understanding material properties. A small highly magnetic sample can have exactly the same moment as a larger weakly magnetic sample (*see* Magnetization). Measured in SI units as $A \cdot m^2$ and in cgs units as emu. $1 \text{ emu} = 10^{-3} A \cdot m^2$.
- magnetic units.** Units used in measuring magnetic quantities. Includes ampere-turn, gauss, gilbert, line of force, maxwell, oersted, and unit magnetic pole.
- magnetization (M).** This is a material specific property defined as the magnetic moment (m) per unit volume (V). $M = m/V$. Measured in SI units as A/m and in cgs units as emu/cm³. $1 \text{ emu/cm}^3 = 10^3 \text{ A/m}$. Since the mass of a sample is generally much easier to determine than the volume, magnetization is often alternately expressed as a mass magnetization defined as the moment per unit mass.
- microcontroller.** A microcomputer, microprocessor, or other equipment used for precise process control in data handling, communication, and manufacturing.¹
- MKSA System of Units.** A system in which the basic units are the meter, kilogram, and second, and the ampere is a derived unit defined by assigning the magnitude $4\pi \times 10^{-7}$ to the rationalized magnetic constant (sometimes called the permeability of space).
- negative temperature coefficient (NTC).** Refers to the sign of the temperature sensitivity. For example, the resistance of a NTC sensor decreases with increasing temperature.
- National Institute of Standards and Technology (NIST).** Government agency located in Gaithersburg, Maryland and Boulder, Colorado, that defines measurement standards in the United States.
- noise (electrical).** Unwanted electrical signals that produce undesirable effects in circuits of control systems in which they occur.²
- normalized sensitivity.** For resistors, signal sensitivity (dR/dT) is geometry dependent; i.e., dR/dT scales directly with R; consequently, very often this sensitivity is normalized by dividing by the measured resistance to give a sensitivity, s_T , in percent change per Kelvin. $s_T = (100/R) (dR/dT) \%K$, where T is the temp. in Kelvin and R is the resistance in ohms.
- normally closed (N.C.).** A term used for switches and relay contacts. Provides a closed circuit when actuator is in the free (unenergized) position.
- normally open (N.O.).** A term used for switches and relay contacts. Provides an open circuit when actuator is in the free (unenergized) position.
- oersted (Oe).** The cgs unit for the magnetic field strength (H). $1 \text{ oersted} = 10^3/4\pi \text{ ampere/meter} \approx 79.58 \text{ ampere/meter}$.
- ohm (Ω).** The SI unit of resistance (and of impedance). The ohm is the resistance of a conductor such that a constant current of one ampere in it produces a voltage of one volt between its ends.²
- open-loop.** A control system in which the system outputs are controlled by system inputs only, and no account is taken of actual system output.¹
- pascal (Pa).** The SI unit of pressure equal to 1 N/m^2 . Equal to 1.45×10^{-4} psi, $1.0197 \times 10^{-5} \text{ kg}_f/\text{cm}^2$, 7.5×10^{-3} torr, 4.191×10^{-3} inches of water, or 1×10^{-5} bar.

permeability. Material parameter which is the ratio of the magnetic induction (B) to the magnetic field strength (H):
 $\mu = B/H$. Also *see* Initial Permeability and Differential Permeability.

platinum (Pt). A common temperature sensing material fabricated from pure platinum to make the Lake Shore PT family of resistance temperature sensor elements.

polynomial fit. A mathematical equation used to fit calibration data. Polynomials are constructed of finite sums of terms of the form $a_i x_i$, where a_i is the i^{th} fit coefficient and x_i is some function of the dependent variable.

positive temperature coefficient (PTC). Refers to the sign of the temperature sensitivity. For example, the resistance of a PTC sensor increases with increasing temperature.

pounds per square inch (psi). A unit of pressure. 1 psi = 6.89473 kPa. Variations include psi absolute (psia) measured relative to vacuum (zero pressure) where one atmosphere pressure equals 14.696 psia and psi gauge (psig) where gauge measured relative to atmospheric or some other reference pressure.

ppm. Parts per million, e.g., 4×10^{-6} is four parts per million.

precision. Careful measurement under controlled conditions which can be repeated with similar results. *See* repeatability. Also means that small differences can be detected and measured with confidence. *See* resolution.

