



User's Manual

Model 625

Superconducting Magnet Power Supply



Lake Shore Cryotronics, Inc.
575 McCorkle Blvd.
Westerville, Ohio 43082-8888 USA

E-mail Addresses:

sales@lakeshore.com
service@lakeshore.com

Visit Our Website At:

www.lakeshore.com

Fax: (614) 891-1392

Telephone: (614) 891-2243

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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: **EN61010-1:2001**
Overvoltage II
Pollution Degree 2
EN61326 A2:2001
Class A
Annex B

Model Number: **625**

2/27/04

Ed Maloof
Printed Name

Vice President of Engineering
Position

Electromagnetic Compatibility (EMC) for the Model 625 Superconducting MPS

Electromagnetic Compatibility (EMC) of electronic equipment is a growing concern worldwide. Emissions of and immunity to electromagnetic interference is now part of the design and manufacture of most electronics. To qualify for the CE Mark, the Model 625 meets or exceeds the requirements of the European EMC Directive 89/336/EEC as a **CLASS A** product. A Class A product is allowed to radiate more RF than a Class B product and must include the following warning:

WARNING: This is a Class A product. In a domestic environment, this product may cause radio interference in which case the user may be required to take adequate measures.

The instrument was tested under normal operating conditions with sensor and interface cables attached. If the installation and operating instructions in the User's Manual are followed, there should be no degradation in EMC performance.

This instrument is not intended for use in close proximity to RF Transmitters such as two-way radios and cell phones. Exposure to RF interference greater than that found in a typical laboratory environment may disturb the sensitive measurement circuitry of the instrument.

Pay special attention to instrument cabling. Improperly installed cabling may defeat even the best EMC protection. For the best performance from any precision instrument, follow the grounding and shielding instructions in the User's Manual. In addition, the installer of the Model 625 should consider the following:

- Shield measurement and computer interface cables.
- Leave no unused or unterminated cables attached to the instrument.
- Make cable runs as short and direct as possible. Higher radiated emissions is possible with long cables.
- Do not tightly bundle cables that carry different types of signals.

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CHAPTER 1

INTRODUCTION

1.0 GENERAL

This chapter provides an introduction to the Model 625 Superconducting Magnet Power Supply. The Model 625 was designed and manufactured in the United States of America by Lake Shore Cryotronics, Inc. The Model 625 features include the following.

- True 4-quadrant (bipolar) 60 A, 5 V output
- 0.1 mA output setting resolution
- Linear regulation minimizes noise and ripple to 0.006% of maximum current into a 1 m Ω load.
- 1.0 mA stability per hour
- Two units can be connected in parallel for ± 120 A operation
- CE compliance to *both* the low voltage directive *and* the electromagnetic compatibility (EMC) directive (pending)

1.1 DESCRIPTION

The Model 625 Superconducting Magnet Power Supply is the ideal supply for small to medium sized superconducting magnets used in high sensitivity materials research applications. The Model 625 is a practical alternative to both the larger, one size fits all, superconducting magnet supplies and the endless adaptations of generic power supplies. By limiting output power, Lake Shore was able to concentrate on the performance requirements of the most demanding magnet users. The resulting Model 625 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 a challenging load, such as a superconducting magnet, requires a unique solution. The Model 625 delivers up to 60 A at a nominal compliance voltage of 5 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 moderate 300 W output of the Model 625. Linear operation eliminates the radiated radio frequency (RF) noise associated with switching power supplies, allowing the Model 625 to reduce the overall noise in its output and the noise radiated into surrounding electronics.

Safety should never be an afterthought when combining stored energy and liquid cryogens in a superconducting magnet system. The Model 625 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 for convenience and ease of use. The Model 625 includes the features necessary to conveniently manage a superconducting magnet. Features such as a persistent switch heater output, calculated field reading, current ramping, and quench detection are all included. Computer interfaces are also integrated for automation of the magnet system. The Model 625 is truly an excellent one-box solution for controlling a superconducting magnet.

Output Architecture

True 4-quadrant output capability of the Model 625 is ideal for the charge and discharge cycling of superconducting magnets 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 625 has the ability to charge and discharge magnets up to a 5 V rate.

True 4-quadrant operation eliminates the need for external switching or operator intervention to reverse the current polarity, significantly simplifying system design. 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 625 make it possible in many situations to run experiments without going into persistent mode. This can help to reduce the time necessary to gather data.

The Model 625 output architecture relies on low noise, linear input and output stages. The linear circuitry of the Model 625 permits operation with less electrical noise than switch-mode superconducting magnet 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 625 output current is programmed internally via the keypad or the computer interface, externally by the analog programming input, or by the sum of the external and internal settings. For the more popular internal programming, the Model 625 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 625 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 28 times per second. A low-pass filter on the DAC output smoothes the transitions at step changes during ramping. Ramping can also be initiated by the trigger input.

The output compliance voltage of the Model 625 is settable to a value between 0.1 V and 5 V, with a 100 μ V resolution. The voltage is an absolute setting, so a 2 V setting will limit the output to greater than -2.0 V and less than $+2.0$ V.

Output Readings

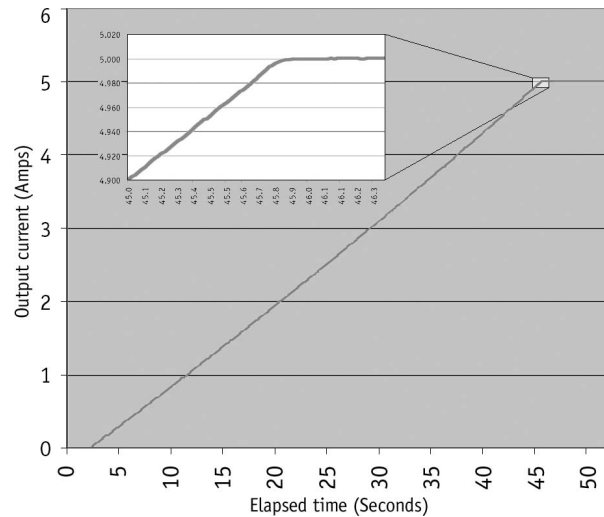
The Model 625 provides high-resolution output readings. The output current reading reflects the actual current in the magnet, and has a resolution of 0.1 mA. The output voltage reading reports the voltage at the output terminals with a resolution of 100 μ V. A remote voltage reading is also available to more accurately represent the magnet voltage by bypassing voltage drops in the leads connecting the power supply to the magnet. All output readings can be prominently displayed on the front panel and read over the computer interface.

Protection

Managing the stored energy in superconducting magnets necessitates several different types of protection. The Model 625 continuously monitors the load, line voltage, and internal circuits for signs of trouble. Any change outside of the expected operating limits triggers the supply to bring the output to zero in a fail-safe mode. When line power is lost, the output crowbar (SCR) will activate and maintain control of the magnet, discharging at a rate of 1 V until it reaches zero. Quench detection is necessary to alert the user and to protect the magnet system. The Model 625 uses a basic and reliable method for detecting a quench. If the current changes at a rate greater than the current step limit set by the operator, a quench is detected and the output current is safely set to zero.

The remote inhibit input allows an external device to immediately set the output current to zero in case of a failure. This input is normally tied to an external quench detection circuit, the fault output of a second power supply, or an emergency shutdown button. The fault output is a relay contact that closes when a fault condition occurs. The contact closure alerts other system components of the fault.

5 Ampere Charge of an 8 Henry Superconducting Magnet*



* 5 A charge of an 8.6 H AMI magnet with a 95 mA/s ramp rate; output current monitor measured at 58.88 Hz. rate with a HP 34401 – data multiplied by 10 \times to obtain output current results.

Parallel Operation

If an application requires more output current than a single Model 625 can provide, two supplies can be connected in parallel for 120 A/5 V operation. Each unit is programmed for half of the total output current, operates independently, and retains 0.1 mA resolution at 60 A operation. When the units are properly configured, either unit can detect a fault, protect itself, and issue a fault output signaling the other unit to automatically enter the proper protection mode.

Persistent Switch Heater Output

The integrated persistent switch heater output is a controlled DC current source capable of driving most switch heaters. It sources from 10 mA to 125 mA with a setting resolution of 1 mA and selectable compliance voltage of 12 V or 21 V. The minimum load that the persistent switch heater can drive is 10 W. Persistent mode operation is integrated into the instrument firmware to prevent mis-operation of the magnet.

Interfaces

The Model 625 includes IEEE-488 and RS-232C interfaces that provide access to operating data, stored parameters, and remote control of all front panel operating functions. In addition, the Model 625 includes a trigger function that is used to start an output current ramp. When the trigger is activated, either by an external trigger or by computer interface command, the power supply will begin ramping to the new setpoint.

The Model 625 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 1 V = 10 A, while the voltage monitor has a sensitivity of 1 V = 1 V.

Display and Keypad

The Model 625 incorporates a large 8-line by 40-character vacuum fluorescent display. Output current, calculated field in tesla or gauss, output voltage, and remote voltage sense readings can be displayed simultaneously. Five LEDs on the front panel provide quick verification of instrument status, including ramping, compliance, fault, PSH status, and computer interface mode. Error conditions are indicated on the main display along with an audible beeper. Extended error descriptions are available under 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 button 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.



625_Front.bmp

Figure 1-1. Model 625 Front Panel

1.2 SPECIFICATIONS

Output

Type:	Bipolar, Four Quadrant, DC Current Source
Current Generation:	Linear regulation with digital setting and analog control
Current Range:	± 60 A
Compliance Voltage:	± 5 V maximum (nominal, both source and sink)
Maximum Power:	300 W
Load Reactance:	0 Ω to 100 Ω
Current Ripple (Max):	4 mA RMS at 60 A, (0.007%) into 1 m Ω load (significantly reduced into a reactive load or at lower current)
Current Ripple Frequency:	Dominated by line frequency and its harmonics
Temperature Coefficient:	± 15 ppm of full scale/ $^{\circ}\text{C}$
Line Regulation:	15 ppm/6% line change
Source Impedance:	25 Ω
Stability (1 h):	1 mA/h (after warm-up)
Stability (24 h):	10 mA/24 h (typical, dominated by temperature coefficient and line regulation)
Isolation:	Output optically isolated from chassis to prevent ground loops
Parallel Operation:	2 units can be paralleled for ± 120 A, ± 5 V operation
Protection:	Quench, Line Loss, Low Line Voltage, High Line Voltage, Output Over Voltage, Output Over Current, Over Temperature, Remote Inhibit (on critical error conditions, magnet discharges at 1 V nominal)

Output Programming

Internal Current Setting	
Resolution:	0.1 mA (20 bit)
Settling Time:	600 ms for 1% step to within 0.1 mA into a resistive load
Accuracy:	± 10 mA $\pm 0.05\%$ of setting
Operation:	Keypad, computer interface
Protection:	Current setting limit
Internal Current Ramp	
Ramp Rate:	0.1 mA/s to 99.999 A/s (compliance limited)
Update Rate:	27.7 increments/s
Ramp Segments:	5
Operation:	Keypad, computer interface, trigger input
Protection:	Ramp rate limit
External Current Programming	
Sensitivity:	6 V = 60 A
Resolution:	Analog
Accuracy:	± 10 mA $\pm 1\%$ of setting
Bandwidth (3 dB):	40 Hz, 2-pole, low-pass filter (10 Hz pass band, compliance limited)
Input Resistance:	> 50 k Ω
Operation:	Voltage program through rear panel
Connector:	Shared 15-pin D-sub
Limits:	Internally clamped at 6.1 V
Compliance Voltage Setting	
Range:	0.1 V to 5.0 V
Resolution:	100 μV
Accuracy:	± 10 mV $\pm 1\%$ of reading

Readings**Output Current**

Resolution:	0.1 mA
Accuracy:	$\pm 1 \text{ mA} \pm 0.05\%$ of reading
Update Rate:	2.5 readings/s display, 10 readings/s interface
Compensation:	Compensated for lead resistance and 25Ω source resistance

Output Voltage (at supply terminals)

Resolution:	100 μV
Accuracy:	$\pm 1 \text{ mV} \pm 0.05\%$ of reading
Update Rate:	2.5 readings/s display, 5 readings/s interface

Remote Voltage (at magnet leads)

Resolution:	100 μV
Accuracy:	$\pm 1 \text{ mV} \pm 0.05\%$ of reading
Update Rate:	1.25 readings/s
Input Resistance:	$> 50 \text{ k}\Omega$
Connector:	Shared 15-pin D-sub

Persistent Switch Heater Output (PSHO)

Current Range:	10 mA to 125 mA
Compliance Voltage (minimum):	12 V or 21 V selectable
Heater Resistance (minimum):	10 Ω
Setting Resolution:	1 mA
Accuracy:	$\pm 1 \text{ mA}$
Operation:	On/Off with lockout delay of 5 s to 100 s
Protection:	Open or shorted heater detection, error message if off and on output currents differ
Connector:	BNC

Front Panel

Display Type:	8-line by 40 character, graphic vacuum fluorescent display module
Display Readings:	Output current, calculated field (T or G), output voltage, remote voltage sense
Display Settings:	Output current, calculated field, compliance voltage, ramp rate
Display Annunciators:	Status and errors
LED Annunciators:	PSHO on, remote, compliance limit, fault, ramping
Keypad Type:	26 full travel keys
Keypad Functions:	Direct access to common operations, menu driven setup

Interface**IEEE-488.2 Interface**

Features:	SH1,AH1,T5,L4,SR1,RL1,PP0,DC1,DT1,C0,E1
Reading Rate:	To 10 readings/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 readings/s
Connector:	9-pin D-sub

Output Current Monitor

Sensitivity:	60 A = 6 V
Accuracy:	$\pm 1\%$ of full scale
Noise:	1 mV
Source Impedance:	20 Ω
Connector:	Shared 15-pin D-sub

Output Voltage Monitor

Sensitivity:	1 V = 1 V
Accuracy:	±1% of full scale
Noise:	1 mV
Source Impedance:	20 Ω
Connector:	Shared 15-pin D-sub

Fault Output

Type:	Relay (closed on fault)
Relay Contact:	30 VDC @ 1 A
Connector:	Shared 25-pin D-sub

Remote Inhibit Input

Type:	TTL or contact closure
Connector:	Shared 25-pin D-sub

Trigger Input

Type:	TTL or contact closure
Connector:	Shared 25-pin D-sub

General

Ambient Temperature:	15 °C to 35 °C
Cooling:	Air cooled with internal 2 speed fan
Warm-up:	30 minutes at output current setting
Line Power:	100, 120, 220, 240 VAC +6% –10%, single phase, 50 or 60 Hz, 850 VA
Size:	483 mm W × 178 mm H × 520 mm D (19 in × 7 in × 20.5 in), rack mount (integrated rack mount ears)
Weight:	27.2 kg (60 lbs)
Approval (pending):	CE Mark – Low voltage compliance to EN61010-3, EMC compliance to EN55022-1
Calibration Schedule:	1 year

Ordering Information

<i>Part Number</i>	<i>Description</i>
625	Superconducting Magnet Power Supply
625-DUAL	Two Model 625s, one dual supply interconnect cable kit

Select a power configuration:

VAC-100-B	Instrument configured for 100 VAC with U.S. power cord
VAC-120-B	Instrument configured for 120 VAC with U.S. power cord
VAC-120-BC	Instrument configured for 120 VAC with U.S. power cord and universal European power cord and fuses for 220/240 setting (extra charge for this option)
VAC-220-C	Instrument configured for 220 VAC with European power cord
VAC-240-C	Instrument configured for 240 VAC with European power cord

Accessories included:

6271	Model 625 user's manual
6241	Two front handles
6242	Two rear handles/protectors
6243	Output shorting bar and terminal fasteners
6251	25-pin D-sub mating connector, digital I/O
6252	15-pin D-sub mating connector, analog I/O
—	Calibration Certificate

Accessories available

6201	1 m (3.3 ft) long IEEE-488 (GPIB) computer interface cable assembly
6261	10 ft – 60 A magnet cable kit, AWG 4
6262	20 ft – 60 A magnet cable kit, AWG 4
6263	Dual supply interconnect cable kit (including magnet cables and safety interlock cable)
CAL-625-CERT	Instrument recalibration with certificate
CAL-625-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 625 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.
- Overvoltage 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 $\pm 10\%$ of the nominal voltage.

Ground The Instrument

To minimize shock hazard, the instrument is equipped with a 3-conductor AC power cable. Plug the power cable into an approved three-contact electrical outlet or use a three-contact adapter with the grounding wire (green) firmly connected to an electrical ground (safety ground) at the power outlet. The power jack and mating plug of the power cable meet Underwriters Laboratories (UL) and International Electrotechnical Commission (IEC) safety standards.

Ventilation

The instrument has ventilation holes in its side covers. Do not block these holes when the instrument is operating.

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.

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 and repair to ensure that safety features are maintained.














Cleaning

Do not submerge instrument. Clean only with a damp cloth and mild detergent. Exterior only.

Moving and Handling

Four handles are provided for ease of moving and handling the Model 625. Always use at least two, and if possible four, handles when carrying the unit.

1.4 SAFETY SYMBOLS

	Direct current (power line).		Equipment protected throughout by double insulation or reinforced insulation (equivalent to Class II of IEC 536 - see Annex H).
	Alternating current (power line).		Caution: High voltages; danger of electric shock. Background color: Yellow; Symbol and outline: Black.
	Alternating or direct current (power line).		Caution or Warning - See instrument documentation. Background color: Yellow; Symbol and outline: Black.
	Three-phase alternating current (power line).		Fuse.
	Earth (ground) terminal.		
	Protective conductor terminal.		
	Frame or chassis terminal.		
	On (supply).		
	Off (supply).		

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CHAPTER 2

MAGNET SYSTEM DESIGN

2.0 GENERAL

This chapter provides information on general magnet system design. It is intended to give the user insight into superconducting materials, superconducting magnets, persistent switches, dewars, and cabling issues. For information on how to install the Model 625 please refer to Chapter 3. Instrument operation information is contained in Chapter 4.

2.1 SUPERCONDUCTING MATERIALS

Superconducting materials have a very special property, that when cooled to very low temperatures, they become perfect conductors of electricity. The transition to the superconducting state happens abruptly as the critical temperature is reached. When the material is in its superconducting state, it has absolutely zero resistance. Such materials have a variety of applications, one of which is for the construction of high field magnets.

The unique properties of superconductors make them ideal for use in high field magnets. Since a superconductor has no resistance it requires no voltage to maintain a current through it. Magnet grade superconductors also have a very high current density allowing a relatively small wire to carry a large amount of current that can be used to generate large magnetic fields.

There are three properties that determine if a material is in its superconducting state. The first property is critical temperature. A superconductor needs to be cooled in order to transition to a superconducting state. This temperature is called its critical temperature. Most materials need to be cooled with liquid helium in order to reach their critical temperatures although some ceramics have shown to have a critical temperature as high as 125 K which would be suitable for nitrogen cooling.

The second property is critical current density. A superconducting wire can only carry a certain amount of current in its superconducting state. The current density of a typical superconducting wire made from niobium-titanium is on the order of 10^{10} A/m², about three orders of magnitude greater than normal house wiring. If the critical current density is exceeded, the wire will return to its normal resistive state.

The last property is critical field. A superconductor will return to its normal resistive state if it is exposed to a magnetic field larger than its critical field. Superconducting wire such as niobium-titanium and niobium-tin have critical fields in excess of 10 T and 20 T respectively. Elemental superconductors, such as lead, have very low critical fields, in this case 0.08 T, and are not suited for creating superconducting magnets.

All three of these properties are related to one another. For instance, a superconducting wire is able to carry more current and withstand a higher magnetic field as it is cooled to a lower temperature. In the case of niobium-titanium, a common superconducting wire, the critical temperature is 9.3 K but at that temperature both the critical field and critical current density are both zero. At a temperature of 6 K, the critical field increases to approximately 7 T and at 4 K it is approximately 11 T.

2.2 SUPERCONDUCTING MAGNETS

Superconducting magnets are wound from many turns of superconducting wire. They are used to generate magnetic fields that are larger than can be achieved with permanent magnets or electromagnets or when field stability is important. They can also be more economical to run than electromagnets since the power needed to maintain the charge is minimal.

2.2.1 Superconducting Magnet Construction

The magnetic field (B) that can be generated by a solenoid is given by the equation $B = \mu_0 n I / l$, where μ_0 is the permeability of air, I is the current in the wire, n is the number of turns, and l is the length of the solenoid. Most superconducting magnets are wound using a conductor made from many fine strands of niobium-titanium (NbTi) or niobium-tin (Nb₃Sn) embedded in a copper matrix. The copper matrix is used for mechanical stability and to provide a path for large currents in the case of a magnet quench. Typically, niobium-tin is only used in magnets that can generate fields in excess of 9 Tesla because it is more expensive and harder to work with than niobium-titanium.

The superconducting wire is wound around a non-magnetic former made from aluminum, brass, stainless steel, or other material as needed. The individual windings are electrically insulated by the insulation on the wire and by an epoxy that is applied to the windings. The epoxy is also necessary to keep the individual windings from moving when the magnet is charged.



Figure 2-1. Typical Superconducting Magnet

2.2.2 Magnet Inductance

The inductance of a solenoid (L) is defined as $L = \mu_0 n^2 A / l$, where μ_0 is the permeability of air, n is the number of turns, A is the cross sectional area of the coil, and l is the length of the solenoid. The inductance of superconducting magnets is fairly large, typically between 10 and 100 Henries. The magnet's inductance limits the rate at which the magnet can be charged or discharged because of the increased voltage required to change current. The formula $V = L (di/dt)$ relates charging voltage to inductance where V is the charging voltage, L is the magnet inductance, and di/dt is the rate of change in current. The Model 625 can charge a magnet up to a 5 V rate, although many magnets are not designed to be charged at that rate. For instance, a 10 Henry magnet can be charged at a rate of 0.5 A/s with a 5 V limit. A rate of 0.1 A/s is more typical.

The resistance of the leads must be taken into account when calculating charge rate since a voltage drop across the leads will limit the voltage that can be delivered to the terminals of the magnet. This becomes especially important as the charging current rises since the voltage drop across the leads will increase.

2.2.3 Maximum Ramp Rate

Not only is the rate at which a magnet can be charged limited to the magnet's inductance but it is also limited by the magnet's construction. When a magnet is charged or discharged, heat is generated in the coils. The faster the ramp rate, the more heat that will be generated. If the heat cannot be conducted out of the magnet fast enough, a section of the superconducting windings can go normal and cause a quench. The magnet manufacturer should state the maximum ramp rate of the magnet. In some magnets, the current cannot be changed at the same rate over the entire current range of the magnet. These magnets need to be charged at a slower rate as they reach their maximum current rating.

2.2.4 Maximum Magnet Current

Although superconducting wire can carry more current than non-superconducting wire of the same size, the amount of current that it can carry is not unlimited. If the critical current of the wire is exceeded, the wire will no longer be superconducting and will revert to its normal state causing the magnet to quench. Commercially purchased magnets have been designed to work up to a maximum stated current. The magnet should be able to handle a quench up to the rated current of the magnet. Do not exceed the maximum current rating of the magnet or the magnet can quench and possibly be damaged.

2.2.5 Magnet Quench Protection Diodes

Many superconducting magnets have protection diodes installed across the terminals of the magnet. These diodes will turn on in the event of a quench and will help dissipate some of the magnet's energy. Typically the diodes are attached to the magnet itself and are submerged in the cryogen. At 4.2 K the forward voltage of the diodes may be on the order of 10 volts. If the magnet quenches, the energy dissipated in the diodes will warm them, resulting in a decrease in their forward voltage. If this voltage drops below the compliance voltage limit of the power supply, the power supply will continue to source current to the diodes eventually damaging them and causing them to short. This would require that the protection diodes be replaced which could be a significant expense especially if the magnet is in a sealed dewar.

To ensure that the diodes are not damaged by the power supply, the compliance voltage limit of the supply should be set to a voltage below the protection diode range. It is also recommended that some form of quench detection be used to force the output of the power supply to 0 amps when a quench is detected ensuring that no additional current is being supplied to the diodes. The Model 625 offers both internal quench detection and a remote inhibit line that can be connected to an external quench detection circuit.

2.3 PERSISTENT SWITCHES

Some superconducting magnets are constructed with a persistent switch. A persistent switch is a length of superconducting wire that shorts across the terminals of the magnet. This length of wire can be heated and drives it into a resistive state so that a voltage can be applied across the magnet terminals and the magnet can be charged or discharged. When the heater is shut off, this section of wire will cool and become superconducting again and the magnet will be in persistent mode. At this time, the power supply can be ramped to zero current and even removed from the system while the magnet holds its charge.

One of the reasons to use a persistent switch is when a very stable field is required. When the magnet is in persistent mode, all of the current is being circulated within the magnet with no interference from outside sources. Another reason to use a persistent switch is when it is desired to hold a particular magnet field for an extended period of time, such as in a MRI system. Once the magnet is in persistent mode, the power supply can be removed from the system and used elsewhere. It is also possible on some systems to remove the vapor cooled leads from the dewar to further reduce the amount of helium boil off.

The magnet manufacturer will specify the current necessary to turn on the persistent switch heater. Do not use any more current than is necessary since that will result in excess helium boil off. It is important when turning on the persistent switch heater that the current setting of the power supply is equal to the current in the magnet. If the current does not match, the current in the magnet will ramp to the current setting of the power supply at the compliance voltage limit. This may cause the power supply to incorrectly detect a quench.

