

**CRYOMAGNETICS, INC.**

OPERATING INSTRUCTION AND MAINTENANCE MANUAL

FOR

IPS 20/50/100 MAGNET POWER SYSTEMS

SN C-10061

CAUTION: DO NOT ATTEMPT TO OPERATE THIS EQUIPMENT  
BEFORE THOROUGHLY READING THIS MANUAL.

INNOVATION AND EXCELLENCE IN CRYOMAGNETICS

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## 1.0 GENERAL INFORMATION

### 1.1 Introduction

Cryomagnetics, Incorporated superconducting magnet power systems are designed to provide stable and efficient energizing, discharging, and controlling of highly inductive loads common to superconductive magnet systems. The IPS (Integrated Power System) series combines the functions of Sweep Generator, High Current Power Supply, Energy Absorber, Quench Protection, Persistent Switch Heater Power Supplies, and System Monitoring Electronics into a single, compact, extremely versatile instrument. Advanced circuit design, and construction and calibration techniques enable the IPS power supply to generate reliably stable output currents with excellent low noise specifications. In addition, the IPS power supplies all contain Cryomagnetics' proprietary quench detection circuitry which automatically and smoothly shuts off the power supply if a sudden load error is sensed.

### 1.2 Description

The three models of IPS power supplies described in this manual all use fully transistorized series-type power regulation. They are linear supplies which utilize a very low noise triac preregulator for high efficiency, excellent regulation, and low ripple. All supplies come with full 19 inch standard width rack-mountable cabinets and are suitable for either rack or bench top use.

The IPS power supplies provide a multitude of features including:

#### 1.2a Current Monitor

A 4½ digit LED display is provided to indicate operating current, charge rate, or the preset current limit in amperes and amperes/second.

#### 1.2b Voltage Monitor

A 3½ digit LED display is provided to indicate the power supply's

output voltage, actual magnet voltage, or the preset voltage limit in volts. Displaying of the actual magnet voltage requires that a pair of voltage taps be connected from the magnet's power leads in the dewar to the rear panel terminal strip on the supply.

#### 1.2c Preset Current Limit

The Current Limit is set on a front panel 10-turn lockable dial between zero and the full scale output of the supply. The limit setting can be displayed before affecting the supply's output. When the supply reaches current limit, a front-panel LED is illuminated indicating that the output current is stable.

#### 1.2d Preset Charge Rate

The Charge Rate for the magnet is set on a lockable 10-turn dial between zero and 1.000 amperes per second. The rate is valid for both the charge and discharge of the magnet. The rate can be displayed and precisely set using the current monitor display.

#### 1.2e Fast Ramp

The Fast Ramp capability allows the user to override the preset charge rate with a faster (10 a/s) ramp. This feature lets the operator quickly bring the supply back to zero current after putting the magnet in persistent mode; or to quickly return the supply's current back to the current limit when coming out of persistent mode.

#### 1.2f Preset Voltage Limit

The Voltage Limit of the supply is set on a front panel 10-turn lockable dial between zero and 5 volts. The voltage limit is used to prevent overvoltage on the magnet. The voltage limit set is valid for both positive and negative output levels (i.e. charging and discharging the magnet). The limit setting can be displayed before affecting the supply's output. When the supply reaches its voltage limit, a front

panel LED is illuminated.

#### 1.2g Energy Absorbing

All supplies contain built-in energy absorbing capabilities to allow the supply to efficiently discharge the energy stored in a magnet. The supply is capable of absorbing energy at up to -5 volts at its full rated current. Output current from the supply is always between zero and + full scale current at +5 to -5 volts (2 quadrant operation). A current reversing switch is available to provide full four (4) quadrant operation. The energy absorber has a built-in automatic thermal shut-down as a safety precaution.

#### 1.2h Quench Protection

Both the superconducting magnet and the IPS power supply are protected from over-voltage damage due to magnet quench through the use of SCR crowbars. The built-in SCR's trip to "short" the supply's output if a voltage of more than 15 volts (+ or -) is detected at the supply's output.

#### 1.2i Quench Detection

Cryomagnetics' proprietary quench detection and automatic shut-down is built into all IPS power supplies. This circuitry monitors the supply's load (superconducting magnet) and is sensitive to sudden changes in this load. If a load change is detected, the supply is smoothly and quickly returned to zero output current. The supply is disabled from ramping back up until the detection circuitry is reset via a rear panel pushbutton switch. A LED is used to indicate that the quench detector has tripped. The quench detector (error detect) can be disabled for use in "noisy" load environments.

### 1.2j Remote Control

All front and rear panel functions can be remotely controlled via a terminal strip including current limit, voltage limit, charge rate, up/pause/down ramp control, error detect reset, and persistent switch heater supplies. In addition, the terminal strip provides the user with output signals such as operating current, current limit LED status, voltage limit LED status, and quench detection circuitry status. A complete RS-232C/IEEE-488 controller is available as an option.

### 1.2k Persistent Switch Heater Power Supplies

Two Persistent Switch Heater Power Supplies are built-in to allow multiple magnets to be powered from a single supply (not available on IPS-20).

### 1.3 Specifications

	IPS-20	IPS-50	IPS-100
OUTPUT POWER RATING	0-20 AMPS, ±5 VOLTS	0-50 AMPS, ±5 VOLTS	0-100 AMPS, ±5 VOLTS
POWER CONSUMPTION	110/115V, 4A*	200/230V, 6A**	200/230V, 12**
OUTPUT CURRENT SETTABILITY	BETTER THAN 0.1%		
OUTPUT CURRENT STABILITY	<0.005% per hour		
RIPPLE AND NOISE (RESISTIVE LOAD)	<100 mA p/p		
LINE REGULATION	0.005%		
LOAD REGULATION	0.05%		
CURRENT MONITOR	0.10 V/A		
EXTERNAL PROGRAMMING	CURRENT LIMIT: 0.10V/A VOLTAGE LIMIT: 1.00V/V UP/PAUSE/DOWN: +5V/0V (TTL COMPATIBLE) CHARGE RATE: 10.0V/(A/S)		
SWITCH HEATER OUTPUT	N/A	2 EACH, 0-100 mA	2 EACH, 0-100 mA
SWEEP RATE	0.010 — 1.000 A/S		
COOLING	FORCED-AIR WITH OVER-TEMPERATURE SHUTDOWN ON TRANSISTOR BANK		
CABINET DIMENSIONS	19" W X 5.187" H X 14.25" D	19" W X 8.75" H X 20" D	19" W X 8.75" H X 20" D
WEIGHT	30 LBS (13.6 KG)	90 LBS (40.9 KG)	110 LBS. (50.0 KG)

\*200/230V, 2A AVAILABLE

\*\*110/115V AVAILABLE (multiply current by 2)

## 1.4 Options

Cryomagnetics manufactures a full line of related support devices for superconducting magnet power systems.

### 1.4a Helium Vapor-Cooled Current Leads

Introducing high currents to a cryogenic environment can cause high heat loads on a system's cryogens. Cryomagnetics manufactures current leads which utilize the cold helium off-gas from a system to cool the high current power leads. These leads are optimized to introduce a minimal heat load into the cryostat. Installation of the leads is simple and retractable accessories are available for ultra low loss systems. Standard designs are optimized for currents up to 3000 amperes.

