OPERATING AND SERVICE MANUAL

DC POWER SUPPLY
LAB SERIES
MODEL 6209B

HEWLETT
PACKARD

TABLE OF CONTENTS

SECTION I
GENERAL INFORMATION

1-1 DESCRIPTION

1-2 This power supply (see cover) is completely transistorized and suitable for either bench or rack operation. It is a compact, well-regulated, Constant Voltage/Constant Current supply that will furnish full rated output voltage at the maximum rated output current or can be continuously adjusted throughout the output range. The front panel CURRENT controls can be used to establish the output current limit (overload or short circuit) when the supply is used as a constant voltage source and the VOLTAGE control can be used to establish the voltage limit (ceiling) when the supply is used as a constant current source. The supply will automatically crossover from constant voltage to constant current operation and vice versa if the output current or voltage exceeds these preset limits.

1-3 The power supply has both front and rear terminals. Either the positive or negative output terminal may be grounded or the power supply can be operated floating at up to a maximum of 300 Volts off ground.

1-4 A single meter is used to measure either output voltage or output current in one of two ranges. The voltage or current ranges are selected by a METER switch on the front panel.

1-5 Barrier strip terminals located at the rear of the unit allow ease in adapting to the many operational capabilities of the power supply. A brief description of these capabilities is given below:

a. Remote Programming. The power supply may be programmed from a remote location by means of an external voltage source or resistance.

b. Remote Sensing. The degradation in regulation which would occur at the load because of the voltage drop in the load leads can be reduced by using the power supply in the remote sensing mode of operation.

c. Series and Auto-Series Operation. Power supplies may be used in series when a higher output voltage is required in the voltage mode of operation or when greater voltage compliance is required in the constant current mode of operation. Auto-Series operation permits one knob control of the total output voltage from a "master" supply.

d. Parallel and Auto-Parallel Operation. The power supply may be operated in parallel with a similar unit when greater output current capability is required. Auto-Parallel operation permits one knob control of the total output current from a "master" supply.

e. Auto-Tracking. The power supply may be used as a "master" supply, having control over one (or more) "slave" supplies that furnish various voltages for a system.

1-6 SPECIFICATIONS

1-7 Detailed specifications for the power supply are given in Table 1-1.

1-8 OPTIONS

1-9 Options are factory modifications of a standard instrument that are requested by the customer. The following options are available for the instrument covered by this manual. Where necessary, detailed coverage of the options is included throughout the manual.

Option No.	Description
08	Current 10-Turn Pot: A single control that replaces both coarse and fine current controls and improves output settability.
13	Three Digit Graduated Decadial Voltage Control: Control that replaces 10-turn voltage control permitting accurate resettability.
14	Three Digit Graduated Decadial Current Control: Control that replaces coarse and fine current controls permitting accurate resettability.
28	230Vac Single Phase Input: Supply as normally shipped is wired for 115Vac input. Option 28 consists of reconnecting the input transformer for 230Vac operation.

1-10 ACCESSORIES

1-11 The accessories listed in the following chart may be ordered with the power supply or separately from your local Hewlett-Packard field sales office (refer to list at rear of manual for addresses).

HP Part No.	Description
C05	8" Black Handle that can be attached to side of supply.

ⓗ Part No.	Description
14513A	Rack Kit for mounting one $3\frac{1}{2}$" high supply. (Refer to Section II for details.)
14523A	Rack Kit for mounting two $3\frac{1}{2}$" high supplies. (Refer to Section II for details.)

1-12 INSTRUMENT IDENTIFICATION

1-13 Hewlett-Packard power supplies are identified by a three-part serial number tag. The first part is the power supply model number. The second part is the serial number prefix, which consists of a number-letter combination that denotes the date of a significant design change. The number designates the year, and the letter A through L designates the month, January through December, respectively, with "I" omitted. The third part is the power supply serial number.

1-14 If the serial number prefix on your power supply does not agree with the prefix on the title page of this manual, change sheets are included to update the manual. Where applicable, backdating information is given in an appendix at the rear of the manual.

1-15 ORDERING ADDITIONAL MANUALS

1-16 One manual is shipped with each power supply. Additional manuals may be purchased from your local Hewlett-Packard field office (see list at rear of this manual for addresses). Specify the model number, serial number prefix, and ⓗ part number provided on the title page.

Table 1-1. Specifications

INPUT:
115Vac ±10% 48-63Hz.

OUTPUT:
0-320 Volts @ 0.1 Amp.

LOAD REGULATION:
Constant Voltage - Less than 0.02% plus 2mV for a full load to no load change in output current.
Constant Current - Less than 200μa for a zero to maximum change in output voltage.

LINE REGULATION:
Constant Voltage - Less than 0.02% plus 2mV for any line voltage change within the input rating.
Constant Current - Less than 200μa for any line voltage change within the input rating.

RIPPLE AND NOISE:
Constant Voltage - Less than 1mVrms/40mV p-p.
Constant Current - Less than 200μArms.

OPERATING TEMPERATURE RANGES:
Operating: 0 to 50°C. Storage: -40 to +75°C.

TEMPERATURE COEFFICIENT:
Constant Voltage - Less than 0.02% plus 1mV per degree Centigrade.
Constant Current - Less than 0.02% plus 150μA per degree Centigrade.

STABILITY:
Constant Voltage - Less than 0.10% plus 5mV total drift for 8 hours after an initial warmup time of 30 minutes at constant ambient, constant line voltage, and constant load.
Constant Current - Less than 0.10% plus 750μA total drift for 8 hours after an initial warmup time of 30 minutes at constant ambient, constant line voltage, and constant load.

INTERNAL IMPEDANCE AS A CONSTANT VOLTAGE SOURCE:
Less than 0.02 ohm from dc to 1kHz.
Less than 0.5 ohm from 1kHz to 100kHz.
Less than 3.0 ohms from 100kHz to 1MHz.

TRANSIENT RECOVERY TIME:
Less than 50μsec for output recovery to within 10mV following a full load current change in the output.

OVERLOAD PROTECTION:
A continuously acting constant current circuit protects the power supply for all overloads including a direct short placed across the terminals in constant voltage operation. The constant voltage circuit limits the output voltage in the constant current mode of operation.

METER:
The front panel meter can be used as either a 0-400 or 0-40 Volt voltmeter or as a 0-0.12 or 0.012 Amp ammeter.

OUTPUT CONTROLS:
Ten-turn voltage control and course and fine current controls.

OUTPUT TERMINALS:
Three "five-way" output posts are provided on the front panel and an output terminal strip is located on the rear of the chassis. All power supply output terminals are isolated from the chassis and either the positive or negative terminal may be connected to the chassis through a separate ground terminal located on the output terminal strip.

ERROR SENSING:
Error sensing is normally accomplished at the front terminals if the load is attached to the front or at the rear terminals if the load is attached to the rear terminals. Also, provision is included on the rear terminal strip for remote sensing.

REMOTE RESISTANCE PROGRAMMING:
Constant Voltage ~~- 300Ω/V.~~ Accuracy: 1%.
Constant Current - 150KΩ/A. Accuracy: 10%.

REMOTE VOLTAGE PROGRAMMING:
Constant Voltage - 1V/V. Accuracy: 1%.
Constant Current - 1.5V/.1A. Accuracy: 10%.

COOLING:
Convection cooling is employed. The supply has no moving parts.

SIZE:
3½" H x 12-5/8" D x 8½" W. Two of the units can be mounted side by side in a standard 19" relay rack.

WEIGHT: 13 lbs. net. 18 lbs. shipping.

FINISH:
Light gray front panel with dark gray case.

POWER CORD:
A three-wire, five-foot power cord is provided with each unit.

SECTION II
INSTALLATION

2-1 INITIAL INSPECTION

2-2 Before shipment, this instrument was inspected and found to be free of mechanical and electrical defects. As soon as the instrument is unpacked, inspect for any damage that may have occurred in transit. Save all packing materials until the inspection is completed. If damage is found, file a claim with the carrier as soon as possible. Hewlett-Packard Sales and Service Office should be notified.

2-3 MECHANICAL CHECK

2-4 This check should confirm that there are no broken knobs or connectors, that the cabinet and panel surfaces are free of dents and scratches, and that the meter is not scratched or cracked.

2-5 ELECTRICAL CHECK

2-6 The instrument should be checked against its electrical specifications. Section V includes an "in-cabinet" performance check to verify proper instrument operation.

2-7 INSTALLATION

2-8 The instrument is shipped ready for bench operation. It is necessary only to connect the instrument to a source of power and it is ready for operation.

2-9 LOCATION

2-10 This instrument is air cooled. Sufficient space should be allotted so that a free flow of cooling air can reach the sides and rear of the instrument when it is in operation. It should be used in an area where the ambient temperature does not exceed 50°C.

2-11 OUTLINE DIAGRAM

2-12 Figure 2-1 is a diagram showing the outline dimensions of this unit.

2-13 RACK MOUNTING

2-14 This instrument may be rack mounted in a standard 19 inch rack panel either alongside a similar unit or by itself. Figures 2-2 and 2-3 show how both types of installations are accomplished.

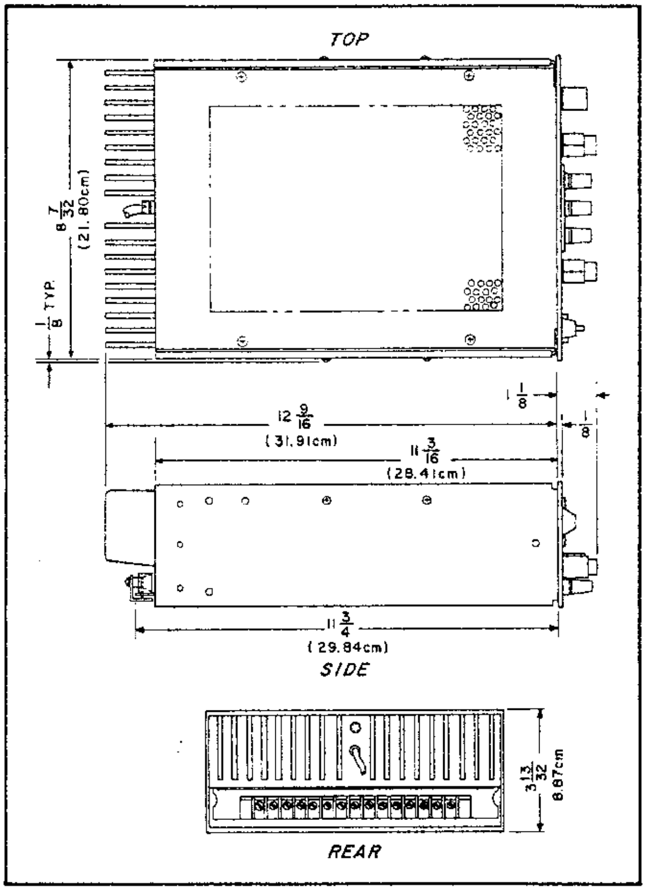


Figure 2-1. Outline Diagram

2-15 To mount two units side-by-side, proceed as follows:

a. Remove the four screws from the front panels of both units.

b. Slide rack mounting ears between the front panel and case of each unit.

c. Slide combining strip between the front panels and cases of the two units.

d. After fastening rear portions of units together using the bolt, nut, and spacer, replace panel screws.