2.4 MAGNET CURRENT LEADS

The power supply should be placed close to the magnet to reduce the length of the lead wires. The resistance of the wires becomes very important when such large currents are being supplied to the magnet. The rate at which a magnet can be charged depends on the voltage that can be supplied across the terminals of the magnet given by the equation $V = L (di/dt)$. The voltage is limited by the maximum voltage the power supply can output minus the voltage that is lost through the magnet leads. Use lead wires heavy enough to limit the voltage drop to less than 0.5 volts per lead and keep conductor temperature under 85 °C for a 35 °C ambient temperature. Table 2-1 lists the current capacity and total lead lengths for lead connections.

Table 2-1. Current Capacity and Total Lead Lengths

AWG	Area (mm ²)	Capacity (A)	Resistivity $\Omega/1000$ feet	Total Lead Length (feet)	
				60 A	120 A
0	53.5	245	0.09827	170	85
2	33.6	180	0.1563	107	53
4	21.2	135	0.2485	67	34
6	13.3	100	0.3951	42	—
8	8.4	75	0.6282	27	—

The Remote Voltage Sense connection can be used to monitor the voltage directly across the terminals of the magnet. This will give a more accurate voltage reading across the terminals of the magnet by eliminating the voltage drop in the leads. Some magnets manufacturers provide voltage sense connections directly at the terminals of the magnet. If these are not available, they can be added and the signals can be brought out of the dewar to be connected to the power supply. If it is not desirable to add wiring inside the dewar, the sense leads can be connected to the magnet current leads at the dewar. The remote voltage sense input can only be used to read the voltage at the magnet terminals and cannot be used to control the voltage limit.

2.5 HELIUM DEWAR¹

Since superconducting magnets need to be run at cryogenic temperatures, they are installed in dewars filled with liquid helium. A dewar usually consists of one or more reservoirs surrounded by a vacuum jacket. This vacuum jacket insulates the reservoir from room temperatures. In dewars with multiple reservoirs, the outside reservoir is normally filled with liquid nitrogen as a way to further reduce the heat transfer from the liquid helium filled inner reservoir. Most dewars are made from stainless steel although they can also be made from glass or epoxy-fiberglass and aluminum. Stainless steel is used because it is very rugged, has low thermal conductivity, and can easily be welded to different types of metals.

The most basic dewars are of an all welded construction with an opening in the top for direct access to the cryogen reservoir. The dewar will have an evacuation valve to evacuate the vacuum jacket surrounding the cryogen reservoir. There will also be a pressure relief valve to protect the vacuum jacket in case a leak should develop. This leak would allow cold cryogen into the vacuum jacket where it will expand upon contact with the room temperature wall. This pressure relief valve is set to open between 2 and 5 psi to safely vent the leaking gas.

The superconducting magnet can either be supported by the insert or supported by a base in the bottom of the dewar. If the magnet is in the base of the dewar, it is usually installed when the dewar is built and can only be removed or serviced by cutting the dewar apart. Any insert that is placed in the helium reservoir should contain a number of radiation baffles in the neck region of the dewar. These baffles are normally made from copper and are cooled by the escaping helium gas. This will help cut down on radiation losses from the room temperature top flange on the insert. It will also help to cut down on conductive heat loss being transferred down the neck of the dewar. The high current leads used for charging the magnet should be vapor cooled to reduce the amount of heat that is transferred into the helium reservoir.

¹ Information gathered from *Introduction to Laboratory Cryogenics*, M.N. Jirmanus, Janis Research Company, Inc.

With the magnet submerged in liquid helium, it will be at a temperature of 4.2 K at atmospheric pressure. Some magnets are rated to work at 2.2 K allowing a larger field to be generated. This temperature can be achieved by lowering the pressure over the helium reservoir thereby lowering the boiling point of the helium. Some dewars will have a pumping port that can be attached to a vacuum pump to reduce the pressure and lower the temperature but will increase the rate of liquid helium consumption.

The amount of energy that can be stored in a magnet is given by the equation $E = \frac{1}{2}LI^2$. Typical laboratory magnets have inductances of 10 to 100 Henries and can have maximum currents of 40 to 120 Amps. The energy stored in a typical magnet can be anywhere from a few thousand Joules to over one hundred thousand Joules. In the case of a magnet quench, all of this energy is going to be dumped into the liquid helium within a matter of a few seconds creating a large amount of helium gas. Any dewar that is used with a superconducting magnet should have a pressure relief port on the helium reservoir to allow the helium gas to be dissipated in the case of a quench.

The level of the liquid helium can be monitored by using a liquid helium level sensor installed in the dewar. The level of the helium should never be allowed to drop below the top of the magnet while the magnet is in operation. Allowing the magnet to become uncovered can cause a quench. Also, the level of the helium should never be higher than the inlets of the vapor cooled current leads. If the inlets are submerged in liquid helium, the helium gas can no longer cool the leads and extra heat will be transferred into the helium reservoir increasing the rate of helium boil off.

2.6 MAGNET QUENCH

A magnet quench occurs when part of the superconducting wire in the magnet becomes normal and has resistance. When a section of the magnet becomes resistive it will begin to heat and will cause more of the magnet to become resistive. This causes an unstoppable chain reaction that will result in the magnet dissipating all of its energy into heat. This can happen if the critical temperature, critical current, or critical field are exceeded. Refer to Paragraph 2.1 for a description of superconductor properties. Even though a quench is not necessarily destructive to the magnet, it should be avoided at all costs. Always check the level of liquid helium and make sure that the magnet is completely covered before operating the magnet. Never ramp a magnet at a ramp rate greater than what is specified by the magnet manufacturer. Never exceed the current rating of the magnet since a quench in this case can easily damage the magnet.

Typically the current in the magnet will be completely dissipated in about a half of a second causing the magnet to heat. It may then take several minutes before the liquid helium cools the magnet back to its superconducting state. Since a quench can boil off a significant amount of helium, always check the helium level before operating the magnet after a quench.

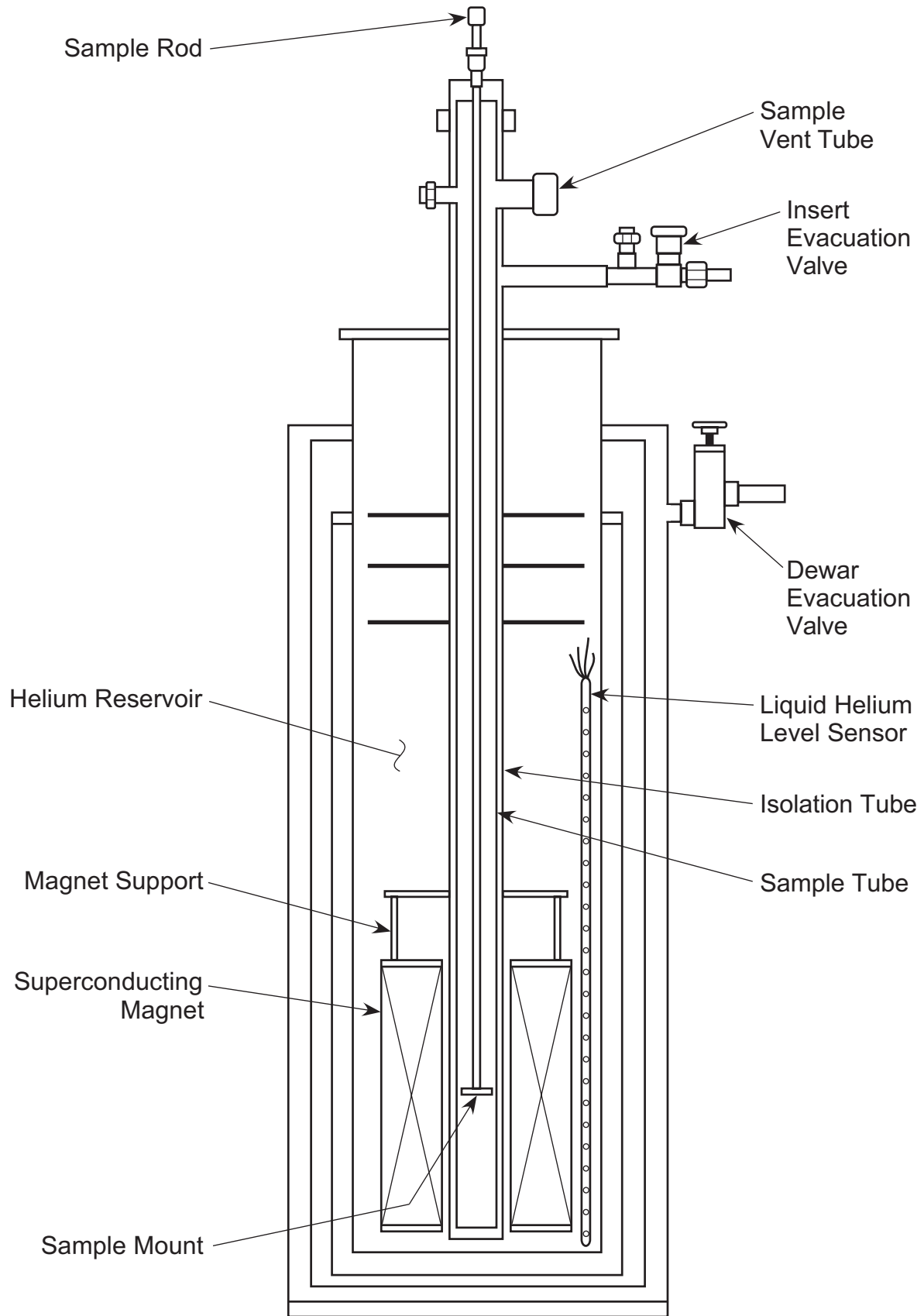


Figure 2-2. Cutaway Of A Typical Helium Dewar, Magnet, and Insert

CHAPTER 3

INSTALLATION

3.0 GENERAL

This chapter provides general installation instructions for the Model 625 Superconducting Magnet Power Supply. Please read this entire chapter before installing the instrument and powering it on to ensure the best possible performance and maintain operator safety. For instrument operating instructions refer to Chapter 4. For computer interface installation and operation refer to Chapter 6.

NOTE: It is recommended that the instrument be powered up and operated with the shorting bar in place before connecting it to a magnet. This will allow the user to setup the supply and become comfortable with its operation without risk of damage to the magnet.

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 625 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 (RA) number must be obtained from a factory representative before it is returned. The Lake Shore RA procedure is given in Paragraph 7.2.

Items Included with Model 625 Superconducting Magnet Power Supply

- 1 Model 625 Instrument
- 1 Model 625 User's Manual
- 2 Front Handles
- 2 Rear Handles
- 1 Digital I/O Mating Connector
- 1 Analog I/O Mating Connector
- 1 Output Shorting Bar and Terminal Fasteners (Installed on output bus bars)
- 1 Line Power Cord
- 1 Fuse Pair for Alternative Voltage *
- 1 Line Power Cord for Alternative Voltage *

* Included only when purchased with VAC-120-ALL Power Option.

3.1.1 Moving and Handling

Four handles are provided for ease of moving and handling the Model 625. Always use at least two, and if possible four, handles when carrying the unit.

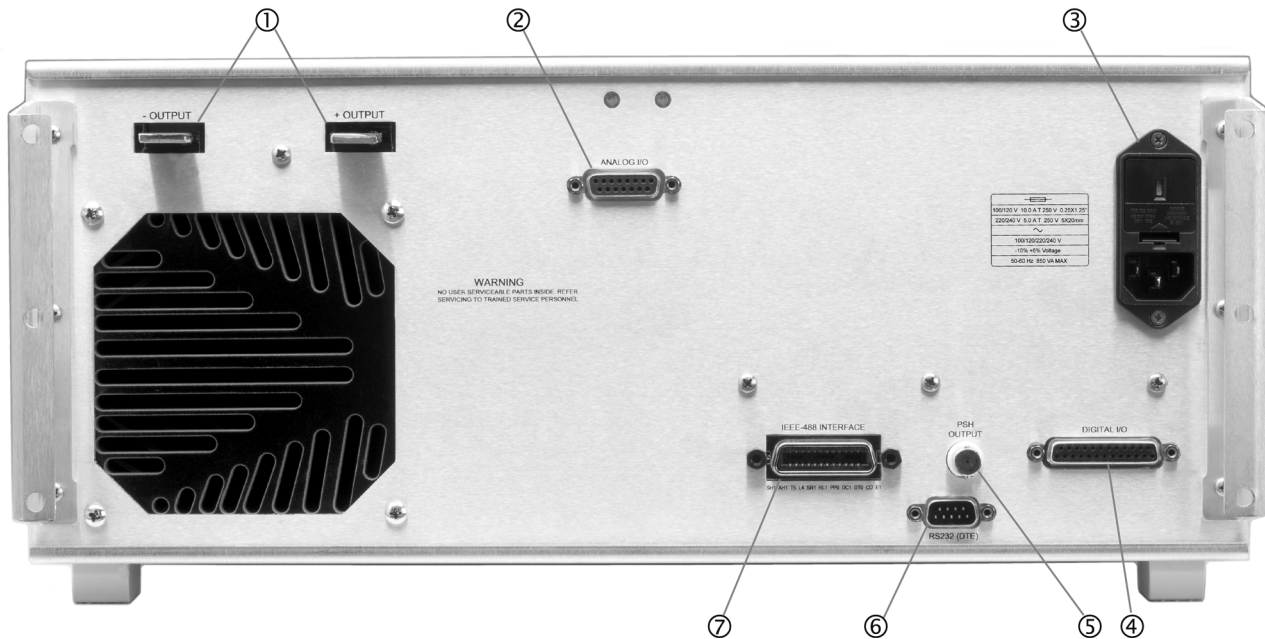
3.2 REAR PANEL DEFINITION

This paragraph defines the rear panel of the Model 625. See Figure 3-1. Readers are referred to paragraphs that contain installation instructions and connector pin-outs for each feature. A summary of connector pin-outs is provided in Paragraph 7.12.

CAUTION: Verify that the AC line voltage indicator in the fuse drawer window shows the appropriate AC line voltage before turning the instrument on.

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

①	-OUTPUT +OUTPUT	Two bus bars for the magnet cable connections. Refer to Paragraph 3.4 for connecting the magnet cables to the instrument.
②	ANALOG I/O	15-pin D subminiature receptacle provides analog monitor outputs as well as analog inputs. Refer to Paragraph 3.5 and see Figure 7-4.
③	Line Input Assembly	Includes the IEC 320-C14 line cord receptacle and line voltage selector with line voltage indicator and line fuse holder. Refer to Paragraph 3.3.
④	DIGITAL I/O	25-pin D subminiature receptacle provides connections for digital inputs and outputs. Refer to Paragraph 3.6 and see Figure 7-6.
⑤	PSH OUTPUT	BNC receptacle provides connections for the Persistent Switch Heater. Refer to Paragraph 3.7 and see Figure 7-5.
⑥	RS-232 (DTE)	9-pin D subminiature plug wired in DTE configuration for use with RS-232C serial computer interface. Refer to Paragraph 5.2.2 and see Figure 7-7.
⑦	IEEE-488 INTERFACE	IEEE-488 compliant interface connector for use with IEEE-488 parallel computer interface. Refer to Paragraph 5.1 and see Figure 7-8.



625_Rear.bmp

Figure 3-1. Model 625 Rear Panel

3.3 LINE INPUT ASSEMBLY

This section describes how to properly connect the Model 625 to line power. Please follow these instructions carefully to ensure proper operation of the instrument and the safety of operators.



Figure 3-2. Line Input Assembly

3.3.1 Line Voltage

The Model 625 has four different AC line voltages configurations so that it can be operated from line power anywhere in the world. The nominal voltage and voltage range of each configuration is shown below. (The recommended setting for 230 V operation is 240 V.)

Nominal	Minimum	Maximum
100 V	90 V	106 V
120 V	108 V	127 V
220 V	198 V	233 V
240 V	216 V	254 V

Verify that the AC line voltage indicator in the fuse drawer window shows the appropriate AC line voltage before turning the instrument on. The instrument may be damaged if it is turned on with the wrong voltage selected. Instructions for changing the line voltage configuration are given in Paragraph 7.4.

3.3.2 Line Fuse and Fuse Holder

The line fuse is an important safety feature of the Model 625. If a fuse ever fails, it is important to replace it with the value and type indicated on the rear panel for the line voltage setting. The letter T on the fuse rating indicates that the instrument requires a time-delay or slow-blow fuse. Fuse values should be verified any time line voltage configuration is changed. Instructions for changing and verifying a line fuse are given in Paragraph 7.5.

3.3.3 Power Cord

The Model 625 includes a 3-conductor power cord that mates with the IEC 320-C14 line cord receptacle. Line voltage is present on the two outside conductors and the center conductor is a safety ground. The safety ground attaches to the instrument chassis and protects the user in case of a component failure. A CE approved power cord is included with instruments shipped to Europe; a domestic power cord is included with all other instruments (unless otherwise specified when ordered). Always plug the power cord into a properly grounded receptacle to ensure safe operation of the instrument.

The delicate nature of measurement being taken near this instrument may necessitate additional grounding including ground strapping of the instrument chassis. In these cases the operators safety should remain the highest priority and low impedance from the instrument chassis to safety ground should always be maintained.

3.3.4 Power Switch

The power switch is on the front panel of the Model 625 and turns line power to the instrument On and Off. When the circle is depressed, power is Off. When the line is depressed, power is On.

3.4 MAGNET CABLE CONNECTIONS

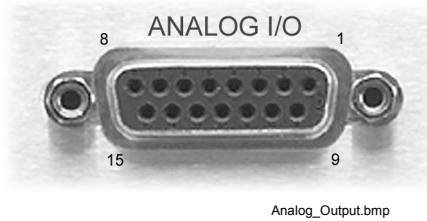
Magnet cable connections are made at the +OUTPUT and –OUTPUT terminals on the rear panel. These plated copper bus bars accommodate ¼ inch (M6) mounting hardware. Use load wires heavy enough to limit the voltage drop to less than 0.5 volts per lead. This ensures proper regulation and prevents overheating while carrying the output current. The remote voltage sense leads can be used to measure the actual magnet voltage. Keep conductor temperature under 85 °C (185 °F) for a 35 °C (95 °F) ambient. Table 3-1 lists the current capacity and total lead lengths for load connections. Lake Shore sells magnet cables in 10 and 20 foot lengths. Refer to Paragraph 6.2 for ordering accessories.

Table 3-1. Current Capacity and Total Lead Lengths

AWG	Area (mm ²)	Capacity (A)	Resistivity Ω/1000 feet	Total Lead Length (feet)	
				60 A	120 A
0	53.5	245	0.09827	170	85
2	33.6	180	0.1563	107	53
4	21.2	135	0.2485	67	34
6	13.3	100	0.3951	42	—
8	8.4	75	0.6282	27	—

3.5 ANALOG INPUT/OUTPUT CONNECTIONS

The Analog I/O connector provides connections to analog signals used to monitor or control the power supply. Two inputs are provided, one to program the current output and one used to monitor the remote voltage sense leads. Two outputs are also provided to monitor the output current and the output voltage. Refer to the instrument specifications in Paragraph 1.2 for input and source impedances.



Analog_Output.bmp

Pin	Name	Pin	Name
1	Voltage Sense –	9	Voltage Sense +
2	NC	10	NC
3	Current Program –	11	Current Program +
4	NC	12	NC
5	Voltage Monitor –	13	Voltage Monitor +
6	NC	14	NC
7	Current Monitor –	15	Current Monitor +
8	NC		

Figure 3-3. Model 625 Analog Input/Output Connector

3.5.1 External Current Programming

The output current can be programmed externally using an analog voltage. This programming voltage can also be summed with the internal current setting. Refer to Paragraph 4.18 to change the external program mode. The external current programming input is a differential input with a sensitivity of 1 V = 10 A and an input impedance of > 50 kΩ. The programming voltage is limited internally to approximately ±6.1 V but care must be taken to insure that maximum current capability of the magnet is never exceeded.

3.5.2 Remote Voltage Sense

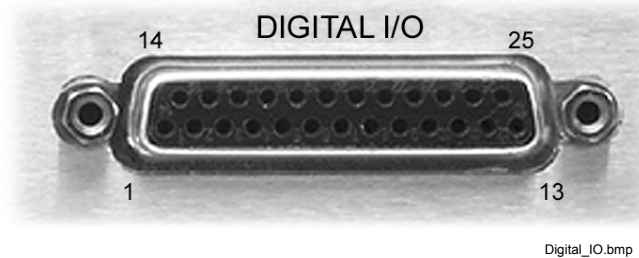
The Model 625 provides a connection for remote voltage sense leads. This connection is normally used to measure the voltage at the magnet allowing a more accurate reading of magnet voltage by eliminating voltage drops in the leads connecting the power supply to the magnet. This voltage reading can be displayed on the front panel or read over the computer interface. Refer to Paragraph 4.4.2 to configure the display to show the remote voltage sense reading. The remote voltage sense connection is a differential input capable of reading ± 5 V and an input impedance of > 50 k Ω .

3.5.3 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 $1 \text{ V} = 10 \text{ A}$ and the voltage monitor has a sensitivity of $1 \text{ V} = 1 \text{ V}$. Both outputs have a source impedance of 20Ω .

3.6 DIGITAL INPUT/OUTPUT CONNECTIONS

The Digital I/O connector provides connections to digital control signals. Two of these connections, Remote Inhibit and Trigger In, are inputs used to control the state of the power supply. The Fault Out is an output that is used to signal error conditions.



Pin	Name	Pin	Name
1	Fault Out Common	14	Fault Out
2	NC	15	NC
3	Remote Inhibit Common	16	Remote Inhibit
4	NC	17	NC
5	Trigger Out Common (not used)	18	Trigger Out (not used)
6	NC	19	NC
7	Trigger In Common	20	Trigger In
8	NC	21	NC
9	NC	22	NC
10	NC	23	NC
11	NC	24	NC
12	NC	25	NC
13	NC		

Figure 3-4. Model 625 Digital Input/Output Connector

3.6.1 Fault Output

The fault output is a relay contact closure that closes to indicate a fault condition. The relay contact is rated at 30 VDC at 1 A. The contact closure alerts other system components of the fault. If the power supply detects an internal hardware fault, the fault relay is closed, the front panel fault LED is lit, and the condition is latched. If the power supply detects an operational fault, the fault relay will close for 1 second and then open and the front panel LED will blink. When two Model 625s are connected in parallel, the fault output should be wired to the remote inhibit line of the other supply. Refer to Paragraph 3.9 for details on connecting two power supplies in parallel.

3.6.2 Remote Inhibit

The Remote Inhibit connection on the Digital I/O connector is an input that instructs the power supply to immediately set the output current to 0 A. This input allows an external device to immediately shut off the output current of the supply in case of a failure. This input is normally tied to an external quench detection circuit, the fault output of a second power supply, or an emergency shut down button. This function will only set the output current to zero, so if the magnet is still charged, it will discharge at a rate determined by the compliance voltage limit. The Remote Inhibit input is TTL compatible and a logic low will activate it. The signal is internally pulled up to allow operation with a simple switch closure. Refer to Figure 3-5.

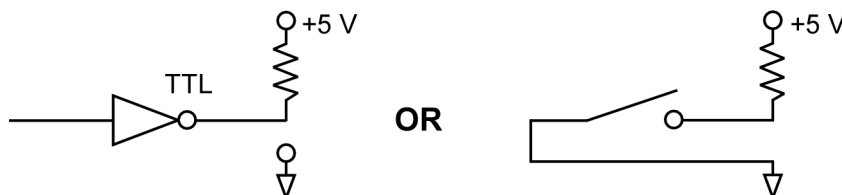


Figure 3-5. Remote Inhibit and Trigger In Operation

3.6.3 Trigger In

The Trigger In connection on the Digital I/O connector is an input that is used to start an output current ramp. The trigger can only be armed from the computer interface using the **TRIG** command to setup a new output current setpoint. When the Trigger In line is activated, the power supply will begin ramping to the new setpoint. Once the instrument has been triggered, the **TRIG** command needs to be sent again along with a new setpoint to rearm the trigger. The Trigger In input is TTL compatible and a logic low will activate it. The signal is internally pulled up to allow operation with a simple switch closure. Refer to Figure 3-5.

3.7 PERSISTENT SWITCH HEATER OUTPUT

The persistent switch heater output is a controlled DC current source capable of sourcing up to 125 mA with a jumper selectable compliance voltage limit of 15 V or 24 V. The default setting is 24V. Refer to Paragraph 7.11 to configure the compliance voltage limit of the persistent switch heater output. The actual voltage compliance limit is dependant on load but guaranteed to be at least 12 V or 21 V depending on the setting. The heater output current is software settable in 1 mA steps from 10 to 125 mA. Typically, the magnet manufacturer specifies the persistent switch heater current. The minimum load that the persistent switch heater can drive is 10 Ω . If the persistent switch heater is less than 10 Ω a series resistance needs to be added or else the PSH circuit will falsely detect a short circuit. Refer to Paragraph 4.14 to setup the persistent switch heater.



Heater Output.bmp

Figure 3-6. Persistent Switch Heater Output Connector

3.7.1 Heater Output Connection

BNC receptacle provides connections for the persistent switch heater output. Signal is carried on the center conductor and heater common is on the outer conductor. The heater output has a maximum voltage of 24 V and can source 125 mA. Mating connector not included.

3.7.2 Heater Output Cabling

Coaxial cable is recommended for the heater output, outside of the test dewar. The center conductor should be large enough to carry the maximum 125 mA current to prevent accidental burn out of the conductor.

