OPERATING INSTRUCTION MANUAL

FOR THE

4G
MAGNET POWER SUPPLY

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Rev. 9.3

CRYOMAGNETICS, INC.
INNOVATIVE TOOLS FOR SCIENTIFIC RESEARCH

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WARNING!
DO NOT ATTEMPT TO OPERATE THIS EQUIPMENT BEFORE THOROUGHLY READING THIS INSTRUCTION MANUAL.

CE

MANUFACTURER'S DECLARATION OF CONFORMITY

In accordance with ISO/IEC 17050-1

Manufacturer's Name: Cryomagnetics, Inc.

Manufacturer's Address: 1006 Alvin Weinberg Drive
Oak Ridge, TN 37830

Declares the product

Product Name: 4G Superconducting Magnet Power Supply
Model Numbers: 4G-100, 4G-150s, 4G-200s, 4G-100/100
Product Options: All Options

Conforms to the following Product Specifications:

Safety: EN61010-1 + Amendment 1
EN61326-1

EMC: EN55011 Conducted Emissions
EN55011 Radiated Emissions
EN61000-4-2 ESD Air Discharge, 2kV, 4kV, 8kV
EN61000-4-2 ESD Contact Discharge, 4kV
EN61000-4-3 Radiated Immunity 3V/m
EN61000-4-4 EFT 500V, 1kV, 2kV
EN61000-4-5 Surge 500V, 1kV L-L
500V, 1kV, 2kV L-G
EN61000-4-6 Conducted Immunity 10Vrms, 20Vrms
EN61000-4-8 Power Freq. Magnetic Field, 30A/m
EN61000-4-11 Voltage Dips and Interrupts

Application of Council Directives:

The product complies with the requirements of the Low Voltage Directive 2014/35/EU and the EMC Directive 2014/30/EU.

D.M. Coffey, President
Cryomagnetics, Inc
Oak Ridge Tennessee February 20, 2020

Symbols and Abbreviations

Warning – Danger of electrical shock

Protective Earth Ground

A	Amperes
°C	degrees centigrade
°F	degrees Fahrenheit
Hz	Hertz
kg	kilograms
kG	kilogauss
mA	milliamperes
mV	millivolts
T	tesla

1. Introduction

1.1. Description

The 4G Superconducting Magnet Power Supply is an advanced instrument designed specifically for powering superconducting magnets. It is a true four-quadrant power supply, meaning it is capable of operating with positive current / positive voltage (sourcing power), positive current / negative voltage (sinking power), negative current / positive voltage (sinking power), and negative current / negative voltage (sourcing power). The supply allows the user to generate smooth sweeps through zero current for performing hysteresis loop experiments or other research requiring smooth magnetic field reversal.

The 4G is available in several configurations using one or two power modules. Power modules are available as 100A, 150A, and 200A units. This architecture allows the 4G to be configured as a single 100A, 150A, 200A, or dual 100A unit. Older dual units may be paralleled externally by the user to provide the full 200A current capability to a single load, but this requires special operational considerations (see Appendix E). All 4G units are capable of delivering up to ±10 volts of output voltage. An easy-to-use menu system is provided to allow the operator to set the supply up using the parameters of his/her particular magnet. Most of the supply operating parameters may be changed or queried through USB and IEEE-488 interfaces.

Power supplies used for energizing superconducting magnets have unique requirements placed upon them. The supplies are used to source energy to magnets which can have a wide range of inductances (mH to kH). In addition, the magnet load can range from a nearly pure resistance to a nearly pure inductance – and everything in between. This places demands on the supply that are far beyond what a typical power supply used for bench top electronics would see. The supply will experience the challenges of sinking energy when a magnet is discharging. At the same time, the potential exists for either the magnet or power supply to be damaged in the event of a power failure or magnet quench. The 4G's advanced circuitry enables it to handle virtually any scenario encountered in superconducting magnet operation in stride. The design of the 4G makes it a low noise, highly efficient supply – and one that is proven stable even on the most sensitive superconducting magnets. Versatile programmability allows the user to specify several different sweep rates for different current ranges of the magnet – making it possible to sweep a magnet slower in a particular range if it is more sensitive there, without user intervention

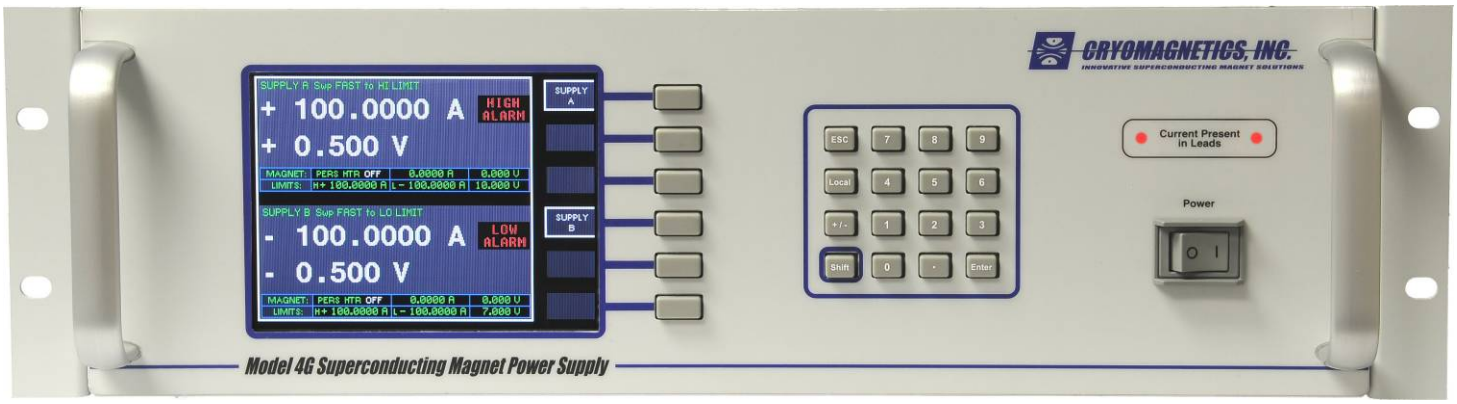

Figure 1: Front View, Dual Supply

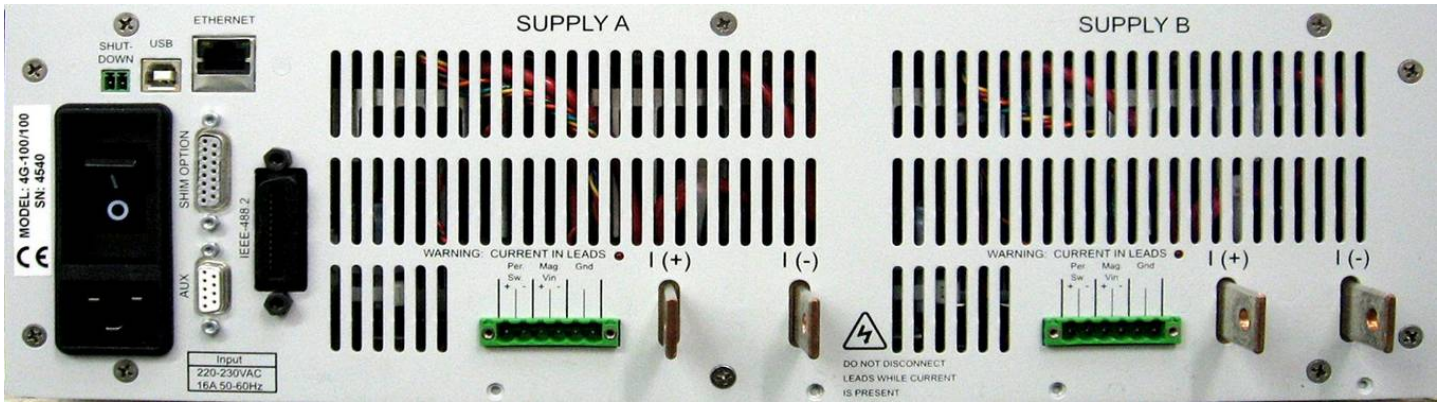

Figure 2: Rear View, Dual Supply

1.2. Features

The 4G has a wide range of features available:

- **True Four-Quadrant Operation**. The supply can provide positive or negative output current along with positive or negative voltage. This gives it the ability to smoothly sweep through zero current without the need for current reversing switches or pauses.

- **User Friendly Menus**. The 4G has intuitive menus to display and enter operating parameters. It can be set up in minutes, and changes during daily operation are simple and quick.

- **Easy to Read Display**. The high quality 5 1/4” color LCD can be read at a glance. The current is displayed in a large font that can be read even from across the lab.

- **High Stability ±10 Volt; ± 100A, ± 150A, and ± 200A Outputs**. The 4G provides quiet, stable output power thanks to its low noise design, precision current monitoring, and control circuits.

- **Power Fail Magnet Discharge**. Should a power failure occur during operation of the magnet, the supply will switch to a “Power Fail” mode where it will discharge the magnet at a low voltage. If power is restored, the user can intervene to stop the discharge and re-energize the magnet. “Power Fail” mode is a convenient feature of the 4G since it allows the user to simply turn off the power switch for the unit at the end of the day to discharge a magnet.

- **Independent Upper and Lower Current Limit Set points**. Independent current limits allow sweeping between two set points without having to re-enter the menu and change limits.

- **PID-Controlled Sweeping**. A PID inside the power supply’s control circuits allows smooth sweeping between set points without the need for magnet voltage taps.

- **Adjustable Settings During Sweep**. The menu system can be entered at any time during operation of the supply to change parameters. While in the menu, the display continues to update the user as to the status of the supply/magnet.

- **Computer Interfacing**. USB and IEEE-488 interfaces are standard. Through either interface, a comprehensive set of monitor and control commands is available. The IEEE-488 interface conforms to the IEEE-488.2-1992 standard.

- **LabVIEW™ Drivers**. Virtual Instrument drivers compatible with National Instruments LabVIEW™ are available for Cryomagnetics’ instrumentation through Cryomagnetics’ website.

- **Persistent Switch Heater Supply**. A persistent switch supply is built into the 4G.

- **Remote Shut-down Input**. A signal can be provided by the user to the 4G which tells it to discharge the magnet. This can be used to lock out operation of the magnet when helium gets too low or when some other user-defined event occurs.

- **Quench Detection and Protection**. The 4G is fully protected from damage due to a quench. In addition, if a quench is detected the 4G will give an audiovisual indication of the quench. The current readings leading up to the quench can be displayed. Since quench detection activates on observed current transients, it must be disabled if automatic recovery is desired from abnormal conditions such as those encountered in several of the CE qualification tests.

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Specifications

Common Specifications	**Current**	**Voltage**
DC Output:	See model specific specs	± 10 V
Output Power	See model specific specs	
Ripple and noise	20 uA rms	10 mV rms @ 100A
Stability (drift) at 25 ± 1C:	± 3mA / °C	± 0.01% Vmax
Display Resolution:	0.1 mA	1 mV
Display Update Rate:	2Hz	
Output Current Granularity:	0.1 mA	5 mV
Sweep Rate Resolution:	0.1 mA/sec	
Source effect (line regulation for any line change within the rated line voltage):	0.005% Imax	0.05% Vmax
Load effect (load regulation for a load change equal to max. voltage in constant current mode or max. current in constant voltage mode):	0.01% Imax	0.01% Imax
Output Protection:	Protected from damage due to quench	
Persistent Switch Heater	0-125mA	0-12V
AC Input:	220-230V AC., 50-60 Hz, 9.5A max	
Circuit Breakers:	16A, 240V AC., slow blow	
Operating Temperature:	15 °C to 35 °C	
Relative Humidity	10% to 95%, non-condensing	
Over-Temperature Protection:	Unit will limit discharge power to prevent overheating.	
Overall Dimensions (excluding front handles):	483 mm W X 133 mm H X 533 mm D	
USB interface:	USB 1.1/2.0 Full-Speed	
IEEE-488 interface:	IEEE-488.2-1992 Standard	
Ethernet:	IEEE-802.3 10/100 BASE-T	
Shut-down Input:	+5V, +24V, or switch closure signaling	

Model Specific Specifications

	Max Current	Max Output Power	Weight (lbs/kg)
4G-100	100A	1000W (10V @ 100A)	29.0/13.2
4G-150s	150A	1500W (10V @ 150A)	43.2/19.7
4G-200s	200A	1600W (8V @ 200A)	43.2/19.7
4G-Dual (100/100)	100A/100A	800W/800W (8V @ 100A)	43.2/19.7

The 4G is designed to operate per the specifications in this table and the instructions provided in this manual. Other use may impair the safety protections provided by the equipment.

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The following section outlines information concerning the installation and setup of the 4G supply. As with any equipment purchase, the user is strongly encouraged to inspect the power supply for shipping damage immediately upon receipt. Proper power and ground connections should be made using the appropriate codes and practices. Should the 4G require return to the factory due to shipping damage or for servicing, contact Cryomagnetics or an authorized service representative for instructions and a return authorization number. The 4G is delivered fully tested, calibrated, and ready to operate. This includes configuring appropriate setup values if the supply is purchased with a magnet system.

1.3. Line Voltage and Fuses

The 4G is fused for operation using 220-230V AC., 50-60 Hz input power by a 16A circuit breaker incorporated in the power entry module. Never use an ungrounded power cord for line power.

It is strongly recommended that AC power provided to the 4G be protected with a Ground Fault Interrupter (GFI) and a surge suppressor. If the unit is operating in an area subject to power failures or brownouts, the user may wish to install an Uninterruptible Power Supply (sine wave) to minimize the chance of inadvertently discharging or quenching the magnet due to line effects.

1.4. Mounting

The 4G is compatible with all standard 19-inch wide rack cabinets. Due to the instrument's weight, it is recommended that rails be located beneath the supply to prevent bending of the supply mounting brackets. Adequate ventilation is essential to the 4G. An unobstructed air path should be available at the ventilation slots in the rear and side panels of the instrument and at the fan outlets to avoid overheating.

1.5. Environment

The 4G is designed for operation in free air, non-condensing atmospheres within a temperature range of 15 to 35C (59 to 95F). It has been designed primarily for laboratory use, so harsh environments of dust or corrosive materials could result in eventual damage. A filtered enclosure is recommended for operation under these conditions.

1.6. Terminal Strip Connections

The rear panel terminal strip of the 4G provides an interface for all analog input and output signals for the 4G. The terminal strip is shown in Figure 3. Table 1 outlines the definition and function of each terminal pair. A cover is provided to prevent electrostatic discharge damage to the electrical connections. A terminal strip is present for each installed power module.

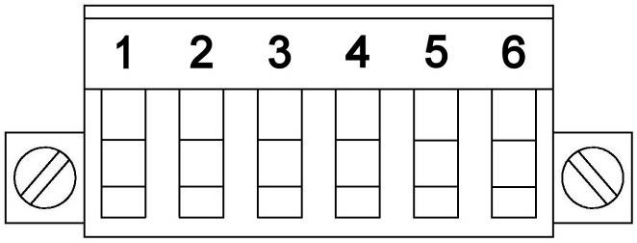


Figure 3: Rear Panel Terminal Strip

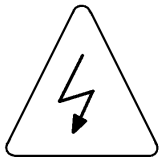
Table 1: Terminal Pinout

Terminal #	Name	Function
1	Pers Sw +	Persistent Switch Heater Power Supply Output
2	Pers Sw -	
3	Mag.Vin +	Magnet Voltage Taps – Input Signal to 4G from Magnet (optional)
4	Mag.Vin -	
5	Ground	Ground connections for I/O Cable and Output Cable shields
6	Ground	

Before making connections to the rear panel terminal strip, make sure the power to the 4G is OFF. Shield cables must be used with shields connected to terminal 6 for CE compliance. Make all connections using the appropriate wire size. The terminal strip is designed to accept AWG 24 – 12 (0.2 – 2.5 mm^2 stranded or 0.2 – 0.4 mm^2 solid) conductor. The ends should be stripped bare 7mm. All connections should be isolated from instrument ground and from each other.

1.7. Power Output Terminals

The high current output terminals are located on the rear panel and are labeled **I(+)** and **I(-)**. Make sure the 4G power is OFF before attaching the terminals to the magnet power leads. Care should be taken in attaching power leads to the magnet to ensure solid contact is made using a ¼-20 bolt and nut on each terminal. Although quench protection is built into the 4G to prevent the occurrence of high voltages, the magnet leads should NEVER be disconnected when current is present. Potentially lethal voltage can easily occur due to the high inductance of superconducting magnets.



CAUTION – RISK OF ELECTRIC SHOCK

Note: Ferrite beads (Fair-Rite P/N 0444177081) must be installed on the output cables for compliance with CE standards for RF conducted immunity. Cables must be shielded with their shields connected to terminal 6 of the terminal block.

1.8. Maintenance

The 4G should be inspected periodically to verify that all connections are secure, fans are operating properly, and ventilation openings are clear.

If cleaning is required, disconnect the power cord and clean the unit with a soft cloth dampened with water.

The 4G does not contain user serviceable parts. If repairs should be required, contact the factory for a repair authorization number, and return the supply to the factory for service to ensure the integrity of the unit is maintained.

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The 4G is designed specifically for operation with superconducting magnets. Before using the supply to energize a magnet, certain parameters specific to the superconducting magnet being used, desired charge rates, and operating current limits should be set. The following procedure is recommended.

1.9. Setting Magnet Parameters

The first thing the user should set up is the magnet parameters. If this is a dual unit, select SUPPLY A or SUPPLY B first. In the sweep menu, press [SETUP], then [MAGNET]. The display will show the Magnet Parameters. If a persistent heater is being used, **Persistent Heater Present** should be set to Yes. If the magnet to be energized is currently at zero field, the **Persistent Mode Current** should be set to 0.0000A. If the magnet is already in persistent mode at some other known current, this current can be entered instead. Be sure the polarity of the magnet current is entered correctly.

The maximum safe operating current for the magnet should be entered in the **Maximum Current Rating** parameter position. The supply will not allow output current to exceed this value. Should the user enter a **Sweep Limit** setting exceeding this value (in the Limits menu), the supply will only sweep to the **Maximum Current Rating** value and indicate MAG LIMIT REACHED on the display.

The **Gauss/Amp Ratio** of the magnet may be entered in the Magnet Parameters setup if desired. The 4G only uses this parameter if the **Display Units** is set to Field rather than Amperes. Setting this parameter is not essential.