2-16 To mount a single unit in the rack panel, proceed as follows:

a. Bolt rack mounting ears, combining straps, and angle brackets to each side of center spacing panels. Angle brackets are placed behind combining straps as shown in Figure 2-3.

b. Remove four screws from front panel of unit.

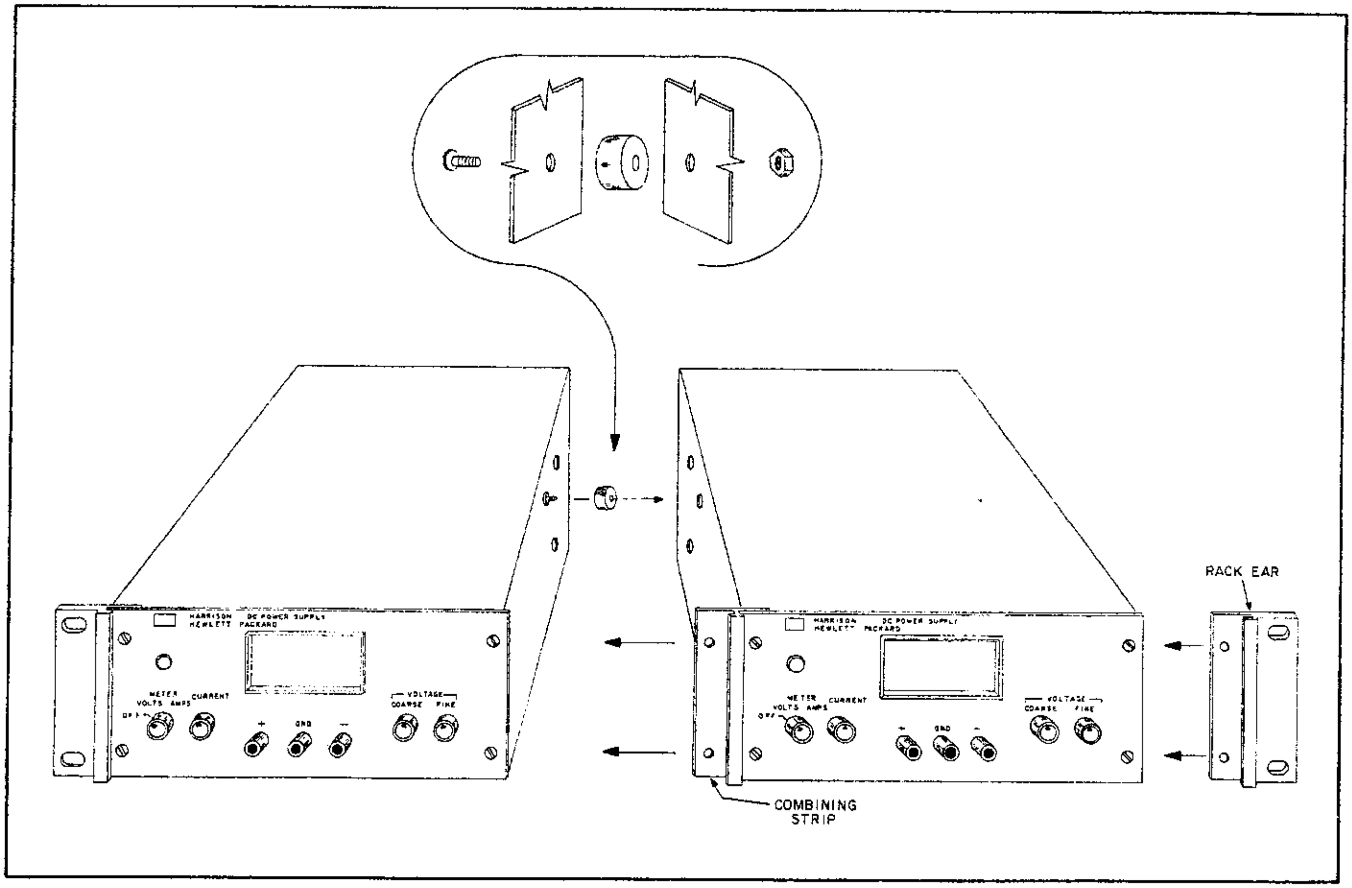


Figure 2-2. Rack Mounting, Two Units

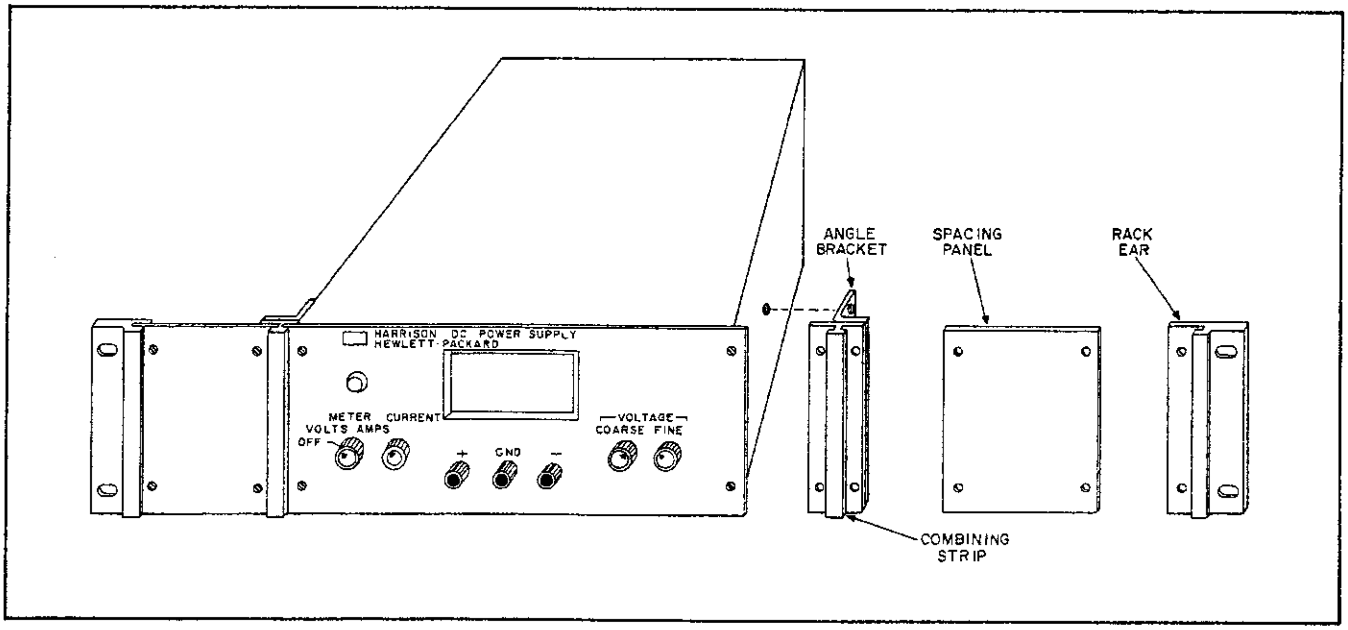


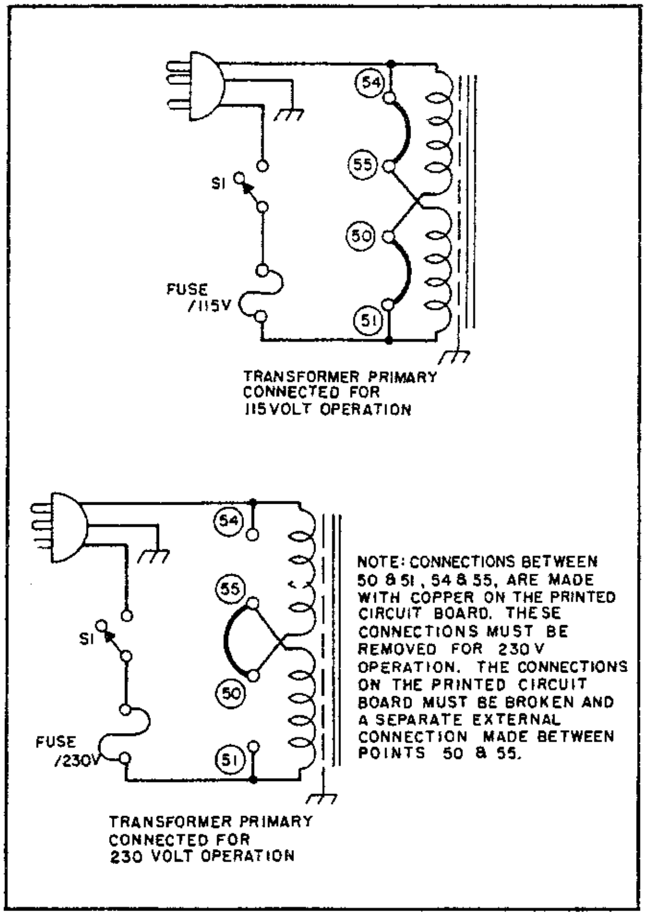
Figure 2-3. Rack Mounting, One Unit

c. Slide combining strips between front panel and case of unit.

d. Bolt angle brackets to front sides of case and replace front panel screws.

2-17 INPUT POWER REQUIREMENTS

2-18 This power supply may be operated from either a nominal 115 Volt or 230 Volt, 48-63Hz power source. The unit, as shipped from the factory, is wired for 115 Volt operation. The input power required when operated from a 115 Volt, 60 Hertz power source at full load is 60 Watts and 1.0 Ampere.