prefixes. SI prefixes used throughout this manual are as follows:

| Factor | Prefix | Symbol | Factor | Prefix | Symbol |
|-----------|--------|--------|------------|--------|--------|
| 10^{24} | yotta | Y | 10^{-1} | deci | d |
| 10^{21} | zetta | Z | 10^{-2} | centi | c |
| 10^{18} | exa | E | 10^{-3} | milli | m |
| 10^{15} | peta | P | 10^{-6} | micro | μ |
| 10^{12} | tera | T | 10^{-9} | nano | n |
| 10^9 | giga | G | 10^{-12} | pico | p |
| 10^6 | mega | M | 10^{-15} | femto | f |
| 10^3 | kilo | k | 10^{-18} | atto | a |
| 10^2 | hecto | h | 10^{-21} | zepto | z |
| 10^1 | deka | da | 10^{-24} | yocto | y |

probe. A long, thin body containing a sensing element which can be inserted into a system in order to make measurements. Typically, the measurement is localized to the region near the tip of the probe.

proportional, integral, derivative (PID). A control function where output is related to the error signal in three ways. Proportional (gain) acts on the instantaneous error as a multiplier. Integral (reset) acts on the area of error with respect to time and can eliminate control offset or droop. Derivative (rate) acts on the rate of change in error to dampen the system, reducing overshoot.

rack mount. An instrument is rack mountable when it has permanent or detachable brackets that allow it to be securely mounted in an instrument rack. The standard rack-mount is 19 inches wide. A full-rack instrument requires the entire width of the rack. Two half-rack instruments fit horizontally in one rack width.

relief valve. A type of pressure relief device which is designed to relieve excessive pressure, and to reclose and reseal to prevent further flow of gas from the cylinder after reseating pressure has been achieved.

remanence. The remaining magnetic induction in a magnetic material when the material is first saturated and then the applied field is reduced to zero. The remanence would be the upper limit to values for the remanent induction. Note that no strict convention exists for the use of remanent induction and remanence and in some contexts the two terms may be used interchangeably.

remanent induction. The remaining magnetic induction in a magnetic material after an applied field is reduced to zero. Also *see* remanence.

repeatability. The closeness of agreement among repeated measurements of the same variable under the same conditions.²

resistance temperature detector (RTD). Resistive sensors whose electrical resistance is a known function of the temperature, made of, e.g., carbon-glass, germanium, platinum, or rhodium-iron.

resolution. The degree to which nearly equal values of a quantity can be discriminated.²

display resolution. The resolution of the physical display of an instrument. This is not always the same as the measurement resolution of the instrument. Decimal display resolution specified as " n digits" has 10^n possible display values. A resolution of n and one-half digits has 2×10^n possible values.

measurement resolution. The ability of an instrument to resolve a measured quantity. For digital instrumentation this is often defined by the analog to digital converter being used. An n -bit converter can resolve one part in 2^n . The smallest signal change that can be measured is the full scale input divided by 2^n for any given range. Resolution should not be confused with accuracy.

RhFe. Rhodium-iron. Rhodium alloyed with less than one atomic percent iron is used to make the Lake Shore RF family of sensors. Rhodium-iron is a spin fluctuation alloy which has a significant temperature coefficient of resistance below 20 K where most metals rapidly lose sensitivity.

root mean square (RMS). The square root of the time average of the square of a quantity; for a periodic quantity the average is taken over one complete cycle. Also known as effective value.¹

RS-232C. Bi-directional computer serial interface standard defined by the Electronic Industries Association (EIA). The interface is single-ended and non-addressable.

Seebeck effect. The development of a voltage due to differences in temperature between two junctions of dissimilar metals in the same circuit.¹

self-heating. Heating of a device due to dissipation of power resulting from the excitation applied to the device. The output signal from a sensor increases with excitation level, but so does the self-heating and the associated temperature measurement error.

sensitivity. The ratio of the response or change induced in the output to a stimulus or change in the input. Temperature sensitivity of a resistance temperature detector is expressed as $S = dR/dT$.

setpoint. The value selected to be maintained by an automatic controller.¹

serial interface. A computer interface where information is transferred one bit at a time rather than one byte (character) at a time as in a parallel interface. RS-232C is the most common serial interface.