If the magnet to be energized is equipped with a persistent mode switch, the heater current necessary to activate it should be entered in the **Persistent Switch Heater (mA)** field. The persistent switch heater power supply is capable of sourcing up to 125 mA of output current at up to 12V.

If quench detection is desired, set **Quench Detection** to On.

Set the magnet's nominal inductance in the **Inductance (H)** field. If the supply was shipped with a magnet, this field should already be set.

When done with the magnet parameters, press EXIT, then SAVE.

The charge rates for energizing the magnet should be entered through the Rates menu. The 4G allows the user to set up to five different charge rates to be used in five current ranges, plus a fast rate. This allows the user to specify a slower rate for a magnet when it is near its maximum rated field.

From the sweep menu, press [SETUP], then [RATES]. Using the inductance of the magnet as a guide, set the desired rates keeping in mind that the best (smoothest) sweeps of the magnet are achieved when a 1V-2V margin is maintained relative to the supply's voltage limit setting. The charging voltage of the magnet is calculated by V = L di/dt, where the value of di/dt is the desired sweep rate in amperes per second indicated in the Rates menu.

Once the rates and their respective current ranges have been set, press [EXIT] then [SAVE] to accept the changes, or [DISCARD] to abort and ignore all changes. If the message 'VALUE TOO LOW' appears, it means that the value in one of the "To" fields is lower than its corresponding "From" field, when it should be greater.

1.10. Setting Limits

The desired operating current for the magnet is set in the Limits menu. The 4G allows the user to enter two different limits – an upper and a lower – to enable smooth sweeps between two points. The upper and lower current limits may be positive or negative, as long as the upper is more positive than the lower.

From the Sweep menu, select [SETUP] then [LIMITS]. Use the arrow keys to select the appropriate current limit and then enter the desired value. If changes to the voltage limit are desired, this can be entered now.

If alarm operation is desired, change the **Alarm HI Limit** and **Alarm LO Limit** to the desired values. This will result in alarm messages on the display when these values are exceeded. If the optional relay outputs are in use, they can be enabled or disabled with the **Alarm Relay Bypass** setting. If set to On, the outputs remain closed all the time.

When an alarm occurs, it can either reset automatically (when the current falls back within limits) or require a button press. To automatically reset this, set **Alarm Relay Autoreset** to On.

Once the settings are made, press [EXIT] and [SAVE] to accept the changes (or [DISCARD] to abort and ignore the changes).

1.11. Energizing the Magnet

Once the magnet parameters, charge rates, and limits have been set, the supply is ready to energize the magnet. If the magnet has a persistent switch installed, go to the supply sweep menu and energize the persistent switch heater supply by pressing [PERS HTR] then [CONFIRM HTR ON]. Pressing either [CANCEL] or [ESC] will cancel turning the heater on. Wait for the magnet's persistent switch heater to warm before beginning a sweep.

Press [HI LIMIT] to begin energizing the magnet in the direction of the upper current limit. Alternatively, the operator can press [LO LIMIT] to begin energizing the magnet in the direction of the lower current limit. Once the appropriate current limit is reached, the 4G will hold that current.

To place the magnet into persistent mode, turn off the persistent switch heater supply by pressing [PERS HTR] then [CONFIRM HTR OFF]. Pressing either [CANCEL] or [ESC] will cancel turning the heater off. Wait for the persistent switch heater to cool before zeroing the current in the leads.

Once the magnet is in persistent mode, the current in the leads may be brought back to zero by pressing the [Zero] key.

IMPORTANT
Be sure to zero the supply by pressing the [ZERO] key.
Pressing [LO LIMIT] will result in the supply sweeping to the lower current limit rather than to zero.

Watch the magnet voltage while the supply begins to sweep toward zero to verify that the magnet has indeed entered persistent mode. If no voltage is detected, press [Shift-ZERO] to bring the supply back to zero output current at the fast sweep rate. When the supply reaches zero output current, it will automatically switch to Standby mode.

1.12. Discharging the Magnet

To discharge a magnet that is in persistent mode, press the [Shift-HI LIMIT] or [Shift-LO LIMIT] to quickly bring the supply output current back to the level of the locked in current in the magnet. Be sure to bring the current back to the same polarity that was left in the magnet.

When the current limit is reached, the supply will stabilize and hold that current. From the main supply sweep menu, energize the persistent switch heater supply by pressing [PERS HTR] then [CONFIRM HTR ON]. Wait for the switch to fully warm before sweeping the magnet. To cancel turning the heater on, press either [CANCEL] or [ESC].
Once the persistent switch is warm, sweep the magnet current back to zero by pressing the [ZERO]

key. Watch the magnet voltage to verify that the magnet is beginning to discharge. When the supply reaches zero output current, it will automatically change to Standby mode. Turn off the persistent switch heater supply by pressing [PERS HTR] then [CONFIRM HTR OFF].

To sweep to the opposite current limit rather than zero, press the appropriate [HI LIMIT] or [LO LIMIT] key rather than the [ZERO] key. The supply will smoothly sweep through zero and on to the other current limit.

1.13. Fast Sweeping

To invoke the fast sweep rate, press and hold SHIFT, and then select the desired sweep function.

Note that fast sweeping is only available under certain conditions in order to avoid accidental exposure of the superconducting magnet to excessive voltage and rapid current changes. For fast sweeping to be enabled:

- The Persistent Heater Present parameter in the MAGNET menu must be set to Yes.
- The persistent switch heater must be OFF.

If the above conditions are not met, fast sweep operation will be disabled (the keys will gray out when SHIFT is pressed).

1.14. Power Fail Mode

Should there be a loss of line power while energizing or discharging the superconducting magnet, the 4G will automatically switch to Power Fail Mode. In Power Fail Mode, the magnet is put into a slow self-discharge by limiting the voltage at the power supply output terminals to roughly 0.7V.

Upon return of line power, the supply displays a “PASSIVE DISCHARGE” message if current is detected in the magnet, and the supply will continue slowly discharging the magnet until the user intervenes. It is not necessary to fully discharge the magnet if this occurs. Pressing [PAUSE] will stop the self-discharge by entering Recovery Mode and, when complete, will allow normal operation to be resumed.

Magnet Quench

The 4G has magnet quench detection built in. In the event a magnet quench is detected, QUENCH DETECTED will be displayed and the supply will switch to Standby mode, removing power from the output. If the Quench Alarm (in the General menu) has been enabled, the unit emits a steady tone. Pressing any key will silence the tone. In the quench state, there are two keys available: QUENCH RESET and QUENCH DATA. QUENCH DATA will show the last few dozen current readings leading up to the quench. QUENCH RESET clears the quench state and puts the supply into STANDBY. If a quench is falsely detected, the power supply will display PASSIVE DISCHARGE, and the magnet will be discharged as described in the Power Fail Mode section.

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Setup and operation of the 4G may be performed either through the front panel keypad and simple menu instructions or through a remote computer interface (USB or IEEE-488.2). The following sections contain descriptions of how to configure and operate the 4G through the front panel.

The 4G Superconducting Magnet Power Supply is available in single or dual power module configurations. With few exceptions, in dual power module configurations, the two modules operate independently and have separate settings. The displays vary slightly between a single and dual module unit. Unless otherwise specified, menu descriptions apply equally to both modules.

Before connecting a magnet or other cabling to the 4G, connect the power cord provided with your 4G to an appropriate power source. Power the instrument ON and familiarize yourself with the display and keypad.

1.15. Normal Operating Displays

The normal operating displays of the 4G are shown in Figure 4 through Figure 6.

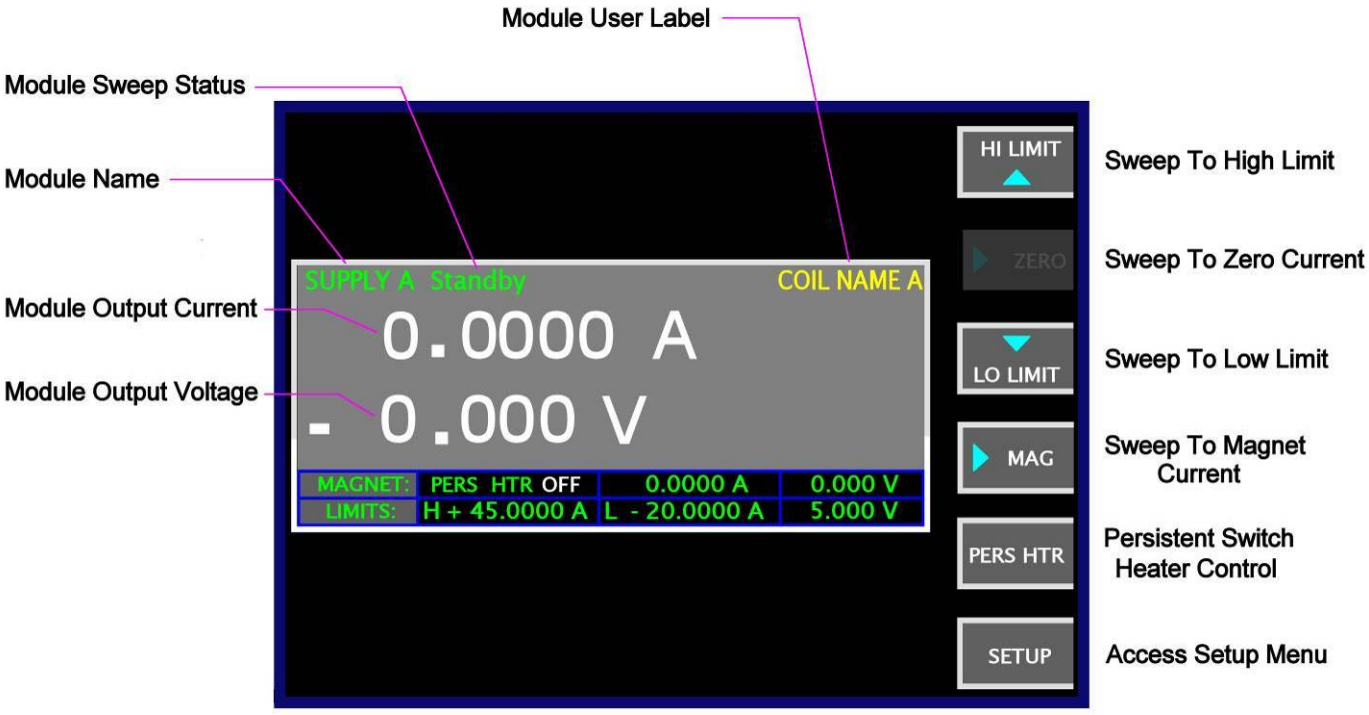

Figure 4: Normal Operating Display, Single Supply

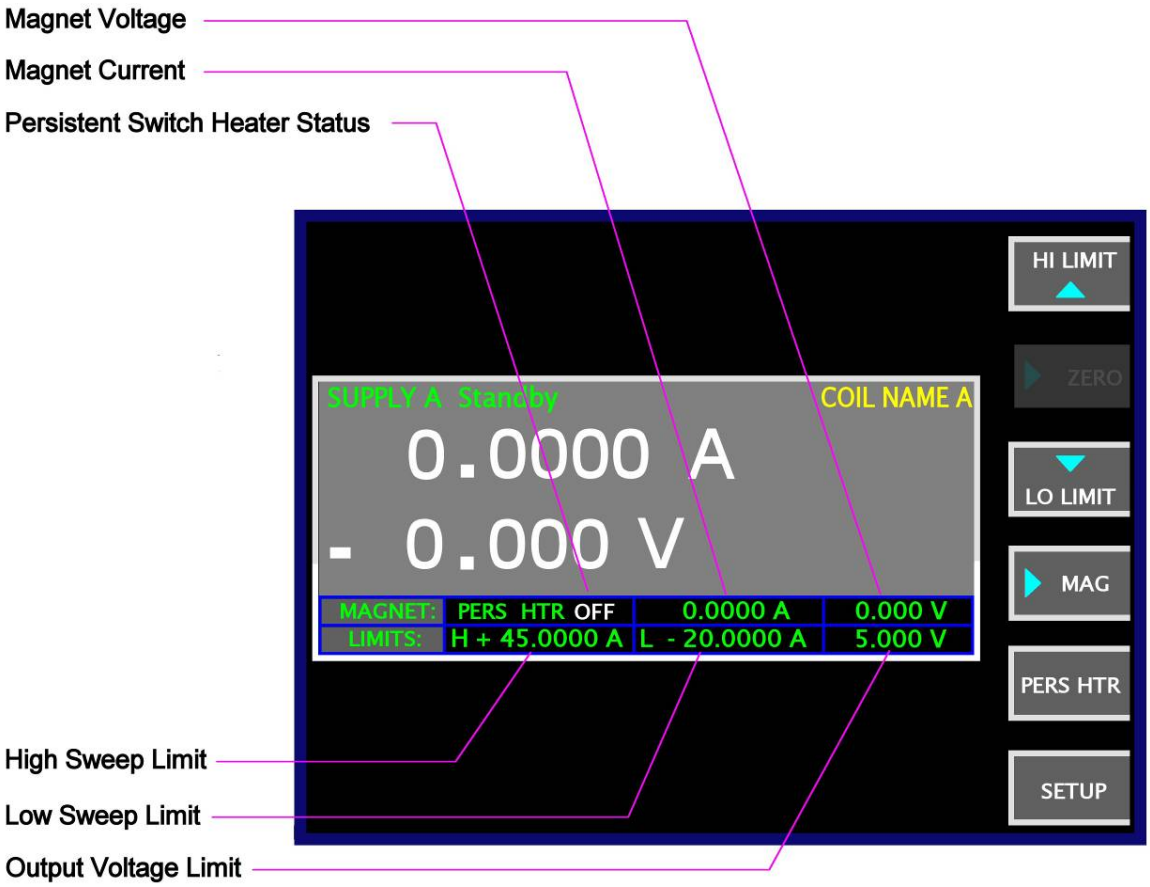

Figure 5: Normal Operating Display, Single Supply

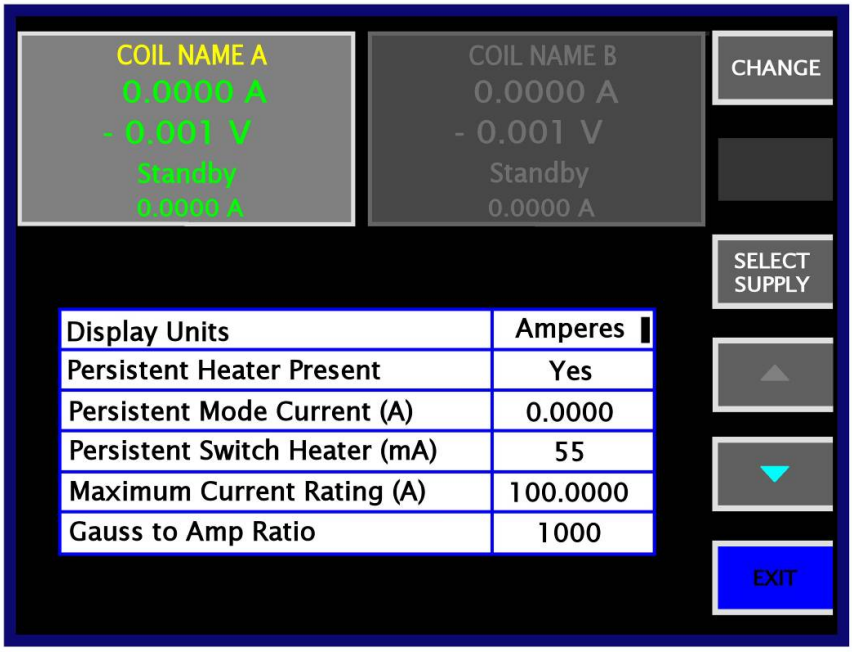

Figure 6: Normal Operating Display, Dual Supply

Display Field Descriptions

Module Name
This field displays which power module's data is being shown.

Module Sweep Status

The Module Sweep Status field indicates the present supply activity. **Standby** indicates that the power supply output module is disabled. **Sweeping to HI LIMIT** indicates that the supply output current is being swept to the upper sweep limit. **Sweeping to LO LIMIT** indicates that the supply output current is being swept to the lower sweep limit. **-Paused-** indicates that the sweep function is not active, and that the supply is maintaining or converging to a constant output current. **Sweeping to ZERO** indicates the supply is discharging the magnet.

When the Sweep Status is **Sweeping to HI LIMIT** or **Sweeping to LO LIMIT** the sweep will continue until the respective upper or lower current limit is reached. When Zeroing, the Sweep Mode of the supply will automatically change to **Standby** when zero current and zero voltage is reached.

Indicators that may appear in the Module Sweep Status field are:

- Standby
- -Paused-
- Sweeping to HI LIMIT
- Sweeping to LO LIMIT
- Sweeping to ZERO
- Sweeping to MAGNET
- Swp FAST to HI LIMIT
- Swp FAST to LO LIMIT
- Swp FAST to ZERO
- Swp FAST to MAGNET

In addition, Module Sweep Status can indicate several module exceptions:

- QUENCH DETECTED
- PASSIVE DISCHARGE
- RECOVERING
- SHUTDOWN COMMAND (rear shutdown input activated)
- OFFLINE (indicates a problem with the module)

Module User Label

The Module User Label is a 16-character alpha-numeric label that is user-settable. This field may be set using a command through the 4G's USB, Ethernet, or GPIB interface.

Module Output Current

This field indicates the output current or field (amperes shown) measured in the output leads.

Module Output Voltage

This field indicates the output voltage at the output terminals of the power supply module. Note that it may differ from magnet voltage due to voltage drop in the magnet power leads. This voltage will be clamped to the voltage limit setting in the LIMITS menu.

Magnet Voltage

This field indicates the voltage sensed at the "Mag. Vin" terminals on the rear panel.

Magnet Current

The magnet current is displayed in this field in the selected units. The magnet current will track the Module Output Current if either:

- There is no persistent switch heater (a setting in the Magnet menu)
- There is a persistent switch heater and it is on.

If a persistent switch heater exists and it is off (magnet is in the persistent mode), this value is either:

- The Module Output Current existing when the heater was turned off
- A value entered by the user when the heater was off.

The magnet current will indicate zero if a quench is detected.