TRANSFORMER PRIMARY CONNECTED FOR 115VOLT OPERATION

NOTE: CONNECTIONS BETWEEN 50 & 51, 54 & 55, ARE MADE WITH COPPER ON THE PRINTED CIRCUIT BOARD. THESE CONNECTIONS MUST BE REMOVED FOR 230 V OPERATION. THE CONNECTIONS ON THE PRINTED CIRCUIT BOARD MUST BE BROKEN AND A SEPARATE EXTERNAL CONNECTION MADE BETWEEN POINTS 50 & 55.

TRANSFORMER PRIMARY CONNECTED FOR 230 VOLT OPERATION

Figure 2-4. Primary Connections

2-19 CONNECTIONS FOR 230 VOLT OPERATION (Figure 2-4)

2-20 Normally, the two primary windings of the input transformer are connected in parallel for operation from 115V source. To convert the power supply to operation from a 230V source, the power transformer windings are connected in series as follows:

a. Unplug the line cord and remove top and bottom covers from unit.

b. Break the copper between 54 and 55 and also between 50 and 51 on the printed circuit board. These are shown in Figure 2-4 and are labeled on copper side of printed circuit board and on schematic.

c. Add strap between 50 and 55.

d. Replace existing fuse with 1 Ampere, 230-Volt fuse. Return unit to case and operate normally.

2-21 POWER CABLE

2-22 To protect operating personnel, the National Electrical Manufacturers' Association (NEMA) recommends that the instrument panel and cabinet be grounded. This instrument is equipped with a three conductor power cable. The third conductor is the ground conductor and when the cable is plugged into an appropriate receptacle, the instrument is grounded. The offset pin on the power cable three-prong connector is the ground connection.

2-23 To preserve the protection feature when operating the instrument from a two-contact outlet, use a three-prong to two-prong adapter and connect the green lead on the adapter to ground.

2-24 REPACKAGING FOR SHIPMENT

2-25 To insure safe shipment of the instrument, it is recommended that the package designed for the instrument be used. The original packaging material is reusable. If it is not available, contact your local Hewlett-Packard field office to obtain the materials. This office will also furnish the address of the nearest service office to which the instrument can be shipped. Be sure to attach a tag to the instrument which specifies the owner, model number, full serial number, and service required, or a brief description of the trouble.

SECTION III
OPERATING INSTRUCTIONS

3-1 TURN-ON CHECK-OUT PROCEDURE

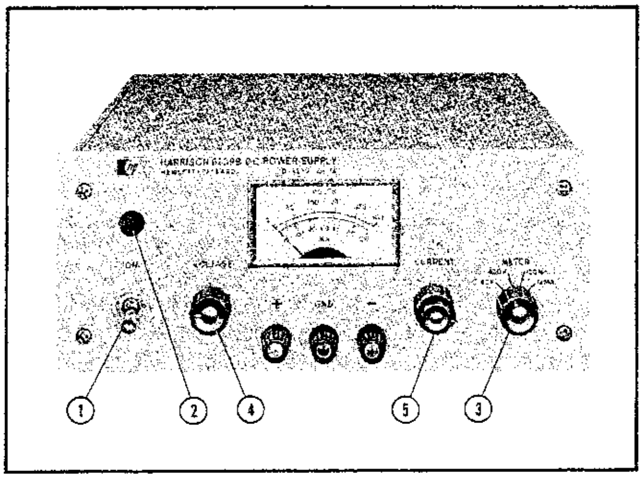


Figure 3-1. Front Panel Controls and Indicators

3-2 The following procedure describes the use of the front panel controls and indicators and ensures that the supply is operational (see Figure 3-1):

a. Set AC Power Switch ① to ON.

b. Observe that Pilot Light ② goes on.

c. Set Meter Switch ③ to desired voltage range.

d. Adjust coarse and fine Voltage Controls ④ until desired output voltage is indicated on Meter.

e. Short circuit output terminals, set meter switch to desired current range and adjust Current Controls ⑤ for desired output current.

f. Remove short and connect load to output terminals (Front or Rear).

3-3 OPERATING MODES

3-4 The power supply is designed so that its mode of operation can be selected by making strapping connections between particular terminals on the terminal strip at the rear of the power supply. The terminal designations are stenciled in white on the power supply above their respective terminals. Although the strapping patterns illustrated in this section show the positive terminal grounded, the operator can ground either terminal or operate the power supply up to 300Vdc off ground (floating). The following paragraphs describe the procedures for utilizing the various operational capabilities of the power supply. A more theoritical description concerning the operational features of this supply is contained in Application Note 90 and in various Tech. Letters. Copies of these can be obtained from your local Hewlett-Packard field office.

3-5 NORMAL OPERATING MODE

3-6 The power supply is normally shipped with its rear terminal strapping connections arranged for Constant Voltage/Constant Current, local sensing, local programming, single unit mode of operation. This strapping pattern is illustrated in Figure 3-2. The operator selects either a constant voltage or a constant current output using the front panel controls (local programming, no strapping changes are necessary).

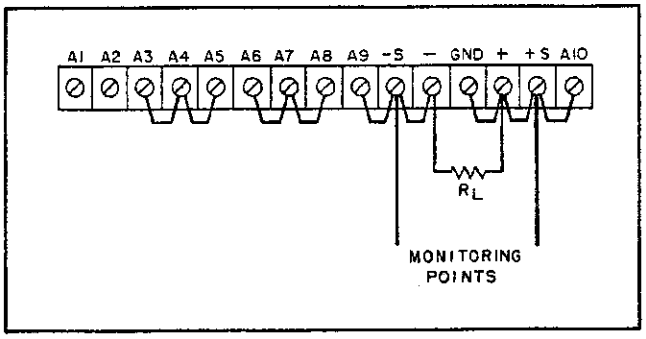


Figure 3-2. Normal Strapping Pattern

3-7 CONSTANT VOLTAGE

3-8 To select a constant voltage output, proceed as follows:

a. Turn-on power supply and adjust VOLTAGE controls for desired output voltage (output terminals open).

b. Short output terminals and adjust CURRENT controls for maximum output current allowable (current limit), as determined by load conditions. If a load change causes the current limit to be exceeded, the power supply will automatically crossover to constant current output at the preset current limit and the output voltage will drop proportionately. In setting the current limit, allowance must be made for high peak current which can cause unwanted cross-over. (Refer to Paragraph 3-48.)

3-9 CONSTANT CURRENT

3-10 To select a constant current output, proceed as follows:

a. Short output terminals and adjust CURRENT controls for desired output current.

b. Open output terminals and adjust VOLTAGE controls for maximum output voltage allowable (voltage limit), as determined by load conditions. If a load change causes the voltage limit to be exceeded, the power supply will automatically crossover to constant voltage output at the preset voltage limit and the output current will drop proportionately. In setting the voltage limit, allowance must be made for high peak voltages which can cause unwanted crossover. (Refer to Paragraph 3-48.)

3-11 CONNECTING LOAD

3-12 Each load should be connected to the power supply output terminals using separate pairs of connecting wires. This will minimize mutual coupling effects between loads and will retain full advantage of the low output impedance of the power supply. Each pair of connecting wires should be as short as possible and twisted or shielded to reduce noise pickup. (If shield is used, connect one end to power supply ground terminal and leave the other end unconnected.)

3-13 If load considerations require that the output power distribution terminals be remotely located from the power supply, then the power supply output terminals should be connected to the remote distribution terminals via a pair of twisted or shielded wires and each load separately connected to the remote distribution terminals. For this case, remote sensing should be used (Paragraph 3-31).

3-14 OPERATION BEYOND NORMAL RATED OUTPUT

3-15 The shaded area on the front panel meter face indicates the amount of output voltage or current that is available in excess of the normal rated output. Although the supply can be operated in this shaded region without being damaged, it cannot be guaranteed to meet all of its performance specifications. Generally when operating the supply in this manner, the output is unstable when a load is connected. However, if the line voltage is maintained above its nominal value, the supply will probably operate within the specifications above the rated output.

3-16 OPTIONAL OPERATING MODES

3-17 REMOTE PROGRAMMING, CONSTANT VOLTAGE

3-18 The constant voltage output of the power supply can be programmed (controlled) from a remote location if required. Either a resistance or voltage source can be used for the programming device. The wires connecting the programming terminals of the supply to the remote programming device should be twisted or shielded to reduce noise pick-up. The VOLTAGE control on the front panel is disabled according to the following procedures.

3-19 Resistance Programming (Figure 3-3). In this mode, the output voltage will vary at a rate determined by the programming coefficient — 300 ohms per Volt (i.e. the output voltage will increase 1 Volt for each 300 ohms added in series with programming terminals). The programming accuracy is 1% of the programmed value. If greater programming accuracy is required, it may be achieved by changing resistor R13 (see Paragraph 5-79).

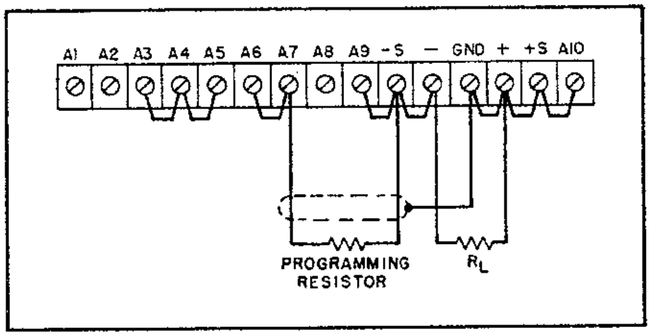


Figure 3-3. Remote Resistance Programming (Constant Voltage)

3-20 The output voltage of the power supply should be zero Volts ±20 millivolts when zero ohms is connected across the programming terminals. If a zero ohm voltage closer than this is required, it may be achieved by changing resistor R6 or R8 as described in Paragraph 5-77.

3-21 To maintain the stability and temperature coefficient of the power supply, use programming resistors that have stable, low noise, and low temperature (less than 30ppm per degree centigrade) characteristics. A switch can be used in conjunction with various resistance values in order to obtain discrete output voltages. The switch should have make-before-break contacts to avoid momentarily opening the programming terminals during the switching interval.

3-22 Voltage Programming (Figure 3-4). Employ the strapping pattern shown on Figure 3-4 for voltage programming. In this mode, the output voltage will vary in a 1 to 1 ratio with the programming voltage (reference voltage) and the load on the programming voltage source will not exceed 25 microamperes. The programming accuracy is 1% of the programmed voltage.