SI. Système International d'Unités. *See* International System of Units.

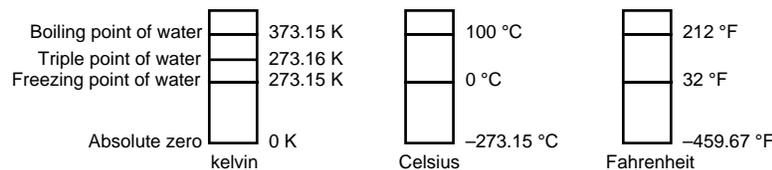
stability. The ability of an instrument or sensor to maintain a constant output given a constant input.

strain relief. A predetermined amount of slack to relieve tension in component or lead wires. Also called stress relief.

susceptance. In electrical terms, susceptance is defined as the reciprocal of reactance and the imaginary part of the complex representation of admittance: [suscept(ibility) + (conduct)ance].

susceptibility (χ). Parameter giving an indication of the response of a material to an applied magnetic field. The susceptibility is the ratio of the magnetization (M) to the applied field (H). $\chi = M/H$. In both SI units and cgs units the volume susceptibility is a dimensionless parameter. Multiply the cgs susceptibility by 4π to yield the SI susceptibility. *See* also Initial Susceptibility and Differential Susceptibility. As in the case of magnetization, the susceptibility is often seen expressed as a mass susceptibility or a molar susceptibility depending upon how M is expressed.

temperature scales. *See* Kelvin Scale, Celsius Scale, and ITS-90. Proper metric usage requires that only Kelvin and degrees Celsius be used. However, since degrees Fahrenheit is in such common use, all three scales are delineated as follows:



To convert Kelvin to Celsius, subtract 273.15.

To convert Celsius to Fahrenheit: multiply °C by 1.8 then add 32, or: $^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$.

To convert Fahrenheit to Celsius: subtract 32 from °F then divide by 1.8, or: $^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$.

temperature coefficient, measurement. The measurement accuracy of an instrument is affected by changes in ambient temperature. The error is specified as an amount of change (usually in percent) for every one degree change in ambient temperature.

tesla (T). The SI unit for magnetic flux density (B). 1 tesla = 10^4 gauss

thermal emf. An electromotive force arising from a difference in temperature at two points along a circuit, as in the Seebeck effect.¹

tolerance. The range between allowable maximum and minimum values.

torr. Unit of pressure. 1 torr \approx 1 mm of mercury. 1 atmosphere = 760 torr.

two-lead. Measurement technique where one pair of leads is used for both excitation and measurement of a sensor. This method will not reduce the effect of lead resistance on the measurement.

Underwriters Laboratories (UL). An independent laboratory that establishes standards for commercial and industrial products.

unit magnetic pole. A pole with a strength such that when it is placed 1 cm away from a like pole, the force between the two is 1 dyne.

volt (V). The difference of electric potential between two points of a conductor carrying a constant current of one ampere, when the power dissipated between these points is equal to one watt.²

volt-ampere (VA). The SI unit of apparent power. The volt-ampere is the apparent power at the points of entry of a single-phase, two-wire system when the product of the RMS value in amperes of the current by the RMS value in volts of the voltage is equal to one.²

watt (W). The SI unit of power. The watt is the power required to do work at the rate of 1 joule per second.²

References:

- 1 Sybil P. Parker, Editor. *McGraw-Hill Dictionary of Scientific and Technical Terms: Fifth Edition*. New York: McGraw Hill, 1994 (ISBN 0-07-113584-7)
- 2 Christopher J. Booth, Editor. *The New IEEE Standard Dictionary of Electrical and Electronic Terms: IEEE Std 100-1992, Fifth Edition*. New York: Institute of Electrical and Electronics Engineers, 1993 (ISBN 1-55937-240-0)
- 3 Nelson, Robert A. *Guide For Metric Practice*, Page BG7 - 8, Physics Today, Eleventh Annual Buyer's Guide, August 1994 (ISSN 0031-9228 coden PHTOAD)