Persistent Switch Heater Status

This field is shown if there is a persistent switch heater present (a setting in the Magnet menu). The values it can show are:

- OFF
- ON
- FAIL No switch heater current detected (check connections).

High Sweep Limit

The target current for a sweep-to-high limit command. This value is entered in the LIMITS menu. If

this value exceeds the Maximum Current Rating (set in the Magnet menu), the supply will only sweep up to the maximum rating and indicate MAG LIMIT REACHED.

Low Sweep Limit

The target current for a sweep-to-low limit command. This value is entered in the LIMITS screen. If this value exceeds the Maximum Current Rating (set in the Magnet menu), the supply will only sweep down to the maximum rating and indicate MAG LIMIT REACHED.

Output Voltage Limit

The module will not allow the output voltage to exceed this value. It is set in the LIMITS menu.

Local / Remote (not shown in pictures)

The Local indication shows that operator has pressed the **Local** button, and that the remote interfaces (USB, Ethernet or GPIB) cannot control the supply until the operator presses the **Local** button again. The Remote indication shows that a remote interface is controlling the supply, and that all buttons except the **Local** button are disabled.

Display Units

The operator may select Amperes or Field to display the output current.

1.16. Keypad Operation

The keypad layout is shown in Figure 5. The six unlabeled (soft) keys next to the display are not shown. Most keys on the keypad are used only for menu navigation and parameter entry.

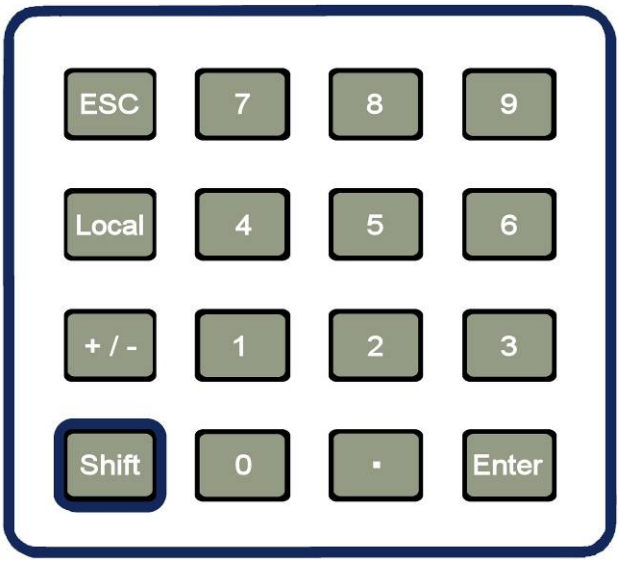

Figure 5: Keypad Layout

The [Local] key is used to put the 4G in local mode, which locks out remote commands. [Local] is the only button active when in REMOTE mode. [ESC] is used to back out of a parameter change and restore the previous value and, if not editing a parameter, behaves the same as the [Exit] key in menus. [Enter] is used to accept parameter changes and parallels the function of the SAVE soft key in menus. [Shift] is used in conjunction with the sweep soft keys to command a fast sweep mode. See Notes about Sweeping.

1.17. Menus

The menus of the 4G are designed to minimize the number of keystrokes required for navigation, while at the same time being intuitive for system operators.

1.18. Organization

The menus have the following overall organization:

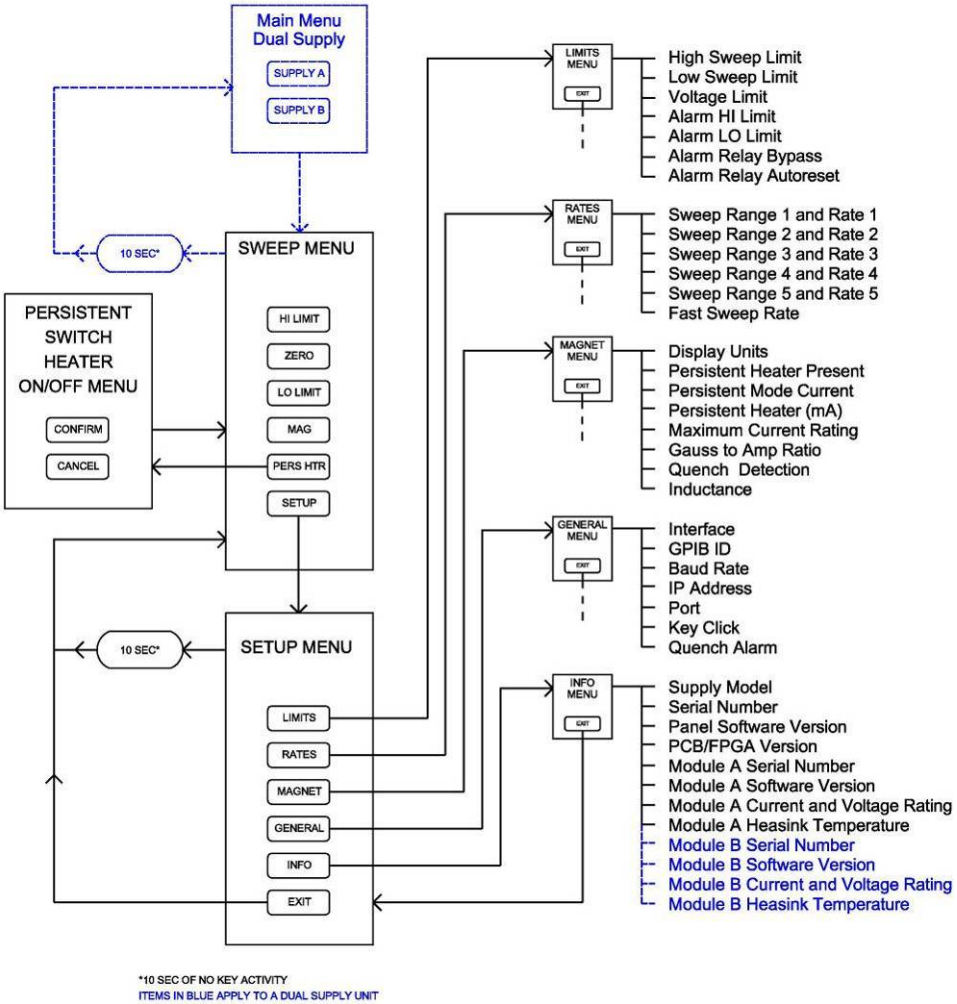

Figure 6: Menu Organization

1.19. General Menu Features

There are two types of parameters in the menus: Numerical and list. Numerical parameters are entered via the keypad 0-9, decimal point, and the change sign key. When starting an entry on a numerical parameter, the field is cleared and changed to a yellow background, and a SAVE soft-key function appears. After the desired value is entered, the SAVE key must be pressed to keep the entry, or the ESC key pressed to abort the change (which restores the old value) before the field can be exited.

List parameters are selected by using the CHANGE soft key, which appears when the cursor is on a list parameter. Press CHANGE to cycle through all the possible values for the field. Like numerical parameters, the field turns yellow while being modified, and either SAVE or ESC must be pressed before exiting the field.

Parameter changes made in any menu are not effective until the menu has been exited and SAVE has been selected at the prompt.

All setup menus share a common upper half where the status of the module(s) is shown in real time. Example:

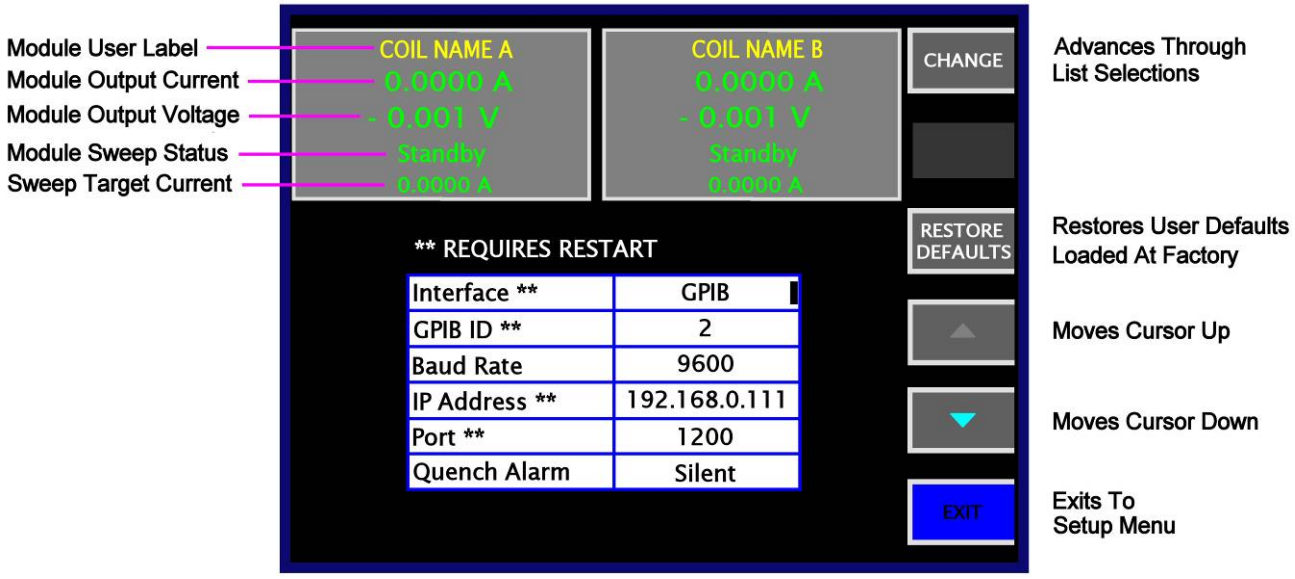

Figure 7: General Setup Menu

1.19.1. Limits Menu

The Limits menu is used to set the sweep limits and voltage limit.

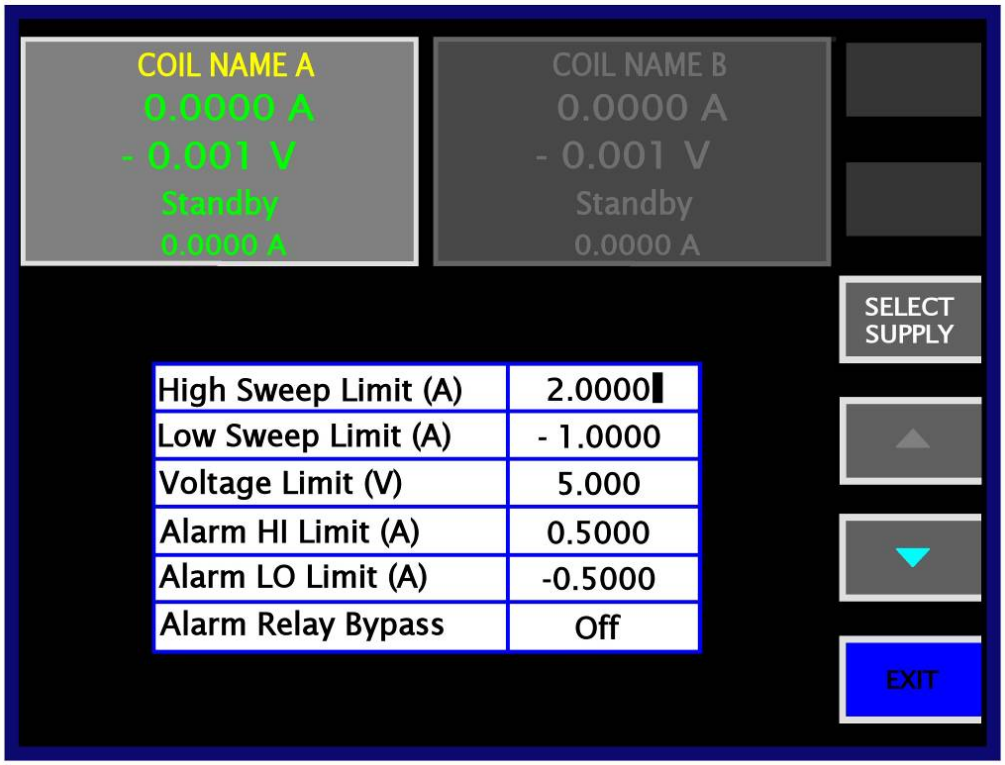

Figure 8: Limits Menu

High and Low Sweep Limits

These are the target sweep limits for the sweep up and sweep down functions. They may be set to anything within the capability of the installed module(s), but the module(s) still obey the Maximum Current Rating setting in the Magnet menu.

Voltage Limit

The voltage limit is used to set the maximum or minimum output voltage that is allowed at the power supply output terminals while charging or discharging. Note that the voltage at the magnet will be slightly higher or lower depending on the direction of current in the current leads and the lead resistance.

Alarm HI and LO Limits

The output current is compared to these values and, if they are exceeded, alarm messages will appear on the monitor display. If the optional alarm relays are installed, they will open upon an alarm condition. If alarm messages are not desired, set these to a high value or to the maximum capability of the module.

Alarm Relay Bypass

If the optional alarm outputs are installed and the user does not want them to open under any condition, Alarm Relay Bypass should be set to ON. The outputs will remain closed as long as the 4G is powered on.

Alarm Relay Autoreset

There are two ways to reset alarms: automatically, when the current falls under the alarm limits, or manually, by using soft keys provided on the display. Set **Alarm Relay Autoreset** to *On* to perform the reset automatically.

1.19.2. Rates Menu

The Rates menu is used to set the sweep ranges and rates.

Figure 9: Rates Menu Current Ranges

Five current ranges may be defined by setting the upper current limits (“To” field) for each limit. Start at the top and work down. After a value is entered for the upper limit of a range, it is automatically copied to the beginning of the next range. The upper limit must be greater than the beginning of the range or else a 'VALUE TOO LOW' error will appear.

Sweep Rates

Sweep rates may be set for each current range. This allows sweep rates to be automatically reduced at high fields and increased at low fields if desired.

Fast Mode

Fast mode sweep rate is used when sweep up fast [Shift-HI LIMIT], sweep down fast [Shift-LO LIMIT], or [Shift-Zero] is selected. These modes are selected by holding the shift key and pressing the appropriate sweep button. Fast mode is only available when the persistent switch heater option is enabled, and the heater is turned off.

1.19.3. Magnet Menu

The Magnet menu should be the first menu configured when preparing the supply for use.

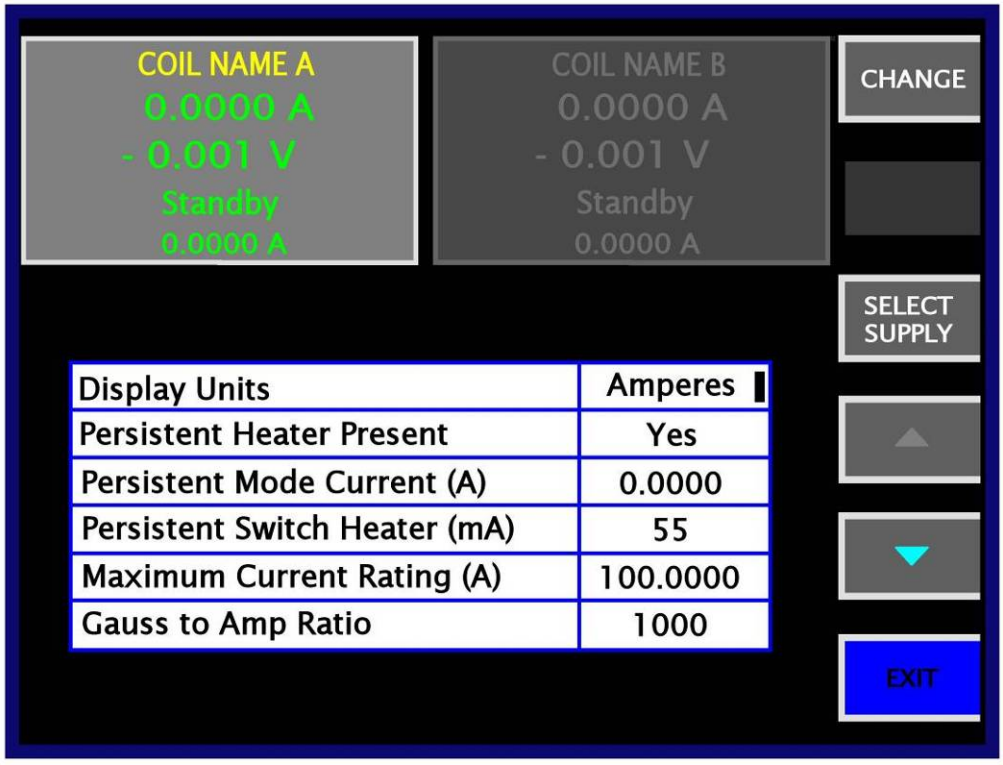

Figure 9: Magnet Parameters Menu

Display Units

The Units menu item allows the user to set the display units of the 4G. Available options are Amperes and Field. The Fields display will auto-range between Gauss, Kilogauss, and tesla. Once the system of units is selected, the 4G uses that system of units for displaying the output current, magnet current, and limits.

Persistent Heater Present

This tells the 4G if a persistent switch heater is present. If not, the capability to use fast sweeps will not be available, and the Persistent Mode Current and Persistent Switch Heater parameters will be unavailable.

Persistent Mode Current

Persistent mode current displays the present magnet current if it is in persistent mode and it was last used with the supply. This field may be edited, in case the magnet was placed in persistent mode using a different power supply, or if the current in the magnet has changed, for example from a magnet quenching while the power supply is turned off.

Persistent Switch Heater Current

The persistent switch heater current can be set from 1 to 125 mA. The switch heater is not turned on until it is selected in the operating display or via a remote interface command.

Maximum Current Rating

This is the maximum current that the supply may output, regardless of the values of the upper or lower current limits. It would normally be set to the magnet's maximum safe operating limit.

Gauss to Amp Ratio

This is entered in units of gauss per ampere. It is used to display the magnetic field instead of output current if Field is selected in the Display Units menu item. It may be set to a whole number ranging from 1 to 3000.

Quench Detection

The supply monitors the output current when quench detect is enabled. If a rapid decrease is detected it assumes that a quench has occurred, and the supply is immediately placed in standby. At this point the supply stops delivering any current to the magnet system, which in turn protects the magnet's quench protection system. The Quench Detection setting allows this feature to be disabled.