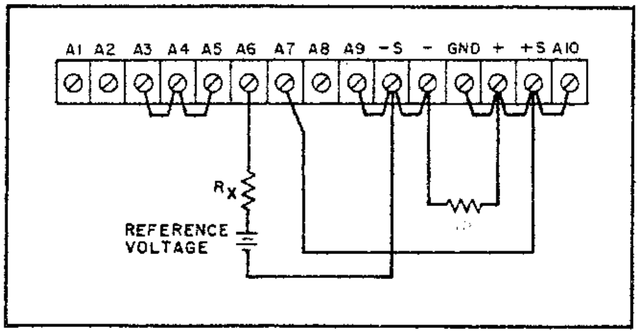


Figure 3-4. Remote Voltage Programming (Constant Voltage)

3-23 The impedance (R_X) looking into the external programming voltage source should be approximately 1000 ohms if the temperature and stability specifications of the power supply are to be maintained.

3-24 Methods of voltage programming with gain are discussed in Application Note 90, Power Supply Handbook; available at no charge from your local Hewlett-Packard Sales Office.

3-25 REMOTE PROGRAMMING, CONSTANT CURRENT

3-26 Either a resistance or a voltage source can be used to control the constant current output of the supply. The CURRENT controls on the front panel are disabled according to the following procedures.

3-27 Resistance Programming (Figure 3-5). In this mode, the output current varies at a rate determined by the programming coefficient — 75K ohms per Amp for Model 6207B, and 150K ohms per Amp for Model 6209B. The programming accuracy is 10% of the programmed current. If greater programming accuracy is required, it may be achieved by changing resistor R19 (see Paragraph 5-82).

3-28 Use stable, low noise, low temperature coefficient (less than 30ppm/°C) programming resistors to maintain the power supply temperature coefficient and stability specifications. A switch may be used to set discrete values of output current. A make-before-break type of switch should be used since the output current will exceed the maximum rating of the power supply if the switch contacts open during the switching interval.

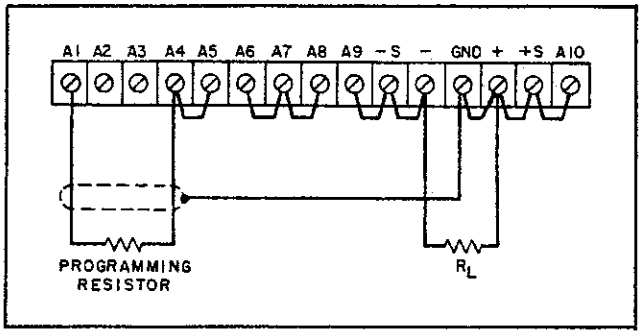


Figure 3-5. Remote Resistance Programming (Constant Current)

CAUTION

If the programming terminals (A1 and A4) should open at any time during this mode, the output current will rise to a value that may damage the power supply and/or the load. To avoid this possibility, connect a 15K resistor across the programming terminals and in parallel with a remote programming resistor. Like the programming resistor, the 15K resistor should be of the low noise, low temperature coefficient type.

3-29 Voltage Programming (Figure 3-6). In this mode, the output current will vary linearly with changes in the programming voltage. The programming voltage should not exceed 1.8 Volts. Voltage in excess of 1.8 Volts will result in excessive power dissipation in the instrument and possible damage.

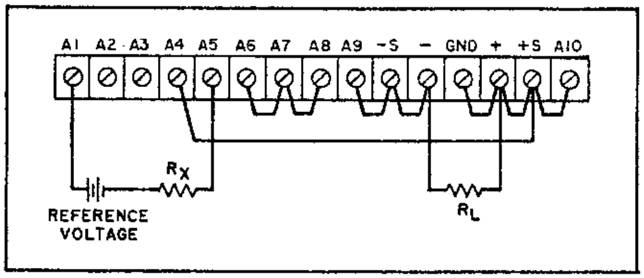


Figure 3-6. Remote Voltage Programming (Constant Current)

3-30 The output current for Model 6207B supplies will be the programming voltage divided by 7.5 ohms. For Model 6209B supplies, it will be the programming voltage divided by 15 ohms. The current required from the voltage source will be less than 25 microamperes. The impedance (R_X) as seen looking into the programming voltage source should be approximately 500 ohms if the temperature coefficient and stability specifications of the power supply are to be maintained. The programming accuracy is 10% of the programmed current.

3-31 REMOTE SENSING (See Figure 3-7)

3-32 Remote sensing is used to maintain good regulation at the load and reduce the degradation of regulation which would occur due to the voltage drop in the leads between the power supply and the load. Remote sensing is accomplished by utilizing the strapping pattern shown in Figure 3-7. The power supply should be turned off before changing strapping patterns. The leads from the +S terminals to the load will carry less than 10 milliamperes of current, and it is not required that these leads be as heavy as the load leads. However, they must be twisted or shielded to minimize noise pick-up.

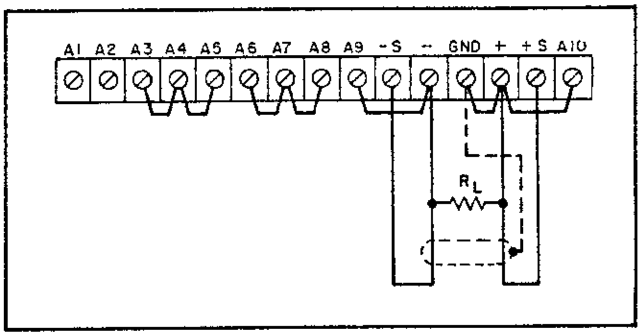


Figure 3-7. Remote Sensing

CAUTION

Observe polarity when connecting the sensing leads to the load.

3-33 For reasonable load lead lengths, remote sensing greatly improves the performance of the supply. However, if the load is located a considerable distance from the supply, added precautions must be observed to obtain satisfactory operation. Notice that the voltage drop in the load leads subtracts directly from the available output voltage and also reduces the amplitude of the feedback error signals that are developed within the unit. Because of these factors it is recommended that the drop in each load lead not exceed 1 Volt. If a larger drop must be tolerated, please consult a Hewlett-Packard Sales Engineer.

NOTE

Due to the voltage drop in the load leads, it may be necessary to readjust the current limit in the remote sensing mode.

3-34 Another factor that must be considered is the inductance of long load leads which could affect the stability of the feedback loop and cause oscillation. In these cases, it is recommended that the output capacitor (C20) be physically removed from the power supply and placed across the load terminals.

3-35 Although the strapping patterns shown in Figures 3-3 through 3-6 employ local sensing, note that it is possible to operate a power supply simultaneously in the remote sensing and Constant Voltage/Constant Current remote programming modes.

3-36 SERIES OPERATION

3-37 Normal Series Connections (Figure 3-8). Two or more power supplies can be operated in series to obtain a higher voltage than that available from a single supply. When this connection is used, the output voltage is the sum of the voltages of the individual supplies. Each of the individual supplies must be adjusted in order to obtain the total output voltage. The power supply contains a protective diode connected internally across the output which protects the supply if one power supply is turned off while its series partner(s) is on.

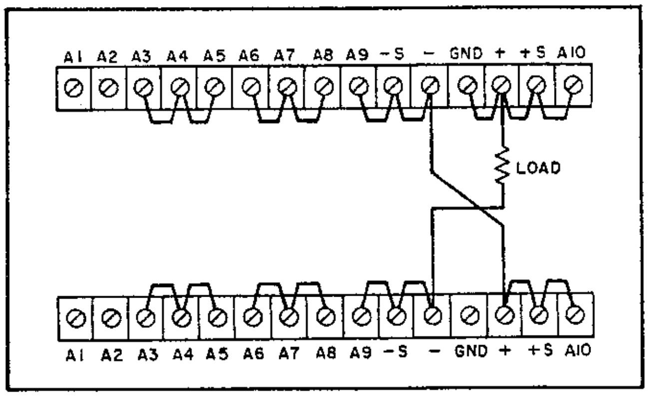


Figure 3-8. Normal Series

3-38 Auto-Series Connections (Figure 3-9). The Auto-Series configuration is used when it is desirable to have the output voltage of each of the series connected supplies vary in accordance with the setting of a control unit. The control unit is called the master; the controlled units are called slaves. At maximum output voltage, the voltage of the slaves is determined by the setting of the front panel VOLTAGE control on the master. The master supply must be the most positive supply of the series. The output CURRENT controls of all series units are operative and the current limit is equal to the lowest control setting. If any output CURRENT controls are set too low, automatic crossover to constant current operation will occur and the output voltage will drop. Remote sensing and programming can be used; however, the strapping arrangements shown in the applicable figures show local sensing and programming.

