

100 Locust Avenue, Berkeley Heights, New Jersey 07922

*For Serials Above
1020A-00121 a change
page may be included.

*For Serials Below
1020A-00121 refer
to Appendix A.

FOR SERIALS 1020A-00121 AND ABOVE*

OPERATING AND SERVICE MANUAL

**DC POWER SUPPLY
DPB SERIES
MODEL 6228B**



SAFETY SUMMARY

The following general safety precautions must be observed during all phases of operation, service, and repair of this instrument. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the instrument. Hewlett-Packard Company assumes no liability for the customer's failure to comply with these requirements.

BEFORE APPLYING POWER.

Verify that the product is set to match the available line voltage and the correct fuse is installed.

GROUND THE INSTRUMENT.

This product is a Safety Class 1 instrument (provided with a protective earth terminal). To minimize shock hazard, the instrument chassis and cabinet must be connected to an electrical ground. The instrument must be connected to the ac power supply mains through a three-conductor power cable, with the third wire firmly connected to an electrical ground (safety ground) at the power outlet. For instruments designed to be hard-wired to the ac power lines (supply mains), connect the protective earth terminal to a protective conductor before any other connection is made. Any interruption of the protective (grounding) conductor or disconnection of the protective earth terminal will cause a potential shock hazard that could result in personal injury. If the instrument is to be energized via an external autotransformer for voltage reduction, be certain that the autotransformer common terminal is connected to the neutral (earthed pole) of the ac power lines (supply mains).

INPUT POWER MUST BE SWITCH CONNECTED.

For instruments without a built-in line switch, the input power lines must contain a switch or another adequate means for disconnecting the instrument from the ac power lines (supply mains).

DO NOT OPERATE IN AN EXPLOSIVE ATMOSPHERE.

Do not operate the instrument in the presence of flammable gases or fumes.

KEEP AWAY FROM LIVE CIRCUITS.

Operating personnel must not remove instrument covers. Component replacement and internal adjustments must be made by qualified service personnel. Do not replace components with power cable connected. Under certain conditions, dangerous voltages may exist even with the power cable removed. To avoid injuries, always disconnect power, discharge circuits and remove external voltage sources before touching components.

DO NOT SERVICE OR ADJUST ALONE.

Do not attempt internal service or adjustment unless another person, capable of rendering first aid and resuscitation, is present.

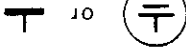
Instruments which appear damaged or defective should be made inoperative and secured against unintended operation until they can be repaired by qualified service personnel.

DO NOT EXCEED INPUT RATINGS.

This instrument may be equipped with a line filter to reduce electromagnetic interference and must be connected to a properly grounded receptacle to minimize electric shock hazard. Operation at line voltages or frequencies in excess of those stated on the data plate may cause leakage currents in excess of 5.0 mA peak.

SAFETY SYMBOLS.

Instruction manual symbol: the product will be marked with this symbol when it is necessary for the user to refer to the instruction manual (refer to Table of Contents).
Indicates hazardous voltages.



Indicate earth (ground) terminal.



The WARNING sign denotes a hazard. It calls attention to a procedure, practice, or the like, which, if not correctly performed or adhered to, could result in personal injury. Do not proceed beyond a WARNING sign until the indicated conditions are fully understood and met.



The CAUTION sign denotes a hazard. It calls attention to an operating procedure, or the like, which, if not correctly performed or adhered to, could result in damage to or destruction of part or all of the product. Do not proceed beyond a CAUTION sign until the indicated conditions are fully understood and met.

DO NOT SUBSTITUTE PARTS OR MODIFY INSTRUMENT.

Because of the danger of introducing additional hazards, do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to a Hewlett-Packard Sales and Service Office for service and repair to ensure that safety features are maintained.

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SECTION I GENERAL INFORMATION

1-1 DESCRIPTION

- 1-2 This instrument is designed to be used in applications such as powering operational amplifiers, push-pull stages, and deflection systems where plus and minus voltages are required to track with an insignificant error, and in any application where two independent power supplies housed in a single package represent an operating convenience.
- 1-3 The instruments consists of two identical, independently adjustable dc power supplies in a half-track case. A front panel switch selects one of two modes of operation: independent or tracking. In the independent mode, the output voltage and current of each supply are controlled separately, and each supply is isolated up to 300V from output to chassis or output to output. In the tracking mode, both outputs are automatically connected in series, and the controls of the left supply adjust the magnitudes of both the positive and negative output voltages. Because the outputs are connected in a tracking configuration, any internal disturbance in the master supply (such as drift or ripple) will cause an equal percentage change in the outputs of both the supplies.
- 1-4 Each power supply is a completely transistorized, well-regulated, constant voltage/constant current supply that will furnish full rated output voltage at the maximum 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 (independent or tracking modes), and the VOLTAGE controls can be used to establish the voltage limit (ceiling) when the supply is used as a constant current source (independent mode only). The supply will automatically cross over from constant voltage to constant current operation (current limited operation in the tracking mode) and vice versa if the output current or voltage exceeds these preset limits.
- 1-5 Each supply has its own front panel meter that can measure output voltage or current. The front panel METER switch on each supply selects either of the two functions.
- 1-6 Each supply has a built in overvoltage protection crowbar for the protection of delicate loads.
- The crowbar sets a limit (adjustable from the front panel) on the output voltage. If this limit is exceeded, a short circuit is applied across the output of the supply.
- 1-7 Both front and rear output terminals are provided on each supply. Either set of terminals can be used in the independent mode; only the front terminals can be used when the instrument is operated in the tracking mode. Either the positive or negative output terminals can be connected to the chassis through a separate ground terminal located adjacent to the output terminals, or the supply can be operated floating at up to a maximum of 300 volts above ground.
- 1-8 Terminals located at the rear of each power supply allow access to various control points within the supply to expand the operating capabilities of the power supply. A brief description of these capabilities is given below:
- a. Remote Programming. In the independent mode, the output voltage or current of each supply may be programmed (controlled) from a remote location by means of an external voltage source or resistance connected to each supply. In the tracking mode, the output voltage of both supplies may be programmed from a remote location by means of an external voltage source or resistance connected to the left (master) supply.
- b. Remote Sensing. The degradation in regulation which occurs at the load due to voltage drop in the load leads can be reduced by employing remote sensing. This is possible with the instrument in the independent mode of operation only.
- c. Auto-Series Operation. Two or more power supplies may be used in series when a higher output voltage is required in the constant 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. Auto-Parallel Operation. Each individual power supply may be operated in parallel with one or more similar units 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 Operation. One power supply may be used as a master supply controlling one or more slave supplies furnishing various voltages for a system. When operated with the

front panel mode switch in the tracking position, the instrument is automatically internally connected in an Auto-Tracking configuration.

1-9 SPECIFICATIONS

1-10 Detailed specifications for the instrument are given in Table 1-1. Unless otherwise noted, the specifications apply equally to both of the independent supplies housed in the instrument.

1-11 OPTIONS

1-12 Options are customer-requested factory modifications of a standard instrument. The following options are available for the instrument covered by this manual. Where necessary, detailed coverage of the options are included throughout the manual.

Option No.	Description
007	Ten-Turn Output Voltage Controls: Two single ten-turn controls that replace both sets of concentric coarse and fine voltage controls. The controls allow greater resolution in setting the output current of each supply.
008	Ten-Turn Output Current Controls: Two single ten-turn controls that replace both sets of concentric coarse and fine current controls. The controls allow greater resolution in setting the output current of each supply.
009	Ten-Turn Output Voltage and Current Controls: Options 007 and 008 on the same instrument.
013	Three Digit Ten-Turn Graduated Decadal Voltage Controls: Two single ten-turn controls with Decadials that replace both sets of concentric coarse and fine voltage controls. The controls allow accurate resetting of the output voltage of each supply.
014	Three Digit Ten-Turn Graduated Decadal Current Controls: Two single ten-turn controls with Decadials that replace both sets of concentric coarse and fine current controls. The controls allow accurate resetting of the output current of each supply.
015	Three Digit Ten-Turn Graduated Decadal Voltage and Current Controls: Options 013 and 014 on the same instrument.

1-13 ACCESSORIES

1-14 The accessories listed in the following chart

HP Part or Model No. Description

1052A Combining Case for mounting one or two units in standard 19" rack (refer to Section II for details).
 Cooling kit for above combining case, 115Vac, 50-60Hz.
 Cooling kit for above combining case, 230Vac, 50-60Hz.
 Filler panel to block unused half of above combining case when mounting only one unit.

1-15 INSTRUMENT IDENTIFICATION

1-16 Hewlett-Packard power supplies are identified by a three-part serial number. The first part is the power supply model number. The second number-letter combination denoting the date of manufacture. The first two digits indicate the year (10 = 1970, 11 = 1971, 20 = 1980, etc); the second and two digits indicate the week (01 through 52); and the letter "A", "G", "J", or "U" designates the U.S.A., West Germany, Japan, or the United Kingdom, respectively, as the country of manufacture. The third part is the power supply serial number; a different 5-digit sequential number is assigned to each power supply, starting with 00101.

1-17 If the serial number prefix on your unit does not agree with the prefix on the title page of this manual, change sheets supplied with the manual or manual backdating changes in Appendix A define the differences between your instrument and the instrument described by this manual.

1-18 ORDERING ADDITIONAL MANUALS

1-19 One manual is shipped with each instrument. 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 HP part number shown on the title page.

may be ordered with the instrument or separately from your local Hewlett-Packard sales office (refer to list at rear of manual for addresses).

Table 1-1. Specifications

<p>TRANSIENT RECOVERY TIME: Less than 50µsec is required for output voltage recovery (in constant voltage operation) to within 10mV of the nominal output voltage following a 1 ampere change in output current.</p> <p>METERS: Each front panel meter can be used as either a 0-60V voltmeter or a 0-1.2A ammeter. Meters are accurate within 2% of full scale; meter switch selects voltage or current readings.</p> <p>OUTPUT CONTROLS: Single-turn concentric coarse and fine voltage and current controls are included on the front panel. Mode switch selects one of two modes of operation; either two independent, isolated outputs; or the two outputs connected in series and referred to a common bus for tracking.</p> <p>SLAVE TRACKING ERROR: During tracking operation, the slave supply is matched to within 0.2% ±2mV of the master supply.</p> <p>REMOTE VOLTAGE PROGRAMMING: All programming terminals on rear barrier strips.</p> <p>REMOTE RESISTANCE PROGRAMMING: All programming terminals on rear barrier strips.</p> <p>CONSTANT VOLTAGE - 1V/volt. CONSTANT CURRENT - 1V/ampere.</p> <p>OVERVOLTAGE PROTECTION CROWBAR: During independent operation, each supply is protected by its own crowbar. In the tracking mode, an overvoltage in either supply results in firing both crowbars. The minimum crowbar trip setting above the desired operating output voltage to prevent false crowbar tripping is 7% of output voltage setting plus 1.5 volt. Nominal trip voltage range is 5 to 55Vdc.</p> <p>COOLING: Convection cooling is employed. The supply has no moving parts.</p> <p>SIZE: 6-17/32" (16,59cm) H x 12-3/8" (31,43cm) D x 7-3/4" (19,69cm) W.</p> <p>FINISH: Light gray panel with dark gray case.</p>	<p>INPUT: 115/230Vac ±10%, single phase, 48-66Hz, 2.7A, 260W @ 115V.</p> <p>OUTPUT: Independent Mode - Two independent outputs, each of which can be set from 0-50 volts at 0-1 ampere. Tracking Mode - Tracking outputs of 0 to ±50 volts at 1 ampere each.</p> <p>LOAD REGULATION: Constant Voltage - Less than 0.01% plus 1mV for a load current change equal to the current rating of the supply. Constant Current - Less than 0.01% plus 250µA for a load voltage change equal to the voltage rating of the supply.</p> <p>LINE REGULATION: Constant Voltage - Less than 1mV for a change in line voltage from 103.5 to 126.5V at any output voltage and current within rating. Constant Current - Less than 100µA for a line voltage change from 103.5 to 126.5V at any output voltage and current within rating.</p> <p>RIPPLE AND NOISE: Constant Voltage - Less than 250µVrms, 4mV p-p (dc to 20MHz). Constant Current - Less than 250µArms, 2mA p-p (dc to 20MHz).</p> <p>TEMPERATURE RATINGS: Operating: 0 to 55°C. Storage: -40 to +75°C.</p> <p>TEMPERATURE COEFFICIENT: Constant Voltage - Less than 0.02% plus 200µV change per degree Centigrade change in ambient following 30 minutes warm-up. Constant Current - Less than 0.02% plus 150µA change per degree Centigrade change in ambient following 30 minutes warm-up.</p> <p>STABILITY: Constant Voltage - Less than 0.2% plus 2mV total drift for 8 hours following 30 minutes warm-up under constant ambient conditions. Constant Current - Less than 0.2% plus 1.5mA total drift for 8 hours following 30 minutes warm-up under constant ambient conditions.</p> <p>OUTPUT IMPEDANCE: A 6mΩ resistor in series with a 6µH inductor.</p> <p>WEIGHT: 24 lbs. (11 kg) net. 28 lbs. (12,9 kg) ship-ping.</p>
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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 received, proceed as instructed in the following paragraphs.