APPENDIX B

UNITS FOR MAGNETIC PROPERTIES

Table B-1. Conversion from CGS to SI Units

| <i>Quantity</i> | <i>Symbol</i> | <i>Gaussian & CGS emu^a</i> | <i>Conversion Factor, C^b</i> | <i>SI & Rationalized mks^c</i> |
|--|-------------------------------------|---|--|--|
| Magnetic flux density, Magnetic induction | B | gauss (G) ^d | 10 ⁻⁴ | tesla (T), Wb/m ² |
| Magnetic Flux | φ | maxwell (Mx), G•cm ² | 10 ⁻⁸ | weber (Wb), volt second (V•s) |
| Magnetic potential difference, magnetomotive force | U, F | gilbert (Gb) | 10/4π | ampere (A) |
| Magnetic field strength, magnetizing force | H | oersted (Oe), ^e Gb/cm | 10 ³ /4π | A/m ^f |
| (Volume) magnetization ^g | M | emu/cm ^{3h} | 10 ³ | A/m |
| (Volume) magnetization | 4πM | G | 10 ³ /4π | A/m |
| Magnetic polarization, intensity of magnetization | J, I | emu/cm ³ | 4π × 10 ⁻⁴ | T, Wb/m ²ⁱ |
| (Mass) magnetization | σ, M | emu/g | $\frac{1}{4\pi} \times 10^{-7}$ | A•m ² /kg Wb•m/kg |
| Magnetic moment | m | emu, erg/G | 10 ⁻³ | A•m ² , joule per tesla (J/T) |
| Magnetic dipole moment | j | emu, erg/G | 4π × 10 ⁻¹⁰ | Wb•m ¹ |
| (Volume) susceptibility | χ, κ | dimensionless emu/cm ³ | $\frac{1}{(4\pi)^2} \times 10^{-7}$ | Henry per meter (H/m), Wb/(A•m) |
| (Mass) susceptibility | χ _p , κ _p | cm ³ /g, emu/g | $\frac{4\pi \times 10^{-3}}{(4\pi)^2} \times 10^{-10}$ | $\frac{m^3}{kg}$ H•m ² /kg |
| (Molar) susceptibility | χ _{mol} , κ _{mol} | cm ³ /mol, emu/mol | $\frac{4\pi \times 10^{-6}}{(4\pi)^2} \times 10^{-13}$ | $\frac{m^3}{mol}$ H•m ² /mol |
| Permeability | μ | dimensionless | 4π × 10 ⁻⁷ | H/m, Wb/(A•m) |
| Relative permeability ^j | μ _r | not defined | — | dimensionless |
| (Volume) energy density, energy product ^k | W | erg/cm ³ | 10 ⁻¹ | J/m ³ |
| Demagnetization factor | D, N | dimensionless | 1/4π | dimensionless |

NOTES:

- a. Gaussian units and cgs emu are the same for magnetic properties. The defining relation is $B = H + 4\pi M$.
- b. Multiply a number in Gaussian units by C to convert it to SI (e.g. $1 \text{ G} \times 10^{-4} \text{ T/G} = 10^{-4} \text{ T}$).
- c. SI (Système International d'Unités) has been adopted by the National Bureau of Standards. Where two conversion factors are given, the upper one is recognized under, or consistent with, SI and is based on the definition $B = \mu_0(H + M)$, where $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$. The lower one is not recognized under SI and is based on the definition $B = \mu_0 H + J$, where the symbol I is often used in place of J.
- d. 1 gauss = 10⁵ gamma (γ).
- e. Both oersted and gauss are expressed as $\text{cm}^{-1/2} \cdot \text{g}^{1/2} \cdot \text{s}^{-1}$ in terms of base units.
- f. A/m was often expressed as "ampere-turn per meter" when used for magnetic field strength.
- g. Magnetic moment per unit volume.
- h. The designation "emu" is not a unit.
- i. Recognized under SI, even though based on the definition $B = \mu_0 H + J$. See footnote c.
- j. $\mu_r = \mu/\mu_0 = 1 + \chi$, all in SI. μ_r is equal to Gaussian μ .
- k. $B \cdot H$ and $\mu_0 M \cdot H$ have SI units J/m^3 , $\text{M} \cdot \text{H}$ and $B \cdot H/4\pi$ have Gaussian units erg/cm^3 .