3.8 INSTRUMENT GROUNDING AND ISOLATION

Chassis grounded circuits should have a low impedance path to Earth ground for both performance and safety. This is achieved by using a 3-conductor power cord in a properly grounded outlet. All instrumentation that is connected to the analog outputs or computer interface (or use Earth ground as measurement common) should have similar low impedance to the same ground. Good grounding of all chassis in a group of instruments prevents voltage differences between their chassis (usually at line frequency) from inducing noise on the measurement. If good quality Earth ground is not available, the chassis of line powered instruments should be strapped together with heavy gauge copper wire or ground strap. Signal leads in communication cables should not be relied on for ground strapping.

The high current output stage in the Model 625 uses a bridging output technology and is optically isolated from power line ground. Optical isolation of the output stage provides noise immunity from power line (Earth) related ground loops with outside measurement equipment.

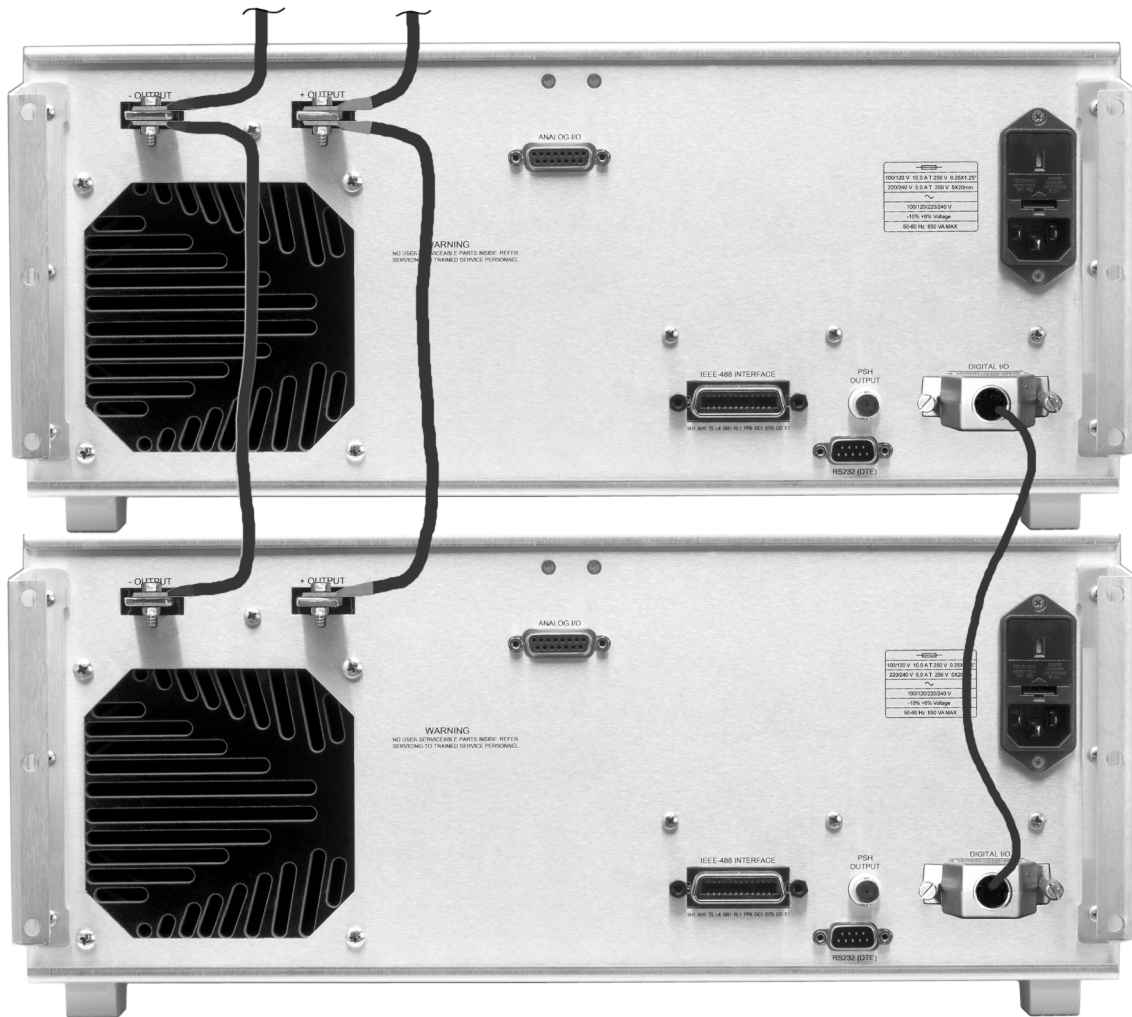
A 100-ohm internal resistor ties the power line ground to the internal output stage common to provide a reference to the output stage in instances where the output is allowed to float. This is to prevent electrostatic build up between the isolated sections of the Model 625. If the magnet coil is left ungrounded, this is the only path that keeps the common-mode voltage of the magnet at or near earth ground. In many instances, it is expected that one of current output terminals will be attached to power line ground. In this instance, it is recommended that the negative terminal be attached to power line ground since tying the positive terminal to ground will result in a small current reading error of 30–70 mA. Either output terminal can be connected to power line ground without damage.

The computer interfaces are still referenced to power line ground. The Output Voltage Monitor and Output Current Monitor outputs are sourced from the isolated output stage but are electronically balanced and have a common-mode voltage limit of 10 V. This limit is more than adequate for any equipment that is referenced to power line ground. Similarly, the External Current Programming and Remote Voltage inputs are differential and allow easy interface to power line grounded equipment.

3.9 CONNECTING MULTIPLE UNITS IN PARALLEL

Up to two Model 625's can be connected in parallel to provide up to 120 A of current at a maximum compliance voltage of 5 V. When the units are connected, they are still operated individually. The total amount of current supplied to the load is the sum of the currents that each supply is delivering. If both supplies are ramping current at the same time, then the total ramp rate is equal to the sum of both the ramp rates as long as neither of the supplies reaches its compliance voltage limit. If the compliance voltage limits of the two supplies are not the same, then the total compliance voltage is limited to the lower setting of the two supplies.

To connect two power supplies together, the +OUTPUT and –OUTPUT terminals of one supply should be connected to the +OUTPUT and –OUTPUT terminals of the other supply respectively. Make these leads as short as possible to minimize output potential differences between the two power supplies and use a heavy enough gauge wire to carry at least 60 A. Refer to Table 3-1 for wire gauge properties. Connect the +OUTPUT and –OUTPUT terminals of one of the supplies to the load using a heavy enough gauge wire to carry 120 A. On the Digital I/O connector, connect the Fault Output of each supply to the Remote Inhibit of the other supply. Be sure to secure the Digital I/O connectors to the power supplies with the connector screws. When all connections are made, power up both supplies at the same time. It is possible that one or both of the supplies will power up with a Remote Inhibit fault detected if both supplies are not powered up at the same time. If this occurs, wait until both units have powered up and then clear the error using the **Status** key. Refer to Paragraph 7.6 for information on clearing errors. Lake Shore sells a Dual Supply Interconnect Cable Kit with all of the necessary cables to connect two supplies in parallel. Refer to Paragraph 6.2 for ordering accessories.



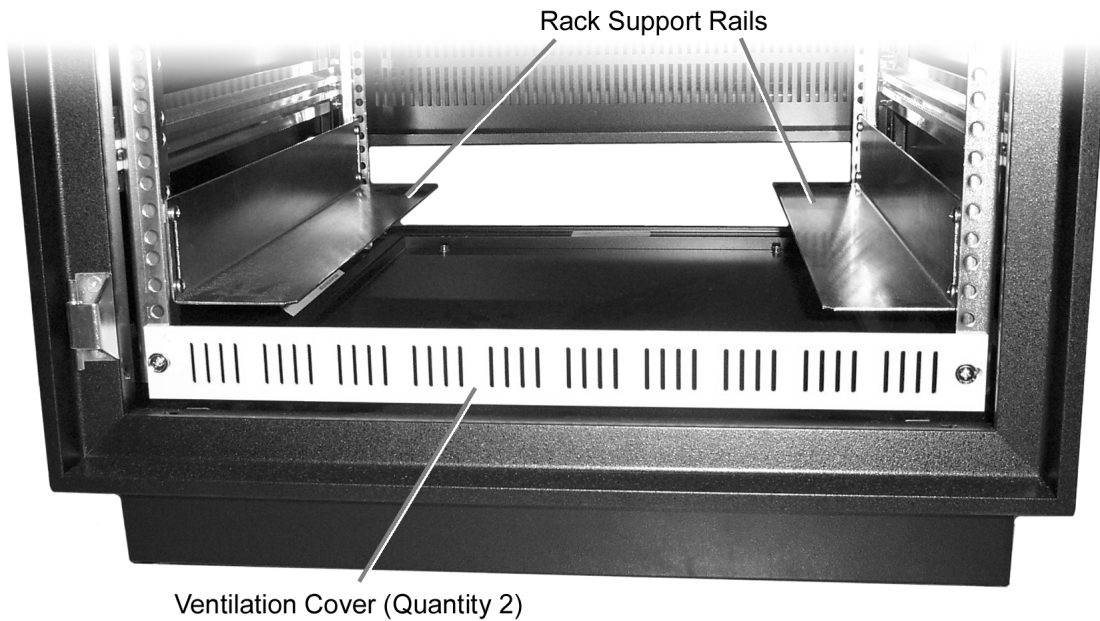
Dual_625_Rear.bmp

Figure 3-7. Connecting Two Power Supplies in Parallel

3.10 RACK MOUNTING

The Model 625 can be installed into a 19-inch rack mount cabinet using the included rack mount hardware and 19-inch rack support rails. The power supply comes from the factory with feet installed. These feet need to be removed if the supply is going to be rack mounted. Be sure to reinstall the screws once the feet are removed. Due to the weight of the power supply, it is recommended that the supply be mounted at the bottom of the rack. For ventilation, the back of the rack should be open and a 1U (44 mm high) ventilation cover should be mounted on the rack above and below the power supply. Use 19-inch rack support rails (not included) fastened to the front and back of the cabinet to support the weight of the supply.

CAUTION: The front panel rack mount brackets are used to hold the power supply securely to the front of the rack. The rack support rails, not the front panel brackets, must support the weight of the supply.



MPS_Rack_Mount.bmp

Figure 3-8. Rack Mounting a Model 625 Power Supply

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CHAPTER 4

OPERATION

4.0 GENERAL

This chapter provides operating instructions for the features of the Model 625 Superconducting Magnet Power Supply. Computer interface instructions are in Chapter 5.

4.1 TURNING POWER ON

Verify that the AC line voltage indicator in the fuse drawer window shows the appropriate AC line voltage before turning the instrument on. The instrument may be damaged if it is turned on with the wrong voltage selected. Instructions for checking line voltage selection are given in Paragraph 3.3.1.

NOTE: It is recommended that the instrument be powered up and operated with the shorting bar in place before connecting it to a magnet. This will allow the user to setup the supply and become comfortable with its operation without risk of damage to the magnet.

When the Model 625 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 while the instrument does an internal diagnostic and makes sure everything is working before the output is turned on. 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. The persistent switch heater, if enabled, will be turned off. When the instrument is powered on for the first time parameter values are set to their defaults, as listed in Table 4-1.

When initialization is complete the instrument will begin its normal reading cycle and current or field readings should appear on the display. Any error messages will appear in the bottom of the display. Messages listed in Table 7-1, Instrument Hardware Errors, are related to the instrument hardware and may require help from Lake Shore service. The messages listed in Table 7-2, Operational Errors, are related to instrument operation and may be corrected with user intervention.

The Model 625 should be allowed to warm up for a minimum of 30 minutes to achieve rated accuracy.

4.2 DISPLAY DEFINITION

The Model 625 has an 8 line by 40 character vacuum fluorescent (VF) display capable of showing both text and graphic images. This paragraph describes features of the display that appear during normal operation including current measurement, voltage measurement, and current programming. Other display configurations appear during parameter setting and data entry operations. These displays are illustrated in their individual operation paragraphs.

4.2.1 Output Current Display

When the instrument is configured to display in output current, the display will look similar to the display shown in Figure 4-1. The output current reading and the output voltage reading are displayed using large 11 × 15 block characters. Below that are the instrument setup parameters including output current setting, current ramp rate, compliance voltage limit, and remote voltage sense reading. Display setup is described in Paragraph 4.4.

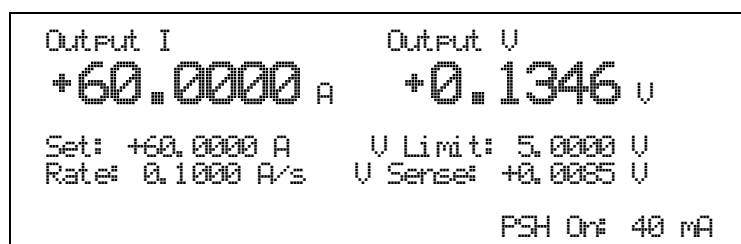


Figure 4-1. Model 625 Output Current Display

4.2.2 Magnet Field Display

The instrument can be setup to display calculated field. See Figure 4-2. This value is calculated using the output current reading and the field constant. See Paragraph 4.13 to setup the field constant. If the instrument is setup to display in field, then only the field reading will be displayed using the large 11×15 block characters. Other information is shown below as well as to the right of the field reading. This includes the output field setting, the current ramp rate, the output current reading, the output current setting, the output voltage reading, the compliance voltage limit, and the remote voltage sense reading. Display setup is described in Paragraph 4.4.

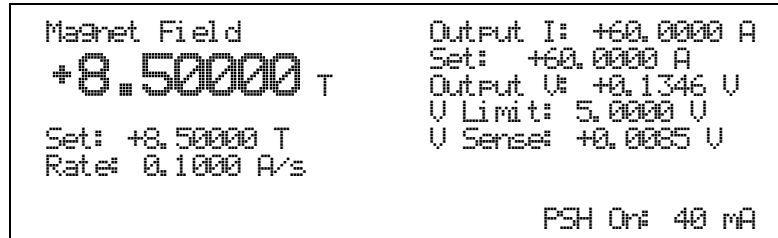


Figure 4-2. Model 625 Magnet Field Display

4.2.3 Persistent Switch Heater Display

The lower right corner of the display shows the status of the persistent switch heater if the persistent switch is enabled. It will indicate if the heater is off, on, warming, or cooling. If the heater is on, it will also display the heater current. This area of the display will be blank if the persistent switch heater is disabled. Refer to Paragraph 4.14 for information on setting up the Persistent Switch Heater Output.

4.2.4 LED Annunciators

There are five LED annunciators on the front panel that are used to indicate the status of the instrument. These are to provide easy verification of the operation of the instrument.

Fault	On when a hardware fault condition exists, blinking when a soft fault condition exists.
Compliance	On when output is in voltage compliance.
Ramping	On when output current is ramping, blinking when ramp is paused.
PSH On	On when persistent switch heater is on, blinking when the heater is warming or cooling.
Remote	On when instrument is in remote computer interface mode.

4.3 KEYPAD DEFINITION

The Model 625 has 26 keys separated into 4 groups on the instrument front panel. The group of keys farthest to the left control the persistent switch heater, the center group combines instrument setup and data entry, the keys farthest to the right control the computer interface mode of the instrument, and the keys at the bottom control the output current.

4.3.1 Key Descriptions

Output Setting	Sets the output current. Refer to Paragraph 4.5.
Ramp Rate	Sets the output current ramp rate. Refer to Paragraph 4.6.
Voltage Limit	Sets the compliance voltage limit for the output. Refer to Paragraph 4.7.
Zero Output	Ramps the current to 0 A at the programmed ramp rate. Refer to Paragraph 4.8.
Stop Output	Stops the output at the present value during a ramp. Refer to Paragraph 4.9.
Pause Output	Pauses the output during a ramp. Press again to continue ramp. Refer to Paragraph 4.10.

PSH Setup	Setup persistent switch heater enable, current, delay time, and persistent mode ramp rate. Refer to Paragraph 4.14.
Quench Detect	Setup quench detect enable and current step limit. Refer to Paragraph 4.16.
Display Setup	Setup display mode and brightness. Refer to Paragraph 4.4.
Escape	Exits from parameter setting sequence without changing the parameter value. Press and hold to reset parameters to default values. Refer to Paragraph 4.21.
Field Constant	Setup the field constant value and units. Refer to Paragraph 4.13.
External Program	Setup the external current programming mode. Refer to Paragraph 4.18.
Computer Interface	Setup RS-232 and IEEE computer interfaces. Refer to Paragraph 4.20.
Ramp Segments	Setup ramp segment values. Refer to Paragraph 4.12.
Max Settings	Setup maximum setting values for output current, voltage, and ramp rate. Refer to Paragraph 4.11.
Status	Displays a summary of the instrument status. Refer to Paragraph 4.17.
Enter	Accepts a new parameter value. Press and hold to lock keypad. Refer to Paragraph 4.19.
0-9, ±, .	Numeric data entry within a setting sequence.
▲ (Up)	Increments a parameter selection or value.
▼ (Down)	Decrements a parameter selection or value.

PSH On	Turns the persistent switch heater on. Refer to Paragraph 4.15.
PSH Off	Turns the persistent switch heater off

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.

4.3.2 General Keypad Operation

The Model 625 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. **Zero Output**, **Stop Output**, and **Pause 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 ▲ and ▼ 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 ▲▼".

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, 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.

4.4 DISPLAY SETUP

The display of the Model 625 is designed so that all of the pertinent operational information is being presented in a logical manner. The most important readings, either output current and voltage or calculated magnetic field, are displayed using large 11×15 block characters that can be seen from across the room. The remote voltage sense readings can be displayed if they are being utilized or they can be removed from the display altogether.

4.4.1 Display Mode

The Model 625 is able to display in two modes, output current mode or magnetic field mode. In output current mode, the output current and voltage are displayed using large 11×15 block characters. In magnet field mode, the calculated magnet field is displayed using large 11×15 block characters. The display mode also changes the way the **Output Setting** key works. In current mode, the output setting value will be in units of amps (A) but in field mode, the output setting value will be in units of field, either kG or T. Refer to Paragraph 4.5 to set the output current.

To configure the display press **Display Setup**. The first display setup screen appears as a prompt for the display mode.

```
Display Setup  
  
Select With ▲▼  
  
Display Mode: Current
```

Use the **▲** or **▼** key to select the display mode, either Current or Field. 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.

4.4.2 Display Remote Voltage Sense

The Model 625 has the ability to display a remote voltage sense reading. This connection is available on the rear panel of the instrument. See Paragraph 3.5.2 for information on how to connect the remote voltage sense leads. These leads are normally used to monitor the voltage at the terminals of the magnet. The remote voltage sense reading can be displayed or hidden if the remote voltage sense leads are not being used. Note that the remote voltage sense leads will always be read, only the display function can be turned on or off. The sense voltage cannot be used as the compliance voltage.

To change the remote voltage sense display, continue from the display mode screen or press **Display Setup** then **Enter** until the following display setup screen appears as a prompt for the remote voltage sense display.

```
Display Setup  
  
Select With ▲▼  
  
Remote Voltage Sense: On
```

Use the **▲** or **▼** key to select the remote voltage sense display, either On or Off. Press **Enter** to accept the new selection and continue to other display features. Press **Escape** to cancel the new selection and return to the normal display.

4.4.3 Display Brightness

The vacuum fluorescent (VF) display on the Model 625 has four brightness settings between 100% and 25% 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% is recommended for most applications.

To change display brightness, continue from the remote voltage sense display screen or press **Display Setup** then **Enter** until the following display setup screen appears as a prompt for display brightness.

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

Use the **▲** or **▼** 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.

4.5 SETTING OUTPUT CURRENT

The main purpose of the Model 625 Superconducting Power Supply is to supply a very precise and stable current to a highly inductive 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, maximum compliance voltage limit, maximum ramp rate, quench detection, and PSH parameters. When a new output current setting is entered, the supply will ramp from the current setting to the new setting at the current ramp rate, unless limited by the compliance voltage. The Ramping LED will be lit while the output current setting 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.

To change the output current setting when in current display mode, 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.

```
Set: + 0.0000 A
```

Use the data entry keys to enter an output current setting value between -60.0000 and + 60.0000. 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 ± 60.1000 A. This can be used to compensate for current loss due to high resistance leads and for variances in calibration. The output current is guaranteed to reach a minimum of 60 A but may not be able to reach 60.1 A in all circumstances.

If the display mode is set to field display mode, then the output setting value is also in units of field, either kG or T. Refer to Paragraph 4.13 to setup the field constant and units. Even when the output is in units of field, the other parameters remain the same. The ramp rate is still in units of A/s and the maximum current setting is still used.

There are certain circumstances in which the current will not be allowed to change. This is done for safety and to protect the magnet system. If the output current is going to be kept from changing, an error box will pop up explaining why the new setting is going to be ignored. These error boxes are described below.

```
Change not allowed while  
PSH is warming or cooling.
```

The output current setting is not allowed to change while the persistent switch heater is warming or cooling. The amount of time it takes for the PSH to warm or cool is system dependant and can be setup under the PSH Setup key. Refer to Paragraph 4.14 to setup the persistent switch heater.

```
Change not allowed while  
in External Current Program Mode.
```

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 4.18 to setup the external program mode.

```
Change not allowed while  
ramp rate > current step limit.
```

The output current setting is not allowed to change if the current ramp rate is greater than the current step limit and quench detection is on. The current step limit is a parameter of quench detection. If the current were allowed to change at a rate greater than the current step limit, then a quench would be falsely detected. Refer to Paragraph 4.16 to setup quench detection.

```
Change not allowed while  
max ramp rate > current step limit.
```

As stated above, the current ramp rate cannot exceed the current step limit used for quench detection. To insure that the ramp rate will never accidentally exceed the current step limit either by entering a ramp rate from the front panel or by having the ramp segments function set a new ramp rate, the maximum ramp rate must be less than the current step limit. Refer to Paragraph 4.11 to setup maximum settings.

4.6 CURRENT RAMP RATE

The output current of the Model 625 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 large as 99.999 A/s can be entered to simulate a step change. On most superconducting magnets, the maximum rate at which it can be charged is usually stated. Exceeding the maximum charging rate can cause the magnet to quench. When the current ramp rate is entered or changed by crossing into a different ramp segment, it will be limited in magnitude by the maximum ramp rate. Refer to Paragraph 4.12 to setup the ramp segments and to Paragraph 4.11 to setup the maximum settings.

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.

```
Rate= 1.0000 A/s
```

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.

If the persistent mode ramp rate is enabled and the magnet is in persistent mode, then the current ramp rate will not be allowed to change using the **Ramp Rate** key. To change the current ramp rate, either disable the persistent mode ramp rate feature or enter a new persistent mode ramp rate using the **PSH Setup** key. Refer to Paragraph 4.14.4 to setup the persistent mode ramp rate. The error box shown below will pop up explaining why the new setting is going to be ignored.

```
Change not allowed while  
using persistent mode ramp rate.
```

4.7 COMPLIANCE VOLTAGE LIMIT

The output compliance voltage limit of the Model 625 can be set between 0.1 and 5 V. The setting is in magnitude only and will limit both positive and negative voltages.

On most superconducting magnets, the maximum compliance voltage is usually stated and can vary depending on the current in the magnet. Exceeding the maximum compliance voltage of the magnet can cause the magnet to quench. The compliance voltage can be limited by setting the maximum compliance voltage setting. Refer to Paragraph 4.11 to setup the maximum settings.

To change the compliance voltage limit press the **Voltage Limit** key. The compliance voltage limit value on the normal display will be highlighted to prompt for the new compliance voltage limit value.



Use the data entry keys to enter the compliance voltage limit value between 0.1000 and 5.0000 V. 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 ZERO OUTPUT CURRENT

The **Zero Output** key on the front panel can be used to set the output current setpoint to 0 A. The current output will then begin to ramp down using the current ramp rate. This key is equivalent to using the **Output Setting** key and entering 0 A. Refer to Paragraph 4.5 to set the output current. There are certain circumstances in which the current will not be allowed to change, just like when entering a new output current setpoint. An error box will pop up explaining why the current is not allowed to change. These error boxes are described in Paragraph 4.5

4.9 STOP OUTPUT CURRENT

The **Stop Output** key will stop the output current ramp within two seconds after the key is pressed even if the magnet is ramping against the compliance voltage. A new output current setpoint must be entered for the output current to begin ramping again.

4.10 PAUSE OUTPUT CURRENT

The **Pause Output** 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 Output** key while the output current ramp is paused will cause the output current ramp to resume ramping to the original output current setpoint.

4.11 MAXIMUM SETTING LIMITS

The Model 625 offers maximum setting limits for output current, compliance voltage limit, and output current ramp rate. Typically the properties of the superconducting magnet will dictate what these maximum settings should be. Exceeding the maximum settings stated by the magnet manufacturer can cause the magnet to quench or be damaged. These maximum settings should be entered before the magnet system is used to prevent a quench if a setting is incorrectly entered. Note that the maximum settings will only limit the value when a new setting is entered. For example, if a maximum ramp rate limit is entered that is less than the present ramp rate, the present ramp rate will not be limited until a new ramp rate is entered.

4.11.1 Maximum Output Current

The maximum output current limits, in magnitude, the maximum 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 provision must be made to insure that the programming voltage will never exceed the desired output current. See Paragraph 4.18 to setup the External 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 60.0000 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 60.1000 A. This can be used to compensate for current loss due to high resistance leads and for variances in calibration. The output current is guaranteed to reach a minimum of 60 A but may not be able to reach 60.1 A in all circumstances.

4.11.2 Maximum Compliance Voltage Limit

The maximum compliance voltage limits, in magnitude, the maximum compliance voltage that can be entered.

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

```
Maximum Settings  
  
Enter a Value For  
Max Voltage: 5.0000 V
```

Use the data entry keys to enter the maximum compliance voltage limit value between 0.1000 and 5.0000 V. 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.