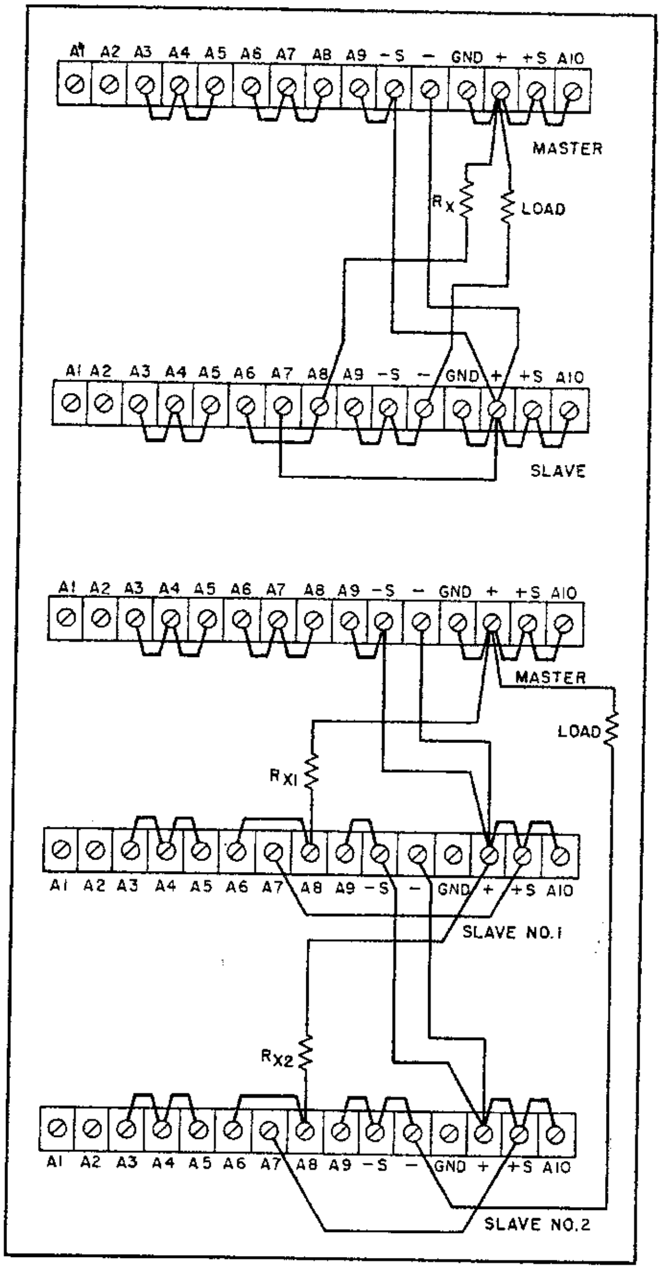


Figure 3-9. Auto-Series, Two and Three Units

3-39 In order to maintain the temperature coefficient and stability specifications of the power supply, the external resistors (R_X) shown in Figure 3-9 should be stable, low noise, low temperature coefficient (less than 30ppm per degree centigrade) resistors. The value of each resistor is dependant on the maximum voltage rating of the "master" supply. The value of R_X is this voltage divided by the voltage programming current of the slave supply ($1/K_p$ where K_p is the voltage programming coefficient). The voltage contribution of the slave is determined by its voltage control setting.

3-40 When the center tap of an Auto-Series combination is grounded, coordinated positive and negative voltages result. This technique is commonly referred to as "rubber-banding" and an external reference source may be employed if desired. Any change in the internal or external reference source (e.g. drift, ripple) will cause an equal percentage change in the outputs of both the master and slave supplies. This feature can be of considerable use in analogue computer and other applications, where the load requires a positive and a negative power supply and is less susceptible to an output voltage change occurring simultaneously in both supplies than to a change in either supply alone.

3-41 PARALLEL OPERATION

3-42 Normal Parallel Connections (Figure 3-10). Two or more power supplies can be connected in parallel to obtain a total output current greater than that available from one power supply. The total output current is the sum of the output currents of the individual power supplies. The output CURRENT controls of each power supply can be separately set. The output voltage controls of one power supply should be set to the desired output voltage; the other power supply should be set for a slightly larger output voltage. The supply set to the lower output voltage will act as a constant voltage source; the supply set to the higher output will act as a constant current source, dropping its output voltage until it equals that of the other supply. The constant voltage source will deliver only that fraction of its total rated output current which is necessary to fulfill the total current demand.

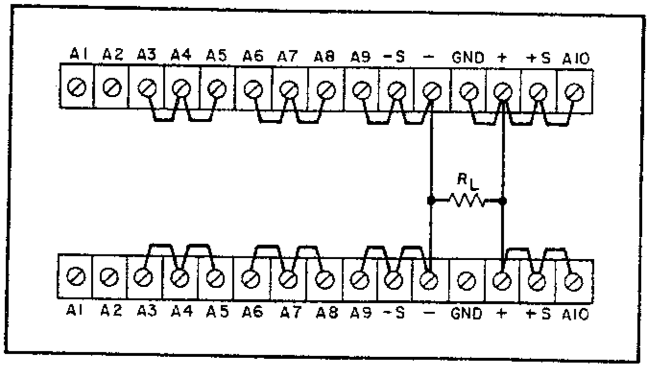


Figure 3-10. Normal Parallel

3-43 Auto-Parallel. The strapping patterns for Auto-Parallel operation of two and three power supplies are shown in Figure 3-11. Auto-Parallel operation permits equal current sharing under all load conditions, and allows complete control of output current from one master power supply. The output current of each slave is approximately equal to the master's. Because the output current controls of each slave are operative, they should be set to

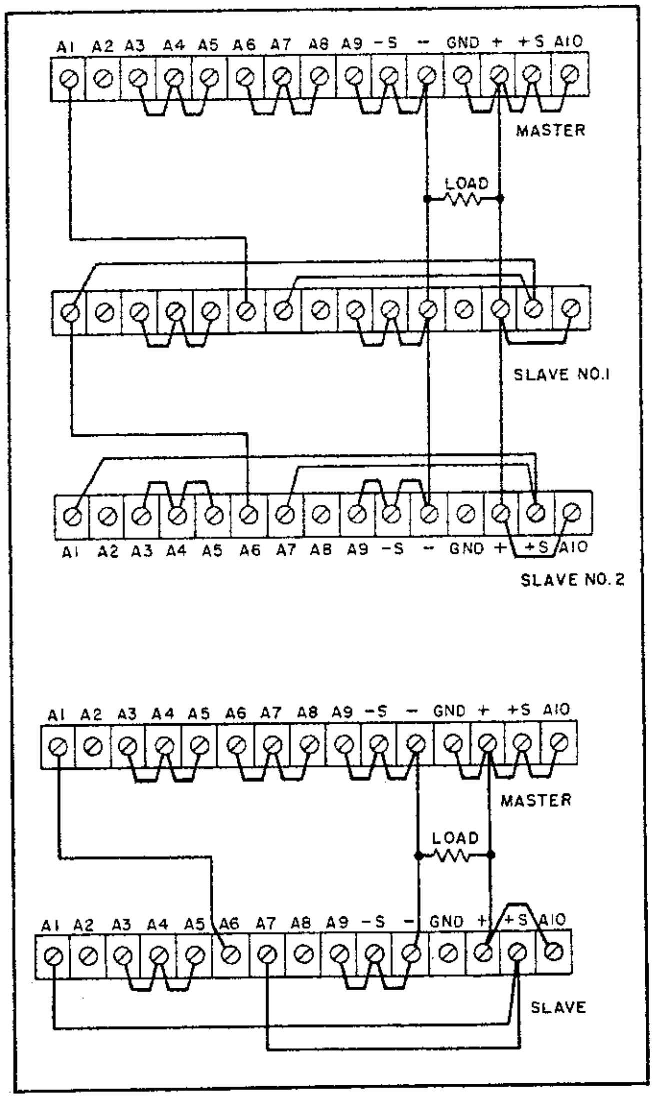


Figure 3-11. Auto-Parallel, Two and Three Units

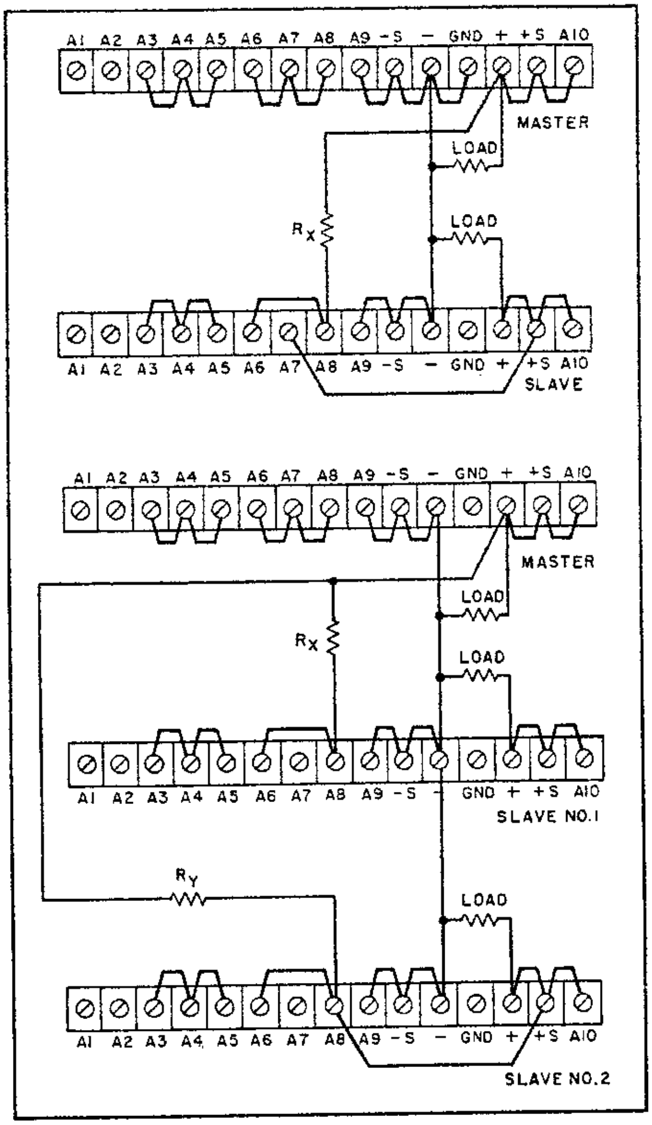


Figure 3-12. Auto-Tracking, Two and Three Units

maximum to avoid having the slave revert to constant current operation; this would occur if the master output current setting exceeded the slave's.

3-44 AUTO-TRACKING OPERATION (See Figure 3-12)

3-45 The Auto-Tracking configuration is used when it is necessary that several different voltages referred to a common bus, vary in proportion to the setting of a particular instrument (the control or master). A fraction of the master's output voltage is fed to the comparison amplifier of the slave supply, thus controlling the slave's output. The master must have the largest output voltage of any power supply in the group (must be the most positive supply in the example shown on Figure 3-12).

3-46 The output voltage of the slave is a percentage of the master's output voltage, and is determined by the voltage divider consisting of R_X (or R_X and R_Y) and the voltage control of the slave supply, R_P where: $E_S = E_M \cdot R_P/(R_X + R_P)$. Turn-on and turn-off of the power supplies is controlled by the master. Remote sensing and programming can be used; although the strapping patterns for these modes show only local sensing and programming. In order to maintain the temperature coefficient and stability specifications of the power supply, the external resistors should be stable, low noise, low temperature (less than 30ppm per $^{\circ}$C) resistors.

3-47 SPECIAL OPERATING CONSIDERATIONS

3-48 PULSE LOADING

3-49 The power supply will automatically cross over from constant voltage to constant current operation, or the reverse, in response to an increase (over the preset limit) in the output current or voltage, respectively. Although the preset limit may be set higher than the average output current or voltage, high peak currents or voltages (as occur in pulse loading) may exceed the preset limit and cause crossover to occur. If this crossover limiting is not desired, set the preset limit for the peak requirement and not the average.