2-3 MECHANICAL CHECK

2-4 If external damage to the shipping carton is evident, ask the carrier's agent to be present when the instrument is unpacked. Check the instrument for external damage such as broken controls or connectors, and dents or scratches on the panel surfaces. If the instrument is damaged, file a claim with the carrier's agent and notify your local Hewlett-Packard Sales and Service Office as soon as possible (see list at rear of this manual for addresses).

2-5 ELECTRICAL CHECK

2-6 Check the electrical performance of the instrument as soon as possible after receipt. Section V of this manual contains performance check procedures which will verify instrument operation within the specifications as stated in Table 1-1. This check is also suitable for incoming quality control inspection. Refer to the inside front cover of the manual for the Certification and Warranty statements.

2-7 REPACKAGING FOR SHIPMENT

2-8 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 specifying the owner, model number, full serial number, and service required, or a brief description of the trouble.

2-9 INSTALLATION DATA

2-10 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.

2-1

2-11 LOCATION

2-12 This instrument is convection cooled. Sufficient space should be allotted so that a free flow of cooling air can reach the top and rear of the instrument when it is in operation. It should be used in an area where the ambient temperature remains between 0°C and +55°C.

2-13 OUTLINE DIAGRAM

2-14 Figure 2-1 illustrates the outline shape and dimensions of the Model 6227B and 6228B supplies.

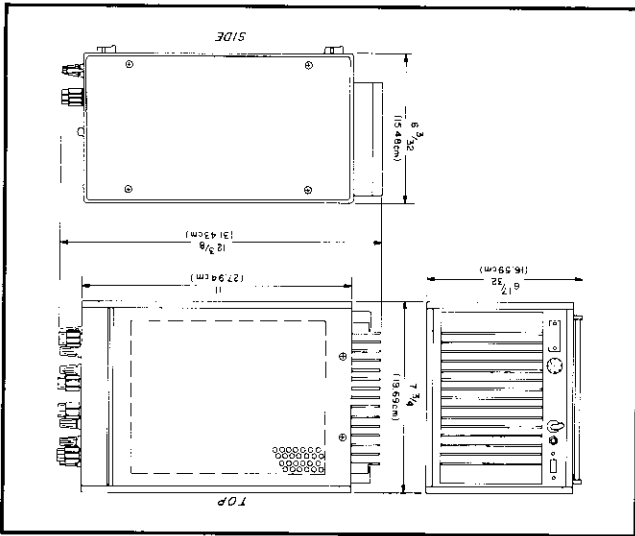


Figure 2-1. Outline Diagram

2-15 RACK MOUNTING

2-16 The Model 6227B and 6228B power supplies are submodular units, which, when used alone, can be bench mounted only. However, when used in combination with other submodular units, they can be bench and/or rack mounted in the HP combining case which is specifically designed for this purpose. The HP "Rack Adapter Frame" cannot be used due to the weight of the instruments.

2-17 The combining case is a full-module unit which accepts varying combinations of submodular units. Since it is a full-module unit, it can be bench or rack mounted analogous to any full-module HP instrument. A cooling kit (see

2-22 A recessed, two-position slide switch located on the lower rear panel permits operation from either a 115 or 230 volt power source. Before

2-21 115/230 VOLT OPERATION

2-20 This power supply may be operated continuously from either a nominal 115 volt or 230 volt, 48-66Hz power source. The input power required when operating from a 115 volt, 60Hz power source at full load is 260 watts, 2.7 amperes.

2-19 INPUT POWER REQUIREMENTS

- a. Remove gray plastic trim strips (glued on) at each side of case by inserting thin screwdriver at edge or top of strip and prying gently away from case.
 - b. Attach rack ears (furnished with each combining case) to side of case using screws supplied with ears.
 - c. Mount unit in rack, using standard mounting screws.
- 2-18 To rack mount the combining case in a standard rack, proceed as follows:

Paragraph 1-14 for HP Part No.) must be installed at the rear of the combining case when operating either one or two Model 6227B or 6228B power supplies in the case. Instructions for installing the Model 6227B or 6228B power supplies in the combining case are given in Figure 2-2.

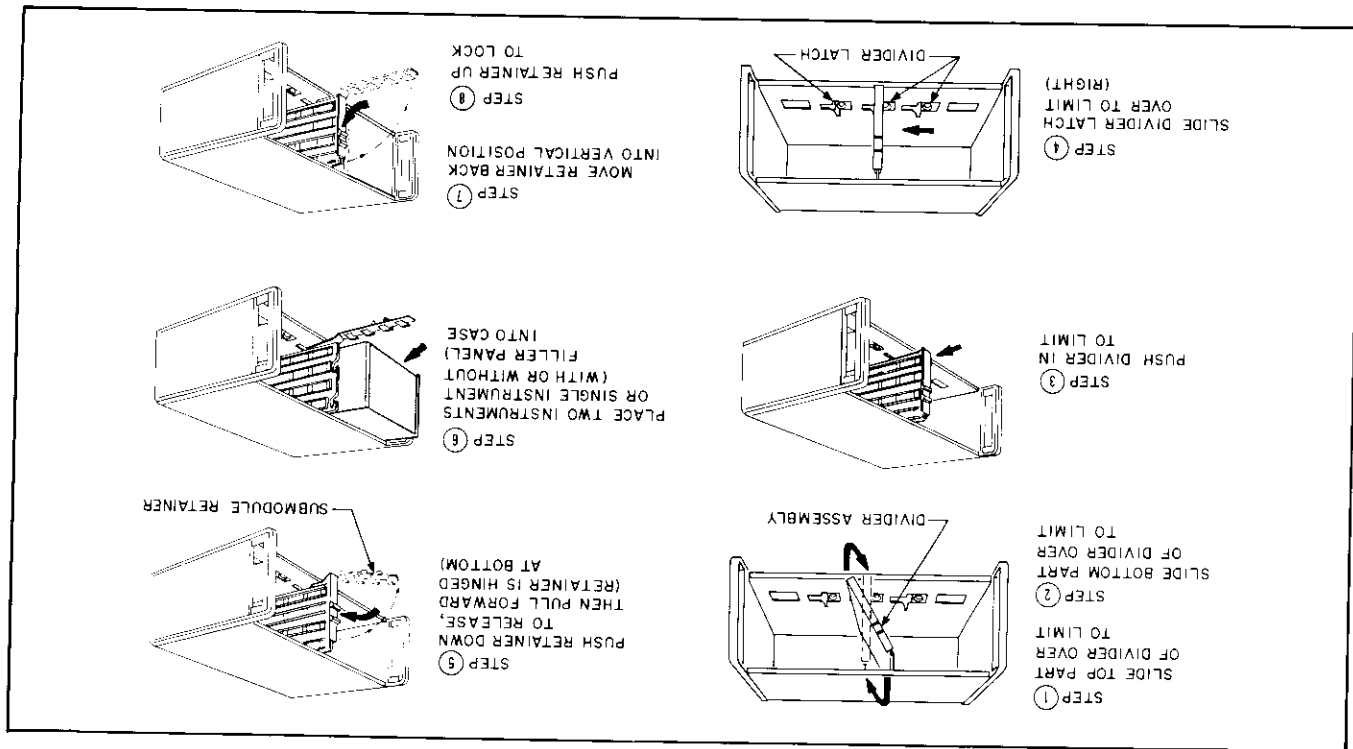
2-25 To protect operating personnel, the National Electrical Manufacturers' Association (NEMA) recommends that the instrument panel and cabinet be grounded. This instrument is equipped with a three conductor power cable. The third conductor is the ground conductor and when the cable is plugged into an appropriate receptacle, the instrument is grounded. The offset pin on the power cable's three-prong connector is the ground connection. 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 POWER CABLE

2-23 When the instrument leaves the factory, the proper fuse is installed for 115 volt operation. An envelope containing a fuse for 230 volt operation is attached to the instrument. Markings on the lower rear panel adjacent to the fuse holder indicate the correct fuse rating for operation from either a 115 volt or a 230 volt power source. Make sure that the correct fuse is installed if the position of the slide switch is changed.

connecting the instrument to the power source, check that the white number visible on the switch slide matches the nominal line voltage of the source. If required, slide the switch to the other position using a thin-bladed screwdriver.

Figure 2-2. Procedure for Installing Instrument(s) in HP Combining Case



SECTION III
OPERATING INSTRUCTIONS

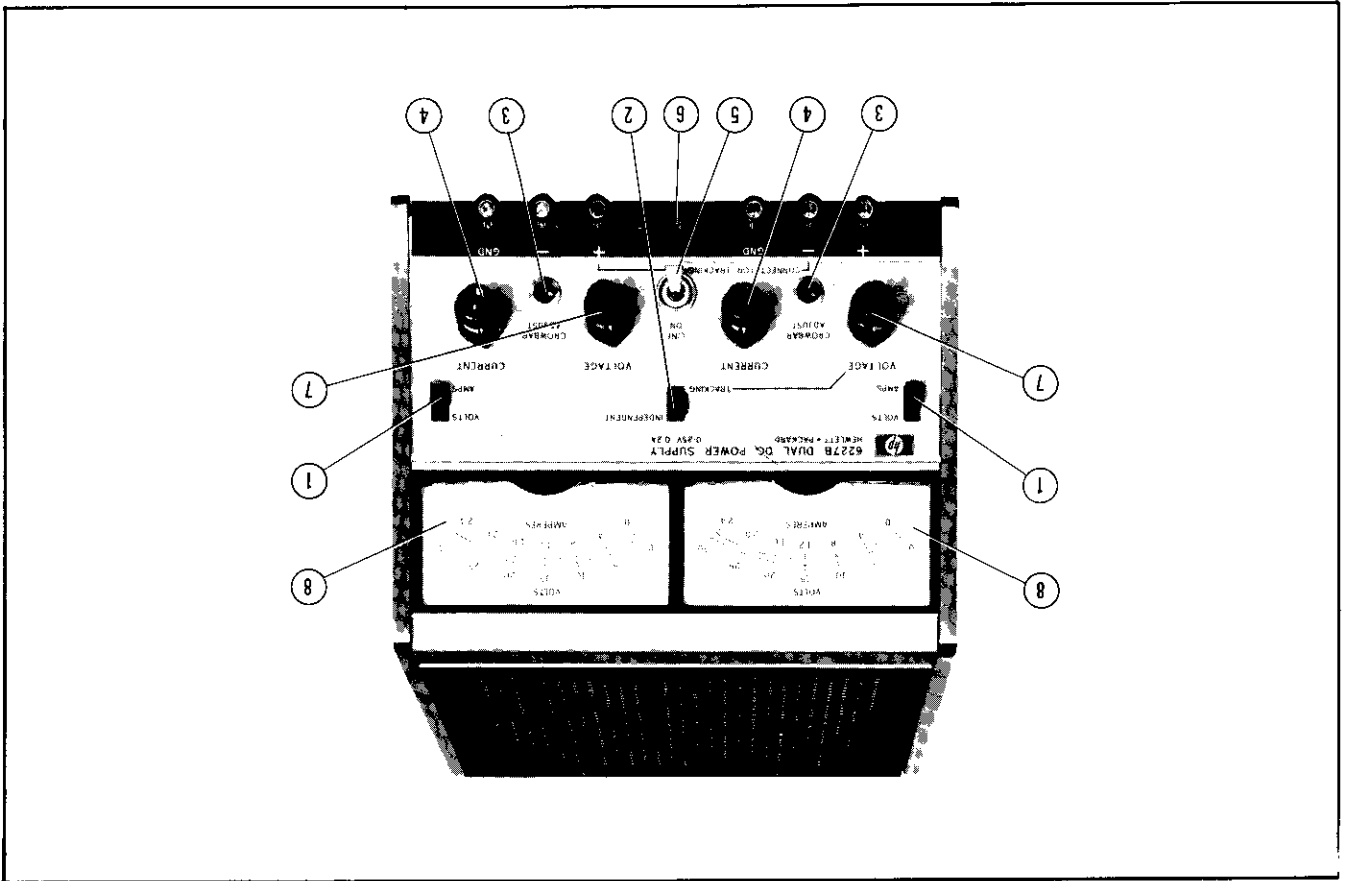


Figure 3-1. Operating Controls and Indicators

3-1 TURN-ON CHECKOUT PROCEDURE

- 3-2 The following checkout procedure describes the use of the front panel controls and indicators (Figure 3-1) and ensures that the supply is operational. This procedure should be performed with no load connected to the supply.
- Set both meter switches ① to VOLTS.
 - Set mode switch ② to INDEPENDENT, rotate both CROWBAR ADJUST controls ③ (screwdriver adjust) fully clockwise, and rotate both sets of CURRENT controls ④ to middle of range (black knobs are coarse controls, red knobs are fine controls).
 - Set LINE switch ⑤ to ON, and observe that pilot lamp ⑥ lights.
 - Adjust both sets of VOLTAGE controls ⑦ (black knobs are coarse controls, red knobs are fine controls) until desired output voltages are indicated on meters ⑧.
- To ensure that overvoltage crowbar circuit is operational, rotate each OVERVOLTAGE ADJUST control counterclockwise until associated supply crowbars. Output voltage of each supply will fall to approximately one volt.
 - To deactivate each crowbar, return its OVERVOLTAGE ADJUST control to maximum clockwise position and turn off supply. Turn supply back on and output voltages should again be value obtained in Step (c).
 - To check out constant current circuit, turn off supply. Short circuit both sets of front panel output terminals (plus to minus), rotate both sets of VOLTAGE controls to middle of range, set both meter switches to AMPS, and turn on supply.
 - Adjust both sets of CURRENT controls until desired output currents are indicated on meters.
 - To check out tracking mode of operation,