4.11.3 Maximum Current Ramp Rate

The maximum current ramp rate limits the maximum current ramp rate that can be entered. 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 4.12 to setup Ramp Segments.

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

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

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.

4.12 RAMP SEGMENTS

Many magnets cannot be charged or discharged at the same rate throughout its entire current capacity. Typically the magnet cannot be charged as fast when the current in the magnet is high. The Model 625 has a ramp segment feature that 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 4.11.3 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.

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

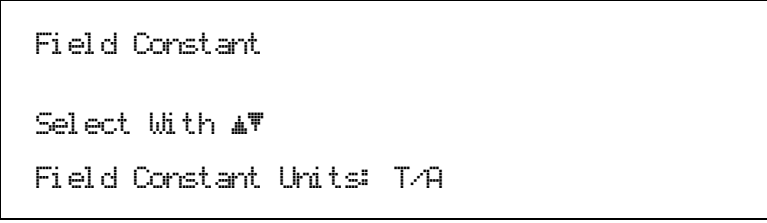
4.13 FIELD CONSTANT

In a superconducting magnet, magnetic field is directly proportional to the current in the magnet. Because of this relationship, the Model 625 is able to display a calculated field based on a user entered field constant in units of T/A or kG/A. This value is usually supplied by the magnet manufacturer. In order to display the field reading, the display must be setup to display in field. Refer to Paragraph 4.4.1 to setup the display mode. Note that the field reading is not an actual measurement of the magnetic field but an approximation calculated by multiplying the measured output current by the field constant. To actually measure the magnetic field, an external gaussmeter must be used.

4.13.1 Field Constant Units

The field constant can be entered in either units of T/A or kG/A. This choice not only changes the way the field constant is entered, but it also chooses the units of the calculated field as well as the output setting units.

To set the field constant press **Field Constant**. The first field constant screen appears as a prompt for the field constant units.

A screenshot of a monochrome display showing the 'Field Constant' screen. The text on the screen is: 'Field Constant' on the first line, 'Select With ▲▼' on the second line, and 'Field Constant Units: T/A' on the third line.

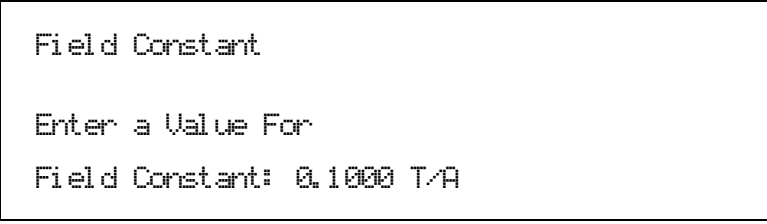
```
Field Constant
Select With ▲▼
Field Constant Units: T/A
```

Use the ▲ or ▼ key to select the field constant units, either T/A or kG/A. 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.

4.13.2 Field Constant Value

The field constant value can be entered in units of T/A or kG/A depending on what was chosen in the previous step. The field constant value will be used to calculate the magnetic field.

To enter a value for the field constant, continue from the field constant units screen or press **Field Constant** then **Enter** until the following display setup screen appears as a prompt for the field constant value.

A screenshot of a monochrome display showing the 'Field Constant' screen for value entry. The text on the screen is: 'Field Constant' on the first line, 'Enter a Value For' on the second line, and 'Field Constant: 0.1000 T/A' on the third line.

```
Field Constant
Enter a Value For
Field Constant: 0.1000 T/A
```

Use the data entry keys to enter the field constant value between 0.00100 and 1.00000 T/A or 0.0100 and 10.0000 kG/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.

4.14 PERSISTENT SWITCH HEATER OUTPUT

Some superconducting magnets are constructed with a persistent switch. A persistent switch is a length of superconducting wire that shorts across the terminals of the magnet. This length of wire can be heated to drive it into a resistive state so that a voltage can be applied across the magnet terminals and the magnet can be charged or discharged. When the heater is shut off, this section of wire will cool and become superconducting again and the magnet will be in persistent mode. At this time, the power supply can be ramped to zero current and even removed from the system while the magnet holds its charge. The magnet will continue to hold its charge indefinitely unless the cryogen is allowed to boil off to the point where there is insufficient cooling to keep the magnet in its superconducting state.

4.14.1 Persistent Switch Heater Output Enable

The persistent switch heater should be enabled only if there is an active persistent switch in the magnet system. If no persistent switch is being used, then the persistent switch heater should be disabled. This will remove the persistent switch heater information from the bottom of the display as well as disable the persistent switch heater on and off buttons. If a persistent switch is being used, then the heater current and delay time should be setup before using the heater.

To configure the persistent switch heater press **PSH Setup**. The first persistent switch heater setup screen appears as a prompt for the persistent switch heater mode.

```
Persistent Switch Heater Output  
  
Select With ▲▼  
  
Persistent Switch Heater: Enable
```

Use the **▲** or **▼** key to select the persistent switch heater 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.

In order for the persistent switch heater to be disabled, the heater must be off. If the heater is on, warming, or cooling, then the persistent switch heater mode will not be allowed to change and an error box will pop up explaining why. One of two boxes will show up, both shown below.

```
Change not allowed while  
PSH is on.
```

```
Change not allowed while  
PSH is warming or cooling.
```

4.14.2 Persistent Switch Heater Current Setting

The next setting that is available for the persistent switch heater is the heater current. This is the current that will be supplied to the heater when the persistent switch heater is on. Typically, the persistent switch heater current is specified by the magnet manufacturer. Exceeding the recommended current will cause excess helium boil off and can possibly damage the heater.

To enter a value for the persistent switch heater current, continue from the persistent switch heater enable screen or press **PSH Setup** then **Enter** until the following persistent switch setup screen appears as a prompt for the persistent switch heater current.

```
Persistent Switch Heater Output  
  
Enter a Value For  
PS Heater Current: 125 mA
```

Use the data entry keys to enter the persistent switch heater current value between 5 and 125 mA. 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.

The persistent switch heater current can only be changed when the heater is off. If the current is changed while the heater is on or warming, the following error box will appear and the new setting will be ignored.

```
Change not allowed while  
PSH is on.
```

4.14.3 Persistent Switch Heater Delay

When a persistent switch heater is turned on or off, it is in an indeterminate state for a period of time while the switch is warming or cooling. The persistent switch heater delay should be set to a value that insures that the persistent switch has fully transitioned from one state to the other. This value is typically not given by the magnet manufacturer but can be estimated by observation. For most systems, a delay time of 10 to 20 seconds is usually sufficient. During this delay time, the Model 625 locks out any changes to the output (magnet) current to insure proper operation. The persistent switch heater delay time can be changed at any time but the new value will not be used until the persistent switch heater is turned on or off again.

To enter a value for the persistent switch heater delay time, continue from the persistent switch heater current screen or press **PSH Setup** then **Enter** until the following persistent switch setup screen appears as a prompt for the persistent switch heater delay time.

```
Persistent Switch Heater Output  
  
Enter a Value For  
PS Heater Delay: 10 s
```

Use the data entry keys to enter the persistent switch heater delay time between 5 and 100 seconds. 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.

4.14.4 Persistent Mode Ramp Rate

A magnet is said to be in persistent mode when the persistent switch heater is off and the magnet is shorted by the persistent switch in its superconducting state. While the magnet is in persistent mode, the output current can be ramped at a faster rate since it is not ramping against the inductance of the magnet. The Model 625 includes the persistent mode ramp rate feature that will automatically switch to the faster ramp rate when the magnet is in persistent mode. If the feature is enabled, the persistent mode ramp rate will be used when the magnet is in persistent mode. When the supply is using this ramp rate, the rate cannot be changed from the front panel using the **Ramp Rate** key since this is setup under the **PSH Setup** key. If the persistent mode ramp rate is disabled, then the ramp rate will remain the same if the magnet is in persistent mode or not but it can be changed at any time from the front panel using the **Ramp Rate** key.

To enable the persistent mode ramp rate, continue from the persistent switch delay screen or press **PSH Setup** then **Enter** until the following persistent switch setup screen appears as a prompt for the persistent mode ramp rate.

```
Persistent Switch Heater Output  
  
Select With ▲▼  
Persistent Mode Ramp Rate: Enabled
```

Use the **▲** or **▼** key to select the persistent mode ramp rate, either Enabled or Disabled. Press **Enter** to accept the new selection and continue to other persistent switch heater features. Press **Escape** to cancel the new selection and return to the normal display.

If the persistent mode ramp rate is enabled, then the ramp rate to be used while the magnet is in persistent mode needs to be entered. Even though this ramp rate is typically much faster than the magnet ramp rate, it should not be set too high as a fast change in current through the persistent switch can cause the switch to become normal and cause a quench. Note that the persistent mode ramp rate will not be limited to the maximum ramp rate. Refer to Paragraph 4.11.3 for information on the maximum ramp rate limit.

To enter a value for the persistent mode ramp rate, continue from the persistent mode ramp rate enable screen or press **PSH Setup** then **Enter** until the following setup screen appears as a prompt for the persistent mode ramp rate.

```
Persistent Switch Heater Output

Enter a Value For

Persistent Mode Ramp Rate: 5.0000 A/s
```

Use the data entry keys to enter the persistent mode ramp rate 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.

4.15 PSH ON/OFF

The persistent switch heater should be properly set up before attempting to turn it on. Refer to Paragraph 4.14 to setup the persistent switch heater. The PSH On and PSH Off buttons will not function unless the persistent switch heater is enabled. When the PSH is off, no current is sourced to the heater and the persistent switch will revert to its superconducting state. The magnet is said to be in “persistent mode” and any changes to the output current of the supply are not reflected in the magnet. When the PSH is on, the persistent switch is heated and becomes resistive. The magnet current can only be changed when the PSH is on.

To turn on the persistent switch heater, press the **PSH On** key. The PSH will begin warming and the PSH On LED will blink. The output current of the power supply cannot be changed while the PSH is in transition. Once the persistent switch has stabilized, as determined by the PSH delay time, the PSH will be on and the PSH On LED will be on solid. Refer to Paragraph 4.14.3 to setup the PSH delay time. Note that the PSH cannot be turned on or off while the output current is ramping or in compliance.

To turn off the persistent switch heater, press the **PSH Off** key. The PSH will begin cooling and the PSH On LED will blink. Once the persistent switch has stabilized, the PSH will be off and the PSH On LED will be off.

When turning on the PSH, it is important that the output current setting of the power supply is equal to the current in the magnet. If the currents are not equal when the PSH is turned on, there is a possibility that the magnet can quench. The Model 625 adds an extra layer of protection to keep this from happening. The Model 625 stores the output current setting of the supply when the PSH was turned off last. If the output current setting does not match this stored setting when the PSH is being turned on, the following message screen will appear.

```
Current output setting is not equal to the
setting when the PSH was shut off last.

Current Setpoint: +20.0000 A
Last Setpoint: + 0.0000 A

Turn on PSH anyway?: No
```

To override the lockout and turn on the PSH anyway, use the **▲** or **▼** key to select Yes and press **Enter**. This should only be done if the user is sure that the output current of the power supply matches the current in the magnet. To cancel this operation, use the **▲** or **▼** key to select No and press **Enter** or press **Escape** at any time.

NOTE: If the PSH is turned on when the output current setting does not equal the current in the magnet, the power supply will ramp the magnet to the output current setting at the compliance voltage limit. It is recommended that the compliance voltage limit be set to an appropriate value for the magnet before turning on the PSH.

4.16 QUENCH DETECTION

A magnet quenches when a part of the superconducting wire in the magnet becomes resistive. When a section of the magnet becomes resistive, it will begin to heat and cause more of the magnet to become resistive. This causes an unstoppable chain reaction that will result in the magnet dissipating all of its energy into heat. There are typically three ways in which a magnet can quench. One way is if the cryogen is allowed to boil off to the point in which the magnet is no longer covered. Another way is to ramp the current in the magnet at a rate that is greater than specified. The final way is to exceed the maximum current specified for the magnet.

Although a magnet quench is undesirable, it typically is non-destructive. Most magnets are designed to be able to handle dissipating the heat generated with the magnet at rated current. Exceeding the maximum current could cause damage to the magnet if it were to quench in this state since there is more energy in the system than it was designed for. If a magnet quench occurs, the level of the cryogen should be checked before operating the magnet system again since much of it may have boiled off.

Quench detection is important to alert the user and to protect the magnet system. When a quench is detected, the output current setting of the supply is immediately set to 0 A. If the power supply was still supplying current to the magnet system after a quench, it is possible that the protection diodes in the magnet would turn on and then the diodes would take the full current load, destroying themselves in the process. During a quench, the current in the magnet will quickly drop to zero. The 625 constantly monitors the output current and calculates an actual current ramp rate. If the current changes at a rate greater than the current step limit then a quench is detected. The current step limit should be set to a value greater than any expected ramp rate.

4.16.1 Quench Detection Enable

Quench detection can be enabled or disabled. If quench detection is disabled, another form of quench detection should be used to avoid damage to the magnet system.

To configure quench detection, press **Quench Detect**. The first quench detection setup screen appears as a prompt for the quench detection mode.

```
Quench Detection

Select With ▲▼

Quench Detection: Enable
```

Use the ▲ or ▼ key to select the quench detection mode, either Enable or Disable. 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.

4.16.2 Current Step Limit

In order for a quench to be detected, the output current must change at a rate greater than or equal to the current step limit setting. The current step limit should be set to a rate greater than what the magnet is capable of ramping at if it were operating correctly. The formula $V = L (di/dt)$ can be used to calculate the maximum ramp rate. For example, the Model 625 has a maximum compliance voltage of 5 V, so for a 10 H magnet, the maximum ramp rate that is possible is 5/10 or 0.5 A/s. The current step limit should be set slightly above the maximum theoretical ramp rate, typically above 0.2 A/s more. Therefore, a good setting for the current step limit for a 10 H magnet would be about 0.7 A/s.

To enter a value for the current step limit, continue from the quench detection mode screen or press **Quench Detect** then **Enter** until the following quench detection setup screen appears as a prompt for the current step limit value. Quench detection must be enabled to set the current step limit.

```
Quench Detection

Enter a Value For

Current Step Limit: 0.7000 A/s
```

Use the data entry keys to enter the current step limit value between 0.0100 and 10.000 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.

4.17 ERROR STATUS DISPLAY

Error messages appear on the lower part of the instrument display when it identifies a problem during operation. The Fault LED will also light to indicate error conditions, blinking for operational errors, on solid 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 lower part of 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. An example of how the magnet quench error is shown on the main display is given below.

```

Output I          Output V
+ 0.0126 A      +0.1346 V

Set: + 0.0000 A    U Limit: 5.0000 V
Rate: 0.1000 A/s   U Sense: +0.0085 V
*** Magnet Quench Detected ***
                                PSH On: 40 mA
  
```

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 the magnet quench error.

```

Magnet quench detected. Current output set
to 0. Normal operation will not be resumed
until the magnet is completely discharged.

Press Status to attempt to clear error.
  
```

4.18 EXTERNAL CURRENT PROGRAMMING

The output current of the Model 625 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 4.5 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 1 V = 10 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 that is set when using the External or Sum modes. A 40 Hz, 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. See Paragraph 2.2.2 for a description of the relationship between voltage and inductance.

To configure the external current program mode press **External Program**. The following setup screen appears as a prompt for the external current program mode.

```

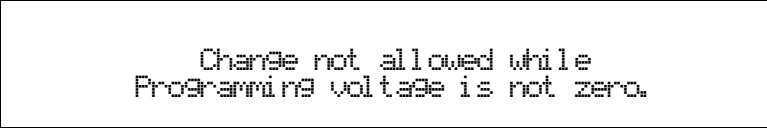
External Program Mode

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 going to be ignored. These error boxes are shown below.



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



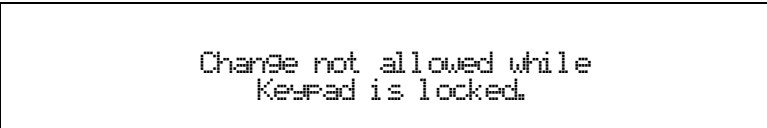
```
Change not allowed while  
Current output setting is not zero.
```

4.19 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 625 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, Voltage Limit, Zero Output, Stop Output, Pause Output, PSH On, and PSH Off. 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 set to default values, 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.

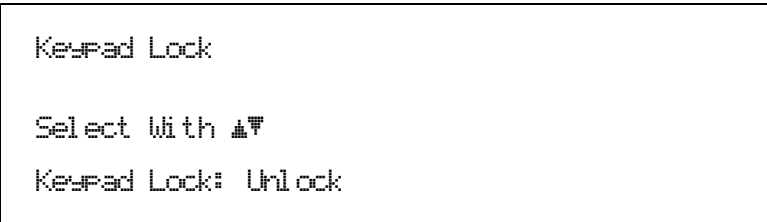
The following message box appears on the display if the user attempts to change a parameter while the keypad is locked.



```
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.

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.

4.20 INTERFACE

There are two computer interfaces included with the Model 625, a serial 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.

4.20.1 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.

4.20.2 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.