### 1.4b Computer Interface Module (CIM)

Cryomagnetics' CIM can be used to control virtually all functions on the IPS power supplies through standard RS-232C or IEEE-488 (GPIB) computer interfaces. Both interfaces are provided. The CIM is extremely versatile in that it can also be used to monitor and/or control other functions in the user's system. In particular, the CIM provides 8 analog ports which can be user defined as inputs or outputs. These analog ports have a +10 to -10 volt range with 13 bit resolution. In addition, the CIM has 18 binary ports which are TTL compatible. The CIM can be configured to take data locally and store it in its 3500 sample memory.

### 1.4c Current Reversing Switch

Cryomagnetics' Current Reversing Switch provides the user with safe reversing of power supply high current leads. The instrument is safety interlocked to prevent switching of the power leads unless zero



current is present in them. The CRS is protected against power failure and quenches also. The CRS can be remotely controlled either, through the user's circuitry or through Cryomagnetics' Computer Interface Module (1.4b above).

## 2.0 INSTALLATION

The IPS power supply has been shipped ready for permanent installation or bench top use. It is only necessary to connect the instrument to a power source and it is ready to operate.

### 2.1 Initial Inspection

Before shipment, this instrument was inspected and found to be free of mechanical and electrical defects. A rigorous check-out, calibration, and burn-in procedure is followed on all supplies.

As the supply is unpacked, inspect it for any damage that may have occurred in transit. Save all packing materials until the inspection and turn-on check-out procedures have been completed. If damage is found during inspection, file a claim with the carrier immediately. Also notify Cryomagnetics as soon as possible.

Initial inspection should include verifications that all knobs and switches operate properly and are undamaged. Also, the cabinet and panels should be checked and free of scratches and dents.

### 2.2 Location and Cooling

All IPS power supplies are fan cooled and must be installed with sufficient space for cooling air to flow freely through them. The IPS power supplies have two exhaust ports exiting the rear of the supplies and two air inlet ports on the sides. All exhaust ports and inlet ports should have free access to air with a minimum of direct recirculation. the supplies should be used in an area where the ambient air temperature at the inlet does not exceed 50°C.

Rack mounting of the instrument is available on the front panel. Due to the weight of the instruments, it is suggested that bottom support in the form of a tray be provided for the supply to eliminate the chance of

bending the front panel of the supply or cabinet.

### 2.3 Input Power Requirements

Input power cords for the supply are provided with the instrument. Standard power connections call for 110/115 VAC single phase power for the IPS-20 and 200/230 VAC single phase power for the IPS-50 and IPS-100. The IPS-20 can be modified for 200/230 VAC use and the IPS-50/100 can be modified for 110/115 VAC use. Consult the factory if this change is necessary. Additional input power requirements are detailed in section 1.3.

### 2.4 Repackaging for Shipment

To insure safe shipment of the instrument, it is recommended that the original package designed for the instrument be saved and reused. The instrument should be wrapped with plastic and then inserted into the box with the foam protection in place. A tag should be attached to the instrument with the serial number of the instrument and the owner's name and phone number on it. A brief description of the problem with the instrument should accompany the supply if it is being returned for repair.

### 3.0 OPERATING INSTRUCTIONS

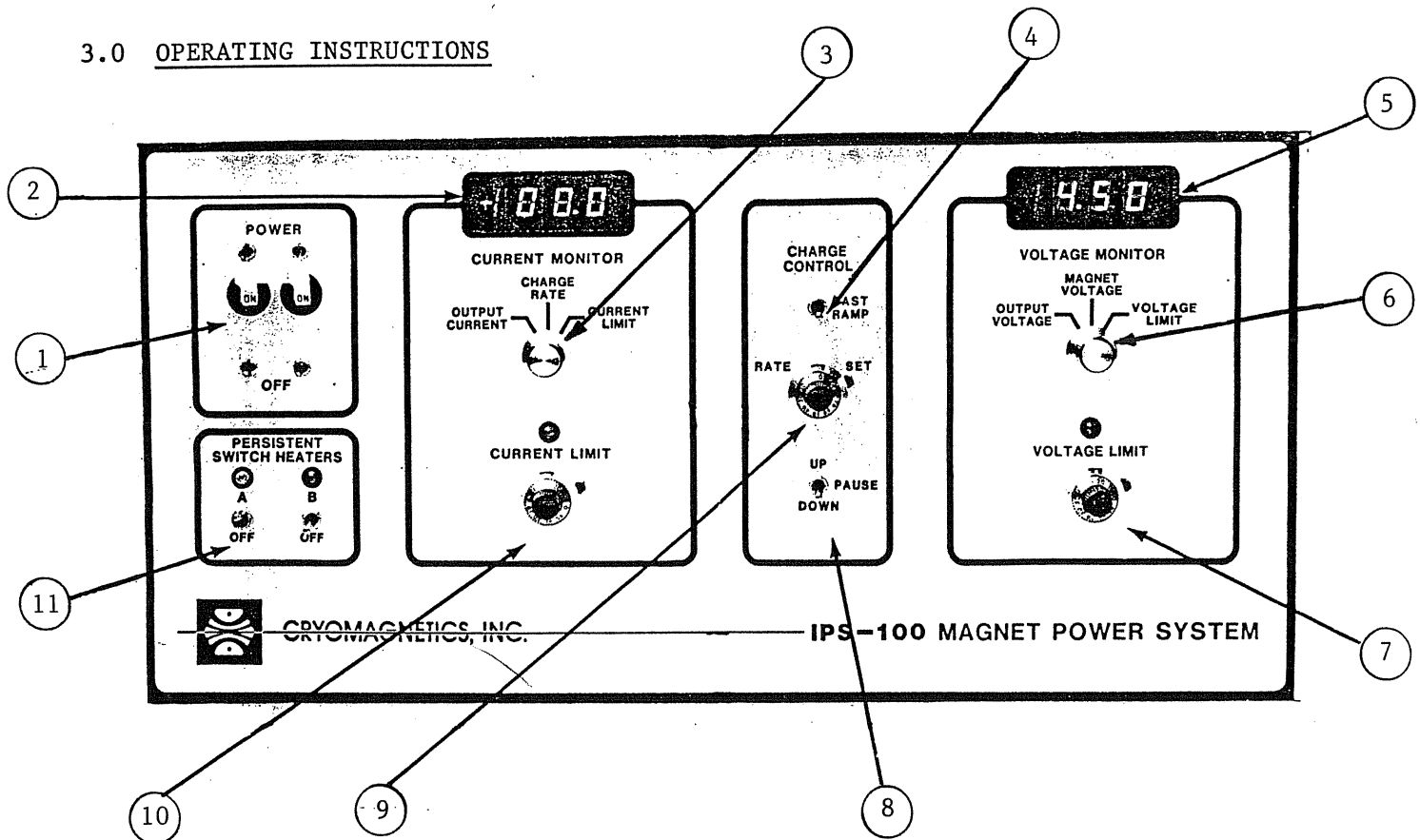


FIGURE 3-1. Front Panel Controls and Displays

The following operating procedures should be observed in order to insure safe and trouble-free performance from the IPS power supply. It is recommended that this section be thoroughly read prior to actually operating the supply.

#### 3.1 Turn-on and Checkout Procedure

The following steps describe use of the front and rear panel controls and indicators detailed in Figures 3-1 and 3-2. These steps provide an initial check of the supply's operational capabilities as well as familiarizing the user with the controls. The procedure does not require the use of the magnet.

3.1a With the POWER OFF and the supply unplugged, connect a short across the output terminals of the supply (19). This short can be either directly on the back of the supply or at the end of the power cables.