3-50 OUTPUT CAPACITANCE

3-51 An internal capacitor (C20), connected across the output terminals of the power supply, helps to supply high-current pulses of short duration during constant voltage operation. Any capacitance added externally will improve the pulse current capability, but will decrease the safety provided by the constant current circuit. A high-current pulse may damage load components before the average output current is large enough to cause the constant current circuit to operate.

3-52 The effects of the output capacitor during constant current operation are as follows:

a. The output impedance of the power supply decreases with increasing frequency.

b. The recovery time of the output voltage is longer for load resistance changes.

c. A large surge current causing a high power dissipation in the load occurs when the load resistance is reduced rapidly.

3-53 REVERSE VOLTAGE LOADING

3-54 A diode (CR34) is connected across the output terminals. Under normal operating conditions, the diode is reverse biased (anode connected to negative terminal). If a reverse voltage is applied to the output terminals (positive voltage applied to negative terminal), the diode will conduct, shunting current across the output terminals and limiting the voltage to the forward voltage drop of the diode. This diode protects the series transistors and the output electrolytic capacitors.

3-55 REVERSE CURRENT LOADING

3-56 Active loads connected to the power supply may actually deliver a reverse current to the power supply during a portion of its operating cycle. An external source cannot be allowed to pump current into the supply without loss of regulation and possible damage to the output capacitor. To avoid these effects, it is necessary to preload the supply with a dummy load resistor so that the power supply delivers current through the entire operating cycle of the load device.

SECTION IV
PRINCIPLES OF OPERATION

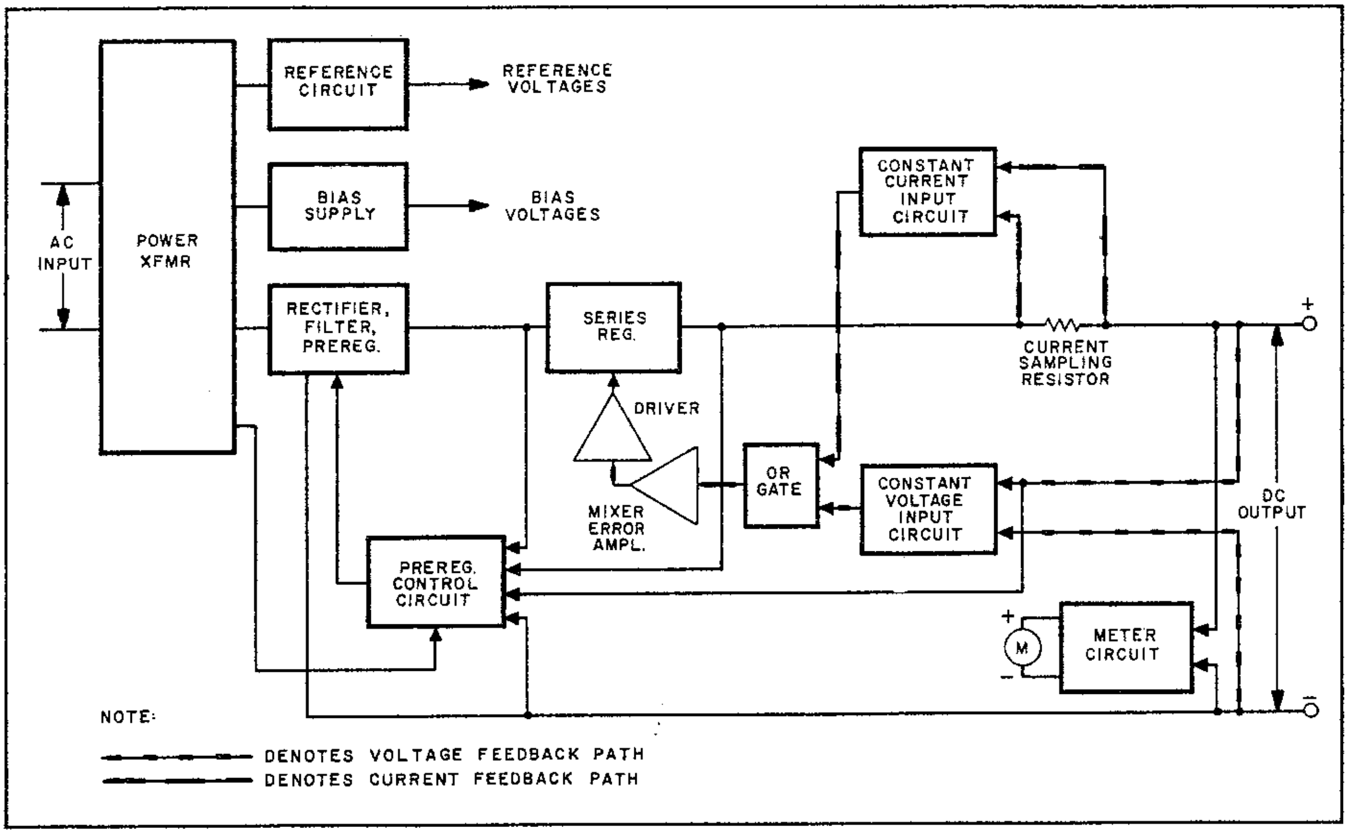


Figure 4-1. Overall Block Diagram

4-1 OVERALL BLOCK DIAGRAM DISCUSSION

4-2 The major circuits of the power supply are shown on the overall block diagram of Figure 4-1. The ac input voltage is first rectified and applied to the preregulator SCR which operates in conjunction with the SCR control circuit to form a feedback loop. This preregulator feedback loop minimizes the power dissipated by the series regulator by keeping the voltage drop across the regulator at a low and constant level.

4-3 To accomplish this, the SCR control circuit issues a phase adjusted firing pulse to the SCR once during each half cycle of the input ac. The control circuit continuously samples the output voltage, the input line voltage (from T3), and the voltage across the series regulator and, on the basis of these inputs, determines at what time each firing pulse is generated.

4-4 The phase adjusted output of the SCR is applied to the series regulator which varies its conduction to provide a regulated voltage or current at the output terminals.

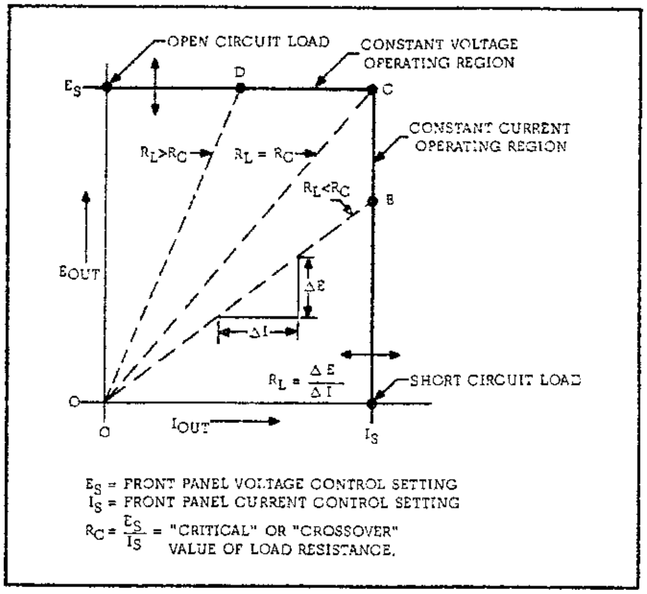
4-5 The series regulator is part of another feedback loop which consists of the error and driver amplifiers and the Constant Voltage/Constant Current comparators. The series regulator feedback loop provides fine and "fast" regulation of the output while the preregulator feedback loop handles large, relatively slow, regulation demands.

4-6 The feedback signals that control the conduction of the series regulator are originated within the constant voltage or constant current comparator. During constant voltage operation the constant voltage comparator continuously compares the output voltage of the supply with the drop across the VOLTAGE controls. If these voltages are not equal, the comparator produces an amplified error signal which is further amplified by the error amplifier and then fed back to the series regulator in the correct phase and amplitude to counteract the difference. In this manner, the constant voltage comparator helps to maintain a constant output voltage and also generates the "error" signals necessary to set the output voltage at the level that is established by the VOLTAGE controls.

4-7 During constant current operation, the constant current comparator detects any difference between the voltage drop across the current sampling resistor and the voltage across the CURRENT controls. The voltage drop across the current sampling resistor is directly proportional to the output current that flows through it. If the two inputs to the comparator are momentarily unequal, an error signal is generated which alters the conduction of the series regulator by the amount necessary to reduce the error voltage at the comparator input to zero. Hence, the IR drop across the current sampling resistor, and therefore, the output current, is maintained at a constant value.

4-8 Since the constant voltage comparator tends to achieve zero output impedance and alters the output current whenever the load resistance changes, while the constant current comparator causes the output impedance to be infinite and changes the output voltage in response to any load resistance change, it is obvious that the two comparison amplifiers cannot operate simultaneously. For any given value of load resistance, the power supply must act either as a constant voltage source or as a constant current source — it cannot be both.

4-9 Figure 4-2 shows the output characteristic of a Constant Voltage/Constant Current power supply. With no load attached ($R_L = \infty$), $I_{OUT} = 0$, and $E_{OUT} = E_S$, the front panel voltage control setting. When a load resistance is applied to the output terminals of the power supply, the output current increases, while the output voltage remains constant; point D thus represents a typical constant voltage operating point. Further decreases in load resistance are accompanied by further increases in I_{OUT} with no change in the output voltage until the output current reaches I_S, a value equal to the front panel current control setting. At this point the supply automatically changes its mode of operation and becomes a constant current source; still further decreases in the value of load resistance are accompanied by a drop in the supply output voltage with no accompanying change in the output current value. With a short circuit across the output load terminals, $I_{OUT} = I_S$ and $E_{OUT} = 0$.



E_S = FRONT PANEL VOLTAGE CONTROL SETTING
I_S = FRONT PANEL CURRENT CONTROL SETTING
$R_C = \frac{E_S}{I_S}$ = "CRITICAL" OR "CROSSOVER" VALUE OF LOAD RESISTANCE.