4.21 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 4-1.

```

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 4-1. Default Parameter Values

Output Settings Output Current* 0 A Current Ramp Rate 0.01 A/s Compliance Voltage Limit 1 V Maximum Settings Max Output Current 60 A Max Compliance Voltage Limit 2 V Max Ramp Rate 1 A/s Calculated Field Field Units Tesla Field Constant 0.1 T/A Quench Detection Quench Detection Enabled Current Step Limit 2 A/s External Program Mode External Program Mode Internal Ramp Segments Ramp Segments Disabled Ramp Segments Current 0 A Ramp Segments Rate 0.0001 A/s	Display Display Mode Current Voltage Sense Display On Brightness 25% Persistent Switch Persistent Switch Mode Disabled PSH Output* Off PSH Current 10 mA PSH Delay Time 5 s Persistent Mode Rate Disabled Persistent Mode Ramp Rate 0.1 A/s Keypad Locking State Unlocked Lock Code 123 Computer Interface Baud 9600 IEEE Address 12 IEEE Terminators CR/LF Mode* Local * Indicates value is also initialized on power up
---	--

CHAPTER 5

COMPUTER INTERFACE OPERATION

5.0 GENERAL

This chapter provides operational instructions for the computer interface for the Lake Shore Model 625 Superconducting Magnet Power Supply. Either of the two computer interfaces provided with the Model 625 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 625 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 625 performs the functions of TALKER and LISTENER but cannot be a BUS CONTROLLER. The BUS CONTROLLER is the digital computer which tells the Model 625 which functions to perform.

Below are Model 625 IEEE-488 interface capabilities:

- **SH1:** Source handshake capability.
- **RL1:** Complete remote/local capability.
- **DC1:** Full device clear capability.
- **DT1:** Complete 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 625 can drive 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 625 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 625 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 625 recognizes two of these messages from the BUS CONTROLLER: **Remote (REN)** and **Interface Clear (IFC)**. The Model 625 sends one Uniline Command: **Service Request (SRQ)**.

REN (Remote) – Puts the Model 625 into remote mode.

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

SRQ (Service Request) – Tells the bus controller that the Model 625 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 625 recognizes two Multiline commands:

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

DCL (Device Clear) – Clears Model 625 interface activity and puts it into a bus idle state.

Finally, Addressed Bus Control Commands are Multiline commands that must include the Model 625 listen address before the instrument responds. Only the addressed device responds to these commands. The Model 625 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.

GET (Group Execute Trigger) – The GET command is used to trigger a device to have its operation started either individually or as part of a group of devices.

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 625 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 625 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 625 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.

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 625 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.

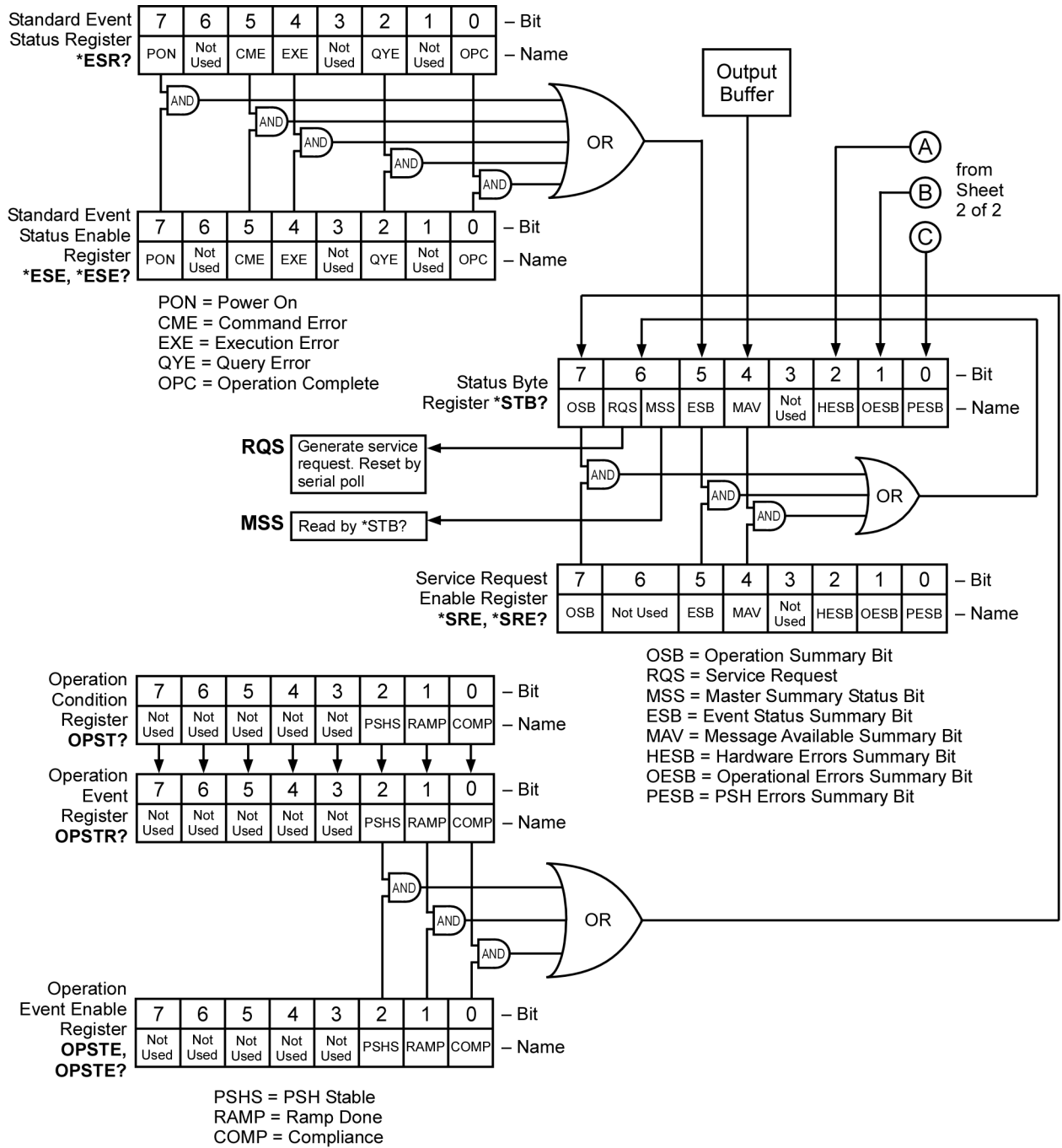


Figure 5-1. Model 625 Status System (Sheet 1 of 2)

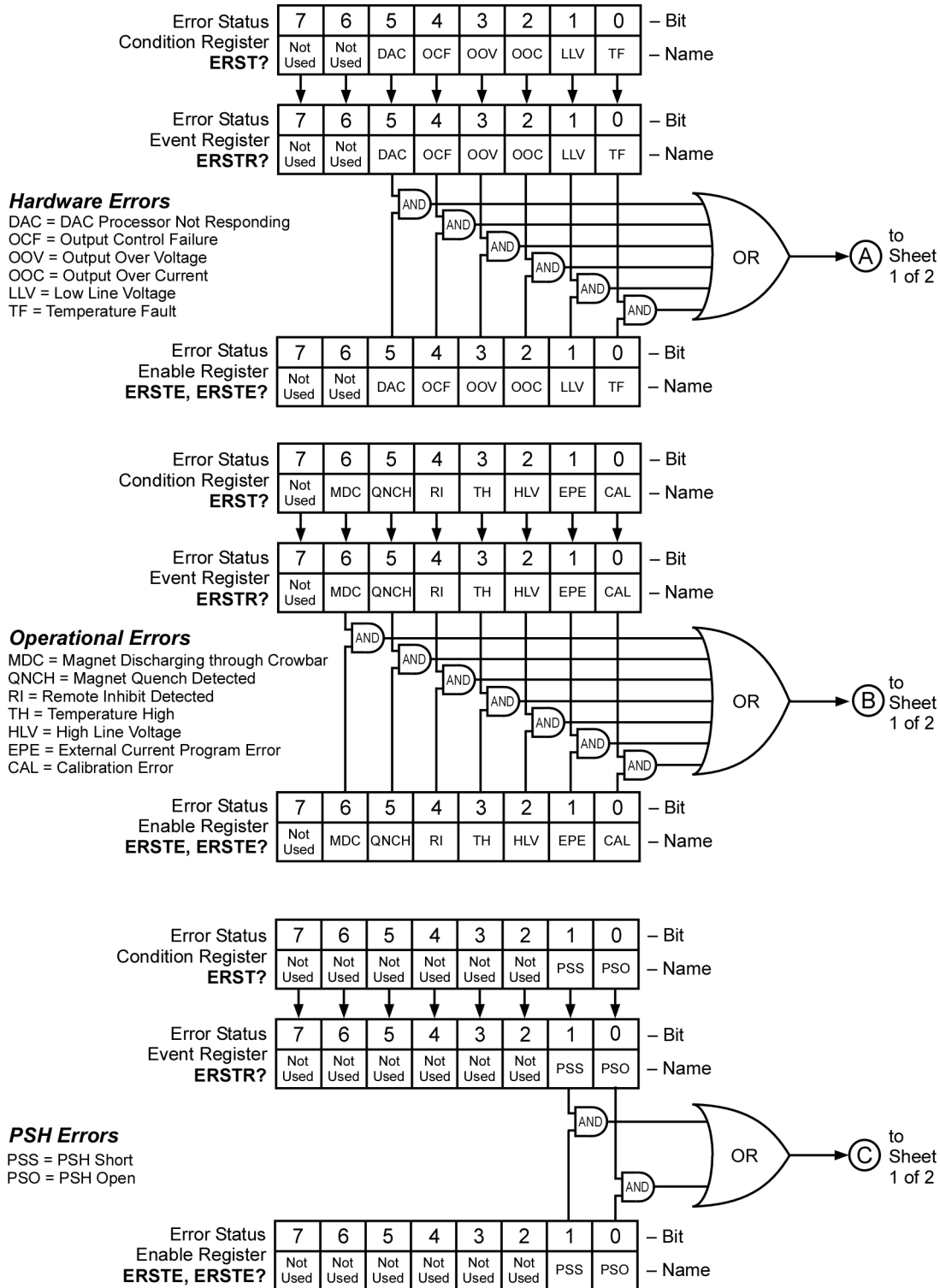


Figure 5-1. Model 625 Status System (Sheet 2 of 2)

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, see 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, see 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 below.

Table 5-2. Register Clear Methods

Register	Method	Example
Condition Registers	None – registers are not latched	—
Event Registers	Query the event register.	*ESR? (clears Standard Event Status register)
Standard Event Status Register Operation Event Register Error Status Event Register	Send *CLS	*CLS (clears both registers)
	Power on instrument	—
Enable Registers:	Write 0 to the enable register.	*ESE 0 (clears Standard Event Status Enable register)
Standard Event Status Enable Register Operation Event Enable Register Error Status Enable Register Service Request Enable Register	Power on instrument	—
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 625; 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.

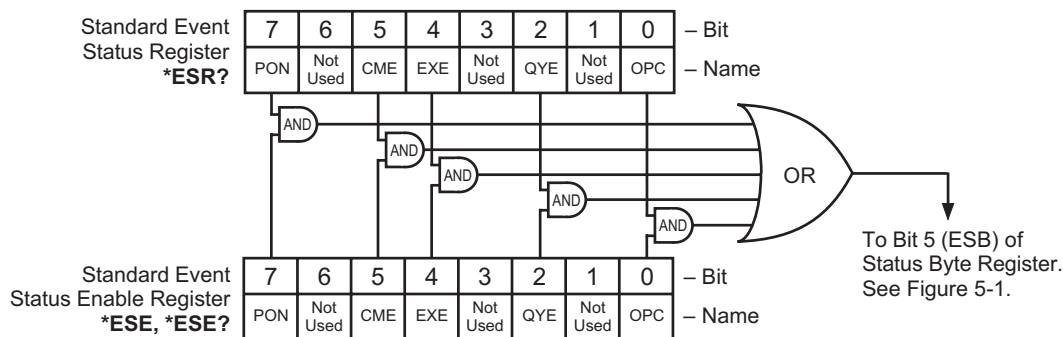


Figure 5-2. Standard Event Status Register

5.1.4.2.2 Operation Event Register Set

The Operation Event Register reports the following instrument events: PSH stable, ramp done, compliance. Any or all of these events may be reported in the operation event summary bit through the enable register, see Figure 5-4. 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:

PSH Stable, Bit (2) – This bit is set when the persistent switch is stable.

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.

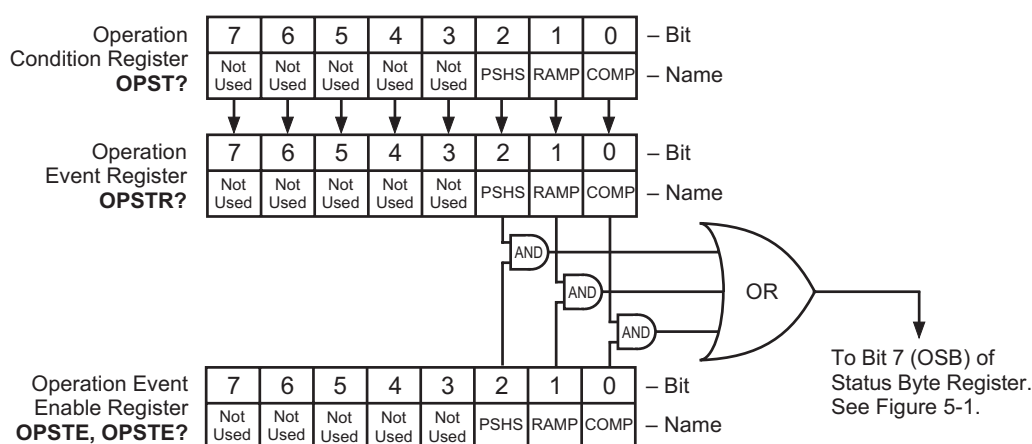


Figure 5-3. Operation Event Register

5.1.4.3 Error Status Register Sets

As shown in Figure 5-1, there are three register sets in the error status system of the Model 625; Hardware Error Status Register, Operational Error Status Register, and the Persistent Switch Error Register.

5.1.4.3.1 Hardware Error Status Register Set

The Hardware Error Status Register reports the following instrument hardware error events: DAC processor not responding, output control failure, output over voltage, output over current, low line voltage, temperature fault. Any or all of these events may be reported in the standard event summary bit through the enable register, see Figure 5-2. The Hardware Error Status Register is the first value of the three 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:

DAC Processor Not Responding (DAC), Bit (5) – This bit is set to indicate that communication to the DAC processor has failed.

Output Control Failure (OCF), Bit (4) – This bit is set if there is a failure on the output control board.

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.

Low Line Voltage (LLV), Bit (1) – This bit is set if the power line voltage drops below an acceptable amplitude.

Temperature Fault (TF), Bit (0) – This bit is set if the internal temperature of the instrument exceeded the maximum safe value of 80 °C.

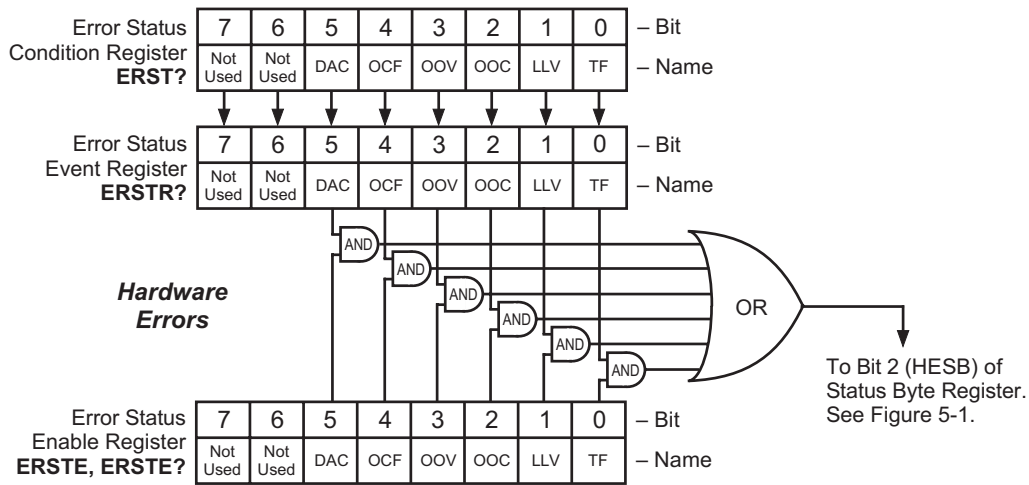


Figure 5-4. Hardware Error Status Register

5.1.4.3.2 Operational Error Status Register Set

The Operational Error Status Register reports the following instrument operational error events: magnet discharging through crowbar, magnet quench detected, remote inhibit detected, temperature high, high line voltage, 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 5-2. The Operational Error Status Register is the second value of the three 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:

Magnet Discharging Through Crowbar (MDC), Bit (6) – This bit is set to indicate that the magnet is currently discharging through the crowbar. This can happen due to a hardware error or a power loss.

Magnet Quench Detected (QNCH), Bit (5) – This bit is set to indicate that a magnet quench has been detected.

Remote Inhibit Detected (OCF), Bit (4) – This bit is set if the remote inhibit condition has been detected.

Temperature High (OOV), Bit (3) – This bit is set if the internal temperature of the instrument exceeded 75 °C. The current ramp will be stopped or the compliance voltage will be limited in an attempt to lower the internal temperature.

High Line Voltage (HLV), Bit (2) – 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.

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.

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

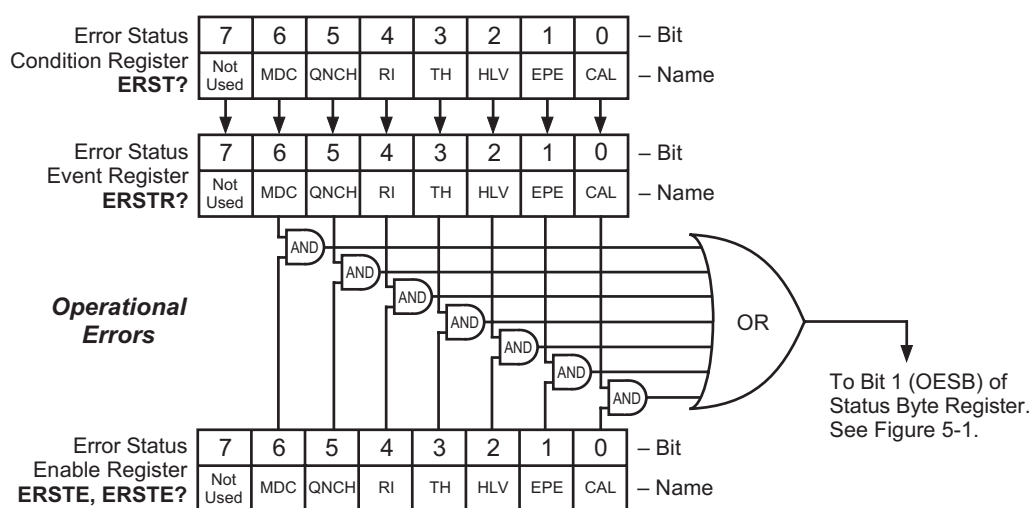


Figure 5-5. Operational Error Status Register

5.1.4.3.3 Persistent Switch Heater Error Status Register Set

The PSH Error Status Register reports the following PSH error events: PSH short, PSH open circuit. Any or all of these events may be reported in the standard event summary bit through the enable register, see Figure 5-2. The PSH Error Status Register is the third value of the three 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:

PSH Short (PSS), Bit (1) – This bit is set if the persistent switch heater circuitry has detected a short circuit condition. This can happen if the heater load falls below $10\ \Omega$.

PSH Open (PSO), Bit (0) – This bit is set if the persistent switch heater circuitry has detected an open circuit condition.

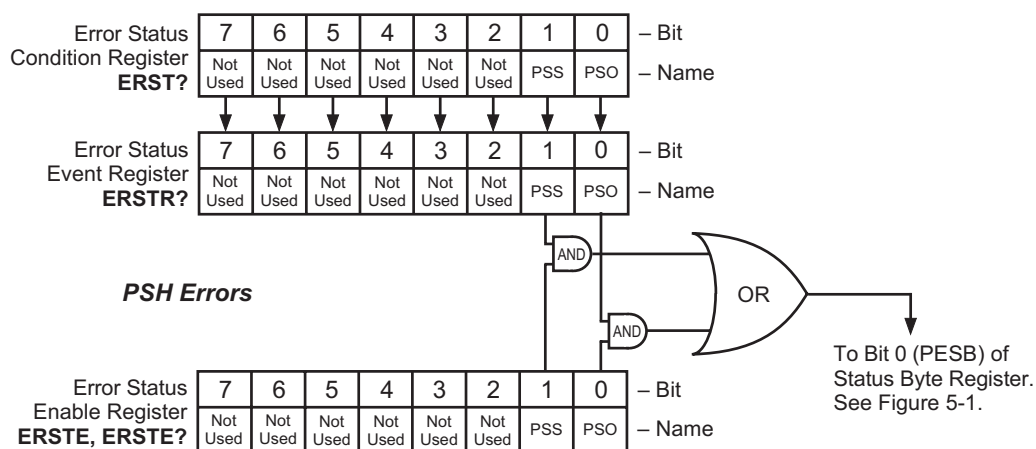


Figure 5-6. PSH Error Status Register

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.

PSH Errors Summary (PESB), Bit (0) – Set summary bit indicates that an enabled persistent switch heater error event has occurred.

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 5-5. 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.

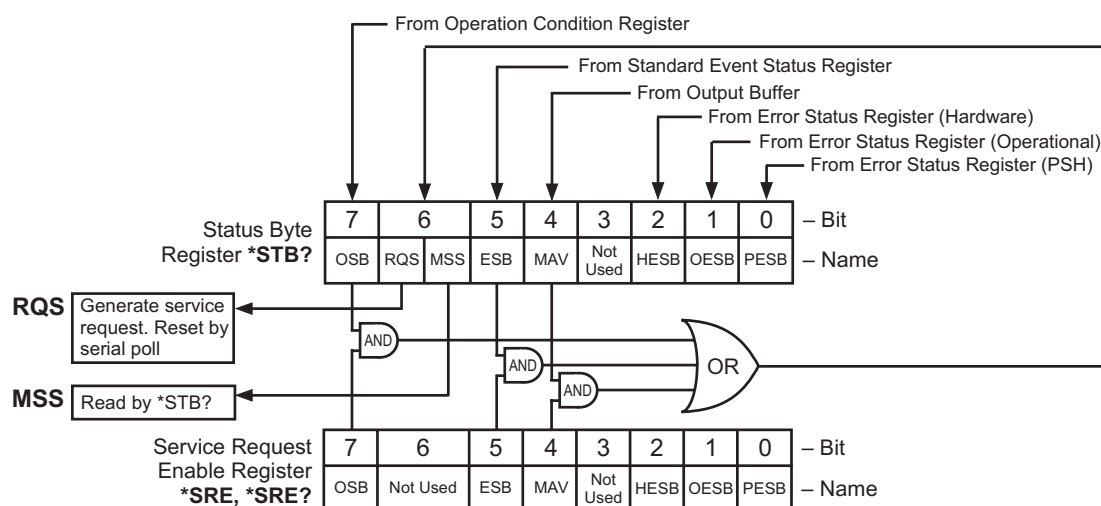


Figure 5-7. Status Byte Register and Service Request Enable Register

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

Command or Operation	Description
*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 the 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 625 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 Interface Example Programs

Two BASIC programs are included to illustrate the IEEE-488 communication functions of the instrument. The first program was written in Visual Basic. Refer to Paragraph 5.1.5.1 for instructions on how to setup the program. The Visual Basic code is provided in Table 5-2. The second program is written in Quick Basic. Refer to Paragraph 5.1.5.3 for instructions on how to setup the program. The Quick Basic code is provided in Table 5-3. Finally, a description of operation common to both programs is provided in Paragraph 5.1.5.5. 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.

5.1.5.1 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 98/95 Control Panel located under Settings on the Start Menu. Configure the GPIB Settings as shown in Figure 5-1. Configure the DEV12 Device Template as shown in Figure 5-2. Be sure to check the Readdress box.

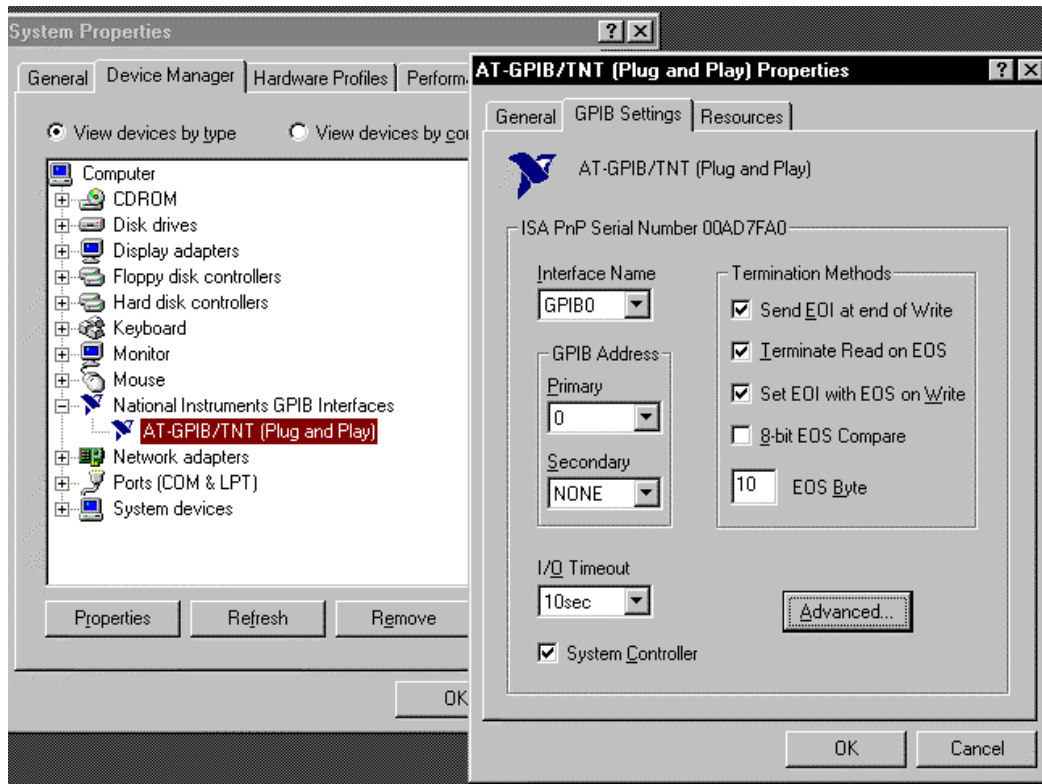


Figure 5-8. GPIB0 Setting Configuration

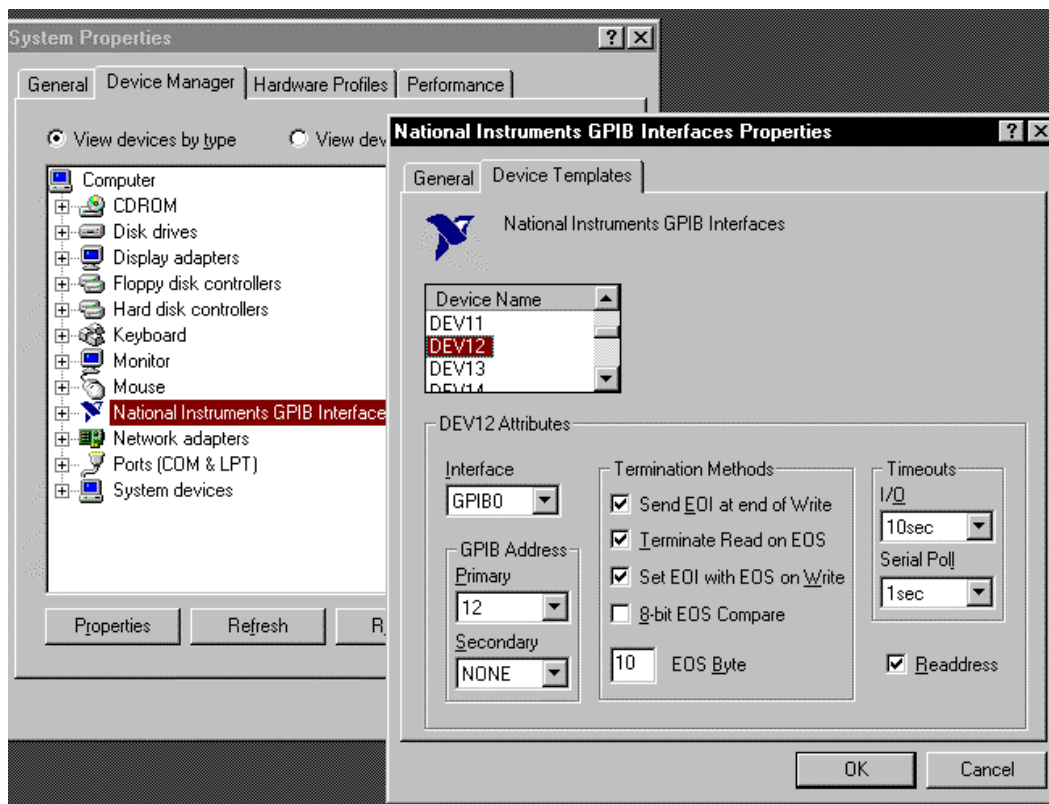
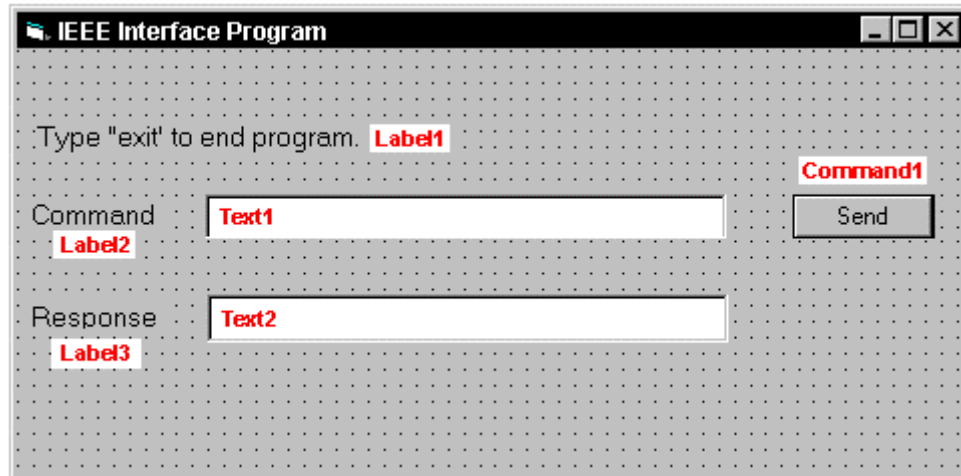


Figure 5-9. DEV 12 Device Template Configuration

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.

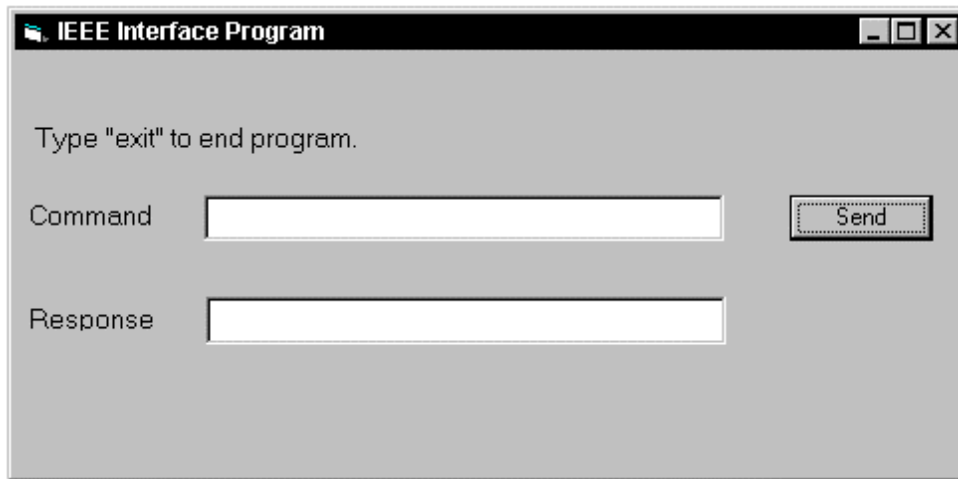


10. Set the properties of the controls as defined in Table 5-4.
11. Save the program.

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

Current Name	Property	New Value
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	frmIEEE IEEE 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

5.1.5.3 IEEE-488 Interface Board Installation for Quick Basic Program

This procedure works on an IBM PC (or compatible) running DOS or in a DOS window. This example uses the National Instruments GPIB-PCII/IIA card.

1. Install GPIB-PCII/IIA card using National Instruments instructions.
2. Install NI-488.2 software (for DOS). Version 2.1.1 was used for the example.
3. Verify that config.sys contains the command: device = \gpib-pc\gpib.com.
4. Reboot the computer.
5. Run IBTEST to test software configuration. Do not install the instrument before running IBTEST.
6. Run IBCONF to configure the GPIB – PCII/IIA board and dev 12. Set the EOS byte to 0AH and Enable Repeat Addressing to Yes. See Figure 5-11 – IBCONF modifies gpib.com.
7. Connect the instrument to the interface board and power up the instrument. Verify the address is 12 and terminators are CR LF.

5.1.5.4 Quick Basic Program

The IEEE-488 interface program in Table 5-6 works with QuickBasic 4.0/4.5 or Qbasic on an IBM PC (or compatible) running DOS or in a DOS window. It assumes your IEEE-488 (GPIB) card is installed and operating correctly (refer to Paragraph 5.1.5.3). Use the following procedure to develop the Serial Interface Program in Quick Basic.

1. Copy c:\gpib-pc\Qbasic\qbib.obj to the QuickBasic directory (QB4).
2. Change to the QuickBasic directory and type: link /q qbib.obj,,,bqlb4x.lib; where $x = 0$ for QB4.0 and 5 for QB4.5. This one-time only command produces the library file qbib.qlb. The procedure is found in the National Instruments QuickBasic readme file Readme.qb.
3. Start QuickBasic. Type: qb /l qbib.qlb. Start QuickBasic in this way each time the IEEE interface is used to link in the library file.
4. Create the IEEE example interface program in QuickBasic. Enter the program exactly as presented in Table 5-6. Name the file "ieeexam.bas" and save.
5. Run the program.
6. Type a command query as described in Paragraph 5.1.5.5.
7. Type "EXIT" to quit the program.

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 5-10. Typical National Instruments GPIB Configuration from IBCONF.EXE

Table 5-6. Quick Basic IEEE-488 Interface Program