SECTION III OPERATING INSTRUCTIONS

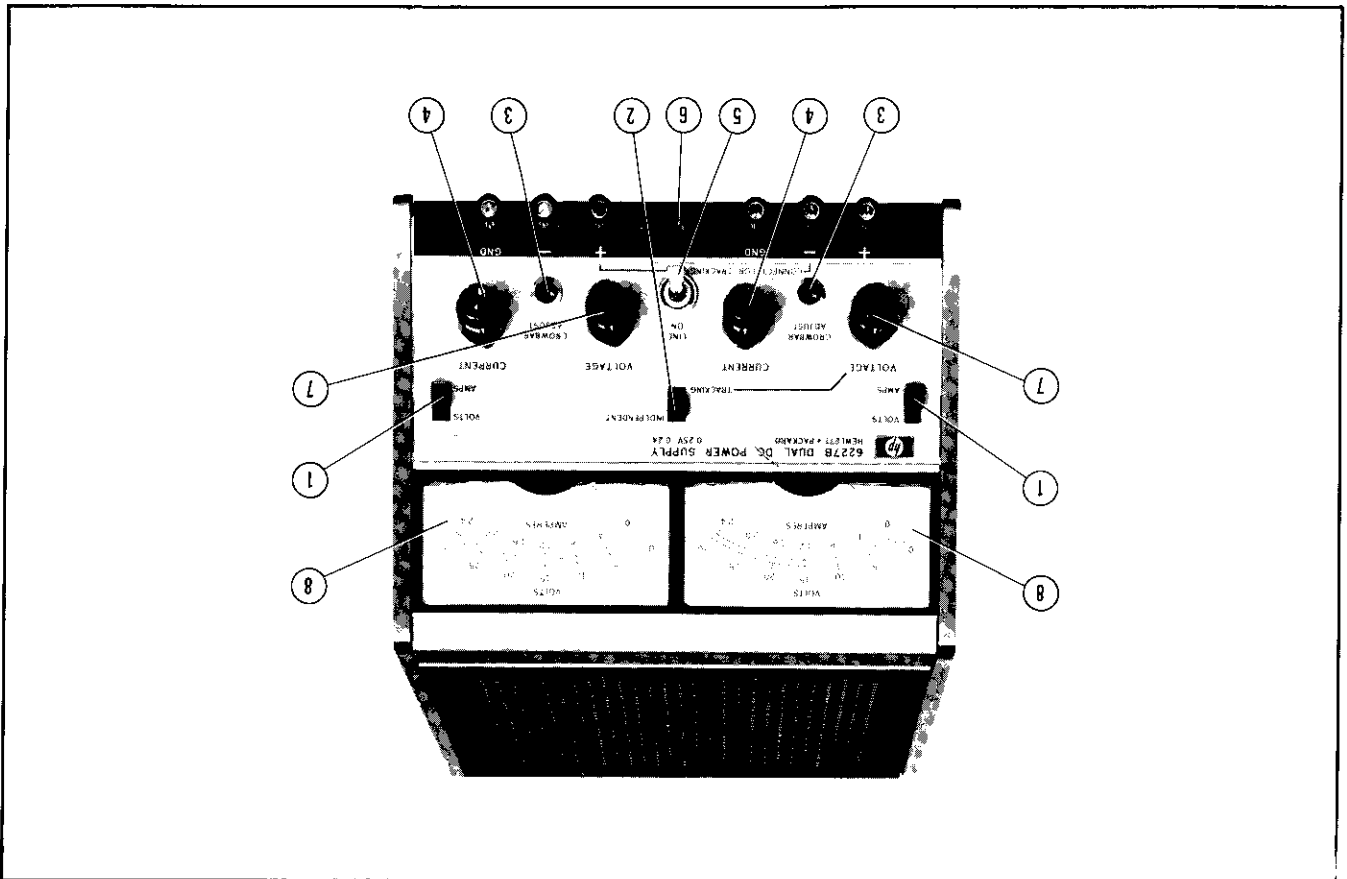


Figure 3-1. Operating Controls and Indicators

3-1 TURN-ON CHECKOUT PROCEDURE

- 3-2 The following checkout procedure describes the use of the front panel controls and indicators (Figure 3-1) and ensures that the supply is operational. This procedure should be performed with no load connected to the supply.
- Set both meter switches **1** to VOLTS.
 - Set mode switch **2** to INDEPENDENT, rotate both CROWBAR ADJUST controls **3** (screwdriver adjust) fully clockwise, and rotate both sets of CURRENT controls **4** to middle of range (black knobs are coarse controls, red knobs are fine controls).
 - Set LINE switch **5** to ON, and observe that pilot lamp **6** lights.
 - Adjust both sets of VOLTAGE controls **7** (black knobs are coarse controls, red knobs are fine controls) until desired output voltages are indicated on meters **8**.
- To ensure that overvoltage crowbar circuit is operational, rotate each OVERVOLTAGE ADJUST control counterclockwise until associated supply crowbars. Output voltage of each supply will fall to approximately one volt.
 - To deactivate each crowbar, return its OVERVOLTAGE ADJUST control to maximum clockwise position and turn off supply. Turn supply back on and output voltages should again be value obtained in Step (c).
 - To check out constant current circuit, turn off supply. Short circuit both sets of front panel output terminals (plus to minus), rotate both sets of VOLTAGE controls to middle of range, set both meter switches to AMPS, and turn on supply.
 - Adjust both sets of CURRENT controls until desired output currents are indicated on meters.
 - To check out tracking mode of operation,

turn off supply, remove short circuits across output terminals, rotate both sets of CURRENT control to middle of range, rotate both sets of VOLTAGE controls fully counterclockwise, set both meter switches to VOLTS, connect jumper between minus output terminal of left supply and plus output terminal of right supply as shown on front panel, and set mode switch to TRACKING.

i. Turn on supply and adjust left (master) set of VOLTAGE controls until desired output voltage age is indicated on both meters.

j. To check out operation of overvoltage crowbar in tracking mode, rotate either OVERVOLTAGE ADJUST control until both supplies crowbar. Output voltage of both supplies will fall to approximately one volt.

k. To deactivate both crowbars, return OVERVOLTAGE ADJUST control to maximum clockwise position and turn off supply. Turn supply back on and both output voltages should again be value obtained in Step (i).

l. Turn off supply and read following paragraphs before connecting actual load to supply.

3-3 BASIC OPERATING MODES

3-4 The instrument has two basic modes of operation: INDEPENDENT, in which the instrument functions as two completely separate power supplies, and TRACKING, in which the instrument functions as a single power supply having two opposite polarity, tracking outputs. Either of these two modes can be selected by simply changing the position of the front panel mode switch. Additional operating modes such as remote programming in the TRACKING mode and series-parallel connections in the INDEPENDENT mode can be selected by making strapping connections between particular terminals on the terminal strips at the rear of the instrument (refer to Paragraphs 3-39 and 3-50). The following paragraphs describe the procedures for utilizing these various operational capabilities of the instrument. A more theoretical description of the operational features of the two power supplies is contained in Application Note 90A, Power Supply Handbook (available at no charge from your local Hewlett-Packard sales office). Sales office addresses appear at the rear of the manual.

3-5 INDEPENDENT OPERATION

3-6 The instrument functions as two completely independent power supplies when the front-panel mode switch is in the INDEPENDENT position. In this mode the operating procedures for each supply are identical, and thus the following paragraphs describe procedures for one supply only.

3-7 The instrument is normally shipped with each supply's rear terminal strapping connections arranged for constant voltage/constant current, 3-79.)

3-11 To select a constant current output, proceed as follows:

a. Short circuit output terminals and adjust CURRENT controls (with meter switch in AMPS position) for desired output current.

b. Open circuit output terminals and adjust VOLTAGE controls (with meter switch in VOLTS position) 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 cross over to constant current output at the preset current limit and the output current will drop proportionately. In setting the current limit, allowance must be made for high peak currents which can cause unwanted crossover. (Refer to Paragraph 3-79.)

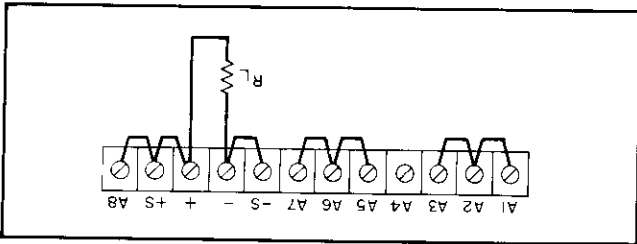
3-10 CONSTANT CURRENT

3-12 To select a constant voltage output, proceed as follows:

a. Turn on power supply and adjust VOLTAGE controls (with meter switch in VOLTS position) for desired output voltage with output terminals open.

b. Short circuit output terminals and adjust CURRENT controls (with meter switch in AMPS position) 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 cross over 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 currents which can cause unwanted crossover. (Refer to Paragraph 3-79.)

Figure 3-2. Normal Strapping Pattern



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).

3-12 OVERVOLTAGE CROWBAR OPERATION

3-13 Trip Point Adjustment. The crowbar trip voltage can be adjusted by using the screwdriver control (CROWBAR ADJUST) on the front panel. The nominal trip voltage range is as follows (clockwise rotation of the control produces higher trip voltages):

- 6227B 5 to 28Vdc
- 6228B 5 to 55Vdc

To adjust the trip point, proceed as follows:

- a. Turn CROWBAR ADJUST control fully clockwise and turn on supply.
- b. Set output voltage to desired trip voltage.
- c. Turn CROWBAR ADJUST control slowly counterclockwise until crowbar is tripped (voltage meter falls to one volt or less).
- d. Turn off supply and turn down output voltage.
- e. Turn on supply and set desired operating output voltage.

3-14 False crowbar tripping must be considered when adjusting the trip point. If the trip voltage is set too close to the operating output voltage of the supply, a transient in the output or load will falsely trip the crowbar. It is recommended that the crowbar trip voltage be set higher than the operating output voltage by 7% plus 1.5 volts.

3-15 Operating Characteristics. When the crowbar trips, the supply output is shorted by an SCR. The output voltage then falls to one volt or less (the forward voltage drop of the SCR), and the current supplied to the load falls to essentially zero. Note that once the crowbar is tripped, the ammeter indicates the current flowing through the SCR. This current is determined by the setting of the CURRENT controls, just as it would be if an external short were connected across the output terminals. If the CURRENT controls are set to a very low level (less than 0.05 amperes), the current supplied to the SCR when the crowbar trips may not be enough to keep the SCR conducting. In this case, the crowbar will oscillate, and the output voltage will cycle between zero and the crowbar trip level. This condition can be prevented by setting the CURRENT controls at a slightly higher level.

3-16 Crowbar Reset. The crowbar may be reset by either of two methods. If the crowbar tripped due to a transient in the output or load, it can be reset by simply turning the power switch off and then on again. The crowbar can also be reset in this manner if it tripped due to the application of an external voltage higher than the output voltage across the output terminals. If the crowbar tripped due to accidentally setting the output voltage higher than intended, it can be reset by turning

3-17 CONNECTING LOAD

3-18 Each load should be connected to the power supply output terminals (front or rear) 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 a shielded pair is used, connect the shield to ground at the power supply and leave the other end unconnected.)

3-19 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 should be separately connected to the remote distribution terminals. For this case, remote sensing should be used. (Refer to Paragraph 3-61.)

3-20 Positive or negative voltages can be obtained from the supply by grounding either one of the output terminals or one end of the load. Always use two leads to connect the load to the supply, regardless of where the setup is grounded. This will eliminate any possibility of output current return paths through the power source ground. The supply can also be operated up to 300Vdc above ground if neither output terminal is grounded.

3-21 OPERATION BEYOND RATED OUTPUT

3-22 The shaded areas on the front panel meter faces indicate the approximate amount of output voltage or current that may be available in excess of the normal rated output. Although the supply can be operated in these shaded regions without being damaged, it cannot be guaranteed to meet all of its performance specifications.

3-23 TRACKING OPERATION

3-24 When operated in the tracking mode (front-panel mode switch in TRACKING position), the instrument functions as a single power supply having equal magnitude positive and negative output voltages, both referred to a common bus. In this mode, the output of the right supply (slave) tracks the output of the left supply (master) to within 0.2% ± 2mV.

3-25 CONSTANT VOLTAGE

3-26 The VOLTAGE controls on the master supply set the output voltage of both the master and the

connected to the rear output terminals. Changing the mode switch position under these circumstances may result in damage to the switch.

3-30 For correct operation in the tracking mode, a jumper capable of carrying the full output current of the supply must be connected between the negative output terminal of the left supply and the positive output terminal of the right supply, as shown on the front panel. If this jumper is not connected when the instrument is used in the tracking mode, the supply will not meet its tracking specifications. In addition, the programming speed of the right supply (slave) will be much slower, and the supply may oscillate under certain load conditions.