Inductance

Set this to the nominal inductance of the attached magnet. It is used to set PID parameters for the sweep algorithm. If a low resistance persistent switch is used in parallel with the magnet, a lower value than the actual magnet inductance may provide faster settling times without inducing overshoot.

1.19.4. General Menu

The General menu is used to select computer interface parameters and other parameters common to either one or two module units.

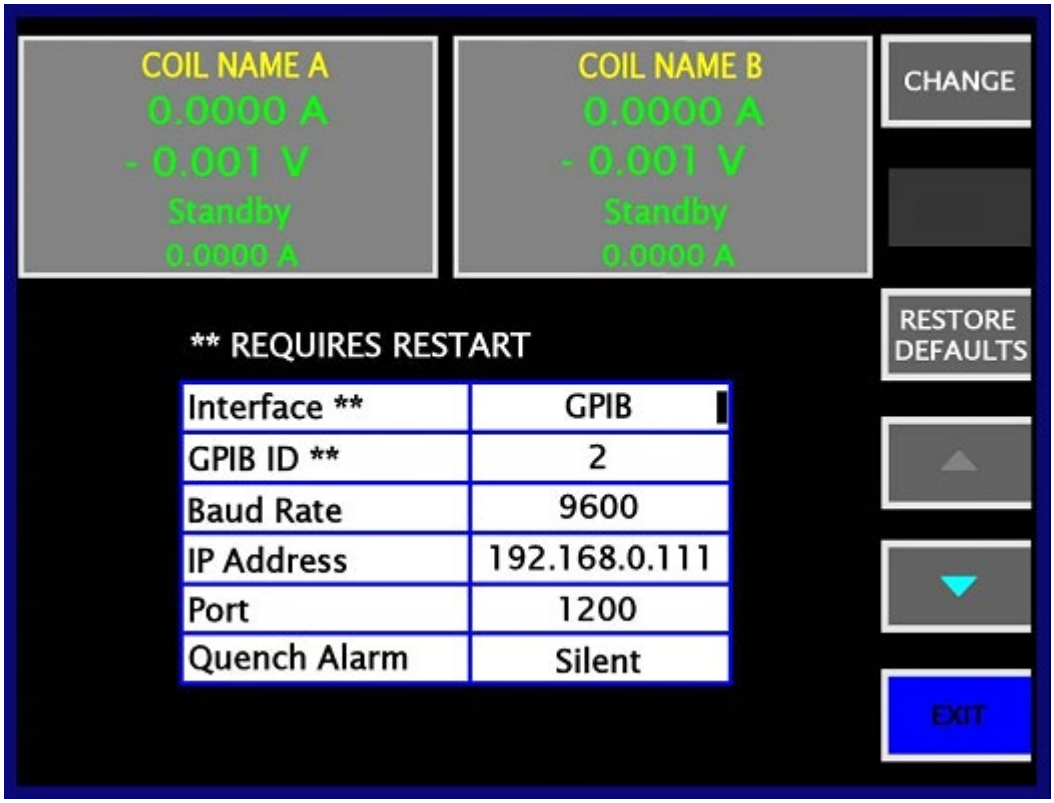

Figure 10: General Power Supply Setup Menu

Interface

The Interface field displays the computer interface. Available interfaces are GPIB, USB, and Ethernet. Power must be cycled for it to take effect.

GPIB Device ID

The GPIB device ID may be set from 0 to 30. Power must be cycled for it to take effect.

Baud Rate

This controls the baud rate used for the USB virtual COM port. It may be set to 9600, 19200, 38400, 57600, and 115200. It does not require power cycling to become effective.

IP Address

Sets the IP address for the Ethernet.

Subnet Mask (not shown)

Sets the Subnet mask for the Ethernet.

Port

Sets the port for the Ethernet.

Quench Alarm

If quench detection is enabled, this allows control over the audible alert. It can be set to Silent or Steady. When the alarm is activated, pressing any key will silence it.

Key Click (not shown)

This provides audible feedback when pressing keys.

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The 4G provides USB, IEEE-488.2, and Ethernet computer interfaces. Front panel functions may be accessed using command strings over the selected interface. Commands available to the 4G operator over the computer interfaces are given in Appendix B. The commands available through USB and Ethernet are identical to those available through IEEE-488.2; however, some commands may be IEEE-488.2 specific and may not provide responses consistent with the USB and Ethernet interfaces. The command set includes “Local”, “Remote”, and “RWLock” which are not applicable to IEEE-488.2.

Command strings are normally limited to 60 characters when the USB and Ethernet interfaces are used. A <RETURN> will be generated internally when any line longer than the maximum is encountered, and any valid commands in the received line prior to the internally generated <RETURN> will be processed. An output buffer of 62 characters is used although longer responses can be successfully generated. All remote commands are case insensitive, allowing upper or lower case to be used without affecting operation of the commands.

When the USB interface is selected, all commands sent to the instrument will be echoed including the terminating ASCII <RETURN> character, followed by a <NEWLINE> character when command processing is complete.

1.20. USB Computer Interface

The USB port is accessed through the USB Type B connector on the rear panel of the instrument. To use the USB interface, a virtual com port driver must be installed on the PC, which then treats the USB interface as a traditional RS-232 interface. The virtual com port driver is available from Cryomagnetics or from https://www.ftdichip.com/. The 4G must be configured for the same baud rate as the virtual com port (See the GENERAL setup menu).

1.21. IEEE-488.2 Computer Interface

The 4G has an IEEE-488.2 computer interface. The 4G implements SH1, AH1, T6, L4, SR1, RL1, PP0, DC1, DT0, C0, and E1 options. The commands are compliant with the IEEE-488.2 standard. The connector is identified on the rear panel of the instrument.

> **Reference:** IEEE Standard Codes, Formats, Protocols, and Common Commands (IEEE Std 488.2-1992) provides a detailed description of the IEEE common commands (identifiable in the command list by the asterisk as the first character.)

1.22. Ethernet Interface

The 4G has an IEEE-802.3 10/100 BASE-T Ethernet interface that supports a socket connection. The IP address, subnet mask, and port address are set in the General Menu (paragraph 4.3.6.) The Ethernet Interface is supported by the LabVIEW VISA driver which uses a Resource string such as tcpip0::192.168.0.254::4444::socket, where 192.168.0.254 is the IP address and 4444 is the port address entered in the General Menu.

2. Theory of Operation

The 4G is a 4-quadrant power supply with glitch free bi-directional output capability and programmable voltage limiting in both polarities.

2.1. Circuit Description

The 4G front panel is a microprocessor-based unit that handles all display, keyboard, and persistent switch heater operation, and all communications with the outside world, including the power modules. User data is stored in non-volatile memory external to the processor.

The power modules are microprocessor-based units that only communicate with the front panel. The microprocessor has built-in EEPROM that is used to hold factory calibration. Consequently, it is not possible to simply change the processor with another. The unit will not work properly with a new processor until it has been initialized by the factory.

Output current is set by a 20-bit digital-to-analog converter controlled by a software PID algorithm updated at a 15Hz rate. A 24-bit sigma-delta analog-to-digital converter is used to sense the output current. The programmable current sweep rate is digitally implemented in the PID algorithm.

The 4G's display is a bright, full-color 5 1/4" LCD display. It is capable of displaying both graphics and full alphanumerics. Both voltage and current can easily be read from a significant distance.

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Limited Warranty Policy

Cryomagnetics, Inc. warrants its products to be free from defects in materials and workmanship. This warranty shall be effective for two (2) years after the date of shipment from Cryomagnetics. Cryomagnetics reserves the right to elect to repair, replace, or give credit for the purchase price of any product subject to warranty adjustment. Return of all products for warranty adjustment shall be FOB Oak Ridge, TN, and must have prior authorization for such return from an authorized Cryomagnetics, Inc. representative.

This warranty shall not apply to any product which has been determined by Cryomagnetics, Inc. inspection to have become defective due to abuse, mishandling, accident, alteration, improper installation, or other causes. Cryomagnetics, Inc. products are designed for use by knowledgeable, competent technical personnel.

In any event, the liability of Cryomagnetics, Inc. is strictly limited to the purchase price of the equipment supplied by Cryomagnetics, Inc. Cryomagnetics, Inc. shall not assume liability for any consequential damages associated with use or misuse of its equipment.

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Notes: _____

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Certified: _____

Date: _____

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Commands available over the computer interface are identified by availability. Commands that are available only when the operational display is active are noted as "Operate", commands that require remote mode are noted as "Remote". All queries and IEEE-488.2 specific commands are always available, regardless of whether the state is Local, Remote, or unassigned. Commands that are IEEE 488.2 specific can be recognized by an asterisk (*) as the first character. All command mnemonics that elicit a response from the instrument (referred to as queries) end with a question (?) character. A general command format is as follows:

<subcommand1>;<subcommand2>;<subcommand3><RETURN>

where a subcommand is formatted

<Command Mnemonic><SPACE><Parameter>

Example:

*IDN?;*ESE 12;*ESE?<RETURN>

Responses to each subcommand are separated by semicolons. The above example would return:

Cryomagnetics,4G,2239,1.14,245;12 <RETURN><LINEFEED>

where the serial number is 2239 and the firmware version number is 1.14,245.

Error Handling and Command Availability

The ERROR command allows error messages to be enabled or disabled when the RS-232 interface is used. The IEEE-488.2 status mechanisms may always be used to determine if an error occurred processing a command, and the category of the error. Some commands are unavailable if the instrument menu is being accessed by an operator at the instrument, or if the instrument is in LOCAL mode. If a command available only in operate mode is received while the menus are being accessed, or if a command available only in remote mode is received while not in remote mode, a device dependent error is reported in the Extended Status Register (ESR), and the message "Command blocked" will be returned if error reporting is enabled when using the RS-232 interface.

Table 2 lists the 4G commands, shows the modes where they may be used, and provides a short command description. Command details are provided in the following reference.

Table 2: Computer Interface Command Summary

Command	Available	Description	Page
CHAN	Remote	Select module for subsequent commands (Dual Supply only)	43
CHAN?	Always	Query module selection (Dual Supply only)	44
ERROR	Remote	Set error response mode for RS-232 interface	44
ERROR?	Always	Query error response mode	44
IMAG	Remote	Set magnet persistent current	45
IMAG?	Always	Query magnet current	45
IOUT?	Always	Query power supply output current	45
LLIM	Remote	Set low current sweep limit	46
LLIM?	Always	Query current sweep limit	46
LOCAL	Always	Return control to front panel (RS-232 Only)	46
MODE?	Always	Query selected operating mode	46
NAME	Remote	Set magnet coil name	47
NAME?	Always	Query magnet coil name	47
PSHTR	Remote	Control persistent switch heater	47
PSHTR?	Always	Query persistent switch heater state	47
QRESET	Remote	Reset quench condition	48
RANGE	Remote	Set range limit for sweep rate boundary	48
RANGE?	Always	Query range limit for sweep rate boundary	48
RATE	Remote	Set sweep rate for selected sweep range	49
RATE?	Always	Query sweep rate for selected sweep range	49
REMOTE	Operate	Select remote operation (RS-232 Only)	49
RWLOCK	Operate	Select remote operation with front panel lock (RS-232 Only)	50
SHIM	Remote	Select shim to be queried or changed (shim option only)	50
SHIM?	Always	Query shim selection (shim option only)	50
SLIM?	Always	Query current limit for selected shim (shim option only)	51
SLIM	Remote	Set current limit for selected shim (shim option only)	51
SWEEP	Remote	Start output current sweep	51
SWEEP?	Always	Query sweep mode	52
ULIM	Remote	Set current sweep upper limit	52
ULIM?	Always	Query current sweep upper limit	52
UNITS	Remote	Select units	52
UNITS?	Always	Query selected units	53
VLIM	Remote	Set voltage limit	53

VLIM?	Always	Query voltage limit	53
VMAG?	Always	Query magnet voltage	53
VOUT?	Always	Query output voltage	54
*CLS	Always	Clear Status Command	54
*ESE	Always	Standard Event Status Enable Command	54
*ESE?	Always	Standard Event Status Enable Query	54
*ESR?	Always	Standard Event Status Register Query	55
*IDN?	Always	Identification Query	55
*OPC	Always	Operation Complete Command	55
*OPC?	Always	Operation Complete Query	56
*RST	Always	Reset Command	56
*SRE	Always	Service Request Enable Command	56
*SRE?	Always	Service Request Enable Query	56
*STB?	Always	Read Status Byte Query	57
*TST?	Always	Self-Test Query	57
*WAI	Always	Wait-to-Continue Command	57

Command Reference

This section describes how each 4G command is used and provides a cross reference to related commands. The command syntax sections show required elements enclosed in <angle brackets> and optional parameters enclosed in [square brackets]. All numbers are decimal (base 10).

CHAN? Query the currently selected module

Availability: Always

Command Syntax: CHAN?

Response: <currently selected module>

Response Example: 2

Description: The **CHAN?** query returns the power module currently selected for remote commands. It returns 1 or 2. A command error is returned if only one module is installed.

Related Commands: CHAN

CHAN Set the module for subsequent remote commands

Availability: Remote Mode

Command Syntax: CHAN [module number]

Example: CHAN 2

Default Parameter: none **Parameter Range:** 1 to 2

Description: The **CHAN** command selects the module for subsequent remote commands. A command error is returned if only one module is installed.

Related Commands: CHAN?

ERROR Set error response mode for USB interface

Availability: Remote Mode

Command Syntax: ERROR <Error Mode>

Example: ERROR 1

Parameter Range: 0 or 1 (0 - disable error reporting, 1 - enable error reporting)

Description: The **ERROR** command enables or disables error messages when the USB interface is used. It is much easier to handle errors under program control when using the USB interface if error messages are disabled, but it is desirable to enable error messages if a terminal program is used to interactively control and query the 4G.

Related Commands: ERROR?

ERROR? Query error response mode

Availability: Always

Command Syntax: ERROR?

Response: <Error Mode>

Response Example: 0 **Response Range:** 0 or 1

Description: The **ERROR?** query returns the selected error reporting mode.

Related Commands: ERROR

IMAG? Query magnet current (or magnetic field strength)

Availability: Always

Command Syntax: IMAG?

Response: <Magnet Current> <Units>

Response Example: 87.9350 A

Description: The **IMAG?** query returns the magnet current (or magnetic field strength) in the present units. If the persistent switch heater is ON, the magnet current returned will be the same as the power supply output current. If the persistent switch heater is off, the magnet current will be the value of the power supply output current when the persistent switch heater was last turned off. The magnet current will be set to zero if the power supply detects a quench. If in SHIM mode, the IMAG? query reports the present current of the shim selected by the SHIM command in Amps. If the optional Shim ID is provided while in shim mode, the present current of the specified shim will be reported.

Related Commands: UNITS, UNITS?

IMAG Sets the magnet current (or magnetic field strength).

Availability: Remote Mode

Command Syntax: IMAG [value]

IMAG <shim_id> <value> (shim mode only)

Example: IMAG 47.1123

IMAG X2 -13.4571 (shim mode only)

Default Parameter: 0.0 **Parameter Range:** ±Maximum Magnet Current

Description: The **IMAG** command sets the magnet current shown on the display. The supply must be in standby or a command error will be returned. The value must be supplied in the selected units - amperes or field (kG). If Shim Mode is enabled, the persistent mode current displayed for the named shim is set if the shim parameter is provided.

Related Commands: IMAG?

IOUT? Query power supply output current

Availability: Always

Command Syntax: IOUT?

Response: <Output Current> <Units>

Response Example: 87.935 A

Description: The **IOUT?** query returns the power supply output current (or magnetic field strength) in the present units.

Related Commands: UNITS, UNITS?

LLIM Set current sweep lower limit

Availability: Remote Mode

Command Syntax: LLIM [Limit]

Example: LLIM 20.1250

Default Parameter: 0.0 **Parameter Range:** ±Maximum Magnet Current

Description: The **LLIM** command sets the current limit used when the next **SWEEP DOWN** command is issued. The value must be supplied in the selected units - amperes or field (kG). An error will be returned if this value is greater than the upper sweep limit.

Related Commands: LLIM?, ULIM, ULIM?, SWEEP, SWEEP?, UNITS, UNITS?

LLIM? Query current sweep lower limit

Availability: Always

Command Syntax: LLIM?

Response: <Limit> <Units>

Response Example: 20.1250 A **Response Range:** ±Maximum Magnet Current

Description: The **LLIM?** query returns the current limit used with the **SWEEP DOWN** command. It is issued in the selected units - amperes or field (kG).

Related Commands: LLIM, ULIM, ULIM?, SWEEP, SWEEP?, UNITS, UNITS?

LOCAL Return control to front panel

Availability: Always (USB and Ethernet Only)

Command Syntax: LOCAL

Description: The **LOCAL** command returns control the front panel keypad after remote control has been selected by the REMOTE or RWLOCK commands.

Related Commands: REMOTE, RWLOCK

MODE? Query selected operating mode

Availability: Always

Command Syntax: MODE?

Response: <Operating Mode>

Response Example: Manual **Response Range:** Shim or Manual

Description: The **MODE?** command returns the present operating mode.

Related Commands: MODE

NAME Sets the name of the coil (magnet) on the display.

Availability: Remote Mode

Command Syntax: NAME <name string>

Example: NAME GUN COIL

Default Parameter: None **Parameter Range:** 0 to 16 characters

Description: The **NAME** command sets the name of the currently selected module for display. Upper and lower case is accepted; however, the string is converted to upper case.

Related Commands: NAME?

NAME? Query the name of the currently selected coil (magnet)

Availability: Always

Command Syntax: NAME?

Response: 0 to 16 characters

Description: The **NAME?** query returns the name of the currently selected module.

Related Commands: NAME

PSHTR Control persistent switch heater

Availability: Remote Mode

Command Syntax: PSHTR <State>

Example: PSHTR ON

Default Parameter: None **Parameter Range:** On or Off

Description: The **PSHTR** command turns the persistent switch heater on or off. Note that the switch heater current can only be set in the Magnet Menu using the keypad. This command should normally be used only when the supply output is stable and matched to the magnet current. If in Shim Mode, the heater for the selected shim is controlled instead of the main switch heater.

Related Commands: PSHTR?

PSHTR? Query persistent switch heater state

Availability: Always

Command Syntax: PSHTR?