```

'      IEEEEXAM.BAS      EXAMPLE PROGRAM FOR IEEE-488 INTERFACE
'
'      This program works with QuickBasic 4.0/4.5 on an IBM PC or compatible.
'
'      The example requires a properly configured National Instruments GPIB-PC2 card. The REM
'      $INCLUDE statement is necessary along with a correct path to the file QBDECL.BAS.
'      CONFIG.SYS must call GPIB.COM created by IBCONF.EXE prior to running Basic. There must
'      be QBIB.QBL library in the QuickBasic Directory and QuickBasic must start with a link
'      to it. All instrument settings are assumed to be defaults: Address 12, Terminators
'      <CR> <LF> and EOI active.
'
'      To use, type an instrument command or query at the prompt. The computer transmits to
'      the instrument and displays any response. If no query is sent, the instrument responds
'      to the last query received. Type "EXIT" to exit the program.
'
'      REM $INCLUDE: 'c:\gpib-pc\qbasic\qbdecl.bas'      'Link to IEEE calls
'      CLS                                              'Clear screen
'      PRINT "IEEE-488 COMMUNICATION PROGRAM"
'      PRINT
'
'      CALL IBFIND("dev12", DEV12%)                    'Open communication at address 12
'      TERM$ = CHR$(13) + CHR$(10)                     'Terminators are <CR><LF>
'
LOOP2:  IN$ = SPACE$(2000)                             'Clear for return string
'
'      LINE INPUT "ENTER COMMAND (or EXIT):"; CMD$     'Get command from keyboard
'      CMD$ = UCASE$(CMD$)                             'Change input to upper case
'      IF CMD$ = "EXIT" THEN END                       'Get out on Exit
'      CMD$ = CMD$ + TERM$
'
'      CALL IBWRT(DEV12%, CMD$)                        'Send command to instrument
'
'      CALL IBRD(DEV12%, IN$)                          'Get data back each time
'
'      ENDTEST = INSTR(IN$, CHR$(13))                  'Test for returned string
'      IF ENDTEST > 0 THEN                             'String is present if <CR> is seen
'          IN$ = MID$(IN$, 1, ENDTEST - 1)             'Strip off terminators
'          PRINT "RESPONSE:", IN$                     'Print return string
'      ELSE
'          PRINT "NO RESPONSE"                         'No string present if timeout
'      END IF
'      GOTO LOOP2                                     'Get next command

```

5.1.5.5 Program Operation

Once either 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,MODEL625,1234567,06122003[term]	
ENTER COMMAND? RDGR? 1	Ohm reading query. Instrument will return a string with the present resistance reading from channel 1.
RESPONSE: +273.150E+00[term]	
ENTER COMMAND? HTRRNG 0	Heater range command. Instrument will turn off the heater. No response will be sent.
ENTER COMMAND? HTRRNG?	Heater range query. Instrument will return a string with the present heater range setting.
RESPONSE: 0[term]	
ENTER COMMAND? HTRRNG 1;HTRRNG?	Heater range command followed by a query. Instrument will change to heater Low setting 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.

5.1.6 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 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

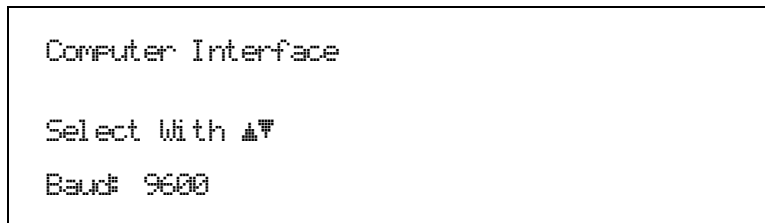
12. Check cable connections and length.
13. Increase delay between all commands to 50 ms to make sure instrument is not being over loaded.

5.2 SERIAL INTERFACE OVERVIEW

The serial interface used in the Model 625 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.