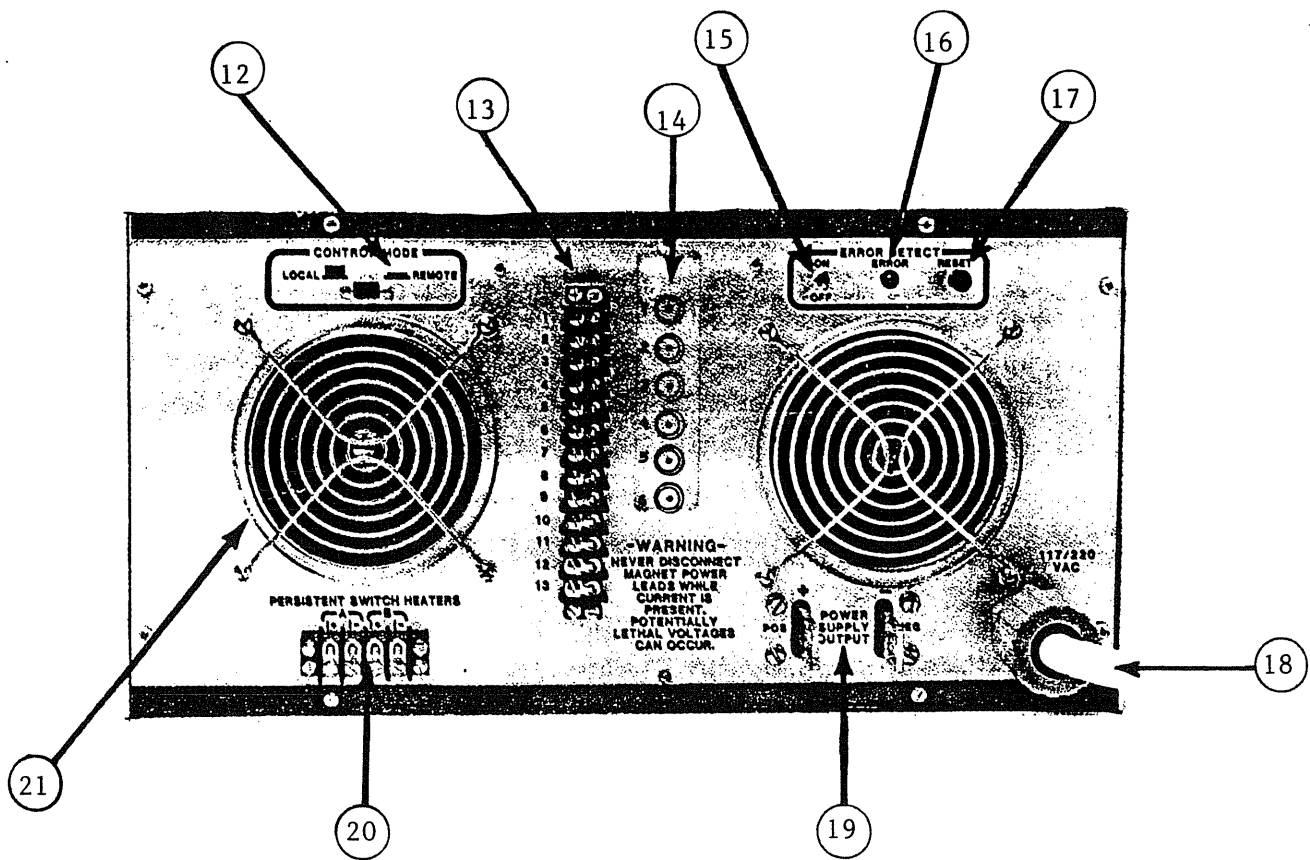


FIGURE 3-2. Rear Panel Controls and Displays

3.1b Plug the supply into the appropriate power source using the provided line cord (18).

3.1c Set the front panel charge control switch (8) to the DOWN position. Turn the Current Limit dial (10), Rate Set dial (9), and Voltage Limit dial (7) to full scale (full clockwise).

3.1d Set the Current Monitor Selector Switch (3) to display Current Limit and the Voltage Monitor Selector Switch (6) to display Voltage Limit.

3.1e Turn off both Persistent Switch Heaters (11).

3.1f Make sure that rear panel Control Mode switch (12) is set to LOCAL and the Error Detect switch (15) is ON.

3.1g POWER ON the supply using the front panel circuit breaker switch (1). The Current Monitor display should read approximately 101.0 amperes and the Voltage Monitor display should read approximately

5.25

5.30 volts. These are the preset limit settings for the supply. Check to see that the Current Limit dial (10) changes the Current Monitor display. Likewise check that the Voltage Limit dial (7) changes the Voltage Monitor display. Return the Limit dials (10) and (7) to the full clockwise position. The instrument has been calibrated such that the LED displays represent the current settings for the limits. The number indicated on the dials (10) and (7) should not be used.

3.1h Switch the Current Monitor Selector Switch (3) to display Charge Rate. The display should read approximately -1.000 amperes per second. Turn the Rate Set dial (9) to check that the displayed charge rate varies. Return the Rate dial to the full clockwise position.

3.1i Switch the Voltage Monitor Selector Switch (6) to display Magnet Voltage. The display should indicate 0.00 volts.

3.1j Switch the Voltage Monitor Selector Switch (6) to display Output Voltage. Again the display should indicate 0.00 volts.

3.1k Switch the Current Monitor Selector Switch (3) to display the supply's Output Current. The Current Limit has been preset to about 100 amps, the Voltage Limit preset to 5.30 volts, and the Charge Rate at one (1) ampere per second.

3.1l Switch the Charge Control (8) to the UP position and see that the current begins to rise at 1 ampere per second. If the current does not rise, check the Error Detect LED (16) for illumination. If the LED is on, press the RESET switch (17) and release it to extinguish the LED. The current should now rise. Eventually, a small voltage will appear on the voltage monitor corresponding to the IR drop across the "shorted" output. Verify that the PAUSE and DOWN positions of the

Charge Control Switch (8) operate properly. ✓

3.1m When the supply reaches Current Limit (100 amperes), verify that the Current Limit LED illuminates. Switch the Charge Control to the DOWN position.

3.1n While the current is ramping down, switch up and hold the FAST RAMP switch (4). Notice that the current decreases much more rapidly. Release the switch and see that the rate returns to 1 ampere per second. Verify that the FAST RAMP works properly when the Charge Control Switch (8) is in the UP position as well. ✓

3.1o Return the supply to zero (0) current. Connect an ammeter between I+ and I- on Persistent Switch Heater output "A" on the rear panel of the supply (20). Switch ON Persistent Switch Heater A on the front panel (11) and check that the LED associated with it illuminates. Check that the current through the ammeter is about 50 mA. This current can be adjusted between 0 and 100 mA using a potentiometer internal to the supply (see section 5.2, Calibration). Switch OFF Persistent Switch Heater A and repeat the procedure using I+ and I- on Heater B. <sup>55mA</sup> 55mA

This completes the preliminary checkout procedure for the supply.

### 3.2 Normal (LOCAL) Operating Mode

The LOCAL Operating mode is the mode in which the user operates the supply via the front and rear panel knobs and switches. The user should be fully familiar with the controls of the supply before attempting to operate it with a magnet. It is recommended that the learning procedures be performed with the rear panel output terminals shorted until he/she is comfortable with the supply. Only then should it be attached to the magnet. This should minimize the chance of an accidental quench.

#### 3.2a Setting the Limits

The Output Current Limit and Voltage Limit Settings are straight

forward on the IPS supplies. The limits can be easily set and displayed prior to affecting the output of the supply. Current Limit is set according to the magnetic field desired, while Voltage Limit is set as a protective measure. Under normal operating conditions the Voltage Limit should not be reached. A smooth linear ramp of a magnet is achieved by maintaining the output voltage of the supply below the Voltage Limit setting.