3-31 The minus output terminal of the master (left) supply should be used as the common output terminal for the positive and negative output voltages. Using the slave positive terminal as the common terminal will result in regulation degradation due to the small but finite resistance of the wire connecting the two terminals. Each pair of loads should be connected to the power supply output terminals using separate sets of three wires. Each set of connecting wires should be as short as possible and twisted or shielded to reduce noise pickup. (If shielded three-conductor cable is used, connect the shield to ground at the power supply and leave the other end unconnected.)

3-32 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 three-conductor shielded cable and each load should be separately connected to the remote distribution terminals. Note, however, that since remote sensing cannot be used when the instrument is operated in the tracking mode, the leads to the distribution terminals should be relatively short if degradation of the regulation specification is to be avoided.

3-33 Any one of the three output terminals (plus, minus, or common) can be grounded. However, three leads should always be used to connect the loads, regardless of where the setup is grounded. This will eliminate any possibility of output current return paths through the power source ground. If none of the output terminals are grounded, the two outputs can be floated at up to 300 volts total above ground.

3-34 The instrument will function as one power supply with twice the output voltage of one of the single supplies if no connection is made to the common terminal when operating in the tracking

slave supplies in the tracking mode. The CURRENT controls of each supply act separately to set the current limit for each supply. When the instrument is used in the tracking mode, neither supply is capable of true constant current operation—the CURRENT controls set a gross current limit only. To select a constant voltage output, proceed as follows:

a. Set mode switch to TRACKING, connect jumper between negative output terminal of left supply and positive output terminal of right supply as shown on front panel, turn on power supply, and adjust left (master) VOLTAGE controls for desired output voltage on master and slave.

b. Short circuit each pair of output terminals and adjust each set of CURRENT controls for maximum output current allowable for each supply (current limit), as determined by load conditions. If a load change causes the current limit on the slave to be exceeded, the slave will automatically cross over into current limited operation (slave output voltage will drop proportionately). Note that since the slave will follow every change in output voltage of the master, the slave voltage will also drop by the same amount. However, if a load change causes the current limit on the slave to be exceeded, the slave will automatically cross over into current limited operation (slave output voltage will drop proportionately) without having any effect on the master.

3-27 It must be understood that the slave will follow one-for-one every change in output voltage of the master. For example, if a load transient causes the master output voltage to change, the same change will appear in the slave output voltage, even though there was no transient in the load connected to the slave, or even if there was no load connected to the slave at all. Similarly, any variation in programming speed, stability, or other master supply parameter will appear in the slave supply's output.

3-28 CONNECTING LOAD

3-29 Only the front output terminals can be used when the supply is in the tracking mode. Because sensing is accomplished at the front terminals when the supply is in the tracking mode, the supply will not meet the tracking or regulation specifications if loads are connected to the rear terminals.

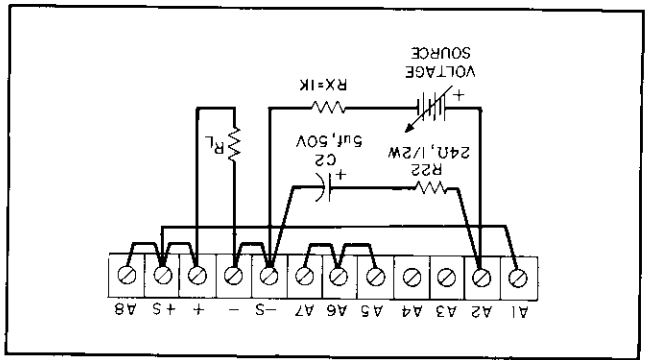
CAUTION

Tracking operation is not possible with loads connected to the rear terminals. Do not switch from independent to tracking mode when loads are

3-48 External resistors R_p and R_f should have stable, low noise, and low temperature coefficient (less than 20ppm per degree Centigrade) characteristics in order to maintain the supply's temperature and stability specifications. The values of reference resistor R_f and programming voltage source V_S should be such that the value of V_S/R_f is equal to or greater than 5mA. The value of resistor R_f should not exceed 10k Ω ; the power rating of resistor R_f should be at least 10 times the actual power dissipated in the resistor. Resistor-capacitor combination R22-C2 should be connected across the programming terminals as shown in Figure 3-5; these components reduce ripple in the supply output. Note that it is possible to use the front panel voltage control already in the supply

3-47 Voltage Programming, Variable Gain (Figure 3-5). The strapping pattern shown in Figure 3-5 can be utilized for programming the power supply with variable voltage gain using an external voltage source. The output voltage in this configuration is found by multiplying the external voltage source by (R_p/R_f) .

Figure 3-4. Remote Voltage Programming, Constant Voltage (Unity Gain)



3-46 Voltage Programming, Unity Gain (Figure 3-4). Employ the strapping pattern shown in Figure 3-4 for voltage programming with unity gain. 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 20 μ A. Impedance matching resistor (R_X) is required to maintain the temperature coefficient and stability specifications of the supply; resistor-capacitor combination R22-C2 is required to reduce ripple in the supply output.

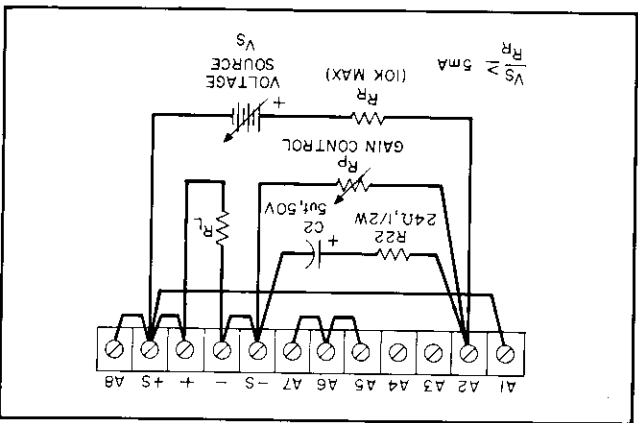
output. A switch can be used in conjunction with various resistance values in order to obtain discrete output voltages. The switch should have make-before-break contacts to avoid momentarily opening the programming terminals during the switching interval.

3-45 Remote Voltage Programming, Variable Gain (Figure 3-5). The output voltage of the supply may be adjusted to exactly zero when the external programming voltage is zero by adjusting potentiometer R24 as discussed in Paragraph 5-82.

3-50 OPTIONAL OPERATING MODES (INDEPENDENT ONLY)

3-51 The following optional programming modes describe methods of (1) programming the constant current outputs, (2) remote sensing, and (3) connecting several supplies in Auto-Series, Auto-Parallel, or Auto-Tracking arrangements. These procedures are for use when the instrument is operated in the independent mode only; they cannot be used when the supply is operated in the tracking mode.

Figure 3-5. Remote Voltage Programming, Constant Voltage (Variable Gain)



(R27A-R27B) as the voltage gain control (R_p) by simply removing the external R_p and strapping terminals A2 and A3 together.

3-53 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 automatically disabled in the following procedures.

3-52 REMOTE PROGRAMMING, CONSTANT CURRENT

3-54 Resistance Programming (Figure 3-6). In this mode, the output current varies at a rate determined by the programming coefficient as follows:

Model	Programming Coefficient
6227B	500 ohms/ampere
6228B	1,000 ohms/ampere

The programming coefficient is determined by the constant current programming current which is adjusted to within 10% of 1mA at the factory. If greater programming accuracy is required, it may be achieved by adjusting R2 as discussed in

Paragraph 5-88. The output current of the supply when zero ohms is placed across the programming terminals may be set to exactly zero by adjusting R5 or R7 as discussed in Paragraph 5-86.

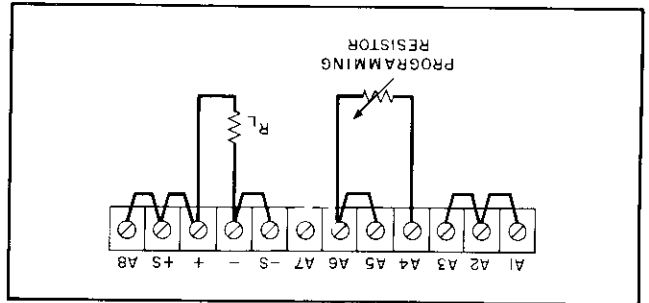


Figure 3-6. Remote Resistance Programming, Constant Current

3-55 Use stable, low noise, low temperature coefficient (less than 20ppm per degree Centigrade) 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.

CAUTION

If the programming terminals (A4 and A6) should open at any time during the remote resistance programming mode, the output current will rise to a value that may damage the power supply and/or the load. If, in the particular programming configuration in use, there is a chance that the terminals might become open, it is suggested that a 1.1K Ω resistor be connected across the programming terminals. Like the programming resistor, this resistor should be a low noise, low temperature coefficient type. Note that when this resistor is used, the resistance value actually programming the supply is the parallel combination of the remote programming resistance and the resistor across the programming terminals.

3-56 Voltage Programming, Unity Gain (Figure 3-7). In this mode, the output current will vary linearly with changes in the programming voltage. The programming voltage should not exceed 1.1

3-57 The output current varies at a rate determined by the programming coefficient as follows:

Model	Programming Coefficient
6227B	0.5 volts/ampere
6228B	1.0 volts/ampere

The current required from the voltage source will be less than 20 μ A. Impedance matching resistor R_X is required to maintain the temperature coefficient and stability specifications of the supply.

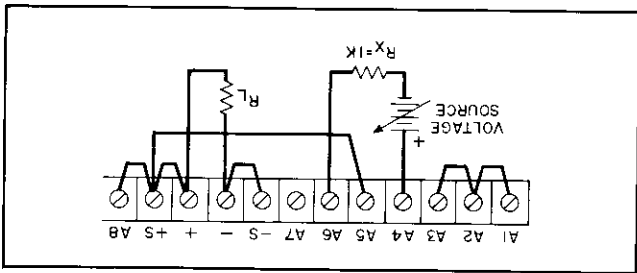


Figure 3-7. Remote Voltage Programming, Constant Current (Unity Gain)

3-58 Voltage Programming, Variable Gain (Figure 3-8). The power supply output current can be programmed with variable gain using an external voltage source by utilizing the strapping pattern shown in Figure 3-8. In this mode, the output current is found by multiplying the external voltage source (V_S) by [R_P/(R_P + K_P)], where K_P is the constant current voltage programming coefficient as given in Paragraph 3-57.

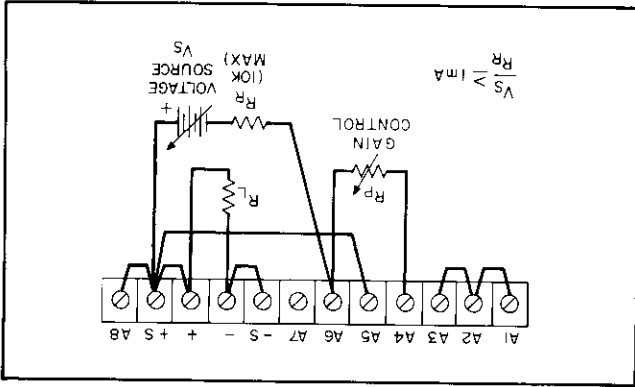


Figure 3-8. Remote Voltage Programming, Constant Current (Variable Gain)

3-59 External resistors R_P and R_L should have stable, low noise, and low temperature coefficient (less than 20ppm per degree Centigrade)

3-63 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

3-64 Observe of the precautions in Paragraph 3-63 will result in a low dc output impedance at the load. However, another factor that must be considered is the inductance of long load leads. This causes a high ac impedance and could affect the stability of the feedback loop seriously enough to cause oscillation. In this case, it is recommended that the following precautions be taken:

- Disconnect output capacitor C1 by unstrapping terminal A8.
- Connect a capacitor having similar characteristics (approximately the same capacitance, the same voltage rating or greater, and having good high frequency characteristics) across the load using short leads.

3-65 Although the strapping patterns shown in Figure 3-3 through 3-8 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.

3-66 AUTO-PARALLEL OPERATION (Figure 3-10)

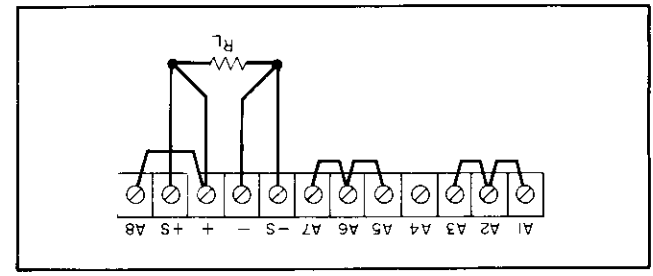
3-67 Two or more power supplies can be connected in an Auto-Parallel arrangement to obtain an output current greater than that available from one supply. Auto-Parallel operation permits equal current sharing under all load conditions, and allows complete control of the output current from one master power supply. The output current of each slave will be approximately equal to the master's output current regardless of the load conditions. Because the output current controls of each slave are operative, they should be set to maximum to prevent the slave reverting to constant current operation; this could occur if the master output current setting exceeded the slave's.