```
Computer Interface  
  
Select With ▲▼  
  
Baud: 9600
```

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 625 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 7.12.1 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 625.

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 7.12.1 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 625 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 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 5-7. 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.

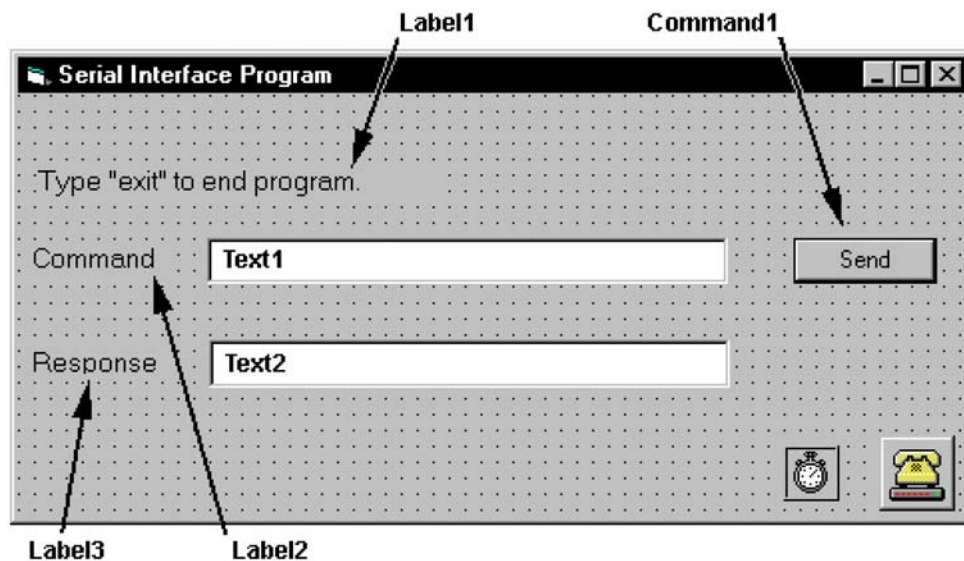
5.2.7 Serial Interface Example Programs

Two BASIC programs are included to illustrate the serial communication functions of the instrument. The first program was written in Visual Basic. Refer to Paragraph 5.2.7.1 for instructions on how to setup the program. The Visual Basic code is provided in Table 5-9. The second program was written in Quick Basic. Refer to Paragraph 5.2.7.2 for instructions on how to setup the program. The Quick Basic code is provided in Table 5-10. Finally, a description of operation common to both programs is provided in Paragraph 5.2.7.3. 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.

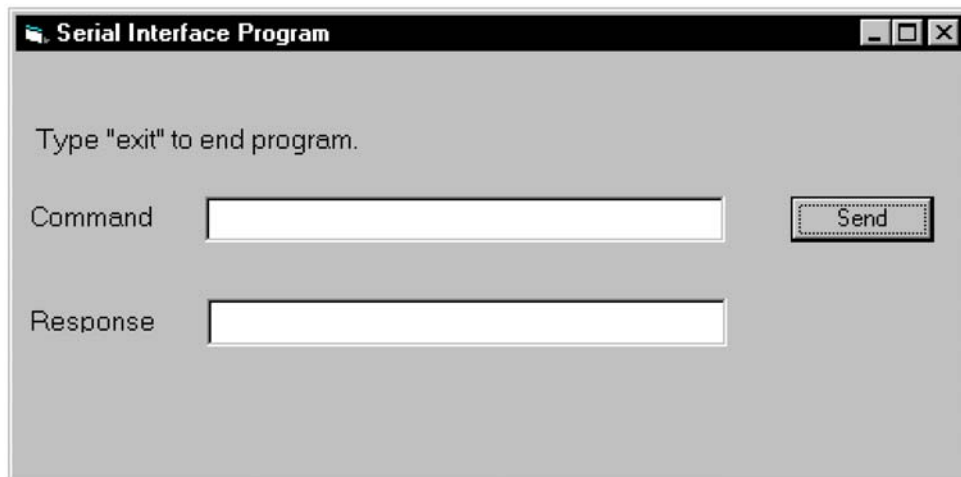


10. Set the properties of the controls as defined in Table 5-8.
11. Save the program.

Table 5-8. Serial Interface Program Control Properties

Current Name	Property	New Value
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 5-9).
 - 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 5-9.
 - 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 5-9.
 - d. Double Click on the Timer control. Add code segment under Private Sub Timer1_Timer() as shown in Table 5-9.
 - 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 5.2.7.3.
16. Press Enter or select the Send button with the mouse to send command.
17. Type Exit and press Enter to quit.

Table 5-9. 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) 'Strip terminators 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 Quick Basic Serial Interface Program Setup

The serial interface program listed in Table 5-10 works with QuickBasic 4.0/4.5 or Qbasic on an IBM PC (or compatible) running DOS or in a DOS window with a serial interface. It uses the COM1 communication port at 9600 Baud. Use the following procedure to develop the Serial Interface Program in Quick Basic.

1. Start the Basic program.
2. Enter the program exactly as presented in Table 5-10.
3. Adjust the Com port and Baud rate in the program as necessary.
4. Lengthen the "TIMEOUT" count if necessary.
5. Save the program.
6. Run the program.
7. Type a command query as described in Paragraph 5.2.7.3.
8. Type "EXIT" to quit the program.

Table 5-10. Quick Basic Serial Interface Program

CLS	'Clear screen
PRINT " SERIAL COMMUNICATION PROGRAM"	
PRINT	
TIMEOUT = 2000	'Read timeout (may need more)
BAUD\$ = "9600"	
TERM\$ = CHR\$(13) + CHR\$(10)	'Terminators are <CR><LF>
OPEN "COM1:" + BAUD\$ + ",O,7,1,RS" FOR RANDOM AS #1 LEN = 256	
LOOP1: LINE INPUT "ENTER COMMAND (or EXIT):"; CMD\$	'Get command from keyboard
CMD\$ = UCASE\$(CMD\$)	'Change input to upper case
IF CMD\$ = "EXIT" THEN CLOSE #1: END	'Get out on Exit
CMD\$ = CMD\$ + TERM\$	
PRINT #1, CMD\$;	'Send command to instrument
IF INSTR(CMD\$, "?") <> 0 THEN	'Test for query
RS\$ = ""	'If query, read response
N = 0	'Clr return string and count
WHILE (N < TIMEOUT) AND (INSTR(RS\$, TERM\$) = 0)	'Wait for response
IN\$ = INPUT\$(LOC(1), #1)	'Get one character at a time
IF IN\$ = "" THEN N = N + 1 ELSE N = 0	'Add 1 to timeout if no chr
RS\$ = RS\$ + IN\$	'Add next chr to string
WEND	'Get chrs until terminators
IF RS\$ <> "" THEN	'See if return string is empty
RS\$ = MID\$(RS\$, 1, (INSTR(RS\$, TERM\$) - 1))	'Strip off terminators
PRINT "RESPONSE: "; RS\$	'Print response to query
ELSE	
PRINT "NO RESPONSE"	'No response to query
END IF	
END IF	'Get next command
GOTO LOOP1	

5.2.7.3 Program Operation

Once either 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,MODEL625,1234567,06122003[term]	
ENTER COMMAND? RDGR? 1	Ohm reading query. Instrument will return a string with the present resistance reading from channel 1.
RESPONSE: +273.150E+00[term]	
ENTER COMMAND? HTRRNG 0	Heater range command. Instrument will turn off the heater. No response will be sent.
ENTER COMMAND? HTRRNG?	Heater range query. Instrument will return a string with the present heater range setting.
RESPONSE: 0[term]	
ENTER COMMAND? HTRRNG 1;HTRRNG?	Heater range command followed by a query. Instrument will change to heater Low setting 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 5-11. 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:	$\pm nn.nnnn$ <current> Specifies the output current setting: 0.0000 – $\pm 60.1000A$.
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:	$\pm nn.nnnn$ (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.
$\pm nnn.nnnE\pm nn$	Number represented in scientific notation format.
[term]	Terminator characters.
<...>	Indicated a parameter field, many are command specific.
<state>	Parameter field with only On/Off states.

NOTE: Any number being represented in scientific notation may also be entered as a string of number characters. If the number is only represented as a string of number characters, it cannot be entered in scientific notation. The following example shows two different ways of sending the same command. Refer to the individual command descriptions for further details.

SETF 2.0E+03[term]	Command will set the output field setting to 2000.
SETF 2000[term]	Command will set the output field setting to 2000.

Table 5-11. Command Summary

<u>Command</u>	<u>Function</u>	<u>Page</u>	<u>Command</u>	<u>Function</u>	<u>Page</u>
*CLS	Clear Interface Cmd.....	34	OPST	Operational Status Query.....	39
*ESE	Event Status Enable Cmd.....	34	OPSTE	Operational Status Enable Cmd.....	39
*ESE?	Event Status Enable Query.....	34	OPSTE?	Operational Status Enable Query.....	39
*ESR?	Event Status Register Query.....	34	OPSTR?	Operational Status Register Query.....	39
*IDN?	Identification Query.....	34	PSH	Persistent Switch Heater Cmd.....	40
*OPC	Operation Complete Cmd.....	35	PSH?	Persistent Switch Heater Query.....	40
*OPC?	Operation Complete Query.....	35	PSHIS?	Last Current Setting for PSH Query.....	40
*RST	Reset Instrument Cmd.....	35	PSHS	Persistent Switch Parameter Cmd.....	40
*SRE	Service Request Enable Cmd.....	35	PSHS?	Persistent Switch Parameter Query.....	40
*SRE?	Service Request Enable Query.....	35	QNCH	Quench Parameter Cmd.....	40
*STB?	Status Byte Query.....	35	QNCH?	Quench Parameter Query.....	41
*TRG	Trigger Event.....	35	RATE	Current Ramp Rate Setting Cmd.....	41
*TST?	Self-Test Query.....	36	RATE?	Current Ramp Rate Setting Query.....	41
*WAI	Wait-To-Continue Cmd.....	36	RATEP	Persistent Mode Ramp Rate Parameter Cmd.....	41
BAUD	RS-232 Baud Rate Cmd.....	36	RATEP?	Persistent Mode Ramp Rate Query.....	41
BAUD?	RS-232 Baud Rate Query.....	36	RDGF?	Field Output Reading Query.....	41
DFLT	Factory Defaults Cmd.....	36	RDGI?	Current Output Reading Query.....	42
DISP	Display Parameter Cmd.....	36	RDGRV?	Remote Voltage Sense Reading Query.....	42
DISP?	Display Parameter Query.....	36	RDGV?	Output Voltage Reading Query.....	42
ERCL	Error Clear Cmd.....	36	RSEG	Ramp Segments Enable Cmd.....	42
ERST?	Error Status Query.....	37	RSEG?	Ramp Segments Enable Query.....	42
ERSTE	Error Status Enable Cmd.....	37	RSEGS	Ramp Segments Parameters Cmd.....	42
ERSTE?	Error Status Enable Query.....	37	RSEGS?	Ramp Segments Parameters Query.....	42
ERSTR?	Error Status Register Query.....	37	SETF	Output Field Setting Cmd.....	43
FLDS	Magnetic Field Parameter Cmd.....	37	SETF?	Output Field Setting Query.....	43
FLDS?	Magnetic Field Parameter Query.....	37	SETI	Output Current Setting Cmd.....	43
IEEE	IEEE-488 Interface Parameter Cmd.....	38	SETI?	Output Current Setting Query.....	43
IEEE?	IEEE-488 Interface Parameter Query.....	38	SETV	Output Voltage Setting Cmd.....	43
KEYST?	Keypad Status Query.....	38	SETV?	Output Voltage Setting Query.....	43
LIMIT	Limit Output Settings Cmd.....	38	STOP	Stop Output Current Cmd.....	43
LIMIT?	Limit Output Settings Query.....	38	TRIG	Trigger Output Setting Cmd.....	44
LOCK	Keypad Lock Cmd.....	38	TRIG?	Trigger Output Setting Query.....	44
LOCK?	Keypad Lock Query.....	39	XPGM	External Program Mode Cmd.....	44
MODE	IEEE Interface Mode Cmd.....	39	XPGM?	External Program Mode Query.....	44
MODE?	IEEE Interface Mode Query.....	39			

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 <i>not</i> 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,aaaaaa,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,MODEL625,1234567,1.0/1.0

*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 <i>no</i> 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

*TRG	Trigger Event
Input:	*TRG[term]
Remarks:	Starts the trigger event. See TRIG command for trigger setup.

*TST?	Self-Test Query
Input:	*TST?[term]
Returned:	<status>[term]
Format:	n <status> 0 = No errors found, 1 = Errors found
Remarks:	The Model 625 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 625.

BAUD	RS-232 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-232 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 <mode>, <volt sense>, <brightness> [term]
Format:	n,n,n <mode> Specifies the display mode: 0 = Current, 1 = Field. <volt sense> Specifies if the remote voltage sense reading is displayed: 0 = Disabled, 1 = Enabled. <brightness> Specifies display brightness: 0 = 25%, 1 = 50%, 2 = 75%, 3 = 100%.

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

ERCL	Error Clear Command
Input:	ERCL [term]
Remarks:	This command will clear the operational and PSH 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>, <PSH errors> [term]**Format:** nnn,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 **ERRCL** command to clear the operational and PSH errors. Hardware errors cannot be cleared.

ERSTE Error Status Enable Command**Input:** **ERSTE <hardware errors>, <operational errors>, <PSH errors> [term]****Format:** nnn,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>, <PSH errors>[term]**Format:** nnn,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>, <PSH errors> [term]**Format:** nnn,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 and PSH errors. Hardware errors cannot be cleared.

FLDS Computed Magnetic Field Parameter Command**Input:** **FLDS <units>, <constant> [term]****Format:** n,+n.nnnn

<units> Specifies the units of the magnetic field constant: 0 = T/A, 1 = kG/A.

<constant> Specifies the magnetic field constant in either T/A or kG/A depending on units:
0.0010 – 1.0000 T/A or 0.0100 – 10.000 kG/A.**Remarks:** The computed magnetic field is calculated by multiplying the current output reading by the constant. The calculated field and the constant are in the units specified.

FLDS? Computed Magnetic Field Parameter Query**Input:** **FLDS? [term]****Returned:** <units>, <constant> [term]**Format:** n,+n.nnnn (Refer to command for description)

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)

KEYST?	Keypad Status Query
Input:	KEYST?[term]
Returned:	<keypad status>[term]
Format:	n 1 = key pressed, 0 = no key pressed.
Remarks:	Returns keypad status since the last KEYST?. KEYST? returns 1 after initial power-up.

LIMIT	Limit Output Settings Command
Input:	LIMIT <current>, <voltage>, <rate> [term]
Format:	+nn.nnnn, +n.nnnn, +n.nnnn <current> Specifies the maximum output current setting allowed: 0 – 60.1000 A. <voltage> Specifies the maximum compliance voltage setting allowed: 0.1000 – 5.0000 V. <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>, <voltage>, <rate> [term]
Format:	+nn.nnnn, +n.nnnn, +n.nnnn (Refer to command for description)

LOCK	Keyboard 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? Keyboard Lock Query**Input:** **LOCK?**[term]**Returned:** <state>, <code>[term]**Format:** n,nnn (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 625 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.

PSH?	Persistent Switch Heater Query
Input:	PSH? [term]
Returned:	<mode> [term]
Format:	n <mode> Specifies the current mode of the persistent switch heater: 0 = Heater off, 1 = Heater on, 2 = Heater warming, 3 = Heater cooling.

PSHIS?	Last Current Setting When PSH Was Turned Off Query	
Input:	PSHIS? [term]	
Returned:	<current> [term]	
Format:	±nn.nnnn	
	<current>	Specifies the output current of the power supply when the persistent switch heater was turned off last. The PSH will not be allowed to turn on unless this current is equal to the present output current or the heater is turned on using the PSH 99 command. If 99.9999 is returned, then the output current when the PSH was turned off last is unknown.

PSHS	Persistent Switch Heater Parameter Command
Input:	PSHS <enable>, <current>, <delay> [term]
Format:	n, +nnn, +nnn [term]
	<enable> Specifies if there is a persistent switch in the system: 0 = Disabled (no PSH), 1 = Enabled.
	<current> Specifies the current needed to turn on the persistent switch heater: 10 – 125 mA.
	<delay> Specifies the time needed to turn the persistent switch heater on or off: 5 – 100 s.
Remarks:	If there is no persistent switch heater in the system, then the switch should be disabled. This command does not turn on the current to the persistent switch. That command is PSH .

PSHS?	Persistent Switch Heater Parameter Query
Input:	PSHS? [term]
Returned:	<enable>, <current>, <delay> [term]
Format:	n, +nnn, +nnn (Refer to command for description)

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QNCH?	Quench Parameter Query
Input:	QNCH? [term]
Returned:	<enable>, <rate> [term]
Format:	n, +n.nnnn (Refer to command for description)

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)

RATEP	Persistent Mode Ramp Rate Parameter Command
Input:	RATEP <enable>, <rate> [term]
Format:	n, +n.nnnn [term] <enable> Specifies if the persistent mode ramp rate is to be used when the magnet is in persistent mode (PSH heater off): 0 = Never use persistent mode ramp rate, 1 = Use persistent mode ramp rate when in persistent mode. <rate> Specifies the ramp rate to use while in persistent mode: 0.0001 – 99.999 A/s.
Remarks:	Typically the current can be ramped faster when the magnet is in persistent mode since the current change is not seen by the inductance of the magnet. This setting will automatically change the ramp rate when the magnet goes into or out of persistent mode.

RATEP?	Persistent Mode Ramp Rate Parameter Query
Input:	RATEP? [term]
Returned:	<enable>, <rate> [term]
Format:	n, +n.nnnn (Refer to command for description)

RDGF?	Field Output Reading Query
Input:	RDGF? [term]
Returned:	<field> [term]
Format:	±nn.nnnnE±nn <field> Calculated output field reading. Field is calculated by multiplying the field constant by the measured current output. Use the FLDS command to set the field constant and field constant units (G or T).

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

RDGRV?	Remote Voltage Sense Reading Query
Input:	RDGRV? [term]
Returned:	<voltage> [term]
Format:	$\pm n.nnnn$ <voltage> Actual voltage measured at the remote voltage sense leads.

RDGV?	Output Voltage Reading Query
Input:	RDGV? [term]
Returned:	<voltage> [term]
Format:	$\pm n.nnnn$ <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 – +60.1000A. <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)

SETF	Output Field Setting Command
Input:	SETF <field> [term]
Format:	$\pm nnn.nnnE\pm nn$ <field> Specifies the output field setting: 0.0000 – $\pm 601.000E+03$ G or 0.0000 – $\pm 60.1000E+00$ T.
Remarks:	Sets the field value that the output will ramp to at the present ramp rate. The setting entered will be based on the field constant and the field units. Refer to the FLDS command.

SETF?	Output Field Setting Query
Input:	SETF? [term]
Returned:	<field> [term]
Format:	$\pm nnn.nnnE\pm nn$ (Refer to command for description)

SETI	Output Current Setting Command
Input:	SETI <current> [term]
Format:	$\pm nn.nnnn$ <current> Specifies the output current setting: 0.0000 – $\pm 60.1000A$.
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:	$\pm nn.nnnn$ (Refer to command for description)

SETV	Output Compliance Voltage Setting Command
Input:	SETV <voltage> [term]
Format:	$+n.nnnn$ <voltage> Specifies the output compliance voltage setting: 0.1000 – 5.0000 V.
Remarks:	Sets the output compliance voltage. This value will be used in both the positive and negative directions. Setting value is limited by LIMIT.

SETV?	Output Compliance Voltage Setting Query
Input:	SETV? [term]
Returned:	<voltage> [term]
Format:	$+n.nnnn$ (Refer to command for description)

STOP	Stop Output Current 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 or the SETF command to set a new output field setpoint.

TRIG Trigger Output Current Setting Command

Input: **TRIG** <I value> [term]

Format: ±nn.nnnn
 <I value> Sets the value in which the output current will ramp to when the instrument is triggered: 0.0000 – ±60.1000A.

Remarks: This command only sets up the trigger. Use the ***TRG** command or the GET (group execute trigger) function to start a trigger over the interface.

TRIG? Trigger Output Current Setting Query

Input: **TRIG?** [term]

Returned: <I value> [term]

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

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 625 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)

CHAPTER 6

OPTIONS AND ACCESSORIES

6.0 GENERAL

This chapter provides information on power line configurations and accessories available for the Model 625 MPS.

6.1 MODELS

The list of Model 625 part numbers is provided as follows.

Part Number	Description
625	Superconducting Magnet Power Supply.
625-DUAL	Two Model 625s and one 6263 dual supply interconnect cable kit.

Line Power Configurations. The instrument is configured at the factory for customer-selected line power as follows. Other country line cords are available, consult Lake Shore.

VAC-100-B	Instrument configured for 100 VAC with U.S. power cord.
VAC-120-B	Instrument configured for 120 VAC with U.S. power cord.
VAC-120-BC	Instrument configured for 120 VAC with U.S. power cord and universal European power cord and fuses for 220/240 setting. (Extra charge for this option.)
VAC-220-C	Instrument configured for 220 VAC with universal European power cord.
VAC-240-C	Instrument configured for 240 VAC with universal European power cord.

6.2 ACCESSORIES INCLUDED

Part Number	Description
6271	Model 625 Superconducting MPS User's Manual.
6241	Two front handles.
6242	Two rear handles/protectors.
6243	Output shorting bar and terminal fasteners.
6251	25-pin D-sub mating connector, digital I/O.
6252	15-pin D-sub mating connector, analog I/O.
—	Calibration Certificate.

6.3 ACCESSORIES AVAILABLE

Part Number	Description
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.
6263	Dual supply interconnect cable kit, including magnet cables and safety interlock cable.
CAL-625-CERT	Instrument recalibration with certificate.
CAL-625-DATA	Instrument recalibration with certificate and data.

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CHAPTER 7

SERVICE

This chapter provides basic service information for the Model 625 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 625 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 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 FUSE DRAWER

The Model 625 may be configured for two basic AC power configurations: 100 or 120 VAC and 220 or 240 VAC. Each configuration requires the appropriate fuses and fuse holder installed. Units produced for use with 100 or 120 VAC have two 0.25×1.25 inch time-delay fuses and the appropriate fuse holder installed. Units produced for use with 220 or 240 VAC have two 5×20 mm time-delay fuses and the appropriate fuse holder installed. To change the AC power configuration from the factory setting, use the fuses and fuse holder in the connector kit shipped with the instrument. The Model 625 requires two good fuses of the same rating to operate safely. Refer to Paragraph 7.5 for details.

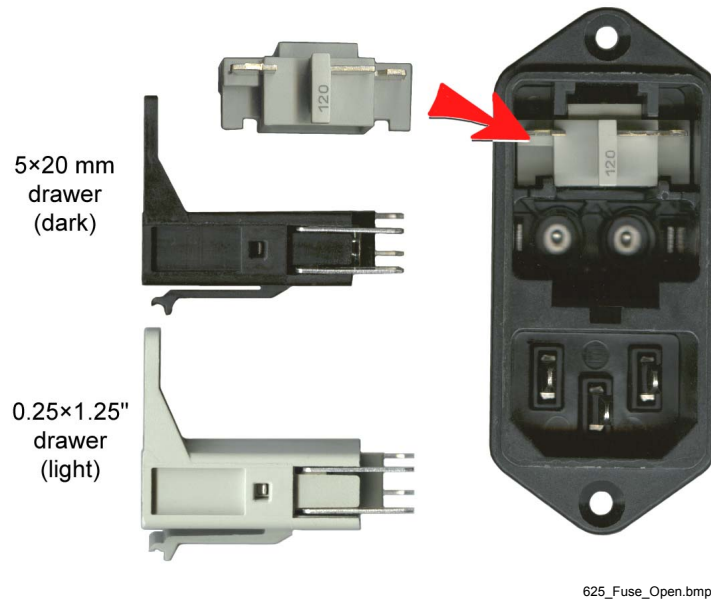


Figure 7-1. Fuse Drawer

7.4 LINE VOLTAGE SELECTION

Use the following procedure to change the instrument line voltage selector. Verify the fuse value and drawer whenever the line voltage is changed.

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

1. Identify the line input assembly on the instrument rear panel. See Figure 7-2.
2. Turn the front panel line power switch OFF (O).
3. Remove the instrument power cord.
4. With a small screwdriver, release the drawer holding the line voltage selector and fuses.
5. Slide out the removable line voltage selector from the drawer.
6. Rotate the line voltage selector until the proper voltage indicator shows through the window.
7. Verify the proper fuse value and fuse drawer.
8. Re-assemble the line input assembly in the reverse order.
9. Verify the voltage indicator in the window of the line input assembly.
10. Connect the instrument power cord.
11. Turn the front panel line power switch On (I).

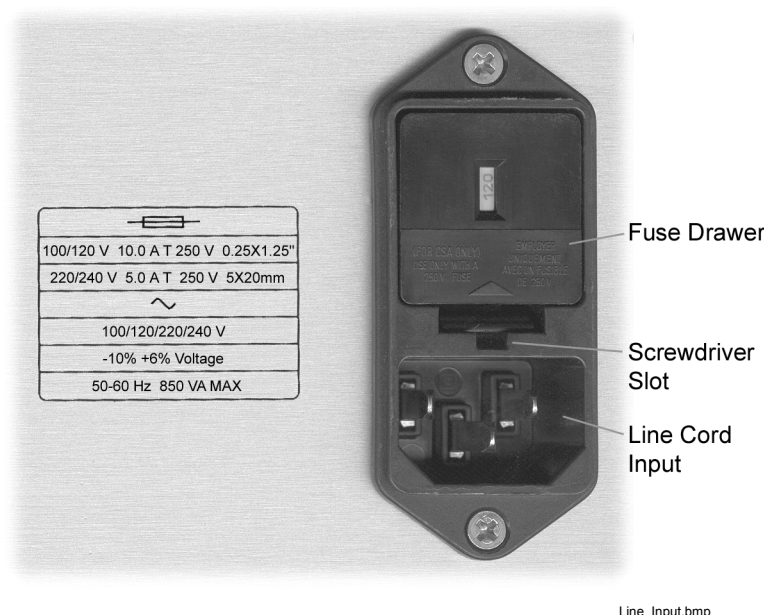


Figure 7-2. Power Fuse Access

7.5 FUSE REPLACEMENT

Use the following procedure to remove and replace the line fuses.

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

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

NOTE: Test fuse with an ohmmeter. Do not rely on visual inspection of fuse.

1. Locate line input assembly on the instrument rear panel. See Figure 7-2.
2. Turn front panel power switch Off (O).
3. Remove instrument power cord.
4. With a small screwdriver, release the drawer holding the line voltage selector and fuses.
5. Remove and discard both existing fuses. Replace with proper Slow-Blow (time-delay) fuse ratings as follows:

100/120 V 10.0 A T 250 V 0.25×1.25"
220/240 V 5.0 A T 250 V 5×20 mm

6. Re-assemble line input assembly in reverse order.
7. Verify voltage indicator in the line input assembly window.
8. Connect instrument power cord.
9. Turn front panel power switch On (I).

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 cleared, it can be done by pressing the **Status** key while in the error status display. Refer to Paragraph 4.17 for a description of the error status display.

The error messages are divided into two groups. Instrument hardware errors are related to the instruments internal circuits. When one of these errors occurs, the output crowbar SCR will be thrown, the Fault LED will be lit and there will be no way to clear the error unless power is cycled. If one of these error messages persist after power is cycled, the instrument requires repair. Instrument hardware errors are listed in Table 7-1. 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 7-2.

Table 7-1. Instrument Hardware Errors

DAC Processor not Responding	The processor that controls the output DAC is not responding or is responding incorrectly. The output crowbar SCR has been thrown to prevent damage to the magnet or the supply.
Output Control Failure	One of the internally monitored voltages is beyond an acceptable range on power up. The output crowbar SCR has been thrown to prevent damage to the magnet or the supply.
Output Voltage > Compliance Setting	The output voltage is greater than the compliance voltage setting indicating a problem with the compliance voltage circuitry. The output crowbar SCR has been thrown to prevent damage to the magnet or the supply.
Output Over Current	The output current exceeded 62 amps. The output crowbar SCR has been thrown to prevent damage to the magnet or the supply.
Low Line Voltage Detected	The input line voltage is detected to be too low. The instrument may not be able to attain the compliance voltage setting. The output crowbar SCR has been thrown to maintain control of the magnet.
Internal Temperature Fault	The internal temperature of the supply has exceeded 80 °C. The output crowbar SCR has been thrown to prevent damage to the supply.

Table 7-2. Operational Errors

Magnet Discharging Through Crowbar	The magnet is currently discharging through the output crowbar SCR. This error can be cleared when the magnet is completely discharged.
Magnet Quench Detected	A magnet quench has been detected because the output current changed at a rate greater than the current step limit. This error can be cleared when the magnet is completely discharged.
Remote Inhibit Detected	An external remote inhibit condition was triggered. The output current is set to zero. This error can be cleared when the remote inhibit trigger is released.
Internal Temperature High	The internal temperature of the supply has exceeded 75 °C. If the output current is increasing, the output current ramp will stop. If the output current is decreasing, the compliance voltage will be limited to 1 V. This error can be cleared when the internal temperature drops below 70 °C.
High Line Voltage Detected	The input line voltage is detected to be too high. This error can be cleared when the input line voltage is within specified tolerances.
External Current Program Error	The instrument was not allowed to change to external or sum current programming modes because the programming voltage is 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 the calibration data has been corrupted. The error can be cleared at any time and the instrument can still be used but there is no guarantee that it is operating within specifications. The instrument needs to be recalibrated to correct this error condition.
PSH Short Detected	The persistent switch heater circuitry has detected a short and the heater has been shut off. This error can be cleared at any time and will be checked again when the heater is turned back on.
PSH Open Circuit Detected	The persistent switch heater circuitry has detected an open circuit and the heater has been shut off. This error can be cleared at any time and will be checked again when the heater is turned back on.

7.7 OUTPUT SOURCE IMPEDANCE

The current output of the Model 625 has a 25 Ω source impedance, resulting from a 25 Ω resistor across the output terminals. This is necessary to keep the output of the power supply stable into the purely inductive load of a superconducting magnet. This is common practice in many superconducting magnet power supplies. This typically results in negligible error when driving a superconducting load. The displayed output current is compensated for the current loss through the resistor and reflects the actual current in the magnet.

This impedance can cause unexpected results in systems that have larger than normal lead resistance or other resistive impedance. If there is a voltage across the output terminals of the supply, then a small amount of current will flow through the stabilizing resistor given by the equation $I = V/25$, where I is the current through the resistor and V is the voltage across the output terminals. This will reduce the amount of current flowing through the magnet. The output current reading is compensated for the current flowing through the resistor and is representative of the current in the magnet. If it is necessary to have the current in the magnet exactly equal a certain value, the output current setting can be increased until the output current reading is equal to the desired amount.

In some circumstances it may be desirable to disable the reading compensation. In this case, the output current reading will closely match the output current setting, but the reading may not be indicative of the current in the magnet since the current in the resistor is not accounted for. To disable the reading compensation of the source impedance, send CALCOMP 1 over the computer interface. To turn on the reading compensation, the default setting, send CALCOMP 0 over the interface. To make the change nonvolatile, send the CALSAVE command after setting the compensation or else the previous setting will be used at the next power up.

There are some magnet systems in which the 25 Ω output resistor is not necessary for stable operation. Many of the magnets that have a persistent switch have enough resistance for the power supply to operate properly. In this case, the resistor can be removed and the reading compensation shut off in software. Please contact Lake Shore for further information on removing this resistor.

CAUTION: If the 25 Ω output resistor is removed and the power supply is operated on a magnet without enough resistance, the power supply can go into oscillation possibly quenching and damaging the magnet. Please contact Lake Shore before attempting this procedure.

7.8 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.

7.8.1 Identification of Electrostatic Discharge Sensitive Components

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



7.8.2 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 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.

7.9 ENCLOSURE BOTTOM REMOVAL AND REPLACEMENT

WARNING: To avoid potentially lethal shocks, discharge the magnet, turn off the power supply, and disconnect it from AC power line before performing this procedure. Only qualified personnel should perform this procedure.

REMOVAL

1. Set power switch to Off (O) and disconnect power cord from rear of unit.
2. Turn power supply over to gain access to the bottom panel.
3. Use 5/64 hex key to remove the screw that attaches the bottom panel to the front panel.
4. Use a Phillips head screwdriver to remove the 7 screws that hold the bottom panel on including the 4 screws that are used to attach the feet.