Response: 0 or 1

Description: The **PSHTR?** query returns 1 if the switch heater is ON or 0 if the switch heater is OFF. If in Shim Mode, the status of the switch heater for the selected shim is returned.

Related Commands: PSHTR

QRESET Reset Quench Condition

Availability: Remote Mode

Command Syntax: QRESET

Description: The **QRESET** command resets a power supply quench condition and returns the supply to STANDBY.

Related Commands: None

RANGE Set range limit for sweep rate boundary

Availability: Remote

Command Syntax: RANGE <Select> <Limit>

Example: RANGE 0 25.0

Default Parameter: None **Parameter Ranges:**

Select: 0 to 4 | **Limit**: 0 to Max Supply Current

Description: The **RANGE** command sets the upper limit for a charge rate range in amps. Range 0 starts at 0A and ends at the limit provided. Range 1 starts at the Range 0 limit and ends at the Range 1 limit. Range 2 starts at the Range 1 limit and ends at the Range 2 limit. Range 3 starts at the Range 2 limit and ends at the Range 3 limit. Range 4 starts at the Range 3 limit and ends at the supply output capacity.

Related Commands: RANGE?, RATE, RATE?

RANGE? Query range limit for sweep rate boundary

Availability: Always

Command Syntax: RANGE? <Select>

Example: RANGE? 1 **Parameter Range:** 0 to 4

Response: <Limit>

Response Example: 75.000 **Response Range:** 0 to Max Magnet Current

Description: The **RANGE?** query returns the upper limit for a charge rate range in amps. See RANGE for further details.

Related Commands: RANGE, RATE, RATE?

RATE Set sweep rate for selected sweep range

Availability: Remote

Command Syntax: RATE <Range> <Sweep Rate>

Example: RATE 0 0.250

Default Parameter: None **Parameter Ranges:**

Range Selection: 0 to 5

Limit: 0 to Max Magnet Current

Description: The **RATE** command sets the charge rate in amps/second for a selected range. A range parameter of 0, 1, 2, 3, and 4 will select Range 1, 2, 3, 4, or 5 sweep rates as displayed in the Rates Menu. A range parameter of 5 selects the Fast mode sweep rate.

Related Commands: RANGE, RANGE?, RATE?

RATE? Query range limit for sweep rate boundary

Availability: Always

Command Syntax: RATE? <Range>

Example: RATE? 1 **Parameter Range:** 0 to 5

Response: <Rate>

Response Example: 0.125 **Response Range:** 0 to Max Magnet Current

Description: The **RATE?** command queries the charge rate in amps/second for a selected range. A range parameter of 0 to 4 will select Range 1 through 5 sweep rates as displayed in the Rates Menu. A range parameter of 5 queries the Fast mode sweep rate.

Related Commands: RANGE, RANGE?, RATE

REMOTE Select remote operation

Availability: Operate (USB Only)

Command Syntax: REMOTE

Description: The **REMOTE** command takes control of the 4G via the remote interface. All buttons on the front panel are disabled except the Local button. This command will be rejected if the menu system is being accessed via the front panel or if LOCAL has been selected via the Local button on the front panel. Pressing the Local button again when the menu is not selected will allow this command to be executed. This command is only necessary for USB operation since the IEEE-488 interface provides for bus level control of the Remote and Lock controls.

Related Commands: LOCAL, RWLOCK

RWLOCK Select remote operation

Availability: Operate (USB Only)

Command Syntax: RWLOCK

Description: The **REMOTE** command takes control of the 4G via the remote interface. All buttons on the front panel are disabled except the Local button. This command will be rejected if the menu system is being accessed via the front panel or if LOCAL has been selected via the Local button on the front panel. Pressing the Local button again when the menu is not selected will allow this command to be executed. This command is only necessary for USB operation since the IEEE-488 interface provides for bus level control of the Remote and Lock controls.

Related Commands: LOCAL, RWLOCK

SHIM Select SHIM to be controlled or queried

Availability: Remote Mode (Shim mode only)

Command Syntax: SHIM [Enable or Disable] <Selection>

Examples:

SHIM Z4	SHIM Enable All
SHIM Enable Z3	SHIM Disable All
SHIM Disable Z3	

Default Parameter: None

Parameter Range: Z, Z2, Z3, Z4, X, Y, ZX, ZY, C2, S2, Z2X, Z2Y

Description: The **SHIM** command selects a shim to be controlled or queried. It also allows selected shims or all shims to be disabled or enabled. The command is only valid when operating in SHIM mode. The switch heater must be off when making a shim selection.

Related Commands: IMAG?, SHIM?, SLIM, SLIM?

SHIM? Query SHIM selection

Availability: Always (Shim mode only)

Command Syntax: SHIM? [Query selection]

Response: <Shim selection> <Enabled or Disabled>

Response Example: ZX Enabled

Response Range: Z, Z2, Z3, Z4, X, Y, ZX, ZY, C2, S2, Z2X, Z2Y

Description: The **SHIM?** command identifies the shim selected to be controlled or queried and reports the enable/disable status. If the optional Shim ID is provided as a parameter, the command reports the enable/disable status of the specified shim. The command is only valid when operating in SHIM mode.

Related Commands: IMAG?, SHIM, SLIM, SLIM?

SLIM Set current limit for selected shim

Availability: Remote Mode (Shim mode only)

Command Syntax: SLIM <Limit>

Example: SLIM –5.837

Default Parameter: 0.0 **Parameter Range:** ±30.000

Description: The **SLIM** command sets the current limit for the selected shim. The command is only valid when operating in SHIM mode with the persistent switch heater off. The maximum value for the current limit is set in the setup screen of the main menu when in Manual mode. The SWEEP command is used to sweep the power supply to the target current of the selected shim.

Related Commands: IMAG?, SHIM?, SLIM, SLIM?, SWEEP

SLIM? Query current limit for selected shim

Availability: Always (Shim mode only)

Command Syntax: SLIM?

Response: <Limit> A

Response Example: 5.923 A **Response Range:** ±30A (See 4.3.5.4)

Description: The **SLIM?** Query returns the current limit used when the next SWEEP UP or SWEEP DOWN command is issued.

Related Commands: IMAG?, SHIM, SLIM, SLIM?, SWEEP

SWEEP Start output current sweep

Availability: Remote Mode

Command Syntax: SWEEP <Sweep Mode> [fast or slow]

Examples: SWEEP UP

SWEEP UP FAST

Default Parameter: None **Parameter Range: UP, DOWN, PAUSE, or ZERO**

Shim Mode Only: LIMIT

Description: The **SWEEP** command causes the power supply to sweep the output current from the present current to the specified limit at the applicable charge rate set by the range and rate commands. If the FAST parameter is given, the fast mode rate will be used instead of a rate selected from the output current range. SLOW is required to change from fast sweep. SWEEP UP sweeps to the Upper limit, SWEEP DOWN sweeps to the Lower limit, and SWEEP ZERO discharges the supply. If in Shim Mode, SWEEP LIMIT sweeps to the shim target current.

Related Commands: LLIM, LLIM?, SLIM, SLIM?, SWEEP?, ULIM, ULIM?, UNITS, UNITS?

SWEEP? Query sweep mode

Availability: Always

Command Syntax: SWEEP?

Response: <Mode> [fast]

Response Example: sweep up fast **Response Range:** sweep up, sweep down, sweep paused, or zeroing

Description: The **SWEEP?** query returns the present sweep mode. If sweep is not active, then 'sweep paused' is returned.

Related Commands: LLIM, LLIM?, SLIM, SLIM?, SWEEP, ULIM, ULIM?, UNITS, UNITS?

ULIM Set current sweep upper limit

Availability: Remote Mode

Command Syntax: ULIM [Limit]

Example: ULIM 65.327

Default Parameter: 0.0 **Parameter Range:** ±Maximum Supply Current

Description: The **ULIM** command sets the current limit used when the next **SWEEP UP** command is issued. The value must be supplied in the selected units - amperes or field (kG). An error will be returned if this value is less than the lower sweep limit.

Related Commands: LLIM, LLIM?, SWEEP, SWEEP?, ULIM?, UNITS, UNITS?

ULIM? Query current sweep upper limit

Availability: Always

Command Syntax: ULIM?

Response: <Limit> <Units>

Response Example: 65.327 A **Response Range:** ±Maximum Supply Current

Description: The **ULIM?** query returns the current limit used for the **SWEEP UP** command. It is issued in the selected units - amperes or field (kG).

Related Commands: LLIM, LLIM?, SWEEP, SWEEP?, ULIM, UNITS, UNITS?

UNITS Select units

Availability: Remote Mode

Command Syntax: UNITS <Unit Selection>

Example: UNITS A **Parameter Range:** A, G

Description: The **UNITS** command sets the units to be used for all input and display operations. Units may be set to Amps or Gauss. The unit will autorange to display Gauss, Kilogauss or tesla.

Related Commands: IMAG?, IOUT?, LLIM, LLIM?, ULIM, ULIM?, UNITS?

UNITS? Query selected units

Availability: Always

Command Syntax: UNITS?

Response: <Selected Units>

Response Example: G **Response Range:** A, G

Description: The **UNITS?** command returns the units used for all input and display operations.

Related Commands: IMAG?, IOUT?, LLIM, LLIM?, ULIM, ULIM?, UNITS

VLIM Set voltage limit

Availability: Remote Mode

Command Syntax: VLIM <Voltage Limit>

Example: VLIM 5.0 **Parameter Range:** 0.0 to 10.0

Description: The **VLIM** command sets the power supply output voltage limit to the voltage provided.

Related Commands: VLIM?, VMAG?, VOUT?

VLIM? Query voltage limit

Availability: Always

Command Syntax: VLIM?

Response: <Voltage Limit>

Response Example: 4.75 V **Response Range:** 0 to 10.00

Description: The **VLIM?** command returns the power supply output voltage limit.

Related Commands: VLIM, VMAG?, VOUT?

VMAG? Query magnet voltage

Availability: Always

Command Syntax: VMAG?

Response: <Magnet Voltage>

Response Example: 4.75 V **Response Range:** -10.00 to +10.00

Description: The **VMAG?** command returns the present magnet voltage.

Related Commands: VLIM, VLIM?, VOUT?

VOUT? Query output voltage

Availability: Always

Command Syntax: VOUT?

Response: <Output Voltage>

Response Example: 4.75 V **Response Range:** -12.80 to +12.80

Description: The **VOUT?** command returns the present power supply output voltage.

Related Commands: VLIM, VLIM?, VMAG?

***CLS** Clear Status Command

Availability: Always

Command Syntax: *CLS

Description: The ***CLS** command operates per IEEE Std 488.2-1992 by clearing the Standard Event Status Register (ESR) and resetting the MAV bit in the Status Byte Register (STB).

Related Commands: None

***ESE** Standard Event Status Enable Command

Availability: Always

Command Syntax: *ESE <mask>

Example: *ESE 255

Default Parameter: 0 **Parameter Range:** 0 to 255

Description: The ***ESE** command operates per IEEE Std 488.2-1992 by setting the specified mask into the Standard Event Status Enable Register (ESE).

Related Commands: *ESE?

***ESE?** Standard Event Status Enable Query

Availability: Always

Command Syntax: *ESE?

Response: <ESE Mask>

Response Example: 255 **Response Range:** 0 to 255

Description: The ***ESE?** command operates per IEEE Std 488.2-1992 by returning the mask set in the Standard Event Status Enable Register (ESE) by a prior *ESE command.

Related Commands: *ESE

***ESR?** Standard Event Status Register Query

Availability: Always

Command Syntax: *ESR?

Response: <Standard Event Status Register>

Response Example: 128 **Response Range:** 0 to 255

Description: The ***ESR?** command operates per IEEE Std 488.2-1992 by returning the contents of the Standard Event Status Register and then clearing the register. The User Request bit is set any time the Local or Menu buttons on the front panel are depressed. The remaining bits are defined in the referenced standard.

Status Byte Bit Allocations:

```
X   X   X   X   X   X   0   1
|   |   |   |   |   |   |   |____ Operation Complete
|   |   |   |   |   |   |________ Request Control
|   |   |   |   |   |____________ Query Error
|   |   |   |   |________________ Device Dependent Error
|   |   |   |____________________ Execution Error
|   |   |________________________ Command Error
|   |____________________________ User Request
|________________________________ Power On
```

Related Commands: *ESE, *ESE?

***IDN?** Identification Query

Availability: Always

Command Syntax: *IDN?

Response: <Manufacturer>,<Model>,<Serial #>,<Firmware Level>,<build number>

Response Example: Cryomagnetics,4G,2239,1.02,208

Serial # Range: 2000 to 9999 **Firmware Level Range:** 1.00 to 9.99

Description: The ***IDN?** command operates per IEEE Std 488.2-1992 by returning the 4G manufacturer, model, serial number, firmware level and build level.

Related Commands: None

***OPC** Operation Complete Command

Availability: Always

Command Syntax: *OPC

Description: The ***OPC** command operates per IEEE Std 488.2-1992 by placing the Operation Complete message in the Standard Event Status Register (ESR). The 4G processes each command as it is received and does not defer any commands for later processing.

Related Commands: *OPC?

***OPC?** Operation Complete Query

Availability: Always

Command Syntax: *OPC?

Description: The ***OPC** command operates per IEEE Std 488.2-1992 by placing an ASCII character "1" in the output queue since the 4G does not defer any commands for later processing.

Related Commands: *OPC

***RST** Reset Command

Availability: Always

Command Syntax: *RST

Description: The ***RST** command operates per IEEE Std 488.2-1992 but does not change the power supply operation due to safety concerns.

Related Commands: None

***SRE** Service Request Enable Command

Availability: Always

Command Syntax: *SRE <mask>

Example: *SRE 255

Default Parameter: 0 **Parameter Range:** 0 to 255

Description: The ***SRE** command operates per IEEE Std 488.2-1992 by setting the specified mask into the Service Request Enable Register (SRE).

Related Commands: *SRE?

***SRE?** Service Request Enable Query

Availability: Always

Command Syntax: *SRE?

Response: <SRE Mask>

Response Example: 255 **Response Range:** 0 to 255

Description: The ***SRE?** command operates per IEEE Std 488.2-1992 by returning the mask set in the Service Request Enable Register (SRE) by a prior *SRE command.

Related Commands: *SRE

***STB?** Read Status Byte Query

Availability: Always

Command Syntax: *STB?

Response: <Status Byte>

Response Example: 65 **Response Range:** 0 to 255

Description: The ***STB?** command operates per IEEE Std 488.2-1992 by returning the Status Byte.

Status Byte Bit Allocations:

```
X   X   X   X   X   X   X   X
|   |   |   |   |   |   |   |____ Sweep Mode Active
|   |   |   |   |   |   |________ Standby Mode Active
|   |   |   |   |   |____________ Quench condition present
|   |   |   |   |________________ Power Module Failure
|   |   |   |____________________ MAV (Message Available)
|   |   |________________________ ESB (Extended Status Byte)
|   |____________________________ MSS (Master Summary Status)
|________________________________ Menu Mode (Remote Commands Locked Out)
```

*** TST?** Self-Test Query

Availability: Always

Command Syntax: *TST?

Response: <Self test status>

Response Example: 1 **Response Range:** 1

Description: The ***TST?** command operates per IEEE Std 488.2-1992 by returning the self test status. Explicit tests are not performed in response to this command, but a 1 is returned for compliance with the specification.

Related Commands: None

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

Availability: Always

Command Syntax: *WAI

Description: The ***WAI?** command operates per IEEE Std 488.2-1992 by accepting the command without generating an error. Since the 4G only implements sequential commands the no-operation-pending flag is always TRUE.

Related Commands: OPC, *OP

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Appendix C: Shared Output Leads

In rare cases it may be necessary for multiple power supplies to have their outputs connected together in order to share a limited number of current leads. For example, a gyrotron or multi-axis magnet system could have three coils connected in series with only four current leads instead of the typical six (i.e. one pair per coil). Please contact Cryomagnetics for assistance in these situations as care must be taken to ensure proper operation of the 4G Power Supplies.

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Appendix D: Shut-down Input

The rear panel Shut-down input can be configured to accept a +5V signal, +24V signal, or a contact closure to place the supply into shutdown mode. During shutdown, the output power modules sweep to zero current at the programmed rate, and commands that affect module operation (sweep, limits changes, etc.) are inhibited, both on the keyboard and computer interfaces. The status words “SHUTDOWN COMMAND” will show on the display as long as the shutdown signal is active. Once triggered, the supply will sweep down to 0A before restarting. If the shutdown signal is removed in the middle of the discharge cycle, “WAIT FOR REBOOT” will be displayed on the screen and the supply will continue sweeping to 0A.

To configure the interface, disconnect the power and remove the top cover of the 4G by removing the six screws from the top of the cover and the three screws from the lip of the cover in the rear.

Locate the communication module on the rear panel of the unit. On it are four 3-pin headers labeled H1 through H4, each with two possible positions – ON and OFF. Use the following table to configure the interface, by moving the jumpers to the correct positions. Jumpers not labeled ON must be in the OFF position or left off altogether.

Table 3: Shutdown Input Configuration

	24V MODE	5V MODE	SWITCH MODE
H1		**ON**	**ON**
H2	**ON**	**ON**	
H3			**ON**
H4			**ON**

CAUTION: Configurations other than the above could damage the board.

Shut Down Input Electrical Specifications:

5V - Polarity insensitive, optically isolated, approx. 10mA drawn from 5V source.

24V - Polarity insensitive, optically isolated, approx. 10mA drawn from 24V source.

Switch Contact - Non-isolated, 4.3V open circuit, approx. 10mA passed through the switch. Positive terminal is on the left.

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Older 4G 200A supplies (pre model 4G-200S) are composed of two power modules with a common front panel. Operation is nearly identical to that of the single unit 100A supply, with the only differences being the option to enter a higher max current, and the requirement that the outputs be paralleled for proper operation.

To parallel the outputs of the supply, using the provided jumpers, connect the I+ leads together, then connect the I- leads together. Then attach the magnet +/- leads to the corresponding +/- outputs of the supply as normal.