Maximum stability and minimum drift performance of the supply is obtained when the supply is ramped up to the Current Limit and left in the UP mode.

\* \* \* IMPORTANT \* \* \*

IT IS A FAIRLY COMMON HABIT OF USERS TO RAMP THE SUPPLY UP TO THE DESIRED CURRENT LIMIT AND THEN TO SWITCH THE SUPPLY TO "PAUSE". THIS SHOULD NOT BE DONE!! THE POWER SUPPLY CAN DRIFT SOME WHEN PLACED IN THE "PAUSE" MODE FOR EXTENDED PERIODS OF TIME - POSSIBLY RESULTING IN AN EVENTUAL QUENCH. TO ACHIEVE MINIMUM DRIFT OF THE SUPPLY AND TO INSURE THAT THE CURRENT LIMIT IS NEVER EXCEEDED, THE SUPPLY SHOULD BE LEFT IN THE "UP" MODE AGAINST THE CURRENT LIMIT.

\* \* \* \* \*

### 3.2b Setting the Charge Rate

The Charge Rate for Cryomagnetics' Power Supplies are set directly in amperes per second. If one knows the inductance (L) of their magnet, this makes the charge rate very easy to set. Using the

equation 
$$\frac{di}{dt} = \frac{V}{L}$$
 one can easily compute the desired rate for their particular magnet. In this equation, di=amperes, dt=seconds, V=volts and L=henries. Thus  $\frac{di}{dt}$  is specified in ampere/second - the same units used by the power supply. L=9.9 H



For example, if the user has a 9.80 henry magnet and wishes to charge it at 2.00 volts, they could compute

$$\frac{di}{dt} = \frac{2.00}{9.80} = 0.204 \text{ amperes/second}$$

One would then set the Current Monitor Selector switch (3) to display Charge Rate and would adjust the Rate Set dial (9) until 0.204 is displayed. This Charge Rate will be valid for both the charge and discharge of the magnet.

### 3.2c Ramp UP/PAUSE/DOWN and FAST RAMP

The Charge Control switches for the power system are used for ramping the power supply's current up and down. Under normal operating conditions where a superconducting magnet load is attached to the supply, the Charge Rate setting determined in section 3.2b will be used. During times when the supply is being used on a resistive or shorted load, the preset Charge Rate can be over-ridden using the FAST RAMP switch. An example of the proper use of the UP/PAUSE/DOWN and FAST RAMP switches would be the following:

Assume the 9.8 henry superconducting magnet described in section 3.2B is attached to the power supply. The user would first check that the Charge Control switch is in the ramp DOWN position. Then the power to the supply would be turned ON. The user would verify that the Charge Rate is set to 0.204 amperes per second and that the proper Current Limit setting has been entered. Assuming the magnet's persistent switch heater was connected to Persistent Switch Heater Supply A, this heater would be turned ON. After a few seconds for the switch to warm, the Charge Control Switch would be switched to the ramp UP position. The current from the supply would begin to increase at 0.204 amperes per second and the user

would verify that 2.00 volts appear across the magnet terminals.

When Current Limit is reached, the Current Limit LED will illuminate and the voltage across the magnet will be seen to drop to zero indicating a stable output current. The Persistent Switch Heater Supply A would then be switched OFF.

After a few seconds for the switch to cool, the user would switch the Charge Control switch to the ramp DOWN position. The power supply's current will begin to decrease at -0.204 amperes per second. The voltage across the magnet would then be checked to ensure that it is still zero volts (indicating that the magnet is, indeed, locked in persistent mode).

\* \* \* IMPORTANT \* \* \*

ONE SHOULD ALWAYS VERIFY THAT THE MAGNET IS IN PERSISTENT MODE BEFORE USING THE FAST RAMP SWITCH TO BRING DOWN THE POWER SUPPLY CURRENT. IF THE MAGNET IS NOT IN PERSISTENT MODE WHEN THE FAST RAMP IS PRESSED A QUENCH MAY RESULT DUE TO THE SUPPLY ATTEMPTING TO DISCHARGE THE MAGNET TOO QUICKLY!

\* \* \* \* \*

Since the supply is effectively operating with a short as a load now, the supply can be quickly returned to zero current by pressing the FAST RAMP switch and holding it. Likewise, when one is ready to remove the magnet from persistent mode operation, the supply can be ramped quickly back up to Current Limit using the FAST RAMP switch and then the Persistent Switch Heater Supply A turned ON.

### 3.2d ERROR (Quench) DETECTOR

The Error Detector built into the IPS supply is a proprietary circuit that monitors the output current of the supply and watches for

sudden changes. In general, these changes indicate that a quench is occurring. If a quench or load error occurs, the Error Detect circuitry quickly and smoothly shuts down the power supply so that the user's persistent switch and/or quench protection devices are not destroyed by the power supply's attempts to maintain current in its leads.

There are two cases where one could encounter incompatibilities between the Error Detect circuitry and their magnet system. The first potential problem lies in the fact that some magnets have extremely fast quench protection devices across their input leads. If this is the case, it is possible for a quench to go undetected by the Error Detect circuit. This problem is actually fairly rare; however, due to the fact that the Error Detect circuit is very sensitive.

Another potential concern with the Error Detect system is the possibility of a false trigger when a noisy load is placed on the supply. Most superconducting magnets are relatively quiet though, and this problem is usually encountered when a rapidly varying resistive load is on the supply.

Due to the fact that the Error Detector can have potential faults, it can be disabled should the user desire it, simply by switching the Error Detect switch to the OFF position.

### 3.3 REMOTE Operating Mode

The REMOTE Operating Mode is the mode in which the user operates the supply via rear panel connections to the supply rather than using the front panel controls. When the supply is placed in the REMOTE mode, almost all front panel controls are disabled. It is left to the user to generate the appropriate electrical signals to control the supply's

- \* Voltage Limit

- \* Current Limit

- \* Charge Rate
- \* Ramp UP/PAUSE/DOWN
- \* Fast Ramp
- \* Persistent Switch Heaters

All of these functions must be controlled when in the REMOTE mode and the correct signal levels must be maintained. GREAT CARE MUST BE TAKEN NOT TO EXCEED THE RATED VALUES OF INPUT SIGNAL LEVELS OR ELSE UNSTABLE CONDITIONS WITHIN THE SUPPLY MAY OCCUR WHICH COULD POTENTIALLY HARM THE SUPPLY AND/OR QUENCH THE MAGNET.

### 3.3a REMOTE RAMP UP/PAUSE/DOWN and FAST RAMP

Remote control of the front panel Charge Control switches is provided through terminals 2, 3 and 10 on the rear panel terminal strip of the supply. These three pins are compatible with standard Transistor-Transistor Logic (TTL) or can be driven by any other signal between zero (0) and five (+5) volts. A logic diagram indicating the functions of these three input lines is shown in Figure 3-3. A logic 0 corresponds to a  $\leq 0.8$  volt input and a logic 1 corresponds to a  $\geq +3.5$  volt input. Absolute maximum allowable voltages are 0 and +5 volts respectively.