Figure 4-2. Operating Locus of a CV/CC Power Supply

4-10 The "crossover" value of load resistance can be defined as $R_C = E_S/I_S$. Adjustment of the front panel voltage and current controls permits this "crossover" resistance R_C to be set to any desired value from 0 to ∞. If R_L is greater than R_C, the supply is in constant voltage operation, while if R_L is less than R_C, the supply is in constant current operation.

4-11 The turn-on control circuit is a long time constant network which achieves a gradual turn-on characteristic. The slow turn-on feature protects the preregulator SCR's and the series regulator from damage which might occur when power is first applied to the unit. At turn-on, the control circuit and the series regulator (via the error and driver amplifiers). A short time after the unit is in operation, the inhibit voltages are removed and the circuit no longer exercises any control over the operation of the supply.

4-12 The reference supply provides stable reference voltages which are used by the constant voltage and current comparators in the main power supply. Less critical operating voltages are obtained from the bias supply.

4-13 DETAILED CIRCUIT ANALYSIS (Refer to Schematic at Rear of Manual.)

4-14 PREREGULATOR AND CONTROL CIRCUIT

4-15 The preregulator minimizes changes in the power dissipated by the series regulator due to output voltage, load current, or input line voltage changes. Preregulation is accomplished by means of a phase control circuit utilizing an SCR (CR35) as the switching element. The SCR is fired once during each half-cycle (8.33 milliseconds) of the rectified ac (see Figure 4-3). Notice that when the SCR is fired at an early point during the half-cycle the dc level applied to the series regulator is fairly high. When the SCR is fired later during the cycle, the dc level is relatively low.

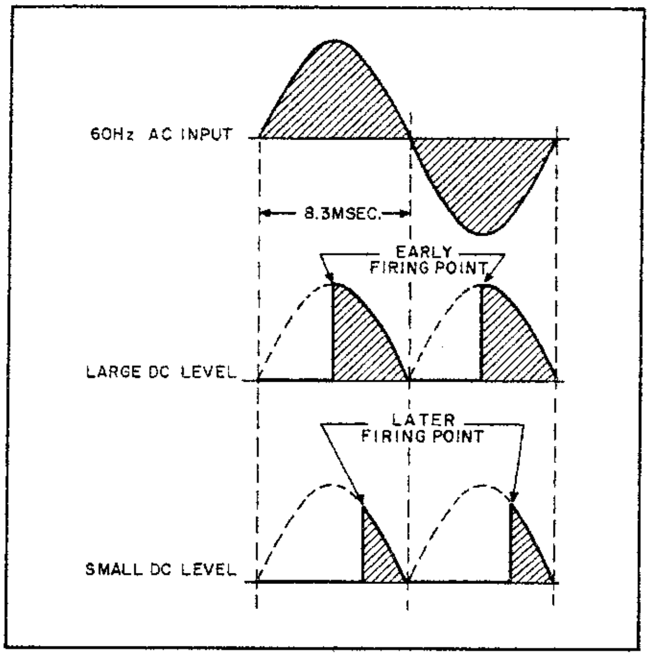
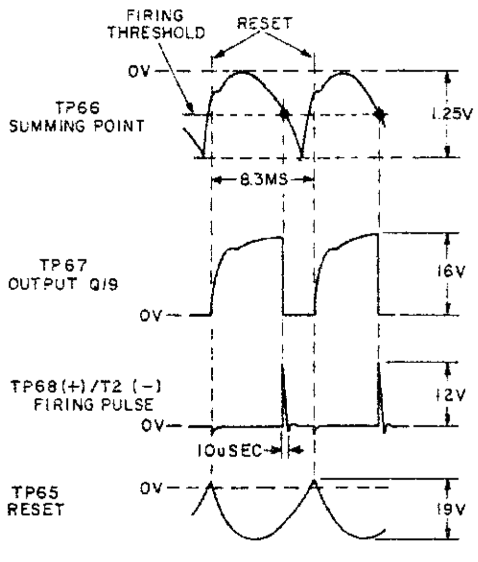


Figure 4-3. SCR Phase Control Over DC Input Level

4-16 The SCR control circuit samples the input line voltage, the output voltage, and the voltage across the series transistor. It generates a firing pulse, at the time required, to fire the SCR so that the voltage across input capacitor C14 will be maintained at the desired level.

4-17 The inputs to the control circuit are algebraically summed across capacitor C22. All inputs contribute to the time required to charge C22. The input line voltage is rectified by CR9 and CR12, attenuated by voltage divider R100 and R101, and applied to the summing point at TP66 via capacitor C22. Capacitor C23 is used for smoothing purposes. Resistor R82, connected between the minus output terminals and the summing point, furnishes a voltage drop which is proportional to the output voltage. Resistors R91 and R92 sample the voltage across the series transistor, Q6. Resistor R93 and capacitor C24 stabilize the control circuit feedback loop. Resistors R97 and R99 are the source of an offset current which varies with the output current. This offset current sustains a negative charging current to the summing capacitor ensuring that the SCR will fire at low output voltages.



NOTES:
1. ALL WAVEFORMS TAKEN AT MAXIMUM RATED OUTPUT VOLTAGE WITH NO LOAD CONNECTED.
2. SCOPE DC COUPLED AND REFERENCED TO INBOARD SIDE OF CURRENT SAMPLING RESISTOR EXCEPT FOR FIRING PULSE.
3. FOR CLARITY, WAVEFORMS ARE NOT DRAWN TO SCALE.

Figure 4-4. Preregulator Control Circuit Waveforms

4-18 The summation of the input signals results in the generation of a voltage waveform similar to that shown on Figure 4-4. The linear ramp portion of the waveform starts at zero Volts (with no load connected and at full rated output voltage) and, when a certain negative threshold voltage is reached, forward biases diodes CR16 and CR17. The negative voltage then is coupled to the base of transistor Q18. Transistors Q18 and Q19 form a squaring circuit similar to a Schmitt trigger configuration. Q18 is conducting, prior to firing time, due to the positive bias connected to its base through R94. Transistor Q19 is cutoff at this time because its base is connected directly to the collector of conducting transistor Q18. When the negative threshold voltage is reached, transistor Q18 is driven towards cutoff and transistor Q19 begins to conduct. The collector voltage of Q19 decays very rapidly as shown on Figure 4-4. The conduction of Q19 allows capacitor C17 to discharge rapidly through pulse transformer T2 resulting in the SCR firing pulse shown on the diagram. The firing pulse is relatively narrow (about 10μsec) because when Q19 reaches saturation the magnetic field surrounding T2 collapses driving the voltage in a negative direction.

4-19 Reset of the control circuit occurs once every 8.33 milliseconds when the rectified ac voltage at TP65 recedes to a level at which diode CR15 becomes forward biased. Summing capacitor C22 is then allowed to completely discharge through CR15. Diodes CR16 and CR17 become reverse biased at reset and transistor Q18 reverts to its "on" state. Consequently, Q19 is turned off and capacitor C17 charges up through R96 at a comparatively slow rate until the collector voltage of Q19 reaches approximately +16 Volts. The above action causes the small negative spike that appears across the winding of pulse transformer T2 at reset time.

4-20 TURN-ON CONTROL CIRCUIT

4-21 This circuit is a long time-constant network which protects the SCR and series regulator from possible damage during turn-on. When the power supply is first turned on, C26 provides a positive voltage to the anode of CR19 which is connected to the base of Q3. Q3 inverts this voltage and passes it on to the series regulator via Q4. The series regulator is thus turned off, until C26 becomes sufficiently charged to reverse bias CR19.

4-22 C26 initially passes a positive voltage to the cathode of CR16, in the SCR control circuit, via R98 and R99. This ensures that this diode is reverse biased and that no firing pulses are generated until C26 is sufficiently charged to provide the proper bias to CR16. CR18 provides a discharge path for C26 during turn-off.

4-23 Capacitor C26, diode CR18, and resistor R98 form a long time constant network which achieves a slow turn-on characteristic. When the unit is first turned on, C26 provides a positive voltage to the cathode of CR16 to ensure that it is intially reverse biased. After C26 becomes fully charged, the control circuit is permitted to fire the SCR. Diode CR18 provides a discharge path for C26 when the unit is turned-off.

4-24 SERIES REGULATOR

4-25 The series regulator, (transistor Q6) serves as the series element, or pass transistor, which provides precise and fast control of the output. The conduction of Q6 is varied in accordance with feedback control signals obtained from driver Q4. Zener diode VR3, connected across Q6 and R54, protects the series transistor if the output terminals of the supply are shorted. Resistor R81 limits the current through VR3.

4-26 CONSTANT VOLTAGE COMPARATOR CIRCUIT

4-27 The circuit consists of the programming resistor (R10) and a differential amplifier stage (Q1 and associated components). Transistor Q1 consists of two silicon transistors housed in a single package. The transistors have matched characteristics minimizing differential voltages due to mismatched stages. Moreover, drift due to thermal differentials is minimized, since both transistors operate at essentially the same temperature.

4-28 The constant voltage comparator circuit continuously compares a fixed reference voltage with a portion of the output voltage and, if a difference exists, produces an error voltage whose amplitude and phase is proportional to the difference. The error output is fed back to the series regulator, through OR gate diode CR3 and the mixer and driver amplifiers. The error voltage changes the conduction of the series regulator which, in turn, alters the output voltage so that the difference between the two input voltages applied to the differential amplifier is reduced to zero. This action maintains the output voltage constant.

4-29 Stage Q1B of the differential amplifier is connected to a common (+S) potential through impedance equalizing resistor R5. Resistor R6 and R8 are used to zero bias the input stage, offsetting minor base to emitter voltage differences in Q1. The base of Q1A is connected to a summing point (A6) at the junction of the programming resistors and the current pullout resistor R12. Instantaneous changes in the output (due to load variations) or changes due to the manipulation of R10, result in an increase or decrease in the summing point potential. Q1A is then made to conduct more or less, in accordance with summing point voltage change. The resultant output "error" voltage is fed back to the series regulator via the remaining components of the feedback loop. Resistor R1, in series with the base of Q1A, limits the current through the programming resistor during rapid voltage turn-down. Diodes CR1 and CR2 form a limiting network which prevents excessive voltage excursions from over driving stage Q1A Capacitors C1 and C2, shunting the programming resistor, increase the high frequency gain of the input amplifier.

4-30 During constant voltage operation, the programming current that flows through the programming resistors (VOLTAGE controls) is constant because the value of shunt resistor R12 is factory selected so that all of the +6.2 Volt reference is dropped across R12 and R13. Linear constant voltage programming is assured with a constant current flowing through R10.