5. Carefully remove the bottom panel from the unit.

INSTALLATION

1. Carefully place the bottom panel on the unit.
2. Use 5/64 hex key to install the screw that attaches the bottom panel to the front panel.
3. Attach the 4 feet to the bottom of the unit.
4. Use a Phillips screwdriver to tighten the 7 screws attaching the bottom panel to unit including the 4 screws that are used to attach the feet.
6. Connect power cord to rear of unit and set power switch to On (I).

7.10 FIRMWARE REPLACEMENT

There are two integrated circuits (IC) that may potentially require replacement. See Figure 7-3 for the IC location.

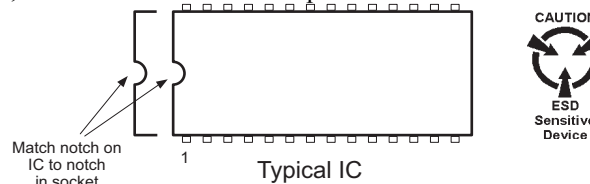
- Main Firmware Erasable Programmable Read Only Memory (EPROM) (U22) – Contains the user interface software. Has a sticker on top labeled “M625F.HEX” and a date.
- DAC Microcontroller (U43) – Contains software that controls the output DAC's. Has a sticker on top labeled “M625DACF.HEX” and a date.

Use the following procedure to replace either of these ICs.

1. Follow the top of enclosure *REMOVAL* procedure in Paragraph 7.9.
2. Locate the IC on the main circuit board. See Figure 7-3. 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.

3. Use IC puller to remove existing IC from the socket.
4. Noting orientation of new IC, use an IC insertion tool to place new device into socket.



Eprom.eps

5. Follow the top of enclosure *INSTALLATION* procedure in Paragraph 7.9.

7.11 PSH OUTPUT COMPLIANCE VOLTAGE CONFIGURATION

The persistent switch heater output maximum compliance voltage is configurable for 15 V or 24 V operation. This is configured by changing an internal jumper. The default setting is for 24 V operation. The actual voltage compliance limit is dependant on load but guaranteed to be at least 12 V or 21 V depending on the setting. Use the following procedures to change the PSH output maximum compliance voltage:

1. Follow the top of enclosure *REMOVAL* procedure in Paragraph 7.9.
2. Locate the jumper (JMP 2) on the main circuit board. See Figure 7-3.
3. Place the jumper on the correct compliance voltage setting. The settings are printed on the circuit board.
4. Follow the top of enclosure *INSTALLATION* procedure in Paragraph 7.9.

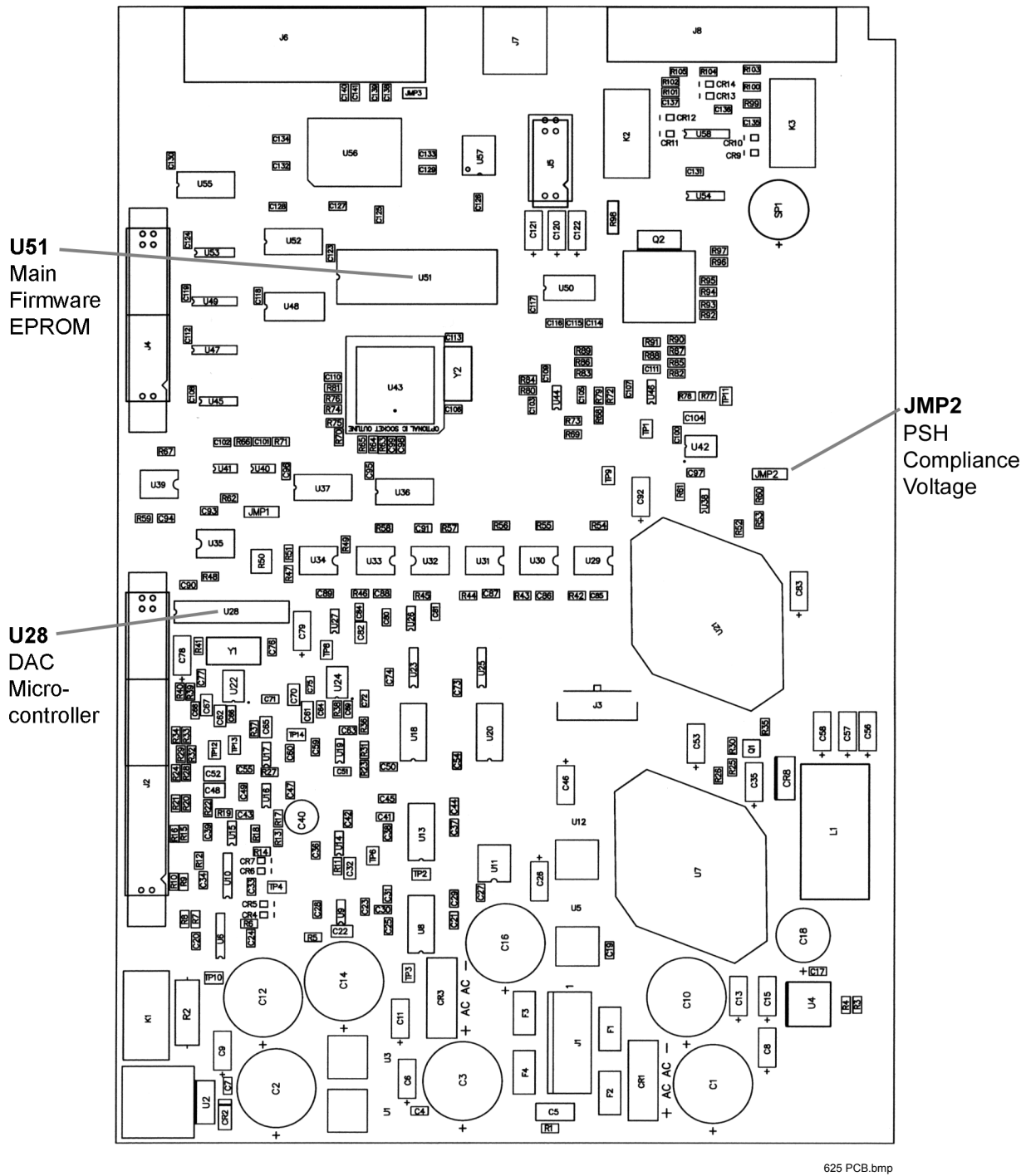
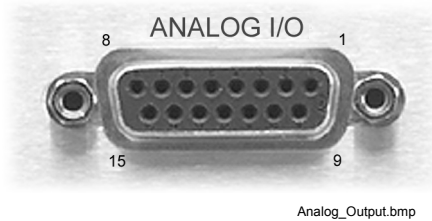


Figure 7-3. Location Of Important Internal Components

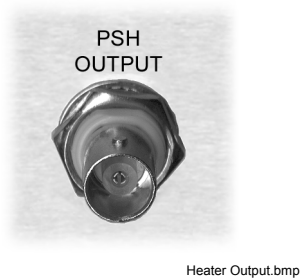
7.12 CONNECTOR AND CABLE DEFINITIONS

The ANALOG I/O, PSH OUTPUT, DIGITAL I/O, and RS-232 (DTE), and IEEE-488 INTERFACE connectors are defined in Figures 7-4 thru 7-8.



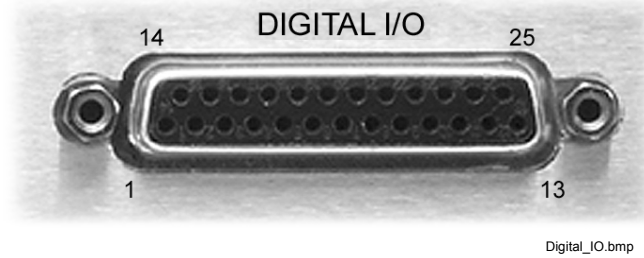
Pin	Name	Pin	Name
1	Voltage Sense –	9	Voltage Sense +
2	NC	10	NC
3	Current Program –	11	Current Program +
4	NC	12	NC
5	Voltage Monitor –	13	Voltage Monitor +
6	NC	14	NC
7	Current Monitor –	15	Current Monitor +
8	NC		

Figure 7-4. ANALOG I/O Connector Details



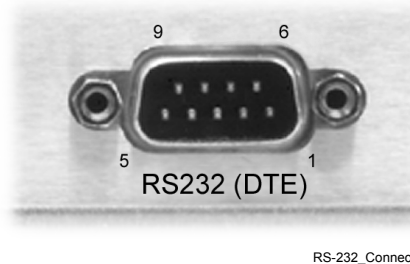
Pin	Description
Center	Signal
Shell	Ground

Figure 7-5. PSH OUTPUT Connector Details



Pin	Name	Pin	Name
1	Fault Out Common	14	Fault Out
2	NC	15	NC
3	Remote Inhibit Common	16	Remote Inhibit
4	NC	17	NC
5	Trigger Out Common (not used)	18	Trigger Out (not used)
6	NC	19	NC
7	Trigger In Common	20	Trigger In
8	NC	21	NC
9	NC	22	NC
10	NC	23	NC
11	NC	24	NC
12	NC	25	NC
13	NC		

Figure 7-6. DIGITAL I/O Connector Details

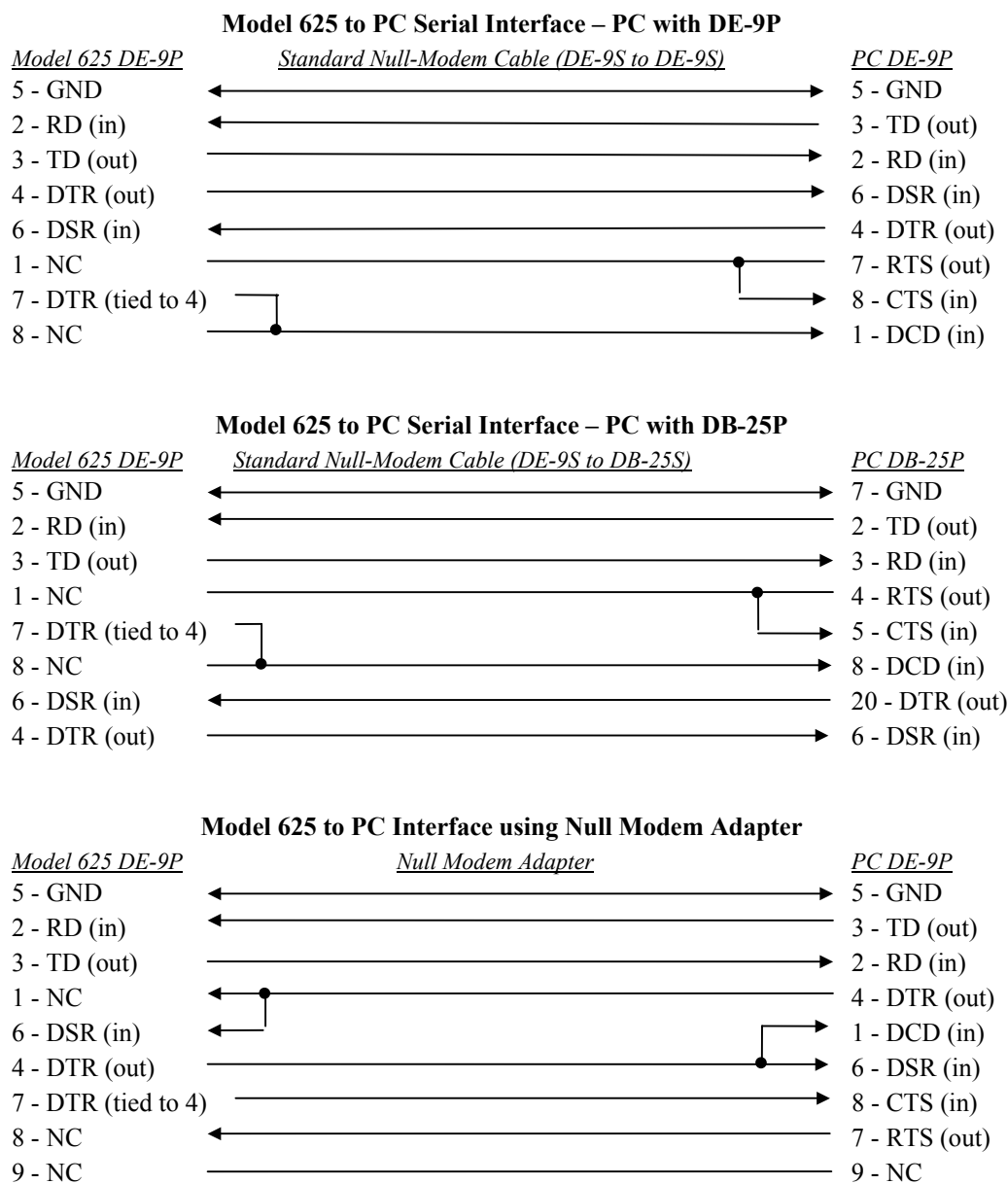


Model 625 Superconducting MPS		Typical Computers			
DE-9P (DTE)		DB-25P (DTE)		DE-9P (DTE)	
Pin	Description	Pin	Description	Pin	Description
1	No Connection	2	TD (out)	1	DCD (in)
2	Receive Data (RD in)	3	RD (in)	2	RD (in)
3	Transmit Data (TD out)	4	RTS (out)	3	TD (out)
4	Data Terminal Ready (DTR out)	5	CTS (in)	4	DTR (out)
5	Ground (GND)	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	No Connection	20	DTR (out)	8	CTS (in)
9	No Connection	22	Ring in (in)	9	Ring in (in)

Figure 7-7. RS232 (DTE) Connector Details

7.12.1 Serial Interface Cable Wiring

The following are suggested cable wiring diagrams for connecting the Model 625 Serial Interface to various Customer Personal Computers (PCs).

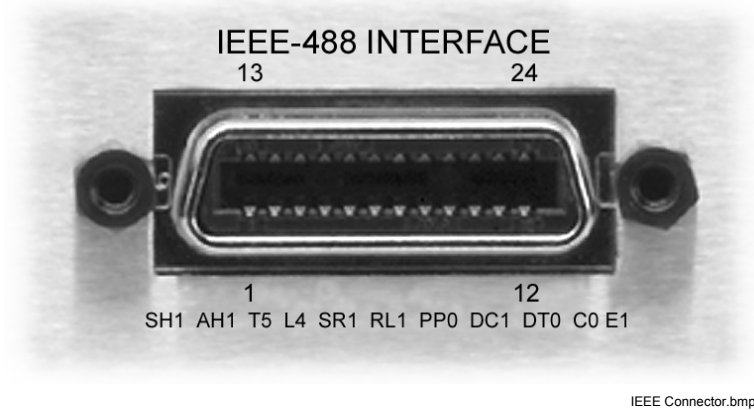


NOTE: Same as null modem cable design except PC CTS is provided from the Model 625 on DTR.

7.12.2 IEEE-488 Interface Connector

Connect to the IEEE-488 Interface connector on the Model 625 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 625 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 7-8 shows the IEEE-488 Interface connector pin location and signal names as viewed from the Model 625 rear panel.



PIN	SYMBOL	DESCRIPTION
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 7-8. IEEE-488 Rear Panel Connector Details

7.13 CALIBRATION

Lake Shore maintains a fully automated calibration fixture for the Model 625 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 625 to Lake Shore to perform the recalibration. In some instances, however, it may be necessary to recalibrate the Model 625 in the field. Calibration information for the following operating parameters is provided:

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

These calibrations are done through the computer interface and the calibration constants are stored in the non-volatile memory in the instrument. There are no trim-pots inside the Model 625 and the cover does not have to be removed to calibrate the instrument. The remaining features of the Model 625 do not require calibration to operate within their specified tolerances.

7.13.1 Calibration Interface

Computer interface commands are included in the Model 625 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: "Instrument Uncalibrated". 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 5.2.7.1 and 5.2.7.2. Some time should be spent becoming familiar with the calibration commands before beginning a calibration. Although the calibration factors are sent to the Model 625 over the computer interface, this procedure is written to obtain the Model 625 readings solely by visual observation of the front panel.

7.13.2 Calibration Equipment

1. **Shunt Resistor.** The output current of the Model 625 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 m Ω , the actual current flowing is calculated by Equation 1.

$$I_{shunt} = \frac{V_{shunt}}{0.99661^{-3}} \quad \text{Equation 1}$$

This resistor must withstand the full current of the Model 625 and do so with a minimum of heating that can easily change the resistance and therefore the current measurement. At 60 A, this resistor only dissipates 3.6 W. Even so, it is highly recommended to mount the resistor on a heat sink with forced air-cooling to minimize temperature rise. (Alpha PSBWR0010F is suggested)

2. **Load Resistor.** This resistor is placed in series with the 1 m Ω resistor to create a compliance voltage to calibrate the voltage reading of the Model 625. This resistor value should be in a range from 0.075 Ω to 5 Ω . The actual value of this resistor is not critical since only a voltage measurement is made to calibrate a voltage reading on the Model 625. To determine the amount of power the resistor will be required to handle, reference the formula in Section 7.13.3.8 step 4. This specifies the amount of current through the resistor. Note the output voltage is compliance limited to 5 V. For example, a 0.075 Ω resistor will develop 270 W and a 5 Ω resistor will develop 5 W.
3. **PSH Resistor.** This is simply a 1 W, 100 Ω resistor used to develop a voltage from the PSH output current to drive the Analog Current Programming Input for its gain calibration. During the procedure, this resistor will dissipate only 0.25 W.
4. **DC Voltmeter (DVM).** The voltmeter must measure VDC accurately to 10's of μ V if resolution to 10's of mA (from the Model 625) is to be assured. The HP34401 or better is suggested.

7.13.3 Calibration Procedure

The following calibration steps should be performed exactly in the order provided.

7.13.3.1 Calibrate Current Output Zero

The 1 m Ω shunt resistor is wired directly across the Model 625 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.

1. Send "CALZ 10, 0" to set the output offset constant to 0.
2. Set the Model 625 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 625 output current to 0 A (loads the new offset setting).
7. Verify the actual output current to be less than ± 1 mA.
8. Send "CALSAVE" to write this calibration to non-volatile memory.

7.13.3.2 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 625 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 625 output current reading to match the actual output current within ± 0.0005 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 625 output terminals.

1. Send "CALZ 5, 0" to set the current reading offset constant to 0.
2. Get the Model 625 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 625 output voltage reading to be $0 \pm 0.0001 \text{ V}$.
6. Send "CALSAVE" to write this calibration to non-volatile memory.

7.13.3.4 Calibrate Remote Voltage Sense Reading Zero

1. Short the remote voltage sense lines (pins 1 and 9 of the analog I/O connector).
2. Send "CALZ 6, 0". To set the remote voltage reading offset constant to 0.
3. Get the Model 625 remote voltage sense reading (by front panel or interface).
4. Calculate zero offset constant: $-(\text{remote voltage sense reading})$.
5. Send "CALZ 6, zero offset constant".
6. Verify the Model 625 remote voltage reading to be $0 \pm 0.0001 \text{ V}$.
7. Send "CALSAVE" to write this calibration to non-volatile memory.

7.13.3.5 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 625 external programming voltage reading.

NOTE: To get this reading from the Model 625, 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, "REMOTE I", 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 625 external programming voltage reading to be $0 \pm 0.0001 \text{ V}$.
7. Send "CALSAVE" to write this calibration to non-volatile memory.

7.13.3.6 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 55 A set point for calibration is chosen because the maximum trim range at 60 A forces the current past the 61 A internal analog limit and therefore creates significant error. Yet another source of lesser error is the 25Ω parallel damping resistor that is part of the output circuitry of the Model 625. While at a 0 volt output, this resistance contributes no error but when there is voltage created by the current, this error becomes significant. Even though small, wiring resistance may allow the voltage across the output terminals of the Model 625 to reach 0.5 V or so at 55 A depending upon length. This reduces the measured shunt current by $0.5 \text{ V} / 25 \Omega$ or 0.020 A and therefore, must be considered during the calibration. The shunt resistor remains connected to the output terminals for this procedure.

Calibrate Output Current Gain (Continued)

1. Send "CALG 10, 0". To set the output current gain trim constant to 0.
2. Set the Model 625 output current to +55 A (ramp rate 20 A/s nominal).
3. Wait 30 seconds for settling.
4. Measure the Model 625 actual output voltage at the output terminals and record (V_{measured}).
5. Measure the actual voltage across the shunt and record (V_{shunt}).
6. Calculate and record (I_{max}): $V_{\text{shunt}}/R_{\text{shunt}}$.
7. Send "CALG 10, -100". To set the output current gain trim constant to maximum.
8. Wait 10 seconds.
9. Measure the actual voltage across the shunt and record (V_{shunt}).
10. Calculate and record ($I_{\text{maxpostrim}}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
11. Send "CALG 10, +100". To set the output current gain trim constant to minimum.
12. Wait 10 seconds.
13. Measure the actual voltage across the shunt and record (V_{shunt}).
14. Calculate and record ($I_{\text{minpostrim}}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
15. Set the Model 625 to -55A V (ramp rate 20 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}): $V_{\text{shunt}}/R_{\text{shunt}}$.
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 ($I_{\text{maxnegtrim}}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
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 ($I_{\text{minnegtrim}}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
27. Send "CALG 10, 0". To return the output current gain trim constant to 0.
28. Set the Model 625 output current to 0 A.
29. Calculate the gain constant per Equation 2.

$$\text{Gain Constant} = \frac{\left((I_{\text{max}} - I_{\text{min}}) - \left(110 - \left(\frac{2 \times V_{\text{measured}}}{25} \right) \right) \right)}{(I_{\text{maxpostrim}} - I_{\text{minpostrim}}) - (I_{\text{maxnegtrim}} - I_{\text{minnegtrim}})} \times 200 \quad \text{Equation 2}$$

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. It also measures the output terminal voltage and subtracts the calculated current through the internal 25 Ω damping resistor from the total ideal span.

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).

Calibrate Output Current Gain (Continued)

NOTE: The Model 625 has an internal, 25 Ω resistor in parallel with the output terminals.

The “ $V_{\text{measured}}/25$ ” factor accounts for the current that is diverted from the external shunt that flows through the internal resistor. See Section 7.7 for further details.

33. Set the Model 625 output current to 55 A (ramp rate 20 A/s nominal).
34. Wait 30 seconds.
35. Measure the actual voltage across the shunt and record (V_{shunt}).
36. Calculate and record ($I_{\text{out}+}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
37. Calculate and record (I_{verify}): $55 - (V_{\text{measured}}/25)$ **NOTE:** V_{measured} is from Step 4 of this section.
38. Verify $I_{\text{out}+} = I_{\text{verify}} \pm 0.008$ A (0.015%).
39. Set the Model 625 output current to –55 A (ramp rate 20 A/s nominal).
40. Wait 30 seconds.
41. Calculate and record ($I_{\text{out}-}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
42. Verify $I_{\text{out}-} = -I_{\text{verify}} \pm 0.008$ A (0.015%).
43. Set the Model 625 output current to 0 A.
44. Send “CALSAVE” to write this calibration to non-volatile memory.

7.13.3.7 Calibrate Current Reading Gain

1. Send “CALCOMP 0” (this is a math computation that takes into account the current that flows through the 25 Ω damping resistor that is across the output of the Model 625. “CALCOMP 0” turns the compensation ON so that the reading reflects only the current going through the load by subtracting the current going through the resistor).
2. Send “CALG 0, 1”. To set the output current reading gain constant to 1.
3. Set the Model 625 output current to –60 A. (Ramp rate 20 A/s nominal).
4. Wait 30 seconds.
5. Measure the actual voltage across the shunt and record (V_{shunt}).
6. Calculate and record ($I_{\text{measuredneg}}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
7. Get the Model 625 output current reading (by front panel or interface) and record ($I_{\text{readingneg}}$).
8. Set the Model 625 output current to +60 A (Ramp rate 20 A/s nominal).
9. Wait 30 seconds.
10. Measure the actual voltage across the shunt and record (V_{shunt}).
11. Calculate and record ($I_{\text{measuredpos}}$): $V_{\text{shunt}}/R_{\text{shunt}}$.
12. Get the Model 625 output current reading (by front panel or interface) and record ($I_{\text{readingpos}}$).
13. Calculate gain constant per Equation 3.

$$\text{Current Reading Gain Constant} = \frac{(I_{\text{measuredpos}} - I_{\text{measuredneg}})}{(I_{\text{readingpos}} - I_{\text{readingneg}})} \quad \text{Equation 3}$$

14. Verify gain factor to be 1, ± 0.02 .
15. Send “CALG 0, gain constant”.
16. Verify the Model 625 output current reading to equal $I_{\text{measuredpos}}$, ± 0.008 A.
17. Set the Model 625 output current to 0 A.
18. Send “CALSAVE” to write this calibration to non-volatile memory.

Again, this method is somewhat lengthy, but takes into account the contribution of the damping resistor to the current reading with resistance in the high current cabling even when cable resistance is low. It also averages the differences between positive (+) and negative (–) excursions.

7.13.3.8 Calibrate Voltage Reading Gain

1. Add the larger load resistor in series with the shunt resistor.
2. Set the Model 625 output compliance limit to 5 V.
3. Send "CALG 5, 1". To set the output voltage reading gain constant to 1.
4. Set the Model 625 output current to $I = -(0.18 + (4.5/R \text{ load}))$.
(For example, if $R \text{ load} = 1 \Omega$, set the Model 625 output current to -4.68 A).
5. Wait 30 seconds.
6. Measure the Model 625 actual output voltage at the output terminals and record ($V_{\text{measuredneg}}$).
This voltage must be between 4.0 and 5.0 volts, (4.5 V nominal).
7. Get the Model 625 output voltage reading (by front panel or interface) and record ($V_{\text{readingneg}}$).
8. Set the Model 625 output current to $I = 0.18 + 4.5/R \text{ load}$.
(For example, if $R \text{ load} = 1 \Omega$, set the Model 625 output current to 4.68 A).
9. Wait 30 seconds.
10. Measure the Model 625 actual output voltage at the output terminals and record ($V_{\text{measuredpos}}$).
This voltage must be between 4.0 and 5.0 volts, (4.5 V nominal).
11. Get the Model 625 output voltage reading (by front panel or interface) and record ($V_{\text{readingpos}}$).
12. Calculate gain constant per Equation 4.

$$\text{Voltage Reading Gain Constant} = \frac{(V_{\text{measuredpos}} - V_{\text{measuredneg}})}{(V_{\text{readingpos}} - V_{\text{readingneg}})} \quad \text{Equation 4}$$

13. Verify the gain factor to be $1, \pm 0.02$.
14. Send "CALG 5, gain constant".
15. Verify the Model 625 output voltage reading to match the actual output voltage within, $\pm 0.0005 \text{ V}$.
16. Set the Model 625 output current to 0 A .
17. Send "CALSAVE" to write this calibration to non-volatile memory.

7.13.3.9 Calibrate Remote Voltage Sense Reading Gain

1. Connect the PSH output in parallel with the DVM, a 100Ω resistor (as a load) and the remote voltage sense lines.
2. Send "CALG 6, 1". To set the remote voltage sense reading gain constant to 1.
3. Set the PSH switch heater to 50 mA and turn on the PSH output to provide a 5.0 V DC level to be measured by the remote voltage sense lines.
4. Measure the PSH output voltage and record (V_{measured}).
5. Verify $V_{\text{measured}} = 5.0 \pm 0.1 \text{ V}$.
6. Get the Model 625 output voltage reading (by front panel or interface) and record (V_{reading}).
7. Calculate the gain constant per Equation 5.

$$\text{Voltage Sense Gain Constant} = \frac{V_{\text{measured}}}{V_{\text{reading}}} \quad \text{Equation 5}$$

8. Verify the gain constant to be 1 ± 0.02 .
9. Send "CALG 6, gain constant".
10. Verify the Model 625 remote voltage sense reading to match the measured PSH output voltage within, $\pm 0.0005 \text{ V}$.
11. Send "CALSAVE" to write this calibration to non-volatile memory.
12. Turn off the PSH output.

7.13.3.10 Calibrate External Current Programming Voltage Reading Gain

1. Connect the PSH output in parallel with the DVM, a 100 Ω resistor, (as a load) and the external current programming input lines.
2. Send "CALG 7, 1". To set the external programming voltage reading gain constant to 1.
3. Set the PSH switch heater to 50 mA and turn on the PSH output to provide a 5.0 VDC level to be measured by the external current programming input lines.
4. Measure the PSH output voltage and record (V_{measured}).
5. Verify $V_{\text{measured}} = 5.0 \pm 0.1$ V.
6. Get the Model 625 external programming voltage reading and record (V_{reading}).

NOTE: To get this reading from the Model 625, 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, "REMOTE I", is the reading needed for this step.

7. Calculate the gain constant per Equation 6.

$$\text{Programming Voltage Gain Constant} = \frac{V_{\text{measured}}}{V_{\text{reading}}} \quad \text{Equation 6}$$

8. Verify the gain constant to be 1, ± 0.02 .
9. Send "CALG 7, constant".
10. Verify the Model 625 external programming voltage reading to match the measured PSH output voltage within, ± 0.0005 V.
11. Send "CALSAVE" to write this calibration to non-volatile memory.
12. Turn off the PSH output.

7.13.4 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, \pm nnnnnnnn

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

- 0 = Output Current Reading
- 1 = Bias A Reading *
- 2 = Bias B Reading *
- 3 = CM Voltage Reading *
- 4 = Out Control Reading *
- 5 = Output Voltage Reading
- 6 = Remote Voltage Reading
- 7 = External Programming Voltage
- 8 = Temperature *
- 9 = Raw Supply Voltage *
- 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).

Calibration-Specific Interface Commands (Continued)

CALG? Gain Calibration Constant Query
Input: **CALG?** <type>[term]
Format: nn
 <type> 1 – 10.
Returned: <value>[term]
Format: ±nnnnnnnn (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, ±nnnnnnnn
 <type> Specifies the item to calibrate. Valid entries are:
 0 = Output Current Reading
 1 = Bias A Reading *
 2 = Bias B Reading *
 3 = CM Voltage Reading *
 4 = Out Control Reading *
 5 = Output Voltage Reading
 6 = Remote Voltage Reading
 7 = External Programming Voltage
 8 = Temperature *
 9 = Raw Supply Voltage *
 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> 1 – 10.
Returned: <value>[term]
Format: ±nnnnnnnn (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 Exchange (ACSII). 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																
b ₇	b ₆	b ₅	b ₄	b ₃	b ₂	b ₁	Col	0	0	0	0	1	1	1	1	1
b ₄	b ₃	b ₂	b ₁	Row				0	1	2	3	4	5	6	7	
0	0	0	0	0				NUL	DLE	SP	'	P	@	p		
0	0	0	0	1				SOH	DC1	!	1	A	Q	a	q	
0	0	0	1	0				STX	DC2	"	2	B	R	b	r	
0	0	1	0	1				ETX	DC3	#	3	C	S	c	s	
0	1	0	0	0				EOT	DC4	\$	4	D	T	d	t	
0	1	0	1	0				ENG	NAK	%	5	E	U	e	u	
0	1	1	0	0				ACK	SYN	&	6	F	V	f	v	
0	1	1	1	0				BEL	ETB	,	7	G	W	g	w	
1	0	0	0	0				BS	CAN	(	8	H	X	h	x	
1	0	0	1	0				HT	EM	)	9	I	Y	i	y	
1	0	1	0	0				LF	SS	*	:	J	Z	j	z	
1	0	1	1	0				VT	ESC	+	;	K	[	k	(
1	1	0	0	0				FF	FS	,	<	L	~	l	~	
1	1	0	1	0				CR	GS	=	=	M	]	m)	
1	1	1	0	0				SO	RS	.	>	N	^	n	^	
1	1	1	1	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	AWG	Dia. In.	Dia. mm	AWG	Dia. In.	Dia. mm	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 superconducting magnet. 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 μ_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 $1.45 \times 10^{-4} \text{ psi}$, $1.0197 \times 10^{-5} \text{ kg}_f/\text{cm}^2$, $7.5 \times 10^{-3} \text{ torr}$, $4.191 \times 10^{-3} \text{ inches of water}$, or $1 \times 10^{-5} \text{ bar}$.

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. A 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:

Boiling point of water	373.15 K	100 °C	212 °F
Triple point of water	273.16 K		
Freezing point of water	273.15 K	0 °C	32 °F
Absolute zero	0 K	-273.15 °C	-459.67 °F
	kelvin	Celsius	Fahrenheit

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 ⁱ
(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	$\frac{4\pi \times 10^{-3}}{(4\pi)^2 \times 10^{-10}}$	m ³ /kg H•m ² /kg
(Molar) susceptibility	χ _{mol} , κ _{mol}	cm ³ /mol, emu/mol	$\frac{4\pi \times 10^{-6}}{(4\pi)^2 \times 10^{-13}}$	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:

- Gaussian units and cgs emu are the same for magnetic properties. The defining relation is $B = H + 4\pi M$.
- Multiply a number in Gaussian units by C to convert it to SI (e.g. $1 \text{ G} \times 10^{-4} \text{ T/G} = 10^{-4} \text{ T}$).
- 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 to $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$. 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.
- 1 gauss = 10⁵ gamma (γ).
- Both oersted and gauss are expressed as cm^{-3/2}•g^{1/2}•s⁻¹ in terms of base units.
- A/m was often expressed as "ampere-turn per meter" when used for magnetic field strength.
- Magnetic moment per unit volume.
- The designation "emu" is not a unit.
- Recognized under SI, even though based on the definition $B = \mu_0 H + J$. See footnote c.
- $\mu_r = \mu/\mu_0 = 1 + \chi$, all in SI. μ_r is equal to Gaussian μ .
- $B \cdot H$ and $\mu_0 M \cdot H$ have SI units J/m³, M • H and $B \cdot H/4\pi$ have Gaussian units erg/cm³.

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

Quantity	Symbol	Value (SI units)
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, $\mu_0 e^2 / 2h$	α α^{-1}	0.0073 137.0360
Elementary Charge	e	$1.6022 \times 10^{-19} \text{ C}$
Plank's Constant	h $\hbar = h/2\pi$	$6.6262 \times 10^{-34} \text{ J Hz}^{-1}$ $1.0546 \times 10^{-34} \text{ J s}$
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	$c_1 = 2\pi\hbar c^2$	$3.7418 \times 10^{-16} \text{ W m}^{-2}$
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.

APPENDIX C

HANDLING LIQUID HELIUM AND NITROGEN

C1.0 GENERAL

Use of liquid helium (LHe) and liquid nitrogen (LN₂) is often associated with the Model 625 Superconducting MPS. Although not explosive, there are a number of safety considerations to keep in mind in the handling of LHe and LN₂.

C2.0 PROPERTIES

LHe and LN₂ are colorless, odorless, and tasteless gases. Gaseous nitrogen makes up about 78 percent of the Earth's atmosphere, while helium comprises only about 5 ppm. Most helium is recovered from natural gas deposits. Once collected and isolated, the gases will liquefy when properly cooled. A quick comparison between LHe and LN₂ is provided in Table C-1.

Table C-1. Comparison of Liquid Helium and Liquid Nitrogen

PROPERTY	LIQUID HELIUM	LIQUID NITROGEN
Boiling Point @1 atm, in K	4.2	77
Thermal Conductivity (Gas), w/cm-K	0.083	0.013
Latent Heat of Vaporization, Btu/liter	2.4	152
Liquid Density, pounds/liter	0.275	0.78

C3.0 HANDLING CRYOGENIC STORAGE DEWARs

Cryogenic containers (dewars) must be operated in accordance with manufacturer instructions. Safety instructions will also be posted on the side of each dewar. Cryogenic dewars must be kept in a well-ventilated place where they are protected from the weather and away from any sources of heat. A typical cryogenic dewar is shown in Figure C-1.

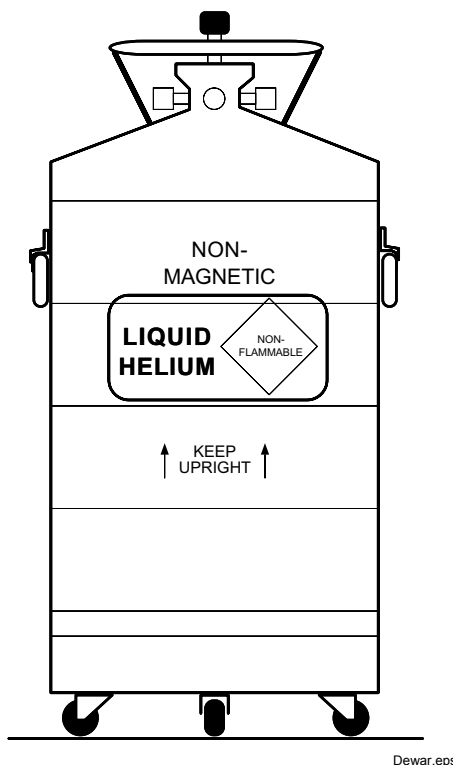


Figure C-1. Typical Cryogenic Storage Dewar

C4.0 LIQUID HELIUM AND NITROGEN SAFETY PRECAUTIONS

Transferring LHe and LN₂ and operation of the storage dewar controls should be in accordance with the manufacturer/supplier's instructions. During this transfer, it is important that all safety precautions written on the storage dewar and recommended by the manufacturer be followed.

WARNING: Liquid helium and liquid nitrogen are potential asphyxiants and can cause rapid suffocation without warning. Store and use in area with adequate ventilation. DO NOT vent container in confined spaces. DO NOT enter confined spaces where gas may be present unless area has been well ventilated. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical help.

WARNING: Liquid helium and liquid nitrogen can cause severe frostbite to the eyes or skin. DO NOT touch frosted pipes or valves. In case of frostbite, consult a physician at once. If a physician is not readily available, warm the affected areas with water that is near body temperature.

The two most important safety aspects to consider when handling LHe and LN₂ are adequate ventilation and eye and skin protection. Although helium and nitrogen gases are non-toxic, they are dangerous in that they replace the air in a normal breathing atmosphere. Liquid products are of an even greater threat since a small amount of liquid evaporates to create a large amount of gas. Therefore, it is imperative that cryogenic dewars be stored and the cryogenic system be operated in open and well ventilated areas.

Persons transferring LHe and LN₂ should make every effort to protect eyes and skin from accidental contact with liquid or the cold gas issuing from it. Protect your eyes with full face shield or chemical splash goggles. Safety glasses (even with side shields) are not adequate. Always wear special cryogenic gloves (Tempshield Cryo-Gloves® or equivalent) when handling anything that is, or may have been, in contact with the liquid or cold gas, or with cold pipes or equipment. Long sleeve shirts and cuffless trousers that are of sufficient length to prevent liquid from entering the shoes are recommended.

C5.0 RECOMMENDED FIRST AID

Every site that stores and uses LHe and LN₂ should have an appropriate Material Safety Data Sheet (MSDS) present. The MSDS may be obtained from the manufacturer/distributor. The MSDS will specify the symptoms of overexposure and the first aid to be used. A typical summary of these instructions is provided as follows.

If symptoms of asphyxia such as headache, drowsiness, dizziness, excitation, excess salivation, vomiting, or unconsciousness are observed, remove the victim to fresh air. If breathing is difficult, give oxygen. If breathing has stopped, give artificial respiration. Call a physician immediately.

If exposure to cryogenic liquids or cold gases occurs, restore tissue to normal body temperature (98.6°F) as rapidly as possible, then protect the injured tissue from further damage and infection. Call a physician immediately. Rapid warming of the affected parts is best achieved by bathing it in warm water. The water temperature should not exceed 105 °F (40 °C), and under no circumstances should the frozen part be rubbed, either before or after rewarming. If the eyes are involved, flush them thoroughly with warm water for at least 15 minutes. In case of massive exposure, remove clothing while showering with warm water. The patient should not drink alcohol or smoke. Keep warm and rest. Call a physician immediately.