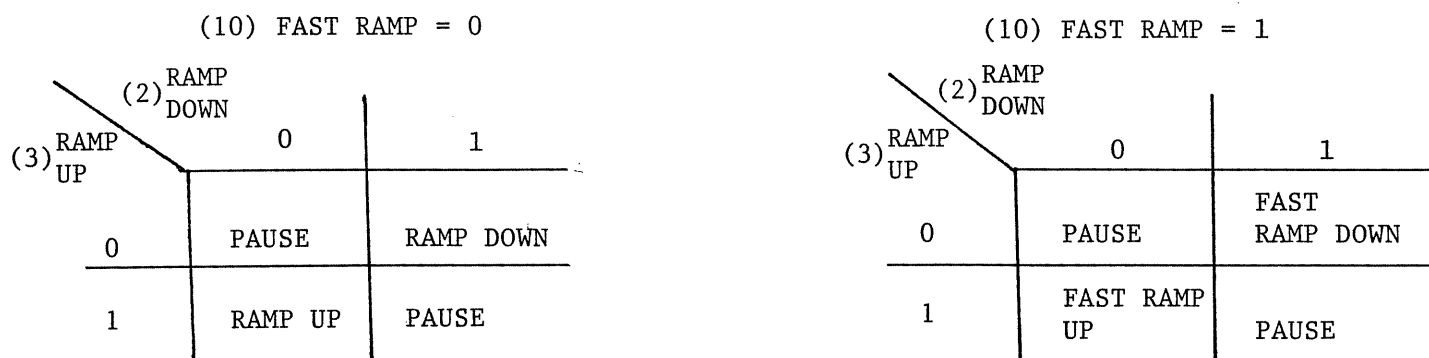


FIGURE 3-3 REMOTE Mode Charge Control Logic Diagram

All three input lines are disabled when the supply is operated in the LOCAL mode.

### 3.3b Persistent Switch Heaters

Persistent Switch Heaters A and B can be remotely operated using terminals 5 and 4 (respectively) on the rear panel terminal strip. These lines also require TTL logic levels to operate (0 to +5 volts) as do the Charge Control inputs. When using the persistent switch heater supplies while in the remote mode, one must leave the front panel switches for the heaters in the up or ON position. If the front panel switches are OFF, terminals 5 and 4 have no effect. When the supply is in the LOCAL mode terminals 5 and 4 are disabled.

### 3.3c Error Detect Enable/Reset and Status

The rear panel Error (Quench) Detect Circuitry can be enabled, disabled, and reset using terminal 6 on the rear panel of the supply when in the REMOTE Operating Mode. This input is TTL (0 to +5 volts) compatible. When terminal 6 is held low ( $\leq 0.8$  volts) the quench detector is enabled. When the terminal is high ( $\geq 3.5$  volts) the detector is disabled. If the error detector trips, it is reset by bringing terminal 6 high and then back low again. The status of the quench detector is provided on terminal 9 of the rear panel terminal strip. If this pin is at a logic high, it is an indication that the quench detector has tripped. If terminal 9 is at a logic low, it is an indication that the quench detector is currently reset or disabled.

### 3.3d Voltage and Current Limit Status

The status of the Voltage and Current Limit LED's on the front panel of the supply can be monitored through terminals 7 and 8 (respectively) on the rear panel terminal strip. These terminals are TTL compatible outputs from the supply. A logic high indicates the corresponding limit has been reached, while a logic low indicates the limit has not been reached.

### 3.3e Magnet Voltage Monitoring

Inputs to the IPS power supply are provided for the user to attach a pair of voltage taps from the magnet. In most cases, these taps are attached to the magnet's current leads as close to the magnet as possible so that the voltage read does not include the resistive voltage drop associated with the system's power leads.

CONNECTION OF THE VOLTAGE TAPS TO THE POWER SUPPLY IS NOT REQUIRED FOR PROPER OPERATION OF THE SUPPLY. IT IS SIMPLY A CONVENIENCE FEATURE ON THE SUPPLY.

Standard practice calls for the voltage taps from the magnet to be made using a twisted pair of ~ 30 gauge teflon insulated wire. The wires should be attached to the rear panel of the IPS supply at terminals 15 and 16 of the terminal strip. These are differential inputs with a 10 kOhm resistance to the system's ground. Terminal 15 is the positive input and 16 is negative.

A fully buffered and ground referenced signal indicating the magnet voltage is made available to the user through BNC (3) on the rear panel of the supply. One (1) volt across the magnet voltage tap inputs yields a one (1) volt output on BNC (3).

THE DIFFERENTIAL INPUTS ON TERMINAL 15 AND 16 SHOULD NOT BE EXPOSED TO MORE THAN ±20 VOLTS FOR EXTENDED PERIODS OF TIME. THE ANALOG OUTPUT VOLTAGE AT BNC (3) HAS A RANGE OF ±14 VOLTS.

The Magnet Voltage Tap Inputs 15 and 16 and the analog magnet voltage output signal at BNC (3) remain valid whether the supply is in the LOCAL or REMOTE mode.

### 3.3f Power Supply Current Monitoring

The output current from the power supply can be monitored with more precision than the 3½ digit display provides using a digital volt-

meter attached to the rear panel of the supply. BNC (1) provides the user with a signal corresponding to 1.000 volt out for each 10.00 amperes in the supply's leads. For instance, if an IPS-100 is sourcing 73.52 amperes, BNC (1) will provide a 7.352 volt signal. The Current Monitor Output BNC (1) has a range of 0 to +10.250 volts and remains active whether the supply is in the LOCAL or REMOTE mode.

### 3.3g Power Supply Voltage Monitoring

A fully buffered and ground referenced signal indicating the voltage across the output terminals of the supply is provided at BNC (2) on the rear panel. The signal on BNC (2) has a one (1) volt per volt ratio and a range of -5.5 to +5.5 volts. Positive voltage indicates the supply is sourcing power while negative voltage is an indication that the supply is absorbing power. The Power Supply Voltage signal on BNC (2) remains active whether the supply is in the LOCAL or REMOTE mode.

### 3.3h REMOTE Current Limit Setting

When the supply is placed into the REMOTE mode, it is left to the user to supply a stable signal to the supply for use as its Current Limit Setting. This voltage must be input to the supply through BNC (4) on its rear panel. Like the Power Supply Current Monitor Output (BNC (1) and section 3.3f above), the Current Limit Setting read by the supply has a 1.000 volt equals 10.00 amperes ratio. For instance if one wished to set the Current Limit on an IPS-50 to 36.25 amperes, a 3.635 volt signal would be placed on BNC (4). All IPS supplies (IPS-20/50/100) use the same ratio for this input.

GREAT CARE SHOULD BE TAKEN NOT TO EXCEED THE LIMITS FOR THE VOLTAGE ON BNC (4) FOR ANY PARTICULAR SUPPLY. THESE LIMITS ARE:

SUPPLY	MINIMUM VOLTAGE	MAXIMUM VOLTAGE
IPS-20	0.000 VOLTS	+ 2.05 VOLTS
IPS-50	0.000 VOLTS	+ 5.10 VOLTS
IPS-100	0.000 VOLTS	+10.25 VOLTS

NOTICE THAT IT IS ESSENTIAL THAT NEGATIVE VOLTAGES NEVER BE APPLIED TO BNC (4) - NEGATIVE VOLTAGES CAN CAUSE INSTABILITIES WITHIN THE SUPPLY RESULTING IN HIGH CURRENTS!

The stability of the output current of the supply when in Current Limit is directly a function of the stability of the user's voltage source. If the voltage source drifts 0.1% over an hour, so will the output current from the supply. A very stable voltage source should be used for generation of the Current Limit signal. The Current Limit setting on BNC (4) is disabled when in the LOCAL mode.