R.B. Goldfarb and F.R. Fickett, U.S. Department of Commerce, National Bureau of Standards, Boulder, Colorado 80303, March 1985, NBS Special Publication 696. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Table B-2. Recommended SI Values for Physical Constants

| <i>Quantity</i> | <i>Symbol</i> | <i>Value (SI units)</i> |
|--|---|---|
| Permeability of Vacuum | μ_0 | $4\pi \times 10^{-7} \text{ H m}^{-1}$ |
| Speed of Light in Vacuum | c | $2.9979 \times 10^8 \text{ m s}^{-1}$ |
| Permittivity of Vacuum | $\epsilon_0 = (\mu_0 c^2)^{-1}$ | $8.8542 \times 10^{-12} \text{ F m}^{-1}$ |
| Fine Structure Constant, $\mu_0 c e^2 / 2h$ | α α^{-1} | 0.0073 137.0360 |
| Elementary Charge | e | $1.6022 \times 10^{-19} \text{ C}$ |
| Planck's Constant | h $h = h/2\pi$ | $6.6262 \times 10^{-34} \text{ J Hz}^{-1}$ $1.0546 \times 10^{-34} \text{ J s}$ |
| Avogadro's Constant | N_A | $6.0220 \times 10^{23} \text{ mol}^{-1}$ |
| Atomic Mass Unit | $1 \text{ u} = 10^{-3} \text{ kg mol}^{-1} / N_A$ | $1.6605 \times 10^{-27} \text{ kg}$ |
| Electron Rest Mass | m_e | $0.9109 \times 10^{-30} \text{ kg}$ $5.4858 \times 10^{-4} \text{ u}$ |
| Proton Rest Mass | m_p | $1.6726 \times 10^{-27} \text{ kg}$ 1.0073 u |
| Neutron Rest Mass | m_n | $1.6749 \times 10^{-27} \text{ kg}$ 1.0087 u |
| Magnetic Flux Quantum | $\phi = h/2e$ h/e | $2.0679 \times 10^{-15} \text{ Wb}$ $4.1357 \times 10^{-15} \text{ J Hz}^{-1} \text{ C}^{-1}$ |
| Josephson Frequency-Voltage Ratio | $2e/h$ | $483.5939 \text{ THz V}^{-1}$ |
| Quantum of Circulation | $h/2m_e$ h/m_e | $3.6369 \times 10^{-4} \text{ J Hz}^{-1} \text{ kg}^{-1}$ $7.2739 \times 10^{-4} \text{ J Hz}^{-1} \text{ C}^{-1}$ |
| Rydberg Constant | R_∞ | $1.0974 \times 10^7 \text{ m}^{-1}$ |
| Proton Moment in Nuclear Magnetons | μ_p / μ_N | 2.7928 |
| Bohr Magnetron | $\mu_B = eh/2m_e$ | $9.2741 \times 10^{-24} \text{ J T}^{-1}$ |
| Proton Gyromagnetic Ratio | γ_p | $2.6752 \times 10^8 \text{ s}^{-1} \text{ T}^{-1}$ |
| Diamagnetic Shielding Factor, Spherical H ₂ O Sample | $1 + \sigma(\text{H}_2\text{O})$ | 1.0000 |
| Molar Mass Constant | R | $8.3144 \text{ J mol}^{-1} \text{ K}^{-1}$ |
| Molar Volume, Ideal Gas ($T_0 = 273.15\text{K}$, $p_0 = 1 \text{ atm}$) | $V_m = RT_0/p_0$ | $0,0224 \text{ m}^3 \text{ mol}^{-1}$ |
| Boltzman Constant | $k = R/N_A$ | $1.3807 \times 10^{-23} \text{ J K}^{-1}$ |
| Stefan-Boltzman Constant | $\sigma = (\pi^2/60) k^4/h^3 c^2$ | $5.6703 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$ |
| First Radiation Constant | $c_1 = 2\pi hc^2$ | $3.7418 \times 10^{-16} \text{ W m}^{-2}$ |
| Second Radiation Constant | $c_2 = hc/k$ | 0.0144 mK |
| Gravitation Constant | G | $6.6720 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$ |

Data (abbreviated to 4 decimal places) from CODATA Bulletin No. 11, ICSU CODATA Central Office, 19 Westendstrasse, 6 Frankfurt/Main, Germany. Copies of this bulletin are available from this office.