3-68 Additional slave supplies may be added in parallel with the master/slave combination. All the connections between the master and slave #1 are duplicated between slave #1 and the added slave supply. In addition, the strapping pattern of the added slave should be the same as slave #1. Remote sensing and programming can be used, though the strapping arrangements shown in Figure 3-10 show local sensing and programming. In order to maintain the temperature coefficient and

3-61 REMOTE SENSING (Figure 3-9)

3-62 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 3-9. Note that terminal A8 should be connected to the (+) terminal rather than +S. The power supply should be turned off before changing strapping patterns. The leads from the sensing ($\pm S$) terminals to the load will carry much less current than the load leads 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 pickup.

Figure 3-9. Remote Sensing



3-60 The output current of the supply may be adjusted to exactly zero when the external program-ming voltage is zero by adjusting resistor R5 or R7 as discussed in Paragraph 5-86.

3-61 The output current of the supply may be adjusted to exactly zero when the external program-ming voltage is zero by adjusting resistor R5 or R7 as discussed in Paragraph 5-86.

3-62 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 3-9. Note that terminal A8 should be connected to the (+) terminal rather than +S. The power supply should be turned off before changing strapping patterns. The leads from the sensing ($\pm S$) terminals to the load will carry much less current than the load leads 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 pickup.

3-63 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

3-64 Observe of the precautions in Paragraph 3-63 will result in a low dc output impedance at the load. However, another factor that must be considered is the inductance of long load leads. This causes a high ac impedance and could affect the stability of the feedback loop seriously enough to cause oscillation. In this case, it is recommended that the following precautions be taken:

- Disconnect output capacitor C1 by unstrapping terminal A8.
- Connect a capacitor having similar characteristics (approximately the same capacitance, the same voltage rating or greater, and having good high frequency characteristics) across the load using short leads.

NOTE

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

0.5 volt. If a larger drop must be tolerated, please consult an HP Sales Engineer.

supply, the external resistors (R_X) shown in Figure 3-11 should be stable, low noise, low temperature coefficient (less than 20ppm per degree Centigrade) resistors. The value of R_X is the maximum voltage rating of the master supply divided by the voltage programming current of the slave supply (I/K_p where K_p is the voltage programming coefficient). The power rating of R_X should be at least 10 times the actual power dissipated in the resistor. The voltage contribution of the slave is determined by its voltage control setting.

stability specifications of the power supply, the external resistors (R_X) should be stable, low noise, low temperature coefficient (less than 20ppm per degree Centigrade) resistors. The power rating of R_X should be at least 10 times the actual power dissipated in the resistor.

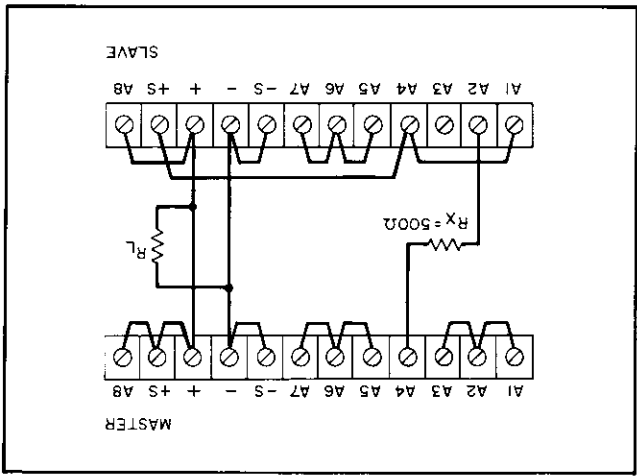


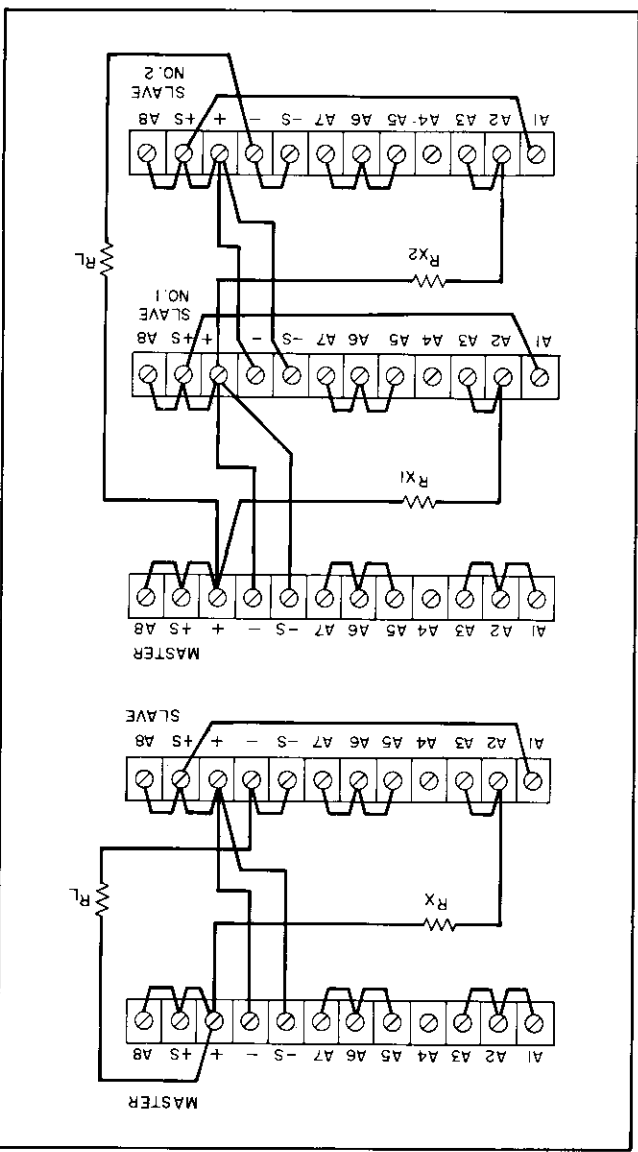
Figure 3-10. Auto-Parallel Operation, Two Units

3-69 The overvoltage crowbar circuit in each supply operates independently; no provision is included for allowing the master crowbar to trigger the slave crowbar. However, since the supplies are in parallel, the crowbars are effectively in parallel, and if one crowbar fires, it will by necessity short out both supplies. Thus it is only necessary to set one CROWBAR ADJUST control; the other control can be turned fully clockwise.

3-70 AUTO-SERIES OPERATION (Figure 3-11) 3-71 Two or more power supplies can be operated in Auto-Series to obtain a higher voltage than that available from a single supply. When this connection is used, the output voltage of each slave supply varies in accordance with that of the master supply; thus the total output voltage of the combination is determined by the setting of the front panel VOLTAGE controls 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 of the 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, though the strapping arrangements shown in Figure 3-11 show local sensing and programming.

3-72 In order to maintain the temperature coefficient and stability specifications of the power

Figure 3-11. Auto-Series Operation, Two and Three Units



3-73 The overvoltage crowbar circuit in each supply operates independently; no provision is included for allowing the master crowbar to trigger the slave crowbar. The CROWBAR ADJUST

potentiometer in each supply should be adjusted so that it trips at a point slightly above the output voltage that the supply will contribute. Note that since a portion of the master supply acts as the reference that sets the output level of the slave, if the master supply crowbars, the total output voltage of the combination will drop to approximately zero. However, the reverse is not true—if the slave crowbar trips, the total output voltage of the combination will drop only to the level of the master supply.

3-74 AUTO-TRACKING OPERATION (Figure 3-12)

3-75 The Auto-Tracking configuration is used when several different voltages referred to a common bus must 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. It must be the most positive supply in the example shown in Figure 3-12.

3-76 The output voltage of the slave (E_S) is a percentage of the master's output voltage (E_M), and is determined by the voltage divider consisting of R_X and the voltage control of the slave supply, R_P , where $E_S = E_M [R_P / (R_X + R_P)]$. Remote sensing and programming can be used (each supply senses at its own load), though the strapping patterns given in Figure 3-12 show only local sensing and programming. In order to maintain the temperature coefficient and stability specifications of the power supply, the external resistors (R_X) should be stable, low noise, low temperature coefficient (less than 20ppm/°C) resistors. The value of R_X is found by multiplying the voltage programming coefficient of the slave supply by the desired difference between the master supply voltage and the slave supply voltage.

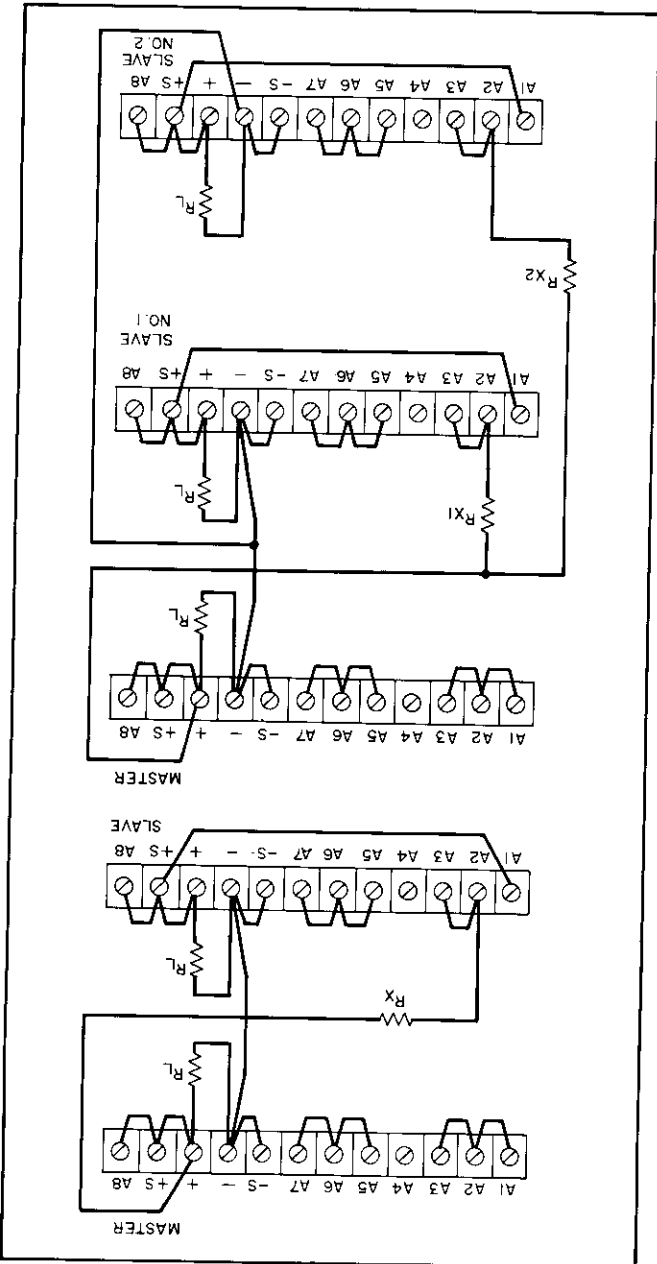
3-77 The overvoltage crowbar circuit in each unit is operable and independently monitors the voltage across its own load. Notice that if the master supply crowbars, the output voltage of each slave will also fall to approximately zero. However, the reverse is not true. If one of the slave units crowbars, the other supplies in the ensemble will not be affected.

3-78 SPECIAL OPERATING CONSIDERATIONS

3-79 PULSE LOADING

3-80 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

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



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 limit is not desired, set the preset limit for the peak requirement and not the average.

3-81 OUTPUT CAPACITANCE

3-82 An internal capacitor (C1) connected across the output terminals of the power supply, helps to supply high-current pulses of short duration during constant voltage operation. To reduce current

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

3-86 REVERSE CURRENT LOADING

3-87 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 operation cycle of the load device.

3-83 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.

3-84 REVERSE VOLTAGE LOADING

3-85 A diode (CR2) is connected across the output terminals. Under normal operating conditions, the

surges, this capacitor can be removed by unstrapping terminal A8. 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.