### 3.3i REMOTE Voltage Limit Setting

When the supply is placed into the REMOTE mode, it is left to the user to supply a stable signal to the supply for use as its Voltage Limit Setting. This voltage must be input to the supply through BNC (5) on its rear panel. The Voltage Limit Setting read by the supply has a 1.00 volt per volt ratio -i.e. if 2.00 volts is applied to BNC (5), the supply will have a 2.00 Volt Voltage Limit. This Current Limit setting will be valid for both the Charge and Discharge cycles of the supply. In other words, when one begins to discharge the magnet, a -2.00 volt Voltage Limit is assumed by the supply even though +2.00 volts is present on BNC (5).

NEGATIVE VOLTAGES SHOULD NEVER BE SUPPLIED TO BNC (5) -  
INSTABILITIES WITHIN THE SUPPLY MAY RESULT!



All IPS supplies have the same minimum and maximum ratings for the signals input to BNC (5):

SUPPLY	MINIMUM VOLTAGE	MAXIMUM VOLTAGE
IPS-20/50/100	0.00 VOLTS	+5.50 VOLTS

The Voltage Limit Setting on BNC (5) is disabled when in the LOCAL mode.

### 3.3j REMOTE Charge Rate Setting

When the supply is placed into the REMOTE mode, it is left to the user to supply a stable signal to the supply for use as its Charge Rate Setting. This voltage must be input to the supply through BNC (6) on its rear panel. The Charge Rate setting read by the supply uses a 1 volt equals 0.100 amperes per second ratio - i.e. if 3.000 volts is placed on BNC (6), a 0.300 ampere per second Charge and Discharge Rate will be used by the supply. This Charge Rate Setting will be valid for both the Charge and Discharge cycles of the supply. In other words, when one begins to Discharge the magnet, a -0.300 ampere per second Discharge Rate is assumed by the supply even though +3.00 volts is present on BNC (6).

NEGATIVE VOLTAGES SHOULD NEVER BY SUPPLIED TO BNC (6) -  
INSTABILITIES WITHIN THE SUPPLY MAY RESULT!

All IPS supplies have the same minimum and maximum ratings for the signals input to BNC (6).

SUPPLY	MINIMUM VOLTAGE	MAXIMUM VOLTAGE
IPS-20/50/100	0.000 VOLTS	+10.25 VOLTS

The Charge Rate Setting on BNC (6) is disabled when in the LOCAL mode.

### 3.3k Summary of REMOTE Mode

Table 3-1 summarizes the signals that can be input to the supply on its rear panel. Essential signals for a minimum of operation in REMOTE mode are:

Function	Terminal Strip or BNC Connector Number
Digital Ground	TS 1
Ramp DOWN	TS 2
Ramp UP	TS 3
Current Limit	BNC (4)
Voltage Limit	BNC (5)
Charge Rate	BNC (6)

Other inputs and outputs detailed in Table 3-1 and in the preceding text are optional and can be added according to the user's needs.

### 3.4 Persistent Switch Heater Supplies

Two Persistent Switch Heater Supplies are built into the IPS-50 and IPS-100. No supplies are available on the IPS-20 but they are available from Cryomagnetics as a separate instrument if they are required for the magnet system. The following explanation pertains only to the IPS-50 and IPS-100 power supplies.

The persistent switch heaters for the supply are labelled A and B. The supplies are set up as independently operable constant current sources. Two supplies are provided so multiple coils can be powered from a single IPS supply. Current outputs for the supplies are found on a four (4) terminal strip under the exhaust port on the rear panel of the supplies. The current can be adjusted using the procedure outlined in section 5.1 Calibration Procedures. The currents can be independently set to any current between 0 and 100 mA. The front panel LED's associated with the heater supplies will illuminate when the supply is ON and when current flow is present in the

TABLE 3-1 SUMMARY OF REAR PANEL CONNECTIONS



TERMINAL STRIP (TS) OR BNC CONNECTOR NUMBER	IPS INPUT OR OUTPUT	FUNCTION	RANGE	ENABLED OR DISABLED WHEN IN LOCAL MODE	
TS 1	COMMON	DIGITAL GROUND		ENABLED	
TS 2	INPUT	RAMP DOWN	0 TO +5V (TTL)	DISABLED	
TS 3	INPUT	RAMP UP	0 TO +5V (TTL)	DISABLED	
TS 4	INPUT	PERSISTENT SWITCH HEATER B	0 TO +5V (TTL)	DISABLED	
TS 5	INPUT	PERSISTENT SWITCH HEATER A	0 TO +5V (TTL)	DISABLED	
TS 6	INPUT	ERROR DETECT ENABLE/RESET	0 TO +5V (TTL)	DISABLED	
TS 7	OUTPUT	VOLTAGE LIMIT STATUS	0 TO +5V (TTL)	ENABLED	
TS 8	OUTPUT	CURRENT LIMIT STATUS	0 TO +5V (TTL)	ENABLED	
TS 9	OUTPUT	ERROR DETECT STATUS	0 TO +5V (TTL)	ENABLED	
TS 10	INPUT	FAST RAMP	0 TO +5V (TTL)	DISABLED	
TS 15	INPUT	+ MAGNET VOLTAGE TAP	} +20V TO -20V DIFFERENTIAL INPUT	ENABLED	
TS 16	INPUT	- MAGNET VOLTAGE TAP		ENABLED	
BNC (1)	OUTPUT	CURRENT MONITOR	0 TO +10.25V	ENABLED	
BNC (2)	OUTPUT	POWER SUPPLY VOLTAGE MONITOR	-5.5V TO +5.5V	ENABLED	
BNC (3)	OUTPUT	MAGNET VOLTAGE MONITOR	-14V TO +14V	ENABLED	
BNC (4)	INPUT	CURRENT LIMIT	} 0 TO +2.05V FOR IPS-20  0 TO +5.10V FOR IPS-50  0 TO +10.25V FOR IPS-100	DISABLED	
BNC (5)	INPUT	VOLTAGE LIMIT		0 TO +5V	DISABLED
BNC (6)	INPUT	CHARGE RATE		0 TO +10V	DISABLED

- NOTES:
- 1) TS 12-14 ARE NOT USED OR CONNECTED TO ANY POINT WITHIN THE POWER SUPPLY.
  - 2) BOTH THE ANALOG AND DIGITAL GROUNDS PROVIDED ON THE TERMINAL STRIP ARE ISOLATED FROM THE CABINET GROUND OF THE SUPPLY. THE ANALOG AND DIGITAL GROUNDS ARE COMMON WITH THE POSITIVE (+) OUTPUT POWER TERMINAL OF THE SUPPLY.
  - 3) TS 11 IS AN OUTPUT WITH A +5 REFERENCE VOLTAGE ON IT.

\* \* \* CAUTION \* \* \*

DO NOT CONNECT THE CABINET (LINE CORD) GROUND OF THE POWER SUPPLY TO THE ANALOG OR DIGITAL GROUNDS FOUND ON THE REAR PANEL OF THE SUPPLY. HIGH CURRENTS MAY RESULT. THE CABINET (LINE) GROUND IS ISOLATED FROM ALL POWER SUPPLY SIGNALS.

\* \* \* \* \*

heater. If the LED does not illuminate when the supply is turned ON, it is an indication that there is an open circuit somewhere in the heater line.

When the persistent switch heater supplies are being operated by REMOTE control, the front panel switches must be in the ON position.

### 3.5 Connecting the Magnet

It is usually a good idea to check out the power supply with the output shorted prior to connecting the magnet. This will insure proper operation of the supply with no chance of harming or quenching the magnet.

Connecting the magnet is a straightforward procedure. It is recommended that the proper size cables be used corresponding to the length and current at which they will be operating. Helium vapor-cooled current leads are recommended to efficiently introduce the high currents to the cryogenic environment with a minimum of heat load.