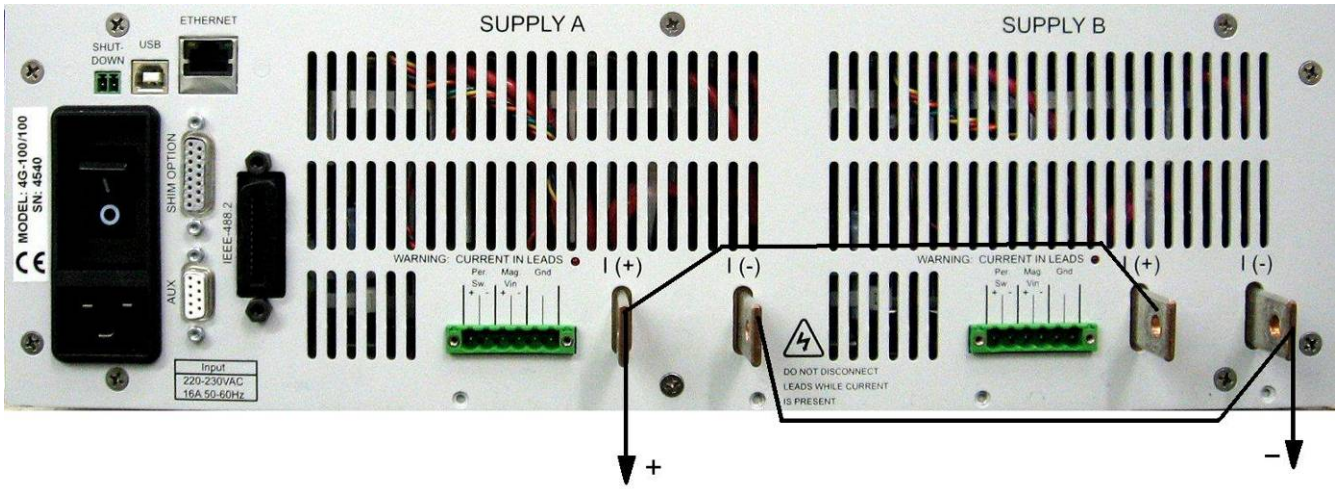

Figure 11: Parallel Supply Connections

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Appendix F: Firmware Upgrading

Upgrades may be done to either the main operating firmware and/or the power module firmware.

To upgrade the main operating firmware, first obtain the upgrade files from Cryomagnetics. The following is required:

- Firmware binary file.
- Flashit programming software.
- FTDI virtual COM port software (if not already installed)

With the supply powered down, press and hold the Shift key and upper most soft key, then power the device on while continuing to hold the two keys. The display will show the Cryomagnetics logo but otherwise will be blank.

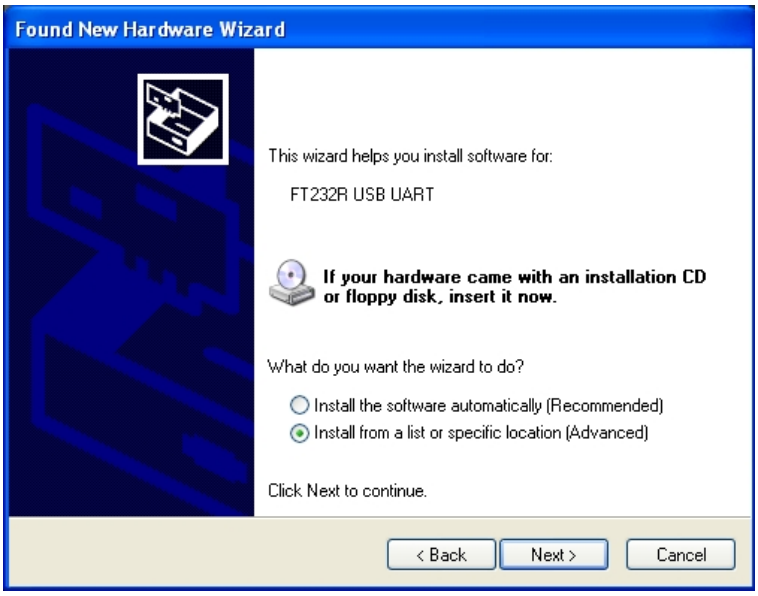
If FTDI virtual COM port drivers are already installed on your PC: When the 4G Supply is connected to the computer's USB port, the computer will enumerate it as a new COM port without running the Found New Hardware wizard. In that case, just go to the control panel/hardware manager and note what COM port it is assigned to.

If FTDI virtual COM port drivers are not installed on your PC: The 4G Supply requires FTDI virtual COM port drivers on the PC to communicate. If they are not installed on your PC, when the 4G is connected to the computer's USB port the PC will begin running the Found New Hardware wizard.

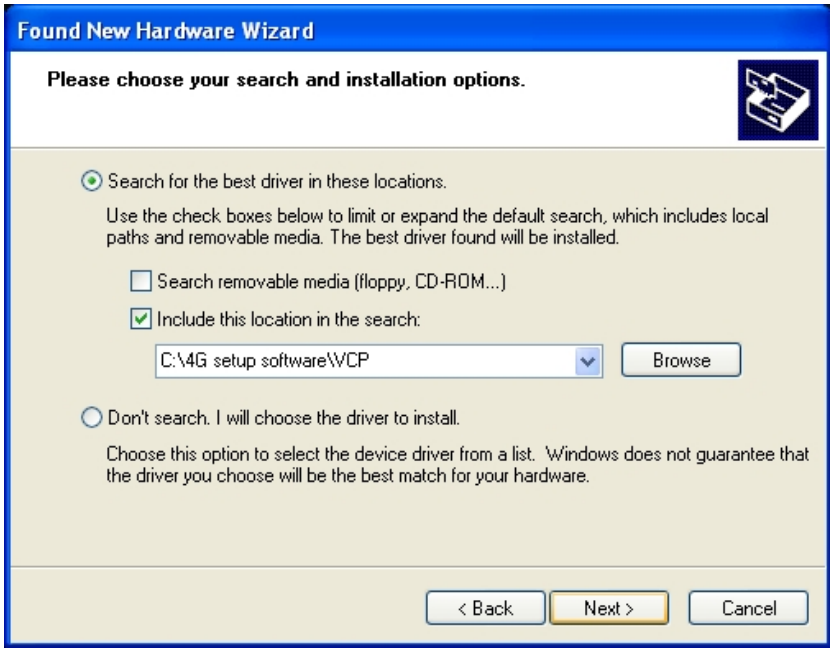
On a new install, do the following. These steps were written for Windows XP:

- Connect the 4G to the computer via the USB cable.
- The computer should find the new hardware.

- Select No, not this time, then click Next >.



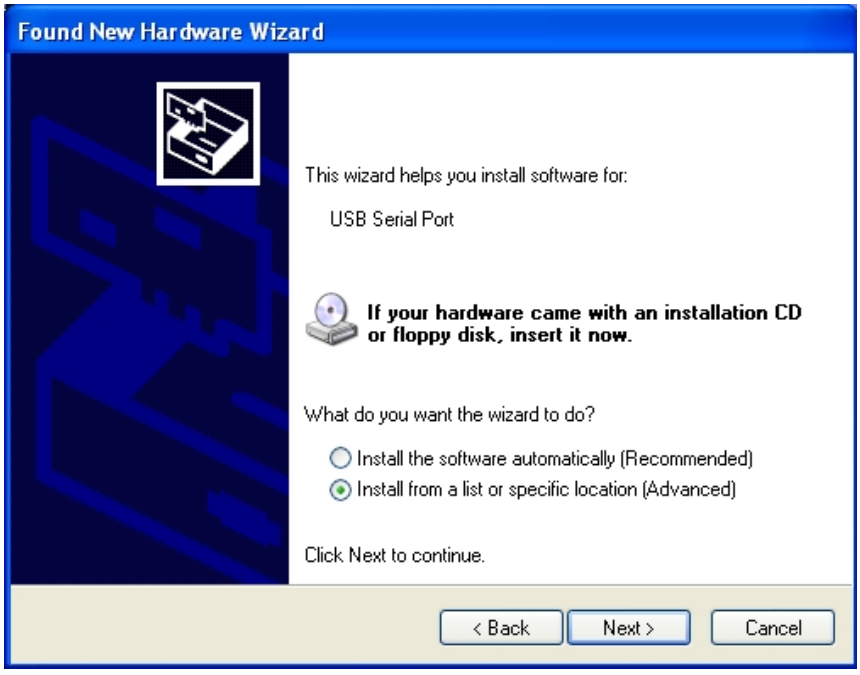
- Tell the wizard to Install from a list or specific location (Advanced) and click Next >



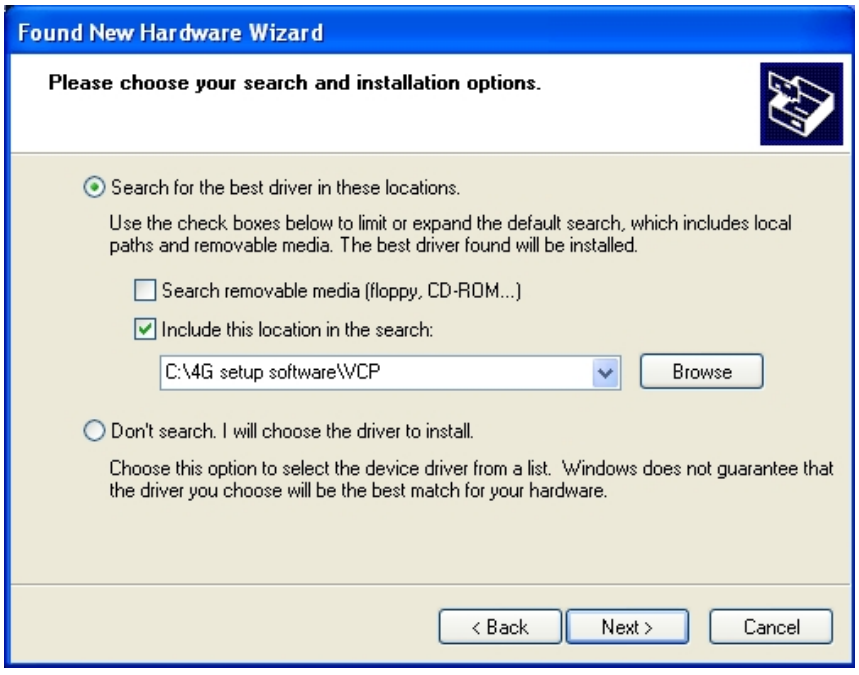
- Browse to the folder containing the virtual COM port software and then click Next >

- Press “Finish” to complete this step.

At this point, the wizard will run a second time. Follow the same steps as before.



- Select Install from a list of specific location (Advanced), then click Next

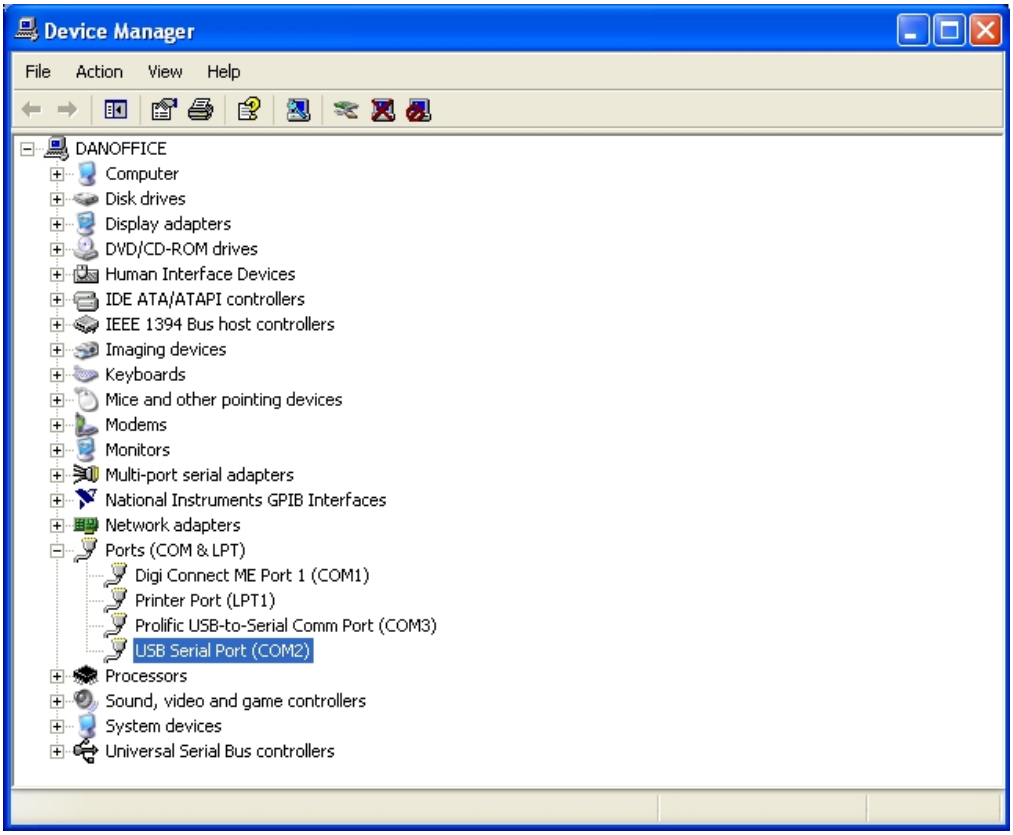


- Browse to the folder containing the virtual COM port files, then click Next >

- Click Finish to complete the COM port driver installation.

Setting up 4G Supply Communications:

To set up communications between your PC and the 4G Supply, open Control Panel and note which COM port was assigned when the 4G was connected.

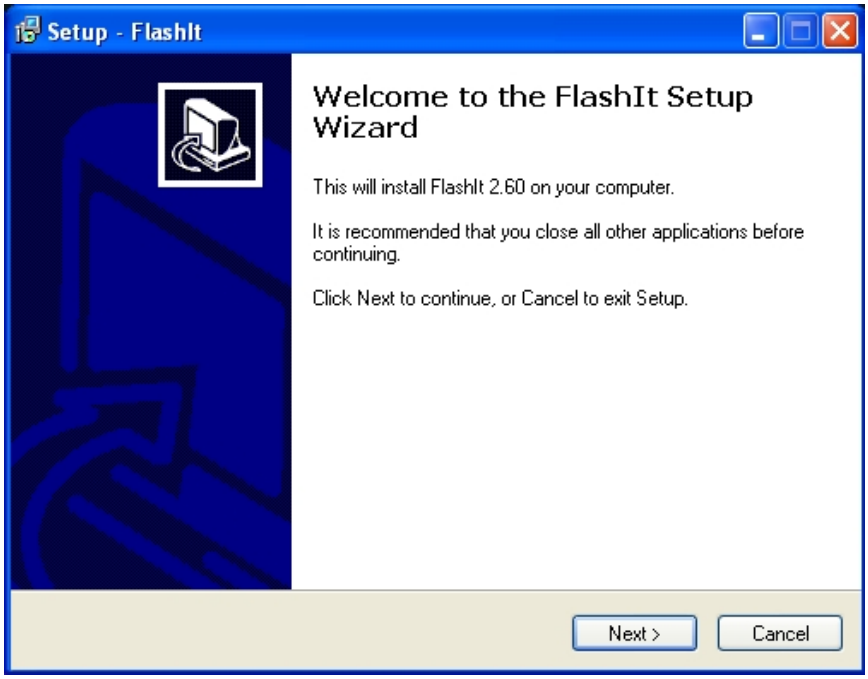


Right-click the COM port to change the assignment if necessary.

Note: The FLASHIT program may not be able to find COM port if the ports are not contiguous. For example, if COM1 and COM2 are active, and the 4G enumerates as COM4, FLASHIT may not see it. This is an open issue.

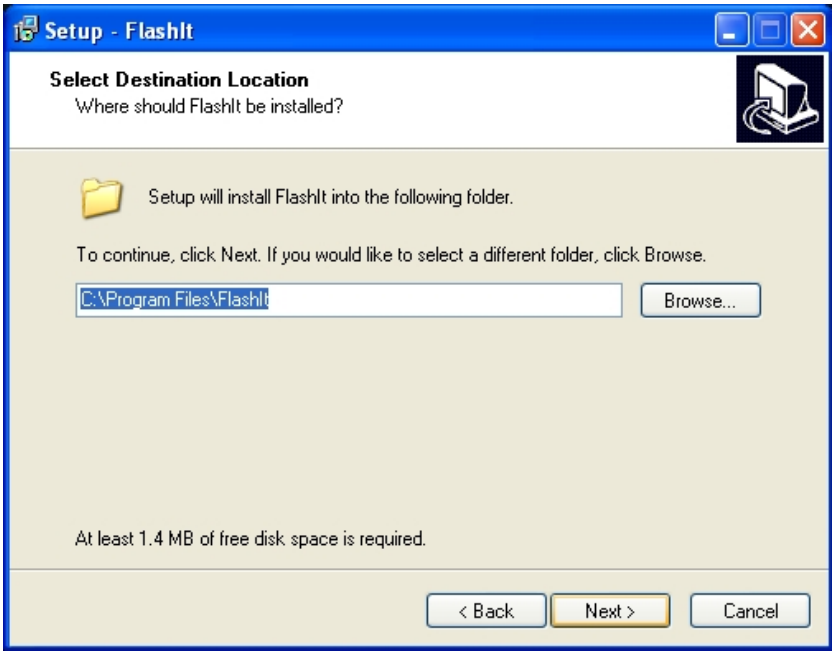
Installing FlashIt.

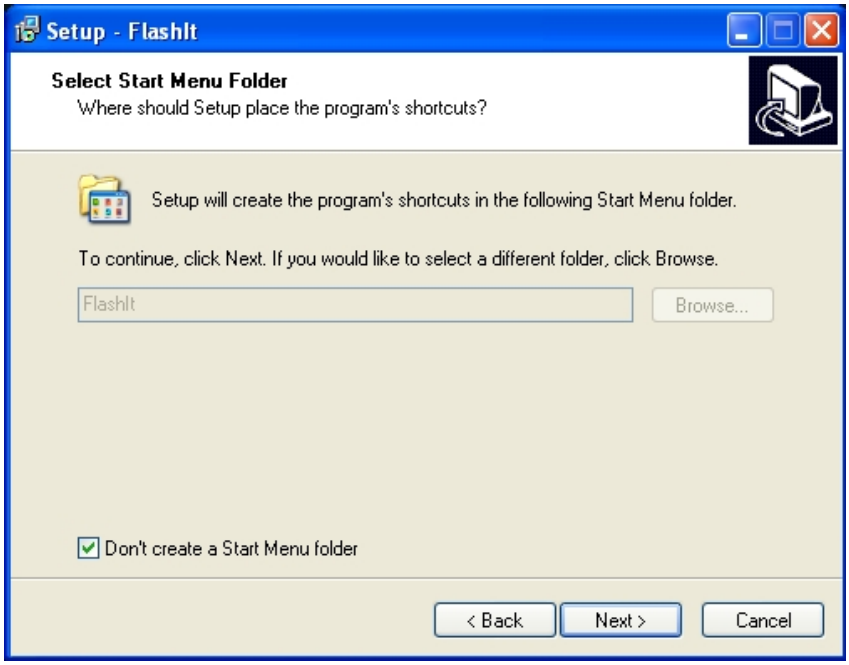
The FlashIt program is required to install new firmware on the 4G Supply. To install the program, run the Flashit installer.