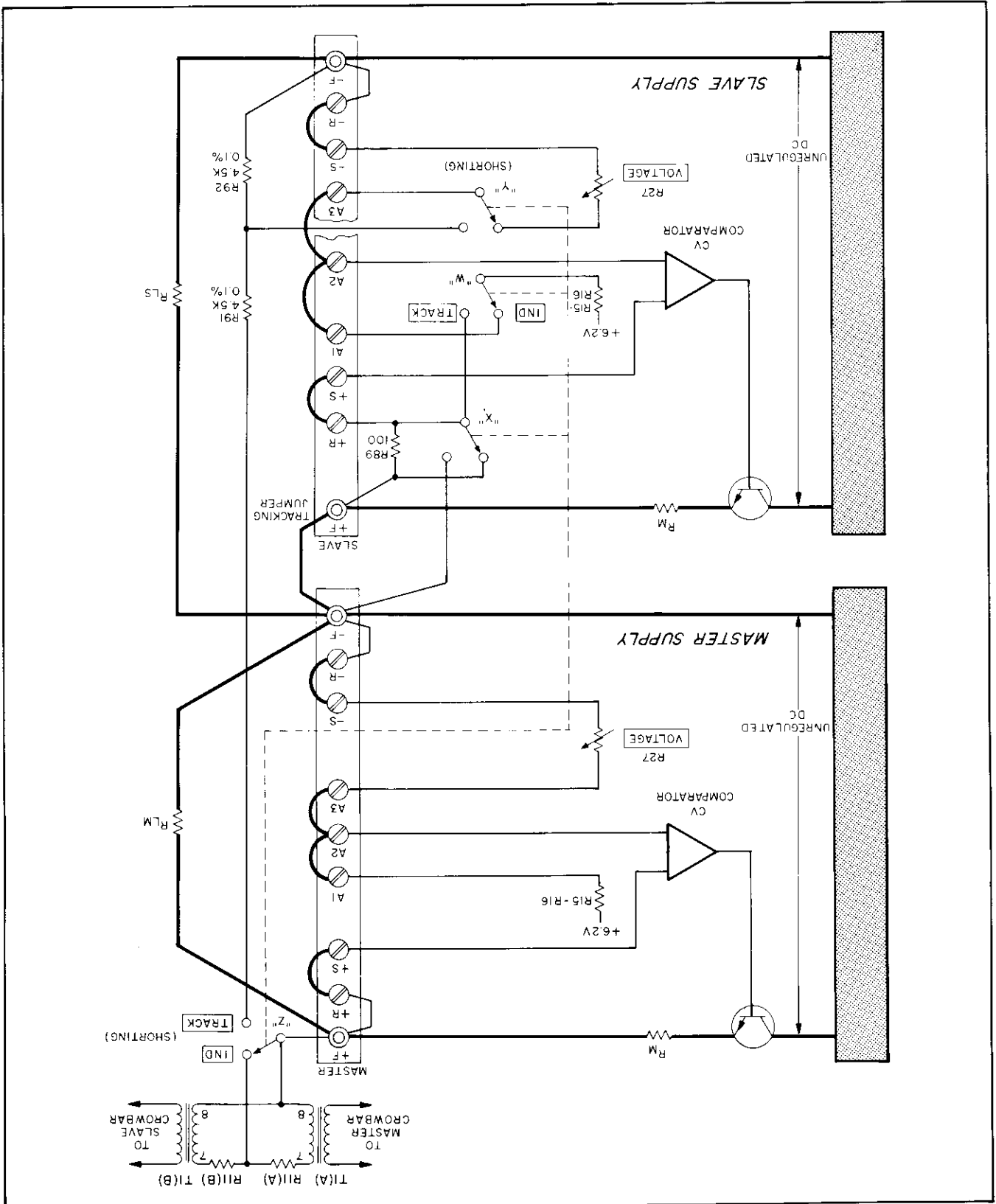
front output terminal and the tracking jumper wire would degrade the slave supply regulation specificity). Protection resistor R89 protects the two-supply combination against operation without the tracking jumper in place; this resistor is normally shorted out by the jumper. Pole "Z" of S2 serves a dual function — in the TRACKING position it connects the R91-R92 voltage divider across the total voltage span, and it allows the crowbars to slave one another. In the INDEPENDENT position it allows the crowbars to function independently. The pole is "shorting" in order to prevent momentarily opening the programming circuit formed by the voltage divider resistors.

4-73 Slaving of the crowbars is achieved by the presence of an extra winding on crowbar transformer T1 (pins 7 and 8) on both the master and slave supplies. These windings are connected in parallel for tracking operation, allowing an overvoltage in either supply to trigger both crowbars. In independent operation, a short is placed across the windings, thus preventing trigger pulses from being transferred from one winding to the other. Resistors R11A and R11B prevent the shorted slaving secondaries from loading the other trigger transformer windings.

programming circuit (this would result in a large output voltage overshoot). Pole "W" moves the end of current pullout resistors R15-R16 from its normal connection at summing point A2 to the positive sensing (+S) terminal. This action maintains the load on the reference supply at a constant value. During independent operation, the reference supply and current pullout resistors supply a constant current through the VOLTAGE pot; during tracking operation this current path is interrupted. Since the reference supply is referenced to +S, connecting the current pullout resistors to +S allows the programming current to flow in a closed loop, thus maintaining a constant load on the reference supply.

4-72 In the INDEPENDENT position, pole "X" of the tracking switch connects together the front and rear positive output terminals of the slave supply. In the tracking position, this pole connects one of the inputs of the voltage comparison amplifier (+S) to the common point of the tracking combination (the negative output terminal of the master supply). This action allows the slave comparison amplifier to sense directly across the slave supply load resistor, rather than through the tracking jumper (the finite voltage drop across the resistance of the

Figure 4-7. Tracking Switch Connections, Simplified Schematic



SECTION IV PRINCIPLES OF OPERATION

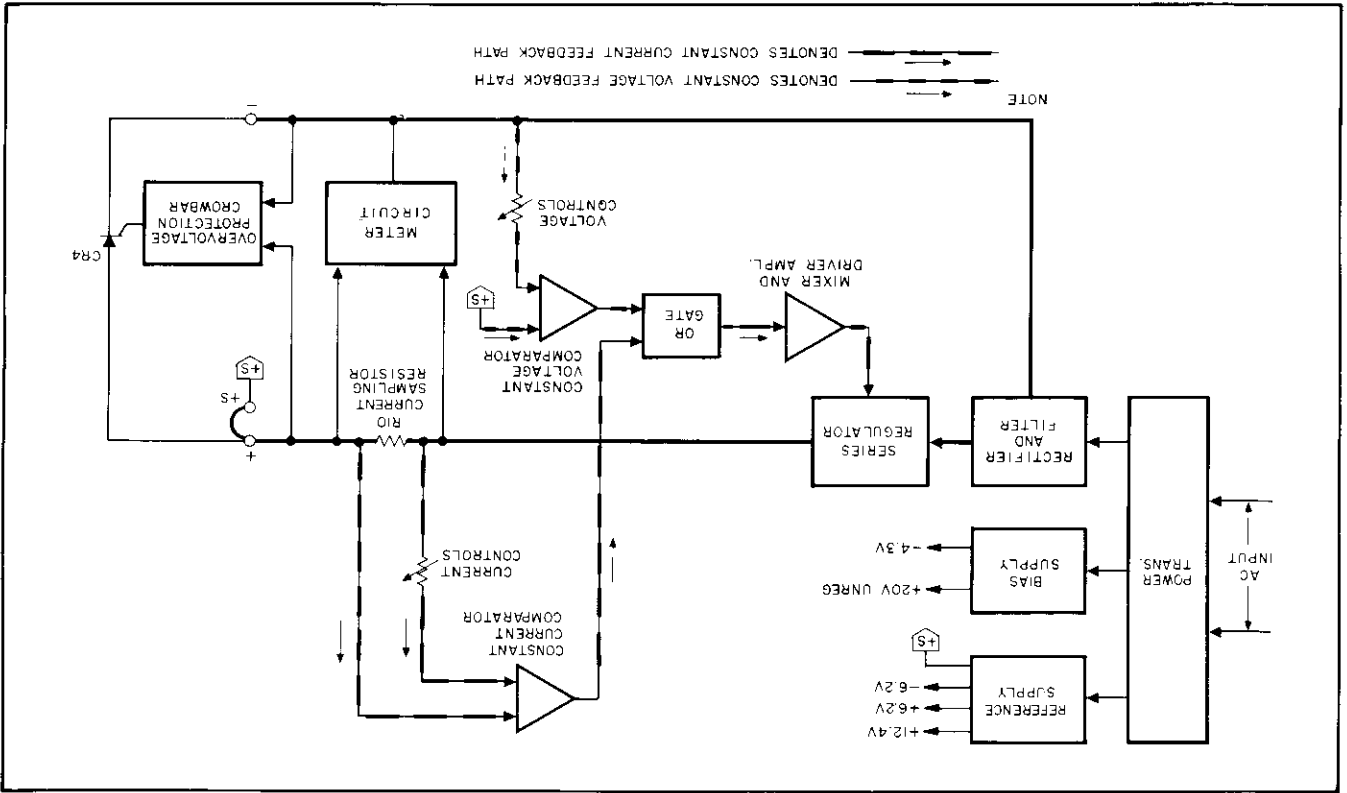


Figure 4-1. Overall Block Diagram

4-1 OVERALL BLOCK DIAGRAM DISCUSSION

4-2 Figure 4-1 shows one section of the Model 6228B dual power supply. The instrument consists of two identical, independently adjustable, dc power supplies in a half-track case. The supplies may be operated in either the independent mode or the tracking mode, depending on the position of the front-panel mode switch. The following discussion describes the theory of operation of only one of the two supplies, since both are identical. The tracking mode of operation is treated separately from the internal theory of operation of the supplies.

4-3 The ac line voltage is first applied to the power transformer, after which it is rectified and filtered. The resulting raw dc is then fed to the series regulator, which varies its conduction to obtain the proper output voltage or current.

4-4 The series regulator is part of a feedback

loop consisting of the mixer and driver amplifiers and the constant voltage/constant current comparators. 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 mixer and driver amplifiers 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 established by the VOLTAGE controls.

4-5 During constant current operation, the constant current comparator detects any difference between the voltage drop developed by the load current flowing through the current sampling resistor and the voltage across the CURRENT controls. If the two inputs to the comparator are momentarily

moderately well regulated potential of +12.4 volts from +S. Resistor R40 limits the current through the zener diodes to establish an optimum bias level.

4-53 The regulating circuit consists of series regulating transistor Q15, driver Q14, and differential amplifier Q12 and Q13. The voltage across zener diodes VR1 and VR2 (+12.4V) and the voltage at the junction of divider Z21-R52 and Z2] are compared, and any difference is amplified by the differential amplifier. The error voltage thus appearing at the collector of Q13 is amplified by driver stage Q14 and applied to series regulator Q15 in the correct phase and amplitude to maintain the +12.4 volt output at a constant level.

4-54 Resistor R46 performs a dual function: first, it acts as a "power-sharing" resistor, reducing the power dissipated in Q15. Second, it serves as a turn-on resistor for the reference regulator. At turn-on, an initial high voltage is coupled into the output of the regulator, causing the feedback loop to start its normal regulating action. Resistor R45 insures that Q15 can be completely turned off by providing a path for leakage current. Capacitor C11, connected across the output of the reference supply, remove spikes and stabilizes the reference once regulator loop.

4-55 Unregulated +20Vdc is supplied from a separate winding on transformer T1 by diodes CR19 and CR20, and filter capacitor C9. An additional unregulated -4.3V reference voltage is supplied from zener diode VR4. Resistor R33, connected across VR4, limits the maximum current through the diode and also reduces overshoot when the supply is turned on or off.

4-56 METER CIRCUIT

4-57 The meter circuit provides continuous indication of either the output voltage or output current. The meter can be used either as an ammeter or a voltmeter, depending on the position of front-panel METER switch S3.

4-58 When measuring voltage, the meter and its series resistors (R86, R85, R80, and R81) are connected between the positive and negative sensing terminals (see Figure 4-5A). Potentiometer R80 allows calibration of the voltmeter circuit. Resistors R87 and R88, connected across the current sampling resistor (R10), act as a "replacement" for the current measuring circuit. These resistors insure that the effect of the meter circuit on the constant current performance of the power supply is the same regardless of the position of the meter switch.

4-59 When measuring current, the meter with its

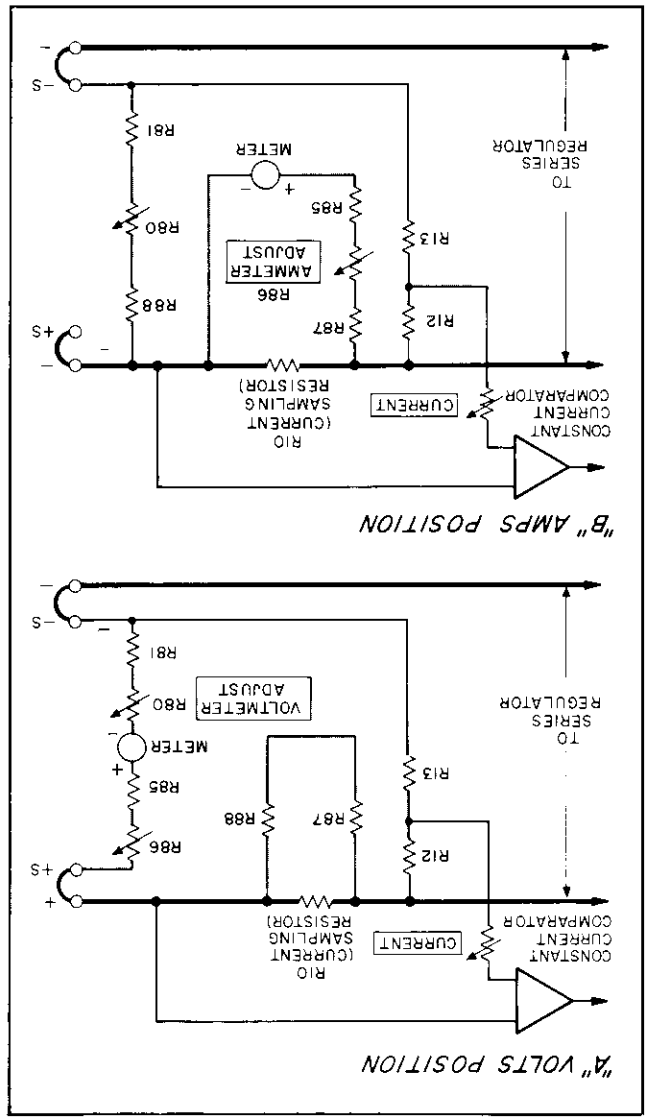


Figure 4-5. Meter Circuit, Simplified Schematic

4-60 During constant current operation, the voltmeter switch is in the AMPS position; it the meter circuit (or its "replacement" resistors, if the shunt load across the output terminals of the power supply, drawing a small amount of current away from the load (0-1mA, depending on the output voltage). The voltage divider formed by R12 and R13 compensates for this decrease in load current by subtracting a small voltage (the portion of the output voltage appearing across R12) from the voltage drop across the current sampling resistor. This

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4-61 ADDITIONAL PROTECTION FEATURES
 The supply contains several "special purpose" components which protect the supply in the event of unusual circumstances. One of these components is diode CR2. Connected across the output terminals of the supply, it prevents internal damage from reverse voltages that might be applied across the supply. This could occur, for example, during Auto-Series operation if one supply was turned on before the other.