\* \* \* IMPORTANT \* \* \*

ALWAYS CONNECT THE POWER LEADS SECURELY TO BOTH THE MAGNET AND THE POWER SUPPLY WHILE THE SUPPLY IS TURNED OFF. NEVER DISCONNECT THE POWER LEADS FROM THE MAGNET UNLESS YOU ARE ABSOLUTELY CERTAIN THAT NO CURRENT IS FLOWING IN THEM. POTENTIALLY FATAL VOLTAGES CAN OCCUR IN THE EVENT OF A QUENCH ALONG WITH PERSISTENT SWITCH AND QUENCH PROTECTION SHUNT FAILURES ON THE MAGNET!

\* \* \* \* \* \* \* \* \* \* \* \* \* \*

#### 4.0 PRINCIPLE OF OPERATION

The IPS series of superconducting magnet power supplies are triac preregulated linear supplies providing exceptionally low ripple and noise along with excellent stability specifications. Many features have been built into the supply to provide ease and versatility in the operation of the supply. A block diagram of the supply is shown in Figure 4-1. The following sections will briefly explain the principles behind the supply's operation.

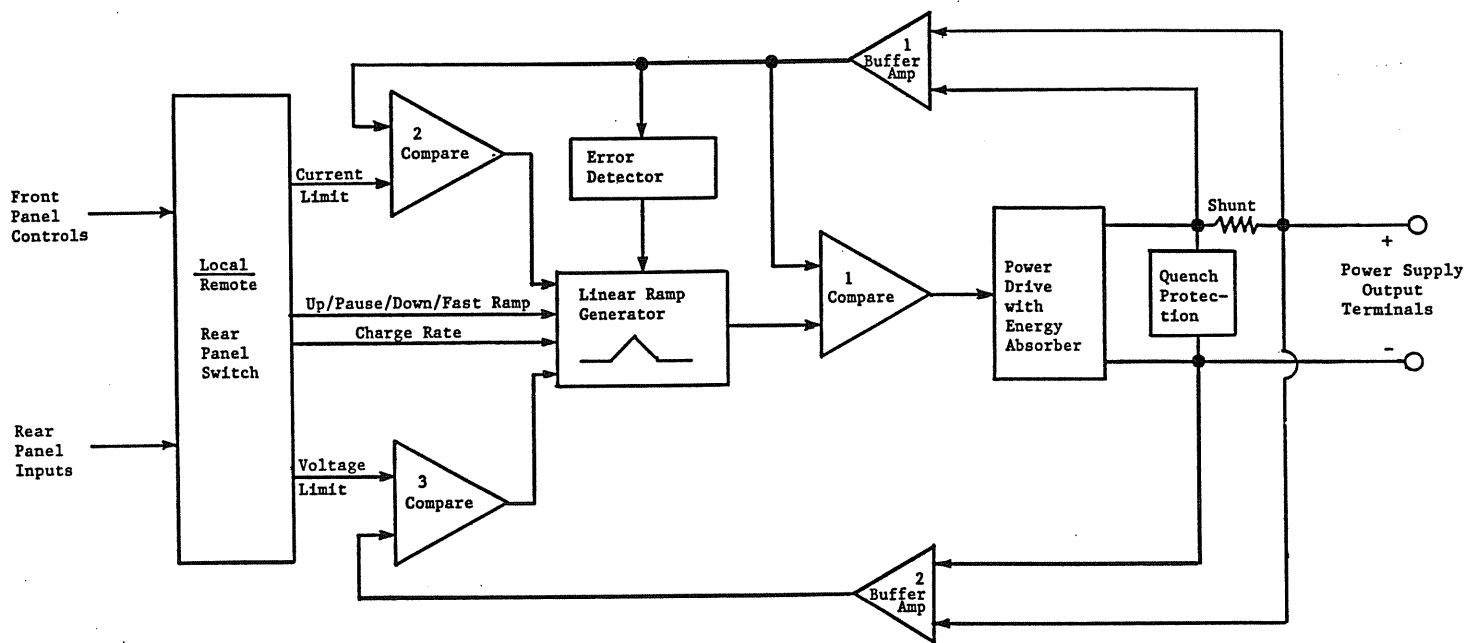


FIGURE 4-1 Integrated Power System Block Diagram

#### 4.1 Ramp Generator

At the heart of the IPS supply's control system lies a precision analog Ramp Generator. This circuit is essentially a precision integrator used as a reference for the output current of the supply. As one can see in Figure 4-1, the Ramp Generator has several inputs and only one output. The output

is an analog signal which is proportional to the output current of the supply. If the output of the Ramp Generator is at 2.37 volts, the supply will (through the feedback loop consisting of Comparator 1, the Power Drive, and Buffer Amplifier 1) be outputting 23.7000 amperes.

The multitude of inputs to the Ramp Generator are required since many different system parameters can effect the output current. For instance, when Current Limit is reached, the Ramp must be stopped so that Current Limit is not exceeded. Likewise, the Voltage Limit must be able to stop the Ramp and the Error (Quench) Detector must not only stop the Ramp but must cause it to return to zero and be disabled.

#### 4.2 Power Section

The Power Section of the IPS Supply consists of a triac preregulator, power transformer, full wave bridge rectifier, and a transistor pass-bank. A block diagram of the Power Section is shown in Figure 4-2. This is a common arrangement for power supplies and has been optimized to provide a high degree of regulation and minimum ripple and noise. A multiple transistor pass-bank is responsible for most of the regulation in the system. The Control Signal driving the pass-bank is generated by Comparator 1 in Figure 4-1.

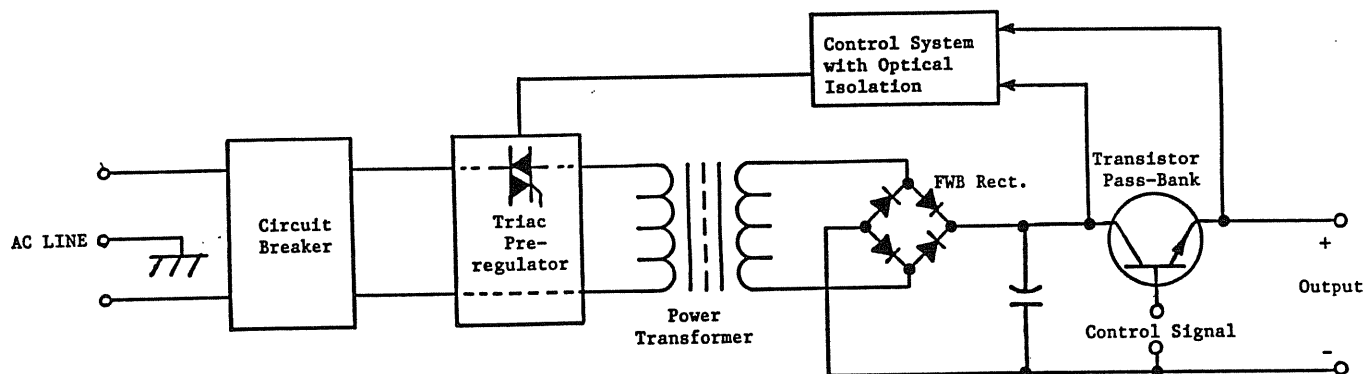


FIGURE 4-2 Simplified Power System Block Diagram

A high degree of RF shielding is built into the IPS supply to minimize the noise passed through the supply to its output and to minimize the noise reflected back into the power line. The low noise specifications of the IPS are some of the best specifications available. The Control System within the Power Section is used to control the turn-on time of the triac in the pre-regulator. The Control System monitors the power being dissipated in the pass-bank and directs the triac to deliver only the required amount of power for optimum regulation. Without this Control System the transistor pass-bank would have to be prohibitively large to constantly dissipate large amounts of energy. The Control System makes the IPS extremely power efficient.