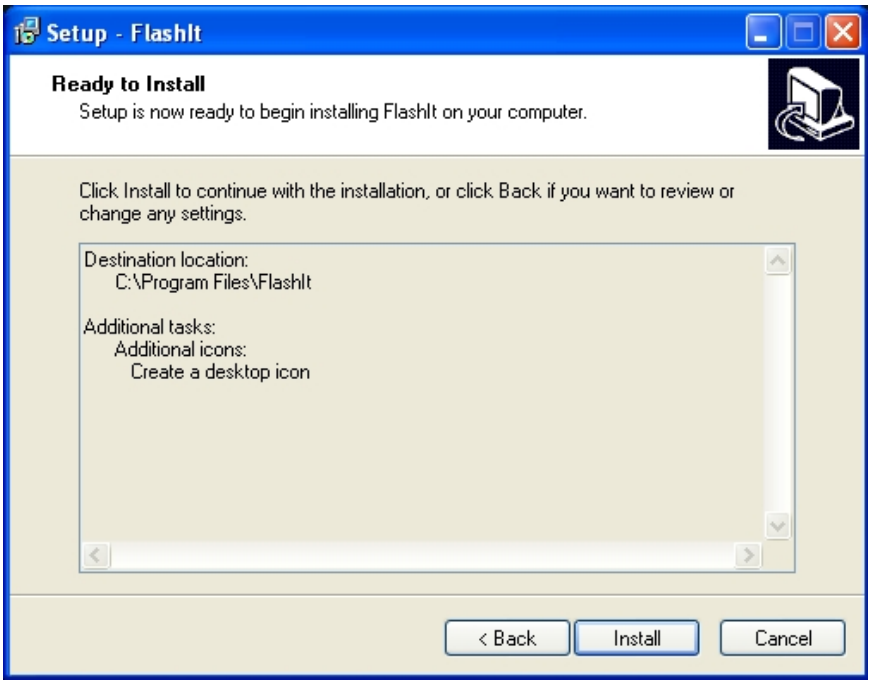
- Select Next >, then accept the EULA.

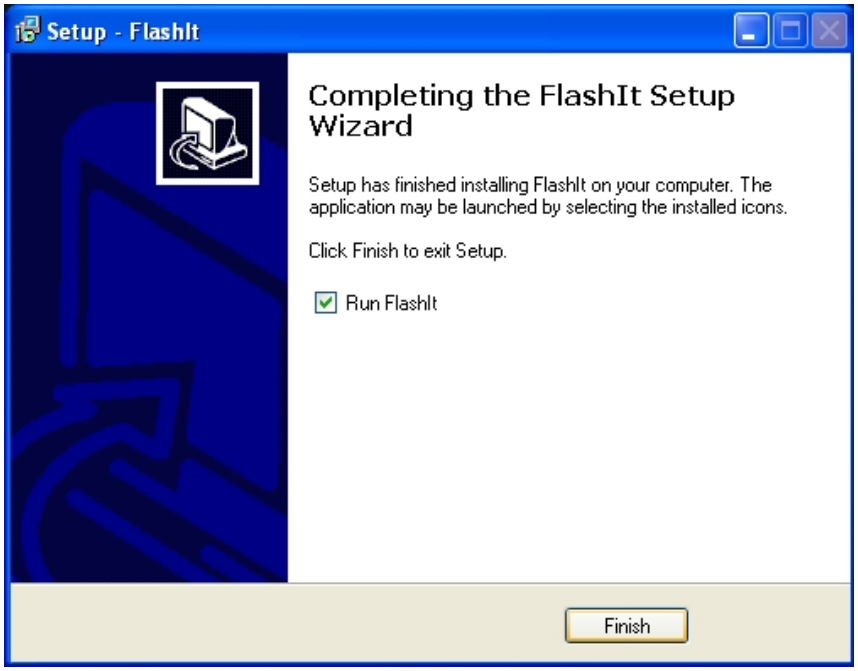
It is recommended that the default install location is used, then click Next >

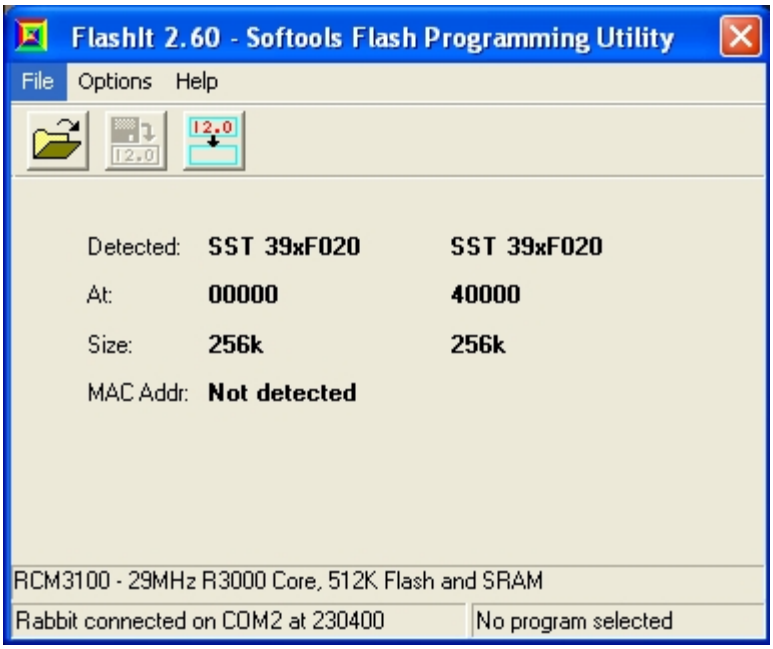




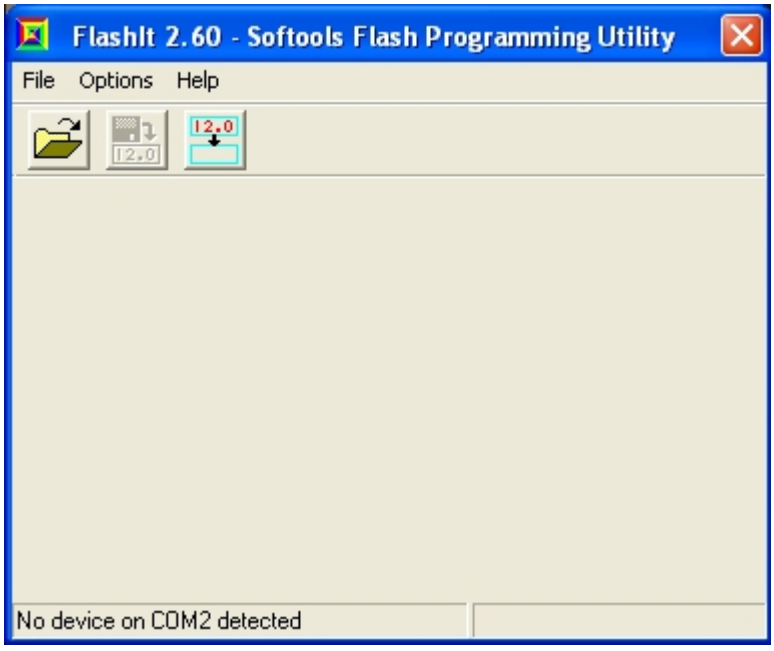
Install the program and run it.





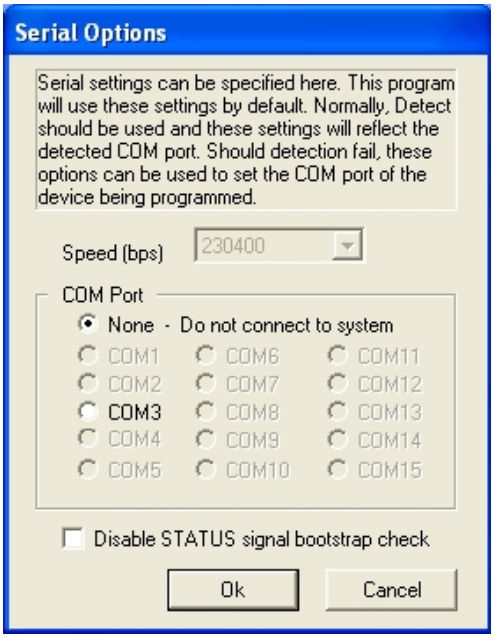


- When FlashIt starts up, it attempts to find the 4G (Rabbit processor) on its selected COM port. If it is successful, the above details are shown. If not, the below will be shown:

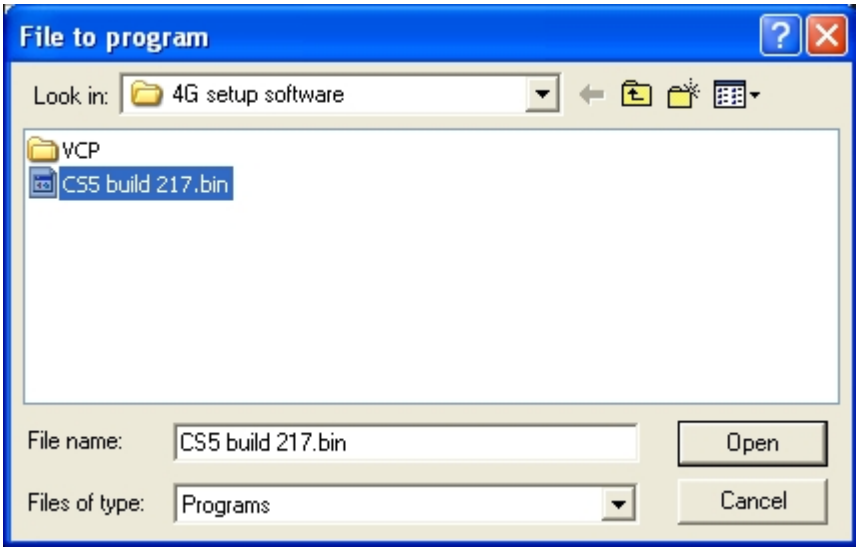


Go to Options and select Detect. The program will search all available COM ports for the 4G.

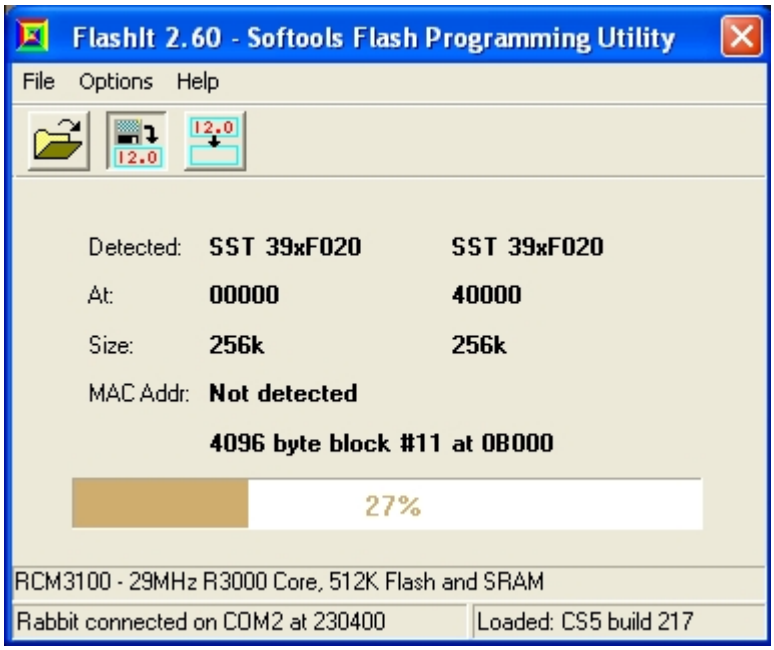
- If that is unsuccessful, go to Options, Serial, and select the 4G's COM port.



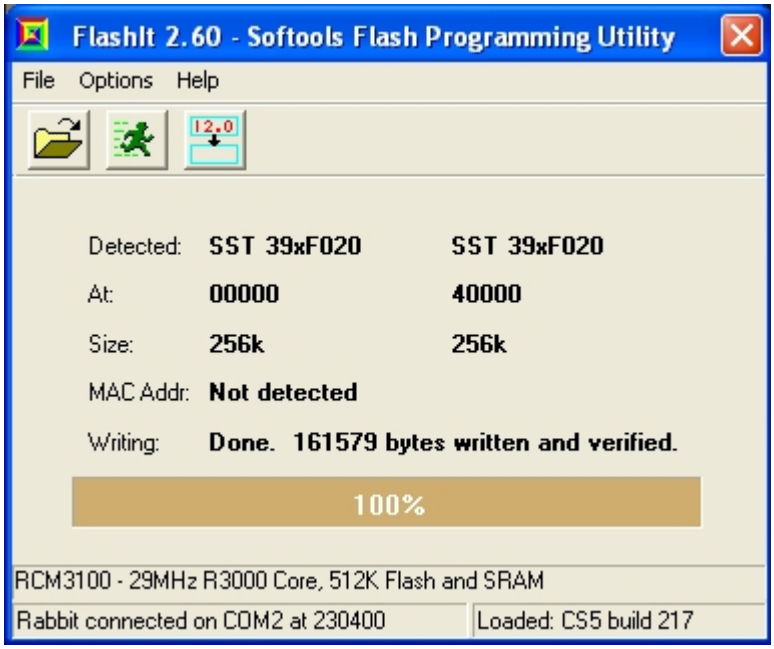
- At this point, the PC should be connected to the 4G. Click on the Folder Icon. Browse for the 4G binary file and select it.



- Press the center button to begin the upload.



- When complete, the following is displayed. FlashIt can be exited.



Power cycle the supply. When the unit is turned back on, a software upgrade message will appear if the software version number is different than the currently installed version, and the supply will automatically finish the update. The supply should restart automatically after completing the update. This process can take a few minutes to complete. If the supply hangs for more than five minutes, restart it and verify that the new version has been installed. If it has not, the update process will need to be repeated.

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Overview

The Shim Supply Option for the 4G Power Supply is a hardware and software upgrade that provides the user with the capability to control up to 12 independent superconducting shim coils in addition to the main superconducting magnet. Typical applications for this option are high homogeneity ICR or NMR magnets that incorporate superconducting shims to adjust and optimize central field shape.

Superconducting shim coils are, in effect, complete and self-contained superconducting magnets. Each consists of its own set of windings, its own persistent switch, and its own quench protection circuits. The coils are used to superimpose known magnetic field gradients over the homogeneous region of a magnet to correct for error components. Figure 12 shows a typical magnet with four superconducting shims (Z, Z2, X, and Y). These shims are typically referred to as “first order shims”, although technically Z2 generates a second order effect.

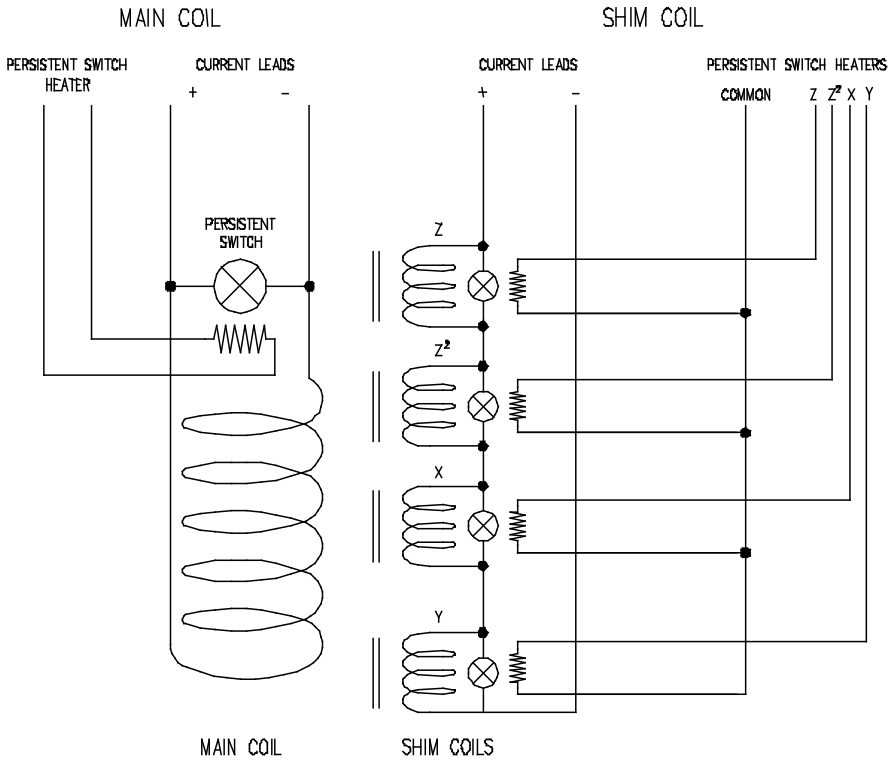

Figure 12: Superconducting Magnet with Shims

A comprehensive overview of superconducting shims and shimming is beyond the scope of this

Appendix. Considerable documentation exists that describes in detail the various inhomogeneities in magnetic fields and how to correct them. The purpose of this Appendix is to give a description of how the Shim Supply Option for the 4G Power Supply works, how to connect the Shim Supply Option to a magnet system, how to set up the supply, and how to operate the supply in Shim Mode.

Shim Option Description

The 4G power supply shim supply option allows the operator to use the 4G for energizing and discharging multiple superconducting shim coils. The option provides the following features:

a) 12 persistent switch heater output channels.
b) Polarity selection to allow shim multiplexing.
c) 0 – 100mA heater current range.
d) +/- 30 amp output current range.
e) Automatic shim dumping during main coil energizing/discharging.
f) Independent shim heater enable/disable.