4-62 The supply contains several "special purpose" components which protect the supply in the event of unusual circumstances. One of these components is diode CR2. Connected across the output terminals of the supply, it prevents internal damage from reverse voltages that might be applied across the supply. This could occur, for example, during Auto-Series operation if one supply was turned on before the other.

4-63 Resistors R18 and R19 limit the output of the supply if the connections between both output terminals and the sensing terminals (±S) are inadvertently removed. Diode CR1, previously mentioned in the driver amplifier description, protects the driver stage from damage due to same-polarity voltages that might be applied to the supply in such applications as battery charging and discharging. Fuse F2, previously mentioned in the series regulator description, protects the power transformer and rectifier diodes against damage due to series regulator failure.

4-64 TRACKING OPERATION

4-65 BASIC CIRCUIT DESCRIPTION

Figure 4-6 illustrates the basic tracking connections for any pair of power supplies. The principle involved is straightforward: the slave supply is connected in series with the master supply, and a voltage divider (resistors R1 and R2) is placed across the series combination. One input of the slave supply comparison amplifier is connected to the junction of the two resistors, while the other input is connected to the positive output terminal of the slave supply. Since the normal feedback action of the slave supply maintains zero error voltage between the two inputs to the comparison amplifier, the slave supply will contribute a fraction of the total output voltage determined by the voltage divider R1 and R2.

4-67 Specifically, if the master output voltage is denoted by E_M and the slave output is denoted by E_S , the total output voltage is $E_T = E_M + E_S$, and $E_S = [E_T \cdot R_2 / (R_1 + R_2)]$. Substituting the first equation into the second and eliminating E_M yields the expression for E_S given in Figure 4-6, $E_S = E_M (R_2 / R_1)$. Thus it is seen that the ratio of the slave output voltage to the master output voltage will always be in the ratio of R_2 to R_1 .

4-68 Note that the tracking combination can be

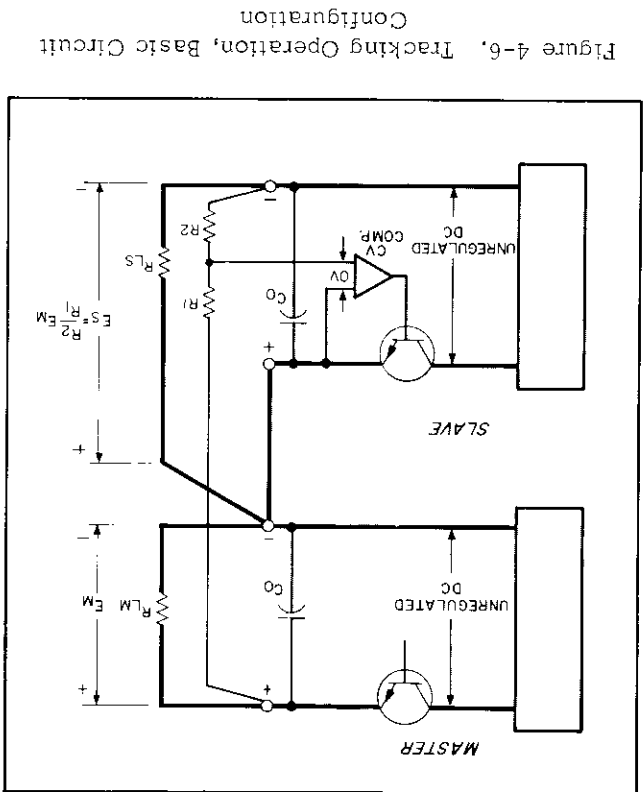


Figure 4-6. Tracking Operation, Basic Circuit Configuration

4-69 DETAILED CIRCUIT DESCRIPTION

4-70 Figure 4-7 is a simplified schematic of the tracking switch (S2) connections. The function of the tracking switch is to allow the power supply mode of operation to be easily changed from independent operation to tracking operation. When the switch is in the TRACKING position, Figure 4-7 can be reduced directly to the circuit configuration shown in Figure 4-6.

4-71 Resistors R91 and R92 form the voltage divider connected across the total voltage span; since these resistors are equal (within 0.1%), the slave supply output voltage equals the master supply output voltage (within 0.2%). Pole "Y" of the tracking switch connects one of the voltage comparison amplifier inputs to either the front-panel VOLTAGE pot for independent operation, or the center tap of voltage divider R91-R92 for tracking operation. The pole is "shorting" (make-before-break) in order to prevent momentarily opening the

an error voltage which ultimately varies the conduction of the series regulator.

4-31 Resistor R20, in series with the summing-point input to the differential amplifier, limits the current through the programming resistors during rapid voltage turn-down. Diodes CR5 and CR6 prevent excessive voltage excursions from overdriving the differential amplifier. Capacitor C2 reduces output ripple at high output voltage levels and prevents the gain of the feedback loop from changing during manipulation of the VOLTAGE controls. Resistors Z2F, Z2M, and Z2N bias the differential amplifier; diode CR7 provides temperature compensation.

4-32 During constant voltage operation, the programming current flowing through the programming resistors (VOLTAGE controls) is held constant because the value of shunt resistor R16 is factory selected to allow all of the +6.2 volt reference to be dropped across R15 and R16. Linear constant voltage programming is thus assured with a constant current flowing through R27A and R27B.

4-33 Main output capacitor C1 stabilizes the series regulator feedback loop when the normal strapping pattern shown on the schematic is employed. Note that this capacitor can be removed (by unstrapping terminal A8) to avoid output current surges or to increase the programming speed of the supply. An additional output capacitor (C13), connected across the front output terminals, helps maintain a low ac output impedance by compensating for the inductive reactance of the main output capacitor at high frequencies. C13 also prevents any spikes in the output from reaching the load.

4-34 CONSTANT CURRENT COMPARATOR

4-35 This circuit is similar in appearance and operation to the constant voltage comparator circuit. It consists of the coarse and fine current controls (R4A and R4B) and a differential amplifier stage (Z1 and associated components). As in the constant voltage comparator, an integrated circuit is used for the differential amplifier in order to minimize differential voltages due to mismatched transistors and thermal differentials.

4-36 The constant current comparator circuit continuously compares the voltage drop across the current sampling resistor, R10. If a difference exists, the differential amplifier produces an error signal which is proportional to this difference. The remaining components in the feedback loop (amplifiers and the series regulator) function to maintain the drop across the current sampling resistors, and hence the output current, at a constant value.

4-37 One input of the differential amplifier (pin 7) is connected to the output bus through matching resistor R6 and is zero-biased by resistors R5 or R7. The values of R5 and R7 are chosen such that the output current can be programmed completely to zero, regardless of any "end resistance" CURRENT control R4 may have. The other input of the differential amplifier (pin 4) is connected via matching resistor R3 to a summing point (terminal A6) at the junction of the programming resistors and the current pulldown resistors R1 and R2. Changes in the output current due to load changes or changes in the voltage at the summing point due to manipulation of the CURRENT controls produce a difference voltage between the two inputs of the differential amplifier. This difference voltage is amplified and appears at the output of the differential amplifier (pin 6) as an error voltage which ultimately varies the conduction of the series regulator.

4-38 Resistor R2 serves as a trimming adjustment for the programming current flowing through R4A and R4B. Diode CR1 limits excessive voltage excursions at the summing-point input to the differential amplifier; the series combination of R8 and C15 shapes the frequency response of the current feedback loop. The comparator is biased through resistors Z2K, Z2N, and Z2F (the latter two are shared with the constant voltage comparator).

4-39 VOLTAGE CLAMP CIRCUIT

4-40 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 A2, the voltage summing point, to a fixed bias voltage. During constant current operation the constant voltage programming resistors are a shunt load across the output terminals of the power supply. When the output voltage changes, the current through these resistors also tends to change. Since the programming current flows through the current sampling resistors, it is erroneously interpreted as a load change by the current comparator circuit. The clamp circuit eliminates this undesirable effect by maintaining this programming current at a constant level.

4-41 Voltage divider Z2A, Z2B, and VR5 reverse biases CR4 and Q3 during constant voltage operation. When the power supply goes into constant current operation, CR4 becomes forward biased by the voltage at pin 12 of Z1. This results in conduction of Q3 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

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4-47 OVERVOLTAGE PROTECTION CROWBAR

4-48 The overvoltage protection circuit protects delicate loads from high voltage conditions such as might result from the failure of the series regulator transistors. It accomplishes this by shorting the output of the supply. Under normal operating conditions (no overvoltage), Q1 is conducting since CR1 is reverse biased, and Q2 is off. Thus no trigger signal is received by SCR CR4 and it acts as an open circuit, having no effect on the normal output voltage.

4-49 Potentiometer R10 (CROWBAR ADJUST), in series with protection resistor R5, adjusts the bias appearing at the cathode of CR1 with respect to +S. The position of the potentiometer establishes the point at which CR1 becomes forward biased and Q1 is turned off. Zener diode VR1 (in series with R9 and biased through R1) provides a reference voltage against which the output of the supply is compared. When Q1 turns off, Q2 begins to conduct, discharging C1 through transformer T1 and sending a positive-going trigger pulse to CR4, causing it to create a near short circuit across the output. CR4 will remain in conduction until the output current decreases below approximately 50mA (the minimum holding current of the SCR).

4-50 Zener diode VR2, biased through R8, establishes a +12.4V bias supply for the crowbar circuit (with respect to the inboard side of the current monitoring resistor). The circuit is referenced to the inboard side of the sampling resistor in order to prevent the crowbar supply current from flowing through the sampling resistor and adversely affecting constant current operation. Diode CR2 protects the base-emitter junction of Q1 by preventing high reverse voltages (developed when the crowbar is set considerably above the operating output voltage) from appearing across it. Diode CR3 clamps out negative ringing in the trigger pulse; R7 limits the current flowing into the gate of the SCR. An extra winding is provided on transformer T1 (terminals 7-8); this facilitates slaving the crowbars when the instrument is operated in the tracking mode (see Paragraph 4-73).

4-51 REFERENCE REGULATOR

4-52 The reference circuit is a feedback power supply similar to the main supply. It provides stable reference voltages used throughout the unit. All the regulated reference voltages are derived from dc obtained from full wave rectifier CR21-CR22 and filter capacitor C10. The total output of the reference circuit is 18.6V. Zener diodes VR1 and VR2 establish very well regulated potentials of +6.2V and -6.2V respectively from the common point +S, while the regulator circuit establishes a

a constant voltage across, and consequently a constant current through, the current pullout resistors R15 and R16.

4-42 MIXER AND DRIVER AMPLIFIERS

4-43 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 resulting transistors. Transistor Q5 receives the error voltage input from either the constant voltage or constant current comparator via the OR-gate diode (CR8 or CR9) that is conducting at the time. Diode CR8 is forward biased and CR9 is reverse biased during constant voltage operation. The reverse is true during constant current operation.

4-44 Transistor Q4 (biased at a constant level by R31 and R32, and temperature-compensated by CR10) supplies a constant current to the emitter of Q5, thus holding the emitter at a constant potential. This is necessary to prevent changes in emitter voltage due to operating level changes from being reflected back through the constant voltage or constant current comparator to the output of the supply. Feedback network R38 and C4 shape the high frequency rolloff in the loop gain response in order to stabilize the series regulator feedback loop.

4-45 Predriver transistor Q6 receives the inverted error signal from Q5 and applies it to driver transistor Q7. Driver Q7 controls the conduction of the series regulator by controlling the amount of drive current diverted away from the regulator. As Q7 increases its conduction, more drive current (flowing from the +20V bias source through R75) is diverted from the bases of Q8-11, causing a decrease in their conduction and a corresponding decrease in the output voltage.

4-46 Driver transistor Q7 performs an additional function, that of discharging the output capacitor during rapid down-programming. When the supply is rapidly down-programmed, diode CR12 conducts; a current path is thus established from the positive output capacitor C1 through Q7 and back to the negative of the capacitor. Resistor R70, in series with CR12, limits the current that can flow through this path. Triple junction diode CR11 protects Q7 from reverse voltages that could be developed across it in situations such as Auto-Series operation when one supply is turned on before the other. In addition, CR11 also maintains the emitter of Q6 and the base of Q7 at a constant potential, thus limiting the power dissipated in Q7 under conditions where an external same-polarity voltage is applied to the output terminals of the supply (such as battery charging/discharging).