#### 4.3 Energy Absorbing

The Energy Absorbing capabilities of the IPS reflect back to the transistor pass-bank in the Power Section. When a magnet is being discharged, it tries to dump energy back into the supply - in particular, back into the pass-bank. The IPS power supply is designed such that the pass-bank is capable of absorbing considerable power. The supply is fully able to absorb 5 volts at its maximum rated current without any problems in the pass-bank. The Control System used to drive the triac preregulator is greatly responsible for this ability to absorb energy.

The transistor pass-bank of the IPS supply is equipped with an emergency thermal shut-down system that shuts the power system and pass transistors down in the event they are overheated. The only case where the supply may be overheated causing this shut-down would be if the airflow through the supply were too hot or blocked off from free flow. Neither the IPS nor the superconducting magnet will be damaged by this thermal shut-down.

#### 4.4 Quench Protection

Quench Protection of the IPS supply and the magnet is provided not only through the Error Detector but also through the use of SCR crowbar circuits on

the supply's output. If a voltage of higher than +15 volts or lower than -15 volts is detected at the supply's output, the appropriate SCR will be turned ON effectively shorting the output terminals of the supply with a diode. This system works very well to eliminate the possibility of having high voltages appear across the magnet or supply. The SCR crowbar circuits are self-powered so the supply and magnet are protected even when the supply's power is shut OFF.



## 5.0 MAINTENANCE

Upon receipt of the IPS power supply, the performance and initial check-out procedures detailed in section 3.1 should be followed. If a problem is encountered during this procedure or during the normal operation of the supply, proceed to the Troubleshooting Section (5.2) of this manual. Once the supply is operating properly, it is ready for recalibration (if necessary) according to section 5.1. Before re-connecting the magnet or other load to the power supply, check again that all problems have been resolved and repeat the routine described in section 3.1. Before attempting any calibration procedures on the supply, turn the supply ON and allow a 30 minute warm-up and stabilization period.

### 5.1 Calibration Procedures

The following adjustments are available to calibrate the IPS supply should it ever become necessary. The IPS is fully burned-in, tested, and precision calibrated when it leaves the factory. If problems arise during calibration of the instrument, consult Cryomagnetics for assistance.

To access the calibration potentiometers in the IPS supply it is necessary to place the IPS supply on a bench with the front panel toward you. Remove the two screws holding the top cover of the supply in place. These screws are at the top of the supply on the rear panel. Carefully slide the top cover of the supply back revealing the main circuit board cover plate. Do not completely remove the cover plate as this will expose dangerous high current components and will impair the temperature stability of the supply by altering the airflow in the cabinet.

The main circuit board cover plate is clearly marked as to the location of all adjustment potentiometers for the system. The following descriptions define the effects of each potentiometer. If you are uncertain about which potentiometer to adjust, ask Cryomagnetics for assistance (preferably before trying).

Potentiometer	Function
P1	CURRENT ZERO OFFSET - this adjustment will trim the output current from the supply to 0.000 amperes when the Charge Control switch is in the DOWN position and has ramped down as far as it will go. An external resistive shunt and precision digital voltmeter may be required for adjustment.
P2	REMOTE MODE CURRENT LIMIT FULL SCALE CAL - this adjustment allows the user to put the proper full scale voltage into BNC (4) while in the REMOTE Mode, and to adjust the resulting output current to precisely full rated current. E.G., for an IPS-50, 5.000 volts would be placed on BNC (4) and P2 would be adjusted until precisely 50.000 amperes is output by the supply. Adjustment may require a precision voltage source, external resistive shunt and a precision digital voltmeter.
P3	CURRENT DISPLAY FULL SCALE CAL - this adjustment allows the current displayed on the front panel of the IPS to be matched to the actual output current of the supply at the full rated current of the supply. Adjustment requires a resistive shunt and precision digital voltmeter.
P4	REMOTE CURRENT MONITOR FULL SCALE CAL - this adjustment allows the precise matching of the actual output current from the supply to the output voltage at BNC (1) at the full rated current of the supply. Adjustment requires a resistive shunt and preferably two precision digital voltmeters.
P5	REMOTE CURRENT MONITOR ZERO CAL - this adjustment allows the precise matching of the actual output current from the supply to the output voltage at BNC (1) at zero (or near zero) currents. Adjustment should be made with approximately 0.500 amperes being sourced by the supply. Adjustment requires a resistive shunt and preferably two precision digital voltmeters.
P6	RAMP TIMING CAL - this adjustment allows the timing of the internal ramp in the IPS to be precisely set. An iterative process is usually used wherein a timing cycle of several minutes is allowed for the system to ramp and this potentiometer is adjusted until the appropriate change in output current is detected.
P7	RAMP RATE DISPLAY CAL - this adjustment allows the Ramp Rate displayed on the front panel of the IPS supply to be matched at its top end such that 10.00 volts input at BNC (6) displays a charge rate of 1.000 amperes per second.

TABLE 5-1 Calibration Description

Potentiometer	Function
P8	IPS DISPLAY REFERENCE - this adjustment is used to set the reference voltage for the front panel displays to precisely 1.000 volts. This reference voltage is found on Pin 36 of both the 40 pin chips near the front of the circuit board.
P9	CURRENT LIMIT FULL SCALE DISPLAY CAL - this adjustment allows the full scale Current Limit displayed by the IPS to be precisely matched to the actual Current Limit current achieved. A resistive shunt and a precision digital voltmeter is required.
P10	-10 VOLT REFERENCE CAL - A precision voltage source is used to generate a highly stable +10 volt reference on the circuit board. The board also requires a closely matched -10 volt stable reference. This adjustment allows that +10 volt reference and the -10 volt reference to be matched to better than 1 mV. A precision digital voltmeter is required.
P11	CURRENT LIMIT ZERO OFFSET CAL - this adjustment allows the precise zero (or near zero) current matching of the Current Limit setting to the actual Current Limit achieved. The adjustment is set by entering a Current Limit setting on the front panel potentiometer of about 0.5 amperes. This adjustment is then set such that the actual output current during Current Limit matches the Current Limit setting. A resistive shunt and precision digital voltmeter are required.
P13	REMOTE MODE CURRENT LIMIT ZERO CAL - this adjustment allows the user to put a near zero voltage into BNC (4) while in the REMOTE mode, and to adjust the resulting output current to the proper value. This adjustment is similar to adjustment P2 except that it is set near zero rather than at full scale.
P14	PERSISTENT SWITCH HEATER B CURRENT CAL - allows the output current to persistent switch heater B to be set between zero and 100 mA.
P15	PERSISTENT SWITCH HEATER A CURRENT CAL - allows the output current to persistent switch heater A to be set between zero and 100 mA.

TABLE 5-1 Calibration Description (Continued)

## 6.0 CRYOMAGNETICS LIMITED WARRANTY POLICY

Cryomagnetics warrants its products to be free from defects in materials and workmanship. This warranty shall be effective for one (1) year 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, Tennessee, and must have prior authorization for such return from an authorized Cryomagnetics representative.

This warranty shall not apply to any product which has been determined by Cryomagnetics inspection to have become defective due to abuse, mishandling, accident, alteration, improper installation or other causes. Cryomagnetics 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 shall not assume liability for any consequential damages associated with use or misuse of its equipment.