The shim supply option provides the operator with 12 persistent switch heater output channels that are independently controllable through the menus of the 4G. The heater outputs may be configured in either “standard” or “multiplexed” arrangement. In the “standard” arrangement, each output channel corresponds to its own shim persistent switch heater. A common return (ground) line is used for all switches. This configuration is directly compatible with Figure 12 above.

Some superconducting magnet systems utilize a multiplexed heater arrangement to reduce the number of heater wires necessary to operate the shims. A multiplexed heater arrangement is shown schematically in Figure 13. Using a simple diode arrangement inside the magnet system, the number of heater wires is reduced by switching polarity of the heater signal to select the appropriate shim. For instance, positive output current on the Z/Z2 line activates the heater on the Z shim, while negative output current activates the heater on the Z2 shim. For multiplexed shim heater systems, the 4G Shim Supply Option offers the flexibility to be configured according to the user’s needs. Shims may be mapped to any of the outputs and may have either positive or negative polarity.

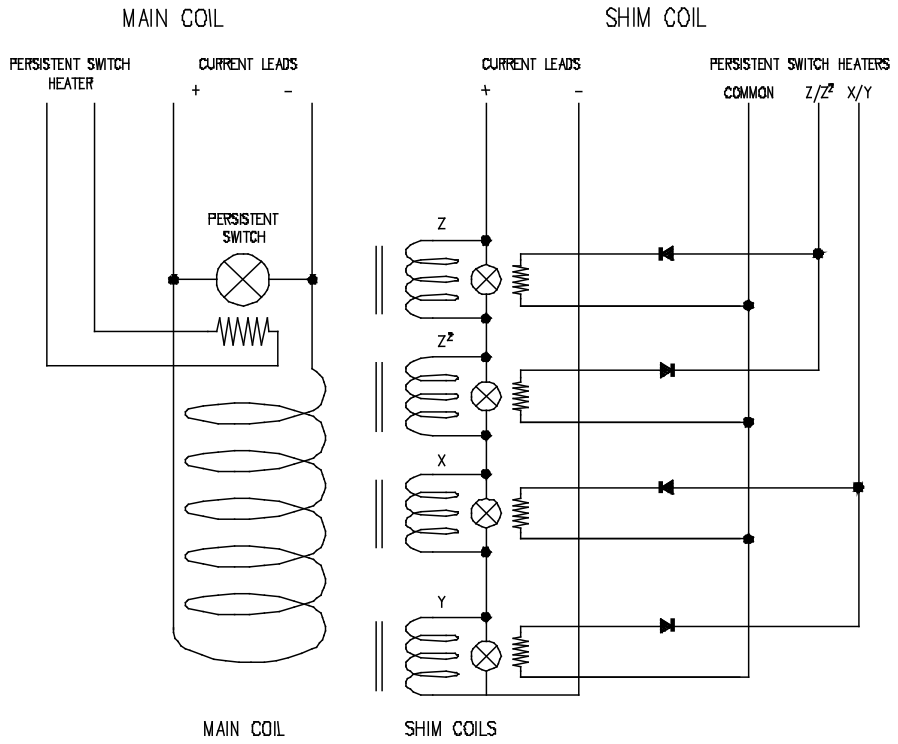

Figure 13: Superconducting Magnet with Multiplexed Shim Persistent Switch Heaters

When the 4G Shim Supply Option is activated, the 4G uses its main current outputs to set the shim coil current. In shim mode the supply is software limited to a maximum current output. The current limit for each shim, the persistent switch heater current for each shim, and its overall status (enabled or disabled) is controlled through the menu system via the front panel keys.

While the 4G is operating in Manual Mode (the standard mode used when energizing the main superconducting magnet), the Shim Supply Option will periodically activate the persistent switch heater of each enabled shim coil for a few seconds to “dump” any current that has been induced in the coil due to coupling (mutual inductance) between the main coil and the shim coil. Without periodic dumping of current induced in superconducting shim coils, current would build to values sufficient to quench the shim coil and possibly the main coil.

Once the main coil has been energized, the user typically will change from Manual Mode to Shim Mode with the 4G. In most systems, changing from main coil energizing to shim coil energizing requires the user to change to a different set of current leads.

Setup

The 4G shim supply option is designed for ease of use and to allow the user to set shim coils using a minimum of keystrokes. It provides considerable flexibility in setup and operation. There are built-in interlocks that reduce the risk of accidental dumping of a shim or quenching of a coil. However, it is still necessary for the operator to be familiar and experienced with shimming to reduce the chance of errors. It is highly recommended that the operator familiarizes themselves with the operation of the 4G shim supply option PRIOR to connecting it to an operating superconducting magnet.

MANUAL Mode

Mutual inductance coupling between shim coils and the main superconducting coil is inevitable. Due to this coupling, if the main coil is energized or discharged while the shim coils are in persistent mode, significant current can be induced in the shim coils. If this current is not periodically “dumped” during the main coil charge cycle, it can build to the point where a quench of the shim coil and/or the main coil occurs.

The 4G shim supply option is designed to periodically scan through the shims installed in the system to dump the current induced in them during main coil charge or discharge. Dumping a shim coil involves activating the persistent switch heater on the shim coil for a period of several seconds. By effectively quenching the persistent switch, the loop is “opened” and any current induced in the coil is converted to heat and is dissipated. While dumping shim coils it is usually a good idea to connect a low resistance (~ 5 ohms) load across the main current leads on the shim coils to prevent large voltage spikes from occurring.

The 4G shim option will step through each of the 12 shim coil heater outputs in the system. The unit activates each heater for approximately 6 seconds – long enough for the persistent switch to change to its “normal” state. Scanning of the shim coil heaters to dump them during main coil energizing or discharge may be inhibited by activating the global inhibit command while in manual mode.

SHIM Mode

The “Shim Mode” setting in the General Menu of the 4G is used to toggle the supply between MANUAL and SHIM modes. The user must have the 4G in an idle (STANDBY) state before a change from MANUAL to SHIM mode will be allowed. Likewise, returning from SHIM mode to MANUAL mode will be allowed only if all shims in the system are either dumped or disabled and the supply is in an idle (STANDBY) state. The “Shim Mode” setting only appears in the General Menu when these conditions are met.

The main operating display of the 4G while in SHIM mode is similar to the main operating display in

MANUAL mode. When in SHIM mode, the selected shim coil appears in the top right corner of the display, and the status of the enabled shims appears below the main portion of the display with the selected shim highlighted. The display indicates the present status of all enabled shim coils in the system.

Figure 14: SHIM Mode Operating Display

When operating in SHIM mode as indicated in Figure 14, the [Down] or [Shift-Up] softkey may be used to select the desired shim. Disabled shims do not appear in the list. If the currently selected shim is active (persistent switch heater ON), changing to another shim is inhibited. While in the Shim Mode Operating Display, the selected shim is the only shim enabled for control and adjustment. The selected shim's persistent switch may be activated, the shim may be swept up to the indicated current limit, the persistent switch heater may be turned off, and the supply may be swept back to zero output current leaving the shim in persistent mode at the desired current. All operations are identical to those found in the operation of the main superconducting magnet in MANUAL mode. Refer to paragraph H.4 for detailed operating instructions.

Setup Menu

Pressing the [Setup] softkey activates the Shim Setup Menu. This display shows the limit current and present current setting for each shim, the output channel and polarity, the enable status, and the programmed heater current. This menu gives access to the General Menu and Info Menu described in the main section of the manual and gives access to the Shim Edit menu.

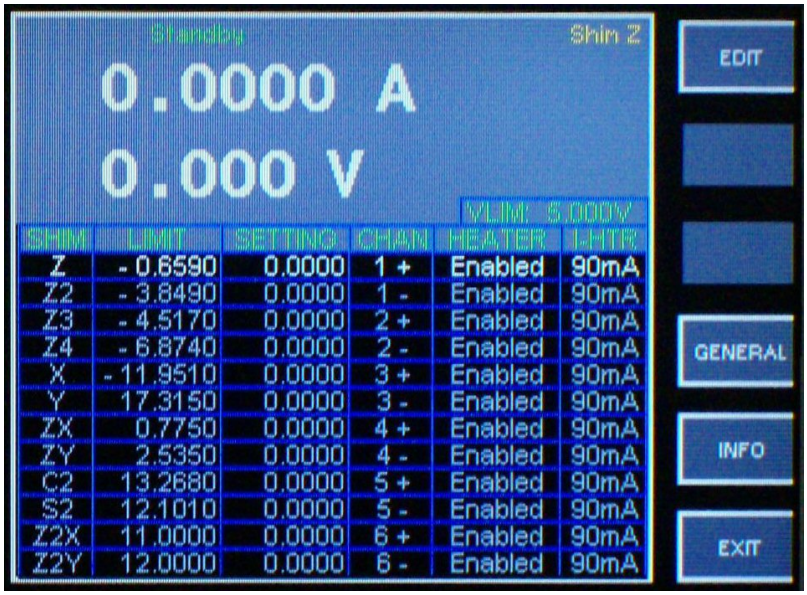

Figure 15: Shim Setup Menu

Edit Menu

The Shim Edit Menu is invoked by pressing the [Edit] softkey in the Shim Setup Menu. The Shim Edit Menu is indicated in Figure 15. Target Current, Present Current, Output Channel and Polarity, Enable/Disable, and Persistent Switch Heater Current are fields that may be edited. The [Down], [Shift-Up], [Right], and [Shift-Left] softkeys may be used to select the desired field.

If the shim name field is selected, the order the shims appear on the display may be changed by pressing [Move], [Up] or [Shift-Down], and finally [Change] to complete the action. A move may be cancelled by pressing the [ESC] key on the keypad.

When a field is selected for editing by the arrow keys, the desired value is entered on the keypad. The change is accepted by pressing the [Save] softkey or cancelled by pressing the [ESC] key. A shim is enabled or disabled by selecting the field and toggling the value with the [Change] softkey and accepting the result with the [Save] softkey.

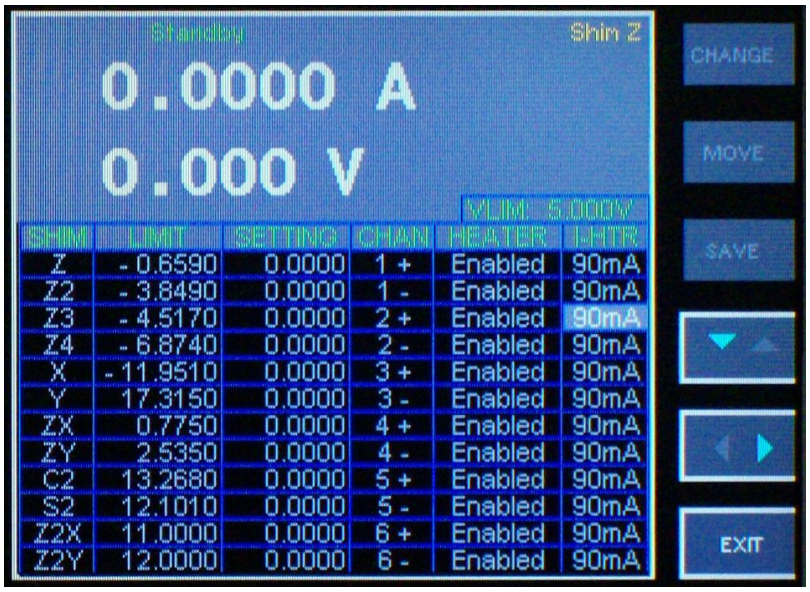

Figure 16: Shim Edit Menu

The “Limit” field is the current limit that will be used when operating the shim coil.

The “Setting” field is the value of current the 4G believes has been left in the shim coil when it was last put into persistent mode. This is an editable field since it is possible for a quench of the shim to occur without the 4G detecting it. If this happens, the user may manually reset the present current value to zero.

The “Chan” field allows the user to map the shim to a specified output channel and with a specified polarity. Valid output channels are 1 through 12 with either + or – polarity. If the user attempts to exit the Edit Menu with more than one shim set to a channel/polarity already occupied by another shim, the changes in the edit session cannot be saved. The changes may only be discarded, or the edit session may be continued to correct the errors.

The “Heater” field allows a particular shim coil to be enabled or disabled. This may be used when the particular shim is not present in the system, or when the user wishes to disable it to lock it down and prevent dumping of the shim during main coil field changes.

The “I-Htr” field is the persistent switch heater current for the particular shim. This current may be anywhere from 0 to 100 milliamps. The current value, along with the channel polarity, determines the polarity and magnitude of the persistent switch heater current applied to the specified channel when the shim is selected. If only six shim outputs are used, the heater current is allowed to be set up to 150 milliamps, which requires two shim outputs to be wired in parallel. The paired outputs

must be 1/7, 2/8, 3/9, 4/10, 5/11, and 6/12. The firmware assumes the outputs are paralleled if a current greater than 100 milliamps is entered for the switch heater current.

Hardware Connections

Connection of the 4G Shim Option to the shim coil persistent switch heaters is done through a DB-15 connector on the rear panel of the supply. Main output current to the shim coils is provided through the high current output terminals. Table 4 indicates wiring assignments.

Table 4: Persistent Switch Heater Pinout

Pin #	Function	Pin #	Function
1	Channel 1	9	Channel 7
2	Channel 2	10	Channel 8
3	Channel 3	11	Channel 9
4	Channel 4	12	Channel 10
5	Channel 5	13	Channel 11
6	Channel 6	14	Channel 12
7	Common	15	Common
8	Common		

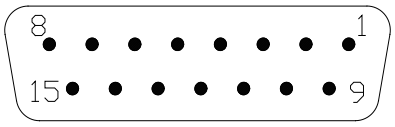

Figure 17: Shim Output Connector

(Facing Panel)

Operation

Once the shims have been set up through the menus of the 4G and all connections are made to the persistent switch heaters and main current leads, the system is ready to operate. The 4G power supply shim supply option is intuitive and designed for ease of use.

Energizing Shims

When starting with fully dumped shims and with the 4G in SHIM mode (main operating display as indicated in Figure 14), the user will typically perform the following sequence of events to set the selected shim.

Procedure for Initial Setting of Shim Coil Currents

a) Use the [Down] or [Shift-Up] softkey to select the first shim to be set.
b) Press the [Pers Htr] softkey and [Confirm Htr On] softkey to confirm and turn ON the persistent switch heater.
c) Wait about 10 seconds for the persistent switch to warm.
d) Press the [Limit] softkey to begin energizing the shim coil. The 4G will begin sweeping in the direction of the requested current limit. Once the limit is reached, the 4G will hold that current.
e) Press the [Pers Htr] softkey and [Confirm Htr Off] softkey to confirm and turn OFF the

persistent switch heater.

f) Wait about 10 seconds for the persistent switch to cool.
g) Press the [Zero] key to bring the current in the power leads back to zero. [Shift-Zero] may be used to more quickly return to zero if desired.

After completing the sequence, the operator will use the [Up] or [Shift-Down] softkey to change to the next shim coil. The procedure will be repeated to set this shim coil current. Likewise, all other shims are set. Once a first pass setting of each shim coil has been made, typically a second pass is made through the shims to minimize the effects of mutual inductance coupling from shim-to-shim. In the second and subsequent passes, the procedure is as follows:

Procedure for Resetting Shim Coil Currents

a) Use the [Up] or [Shift-Down] softkey to select the desired shim.
b) Press the limit or shim softkey to bring the current in the power leads back to the current limit (the same value that was left in the shim coil). Alternatively, the [Shift-Limit] or [Shift-Shim] softkey may be used to fast sweep back to the shim current.
c) Press the [Pers Htr] softkey and [Confirm Htr On] softkey to confirm and turn ON the persistent switch heater.
d) Wait about 10 seconds for the persistent switch to warm and the current in the shim to stabilize at the current limit.
e) Press the [Pers Htr] softkey and [Confirm Htr Off] softkey to confirm and turn OFF the persistent switch heater.
f) Wait about 10 seconds for the persistent switch to cool.
g) At this point, the shim is in persistent mode and the operator has two options – 1) press the [Zero] softkey (or [Shift-Zero]) softkey to bring the current in the power leads back to zero, or 2) use the [Down] or [Shift-Up] softkey to proceed directly to setting the next shim. It is not necessary to sweep the output current of the supply to zero prior to moving on to the next shim.

This process (b through f) should be repeated for each shim.

Discharging Shims

The 4G requires that all shims be either disabled or discharged before it will allow the user to change back to Manual mode for control of the main magnet. If only a minor change in main coil current is desired (e.g., to fine tune Z0), the user may want to leave the currents in the shim coils while the change in main coil current is made. To do this, each shim coil that is not set at zero current must be disabled as described in section H.3.4.

To discharge a shim coil to zero current, the following sequence is typically followed:

a) Use the [Up] or [Shift-Down] softkey to select the desired shim.
b) Press the [Limit] or [Shim] softkey to bring the current in the power leads back to the current limit (the same value that was left in the shim coil). Alternatively, the [Shift-Limit] or [Shift-Shim] softkey may be used to fast sweep back to the current limit or shim current.
c) Press the [Pers Htr] softkey and [Confirm Htr On] softkey to confirm and turn ON the persistent switch heater.
d) Wait about 10 seconds for the persistent switch to warm.
e) Press the [Zero] key to sweep the current in the shim coil back to zero.
f) After the current stabilizes at zero and the 4G enters STANDBY mode, press the [Pers Htr] softkey and [Confirm Htr Off] softkey to confirm and turn OFF the persistent switch heater.
g) Wait about 10 seconds for the persistent switch to cool.
h) Go to step “a” to select the next shim and repeat the process for each shim.

After zeroing or disabling each shim coil, the user may change the 4G back to Manual mode if desired.

CAUTION

When changing the 4G back to MANUAL mode, be aware that the supply’s firmware safety limit (typically +/- 30 amps) is no longer enabled. The 4G becomes capable of sourcing its full output current rating (e.g. 100 amps for a 4G-100). Most shim coils are not designed to handle high currents and could be quenched and/or damaged by them. Be sure to change the 4G’s power leads back to the main coil’s current terminals when changing back to MANUAL mode to avoid damaging the system.