4-31 Main output capacitor C20, connected across the output terminals of the supply, stabilizes the series regulator feedback loop when the normal strapping pattern shown on the schematic is employed. Note that this capacitor can be removed to avoid output current surges or to increase the programming speed of the supply. If C20 is removed, capacitor C19 serves to insure loop stability.

4-32 CONSTANT CURRENT COMPARATOR CIRCUIT

4-33 This circuit is similar in appearance and operation to the constant voltage comparator circuit. It consists of the coarse and fine current programming resistors (R16A and R16B), and a differential amplifier stage (Q2 and associated components). Like transistor Q1 in the voltage input circuit, Q2 consists of two transistors, having matched characteristics, that are housed in a single package.

4-34 The constant current comparator circuit continuously compares a fixed reference voltage with the voltage drop across the current sampling resistor. If a difference exists, the differential amplifier produces an "error" voltage which is proportional to this difference. The remaining components in the feedback loop (amplifiers and series regulator) function to maintain the drop across the current sampling resistor, and consequently the output current, at a constant value.

4-35 Stage Q2B is connected to +S through impedance equalizing resistor R26. Resistors R25 and R28 are used to zero bias the input stage, offsetting minor base to emitter voltage differences in Q2. Instantaneous changes in output current on the positive line are felt at the current summing point (terminal A5) and, hence, the base of Q2A. Stage Q2A varies its conduction in accordance with the polarity of the change at the summing point. The change in Q2A's conduction also varies the conduction of Q2B due to the coupling effects of the common emitter resistor, R22. The error voltage is taken from the collector Q2B and ultimately varies the conduction of the series regulator.

4-36 Resistor R20, in conjunction with R21 and C3, helps stabilize the feedback loop. Diode CR5 limits voltage excursions on the base of Q2A. Resistor R19, shunting the pullout resistor, serves as a trimming adjustment for the programming current flowing through R16A and R16B.

4-37 VOLTAGE CLAMP CIRCUIT

4-38 The voltage clamp circuit keeps the constant voltage programming current relatively constant when the power supply is operating in the constant current mode. This is accomplished by clamping terminal A6, the voltage summing point, to a fixed bias voltage. During constant current operation the constant voltage programming resistor is a shunt load across the output terminals of the power supply. When the output voltage changes, the current through this resistor also tends to change. Since this programming current flows through the current sampling resistor, it is erroneously interpreted as a load change by the current comparator circuit. The clamp circuit eliminates this undesirable effect by maintaining the constant voltage programming current constant.

4-39 The voltage divider, R51, R52, and VR5, back biases CR30 and Q10 during constant voltage operation. When the power supply goes into constant current operation, CR30 becomes forward biased by the collector voltage of Q1A. This results in conduction of Q10 and the clamping of the summing point at a potential only slightly more negative than the normal constant voltage potential. Clamping this voltage at approximately the same potential that exists in constant voltage operation, results in a constant voltage across, and consequently a constant current through, the current pullout resistor (R12).

4-40 MIXER AND DRIVER AMPLIFIERS

4-41 The mixer and driver amplifiers amplify the error signal from the constant voltage or constant current input circuit to a level sufficient to drive the series regulator transistor. Transistor Q3 receives the error voltage input from either the constant voltage or constant current circuit via the OR-gate diode (CR3 or CR4) that is conducting at the time. Diode CR3 is forward biased, and CR4 reversed biased, during constant voltage operation. The reverse is true during constant current operation.

4-42 The RC network, composed of C5 and R30, is an equalizing network which provides for high frequency roll off in the loop gain response in order to stabilize the feedback loop. Amplifier Q4 serves as the driver element for the series regulator.

4-43 REFERENCE CIRCUIT

4-44 The reference circuit is a feedback power supply similar to the main supply. It provides stable reference voltages which are used throughout the unit. The reference voltages are all derived from smoothed dc obtained from the full wave rectifier (CR22 and CR23) and filter capacitor C10. The +6.2 and -6.2 voltages, which are used in the constant voltage and current input circuits for comparison purposes, are developed across temperature compensated Zener diodes VR1 and VR2. Resistor R43 limits the current through the Zener diodes to establish an optimum bias level.

4-45 The regulating circuit consists of series regulating transistor Q9 and error amplifier Q8. Output voltage changes are detected by Q8 whose base is connected to the junction of a voltage divider (R41, R42) connected directly across the supply. Any error signals are amplified and inverted by Q8 and applied to the base of series transistor Q9. The series element then alters its conduction in the direction and by the amount necessary to maintain the voltage across the supply constant. Resistor R46, the emitter resistor for Q8, is connected in a manner which minimizes changes in the reference voltage caused by variations in the input line. Output capacitor C9 stabilizes the regulator loop.

4-46 METER CIRCUIT

4-47 The meter circuit provides continuous indications of output voltage or current on a single multiple range meter. The meter can be used either as a voltmeter or an ammeter depending upon the position of METER switch S2 on the front panel of the supply. This switch also selects one of two meter ranges on each scale. The metering circuit consists basically of a selection circuit (switch S2 and associated voltage dividers), a stable differential amplifier stage (Q11 through Q14), and the meter movement.

4-48 The selection circuit determines which voltage divider is connected to the differential amplifier input. When S2 is in one of the voltage positions, the voltage across divider R59, R60, and R61 (connected across the output of the supply) is the input to the differential amplifier. When S2 is in one of the current positions, the voltage across divider R14, and R55 through R58 (connected across the sampling resistor) is the input to the differential amplifier. The amplified output of the differential amplifier is used to deflect the meter.

4-49 The differential amplifier is a stable device having a fixed gain of ten. Stage Q13 of the differential amplifier receives a negative voltage from the applicable voltage divider when S2 is in one of the voltage positions while stage Q11 is connected to the +S (common) terminal. With S2 in a current position, stage Q11 receives a positive voltage from the applicable voltage divider while stage Q13 is connected to the +S terminal. The differential output of the amplifier is taken from the collectors of Q12 and Q14. Transistor Q15 is a constant current source which sets up the proper bias current for the amplifier. Potentiometer R63 permits zeroing of the meter. The meter amplifier stage contains an inherent current limiting feature which protects the meter movement against overloads. For example, if METER switch S2 is placed in position A11, (low current range) when the power supply is actually delivering a higher Ampere output, the differential amplifiers are quickly driven into saturation; limiting the current through the meter to a safe value.

4-50 Figures 4-5 and 4-6 show the meter connections when S2 is in the higher voltage and current positions, respectively. For the sake of simplicity, some of the actual circuit components are not shown on these drawings. With METER switch S2 in the higher voltage range, position (2), the voltage drop across R59 is the input to the meter amplifier and the meter indicates the output voltage across the +S and -S terminals. For low output voltages, S2 can be switched to position (1) resulting in the application of a larger percentage of the output voltage (drop across R59 and R60) to the meter amplifier.

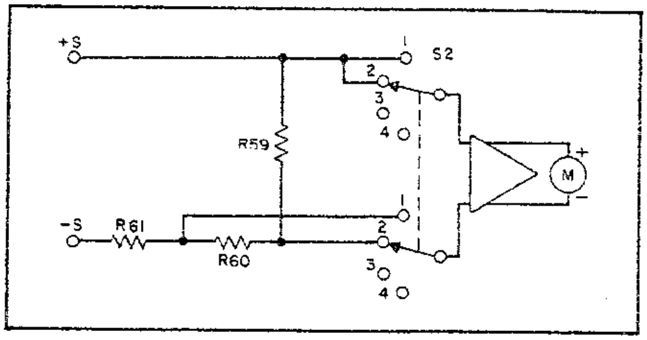


Figure 4-5. Voltmeter Connections, Simplified Schematic

4-51 With S2 in the higher current range position (Figure 4-6) the voltage drop across R58 is applied to the meter amplifier and the meter indicates the output current which flows through R54. For low values of output current, S2 can be switched to position (4) and the voltage drop across R57 and R58 is applied to the meter amplifier.

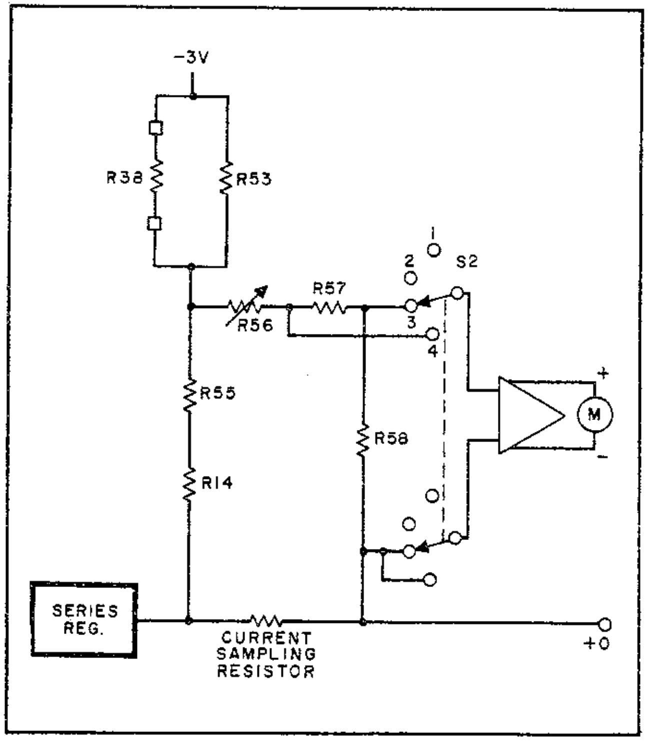


Figure 4-6. Ammeter Connections, Simplified Schematic

4-52 The -3 Volt bias source provides an offset current to the meter circuit which compensates for the programming current that flows through the current sampling resistance. Resistor R38, mounted on stand-offs, is selected so that the offset current bucks out the programming current, allowing the ammeter to be zeroed.

4-53 ADDITIONAL PROTECTION FEATURES

4-54 The supply has several "special purpose" components which protect the supply in the event of unusual circumstances. One of these components is CR34 which is connected across the output terminals of the supply and prevents internal damage from reverse voltage that might be applied across the supply. This could occur, for example, during Auto-Series operation, if one supply were turned on before the other.

4-55 Zener diode, VR3, connected across the series regulator and R54, protects Q6 from the effects of reverse voltages.