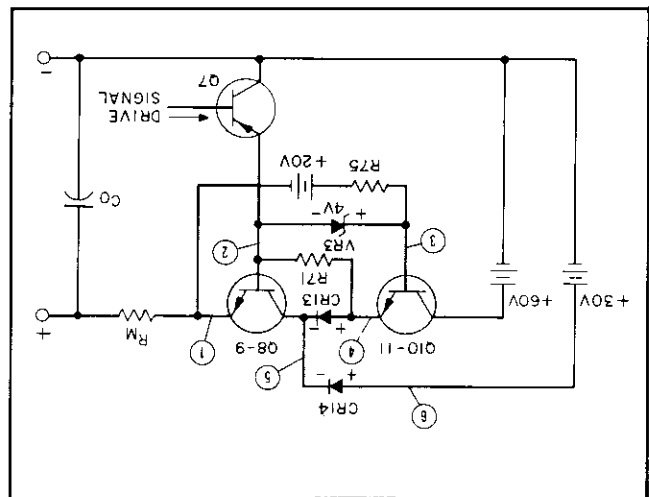


Figure 4-3. Series Regulator, Simplified Schematic

Switching between the two sources is accomplished by diodes CR13 and CR14. In order to best visualize the action of these diodes, the circuit will be analyzed in two separate conditions — high output voltage, and low output voltage. (For the purpose of this discussion, assume that the diode forward voltage drops and the base-emitter junction voltages are all 1V when forward biased, and that the voltage across zener diode VR3 is 4 volts.)

4-22 At a low output voltage (point 1 = 10V), transistors Q8 and Q9 are conducting; this requires point 2 to be at 11V. Zener diode VR3 (biased through R75) thus places the base of Q10 and Q11 (point 3) at 15V. Resistor R71 keeps Q10 and Q11 conducting at least a certain minimum current at all times; thus point 4 is at 14V. Diode CR13 must be either on or off; if it were on, point 5 would be at 13V. Since the anode of CR14 (point 6) is always at 30V, this condition is not possible, and CR13 must be off. Thus CR14 is on, point 5 is at 29V, and the 30V raw-dc source is supplying the load. The power dissipation in Q8 and Q9 is thus approximately 19 watts (19V drop between points 1 and 5) times 1A load current).

4-23 At a high output voltage (point 1 = 50V), transistors Q8 and Q9 are again conducting and point 2 is at 51V. Point 3 is thus at 55V due to zener diode VR3; point 4 is at 54V because (as before) Q10 and Q11 are always conducting at least a certain minimum current. Again diode CR13 must either be on or off; since point 6 is at 30V, CR13 must be on and CR14 must be off (point 5 = 53V). Thus the 60V raw-dc source is supplying the load. The switching point between the two ranges occurs when the voltage at point 4 equals that at point 6 (30V); this occurs when the output is 26V.

4-24 Figure 4-4 illustrates the operation of the

series transistors to decrease their conduction so that they drop more of the raw dc input voltage, thus reducing the output voltage to the original pre-disturbance level.

4-16 CURRENT FEEDBACK LOOP

4-17 If the external load resistance decreases below the "crossover" point discussed in Paragraph 4-8, the supply will operate in the constant current mode. In this mode, the feedback loop functions to maintain the output current at a constant level. For the purposes of this discussion, assume that the output current instantaneously rises (goes positive) due to a change in the external load circuit. This current change causes the voltage across the current sampling resistor to rise; this rise is coupled through CURRENT control R4 to summing point A6 and thus to pin 4 of the constant current comparator. The comparator then decreases its conduction, and its output voltage rises. This positive going error voltage is coupled through OR-gate diode CR9 to mixer amplifier Q5. At this point as discussed in Paragraph 4-15, the positive-going error voltage is amplified, inverted, and fed to the series regulator. The series regulator thus decreases its conduction and returns the output current to the original pre-disturbance level.

4-18 SERIES REGULATOR

4-19 The series regulator consists of transistors Q8 through Q11. The regulator serves as the series or "pass" element that, by varying its conduction in accordance with error signals produced by the constant voltage and constant current comparators, provides precise control of the output voltage and current.

4-20 The regulator utilizes a "power sharing" circuit that results in considerably less internal power dissipation than would be present in a standard single-stage regulator. This saving in dissipation is achieved by dividing the output of the supply into two regions (0-26V and 26-50V), and using separate raw-dc supplies for each region. Maximum dissipation in any single-stage regulator circuit occurs when the supply is short-circuited at full output current; under this condition, the entire raw-dc voltage must be dropped across the series regulator while it is conducting the full output current. It can be seen then that if the raw-dc voltage is made as low as possible when the supply is operating at a low output voltage, the power dissipated in the series regulator will be minimized.

4-21 The rectifier and filter section of the power supply uses a tapped full-wave bridge circuit to obtain two raw-dc supply voltages; these are represented by two independent sources in Figure 4-3.

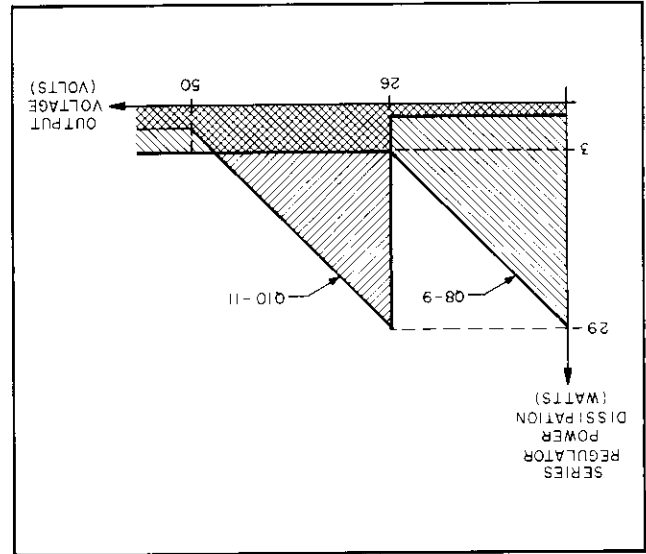


Figure 4-4. Series Regulator Power Dissipation

4-27 CONSTANT VOLTAGE COMPARATOR

currents to be shared equally by the series regulating transistors; capacitor C5 prevents oscillation when switching between raw-dc sources. Resistor R72 minimizes output overshoot at turn-on and turn-off by serving as an alternate path for the series regulator drive current that normally flows through zener diode VR3. Fuse F2 provides protection for the power transformer and rectifier diodes in the event of failure (short circuit) of the series regulator transistors. In this situation, the crowbar will trip due to the higher-than-normal output voltage; up to 2A will then flow from the power transformer secondary winding supplying the defective supply. If no output current is being drawn from the other supply, the primary fuse will not blow since when viewed from the primary, 2A from one secondary and 0A from the other is the same as 1A from each secondary. Fuse F2 is thus provided to prevent damaging the power transformer by drawing twice the rated current from one secondary winding.

4-28 The constant voltage comparator consists of the programming resistors (R27A and R27B) and a differential amplifier stage (Z1 and associated components). An integrated circuit is used for the differential amplifier in order to minimize differential voltages due to mismatched transistors and thermal differentials.

4-29 The constant voltage comparator continuously compares the voltage drop across the VOLTAGE controls with the output voltage and, if a difference exists, produces an error voltage whose amplitude is proportional to this difference. The error signal ultimately alters the conduction of the series regulator which, in turn, alters the output current so that the output voltage becomes equal to the voltage drop across the VOLTAGE controls. Hence, through feedback action, the difference between the two inputs to Z1 is held at zero volts.

4-30 One input of the differential amplifier (pin 10) is connected to the output voltage sensing terminal of the supply (+S) through matching resistor R25. Resistor R26 and potentiometer R24 provide a variable input bias that allows the output voltage of the supply to be adjusted to exactly zero when the supply is programmed for zero output. The other input of the differential amplifier (pin 1) is connected to a summing point (terminal A2) at the junction of the programming resistors and the current pullout resistors R15 and R16. Instantaneous changes in the output voltage at the summing point due to manipulation of the VOLTAGE controls or changes in the external load circuit produce a difference voltage between the two inputs of the differential amplifier. This difference voltage is amplified and appears at the output of the differential amplifier (pin 12) as

series regulator from a power dissipation point of view. When the output voltage is between zero and 26 volts, transistors Q8 and Q9 are controlling the output. In this region, the power dissipation of Q10 and Q11 is very low (approximately 1W), since the only current going through them is that flowing through R71. When the output voltage is between 26 and 50 volts, most of the regulator dissipation occurs in transistors Q10 and Q11. Note, however, that in this region these transistors serve as variable dissipative elements rather than control elements. The actual regulating action is, as in the lower output voltage range, performed by Q8 and Q9, operating at an approximate power dissipation of 3W. (In this region, VR3 maintains point 5 at a constant 3V higher than point 1, resulting in $3V \times 1A = 3W$ power dissipation in Q8 and Q9.)

4-25 The obvious advantage in this type of regulator circuit is the saving in power dissipation. Consider the case discussed in Paragraph 4-22, where the supply output is 10 volts at 1 amp, and the regulator is dissipating 19 watts. If the supply used a conventional single-stage regulator, the raw-dc source would have to be approximately 60V (20% higher than the maximum rated output voltage of 50V). The power dissipated by the regulator would therefore be the voltage drop across it (50 volts) times the current conducted (1A), or 50 watts! The use of the power sharing regulator thus represents a power dissipation saving (in this particular case) of more than 160%.

4-26 Several series regulator components not shown in Figure 4-3 for the sake of clarity can be seen in Figure 7-7 (the foldout schematic diagram). Resistors R68-R69 and R73-R74 allow high output

SECTION V MAINTENANCE

5-1 INTRODUCTION

5-2 Upon receipt of the power supply, the performance check (Paragraph 5-5) should be made. This check is suitable for incoming inspection. If a fault is detected in the power supply while making the performance check or during normal operation, proceed to the troubleshooting procedures (Paragraph 5-56). After repair and replacement (Paragraph 5-71), perform any necessary adjustments and calibrations (Paragraph 5-73). Before returning the power supply to normal operation,

repeat the performance check to ensure that the fault has been properly corrected and that no other faults exist. Before performing any maintenance checks, turn on the power supply and allow a half-hour warm-up.

5-3 TEST EQUIPMENT REQUIRED

5-4 Table 5-1 lists the test equipment required to perform the various procedures described in this section.

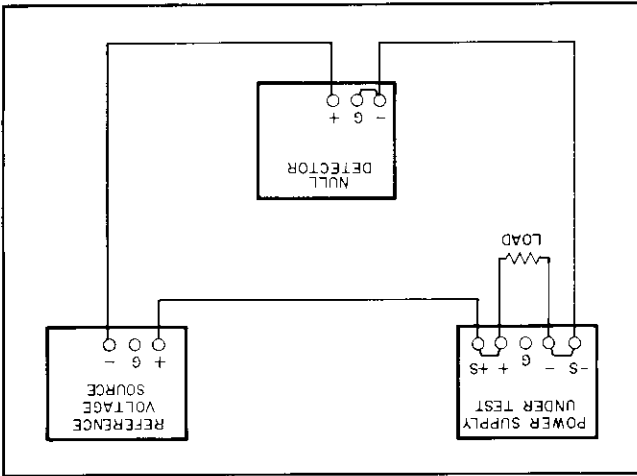
Table 5-1. Test Equipment Required

TYPE	REQUIRED CHARACTERISTICS	USE	RECOMMENDED MODEL
Differential Voltmeter	Sensitivity: 50 μ V full scale (min.). Input impedance: 10M Ω (min.).	Measure dc voltages; calibration procedures.	HP 3420B (See Note on Page 5-2.)
Oscilloscope	Sensitivity and bandwidth: 50 μ V/cm and 300KHz for all measurements except noise spike; 1mV and 20MHz for noise spike measurement.	Measure ripple; display transient recovery waveforms; measure noise spikes.	HP 140A with 1403A vertical plug-in and 1423A time base; HP 180A with 1803A vertical plug-in and 1820A time base for spike measurement.
DC Voltmeter	Sensitivity: 1mV full scale (min.). Accuracy: 1%.	Measure dc voltages.	HP 412A.
AC Voltmeter	Sensitivity: 50 μ V full scale (min.). Frequency range: 5Hz to 250KHz (min.). Accuracy: 3%.	Measure output impedance, ripple, and ac voltages.	HP 3410A.
Oscillator	Frequency range: 5Hz to 20KHz (min.). Output: 5V rms into 600 Ω . Accuracy: 3%.	Measure output impedance.	HP 209A.
Amplifier	Power output: 50 watts. Frequency response: \pm 3dB 5Hz to 20KHz (min.).	Measure output impedance.	HP 6824A.

5-6 The following test can be used as an incoming inspection check and appropriate portions of the test can be repeated either to check the operation of the instrument after repairs or for periodic maintenance tests. The tests are performed using a 115V ac, 60Hz, single phase input power source.

5-5 PERFORMANCE TEST

Figure 5-1. Differential Voltmeter Substitute Test Setup



A satisfactory substitute for a differential voltmeter is a reference voltage source and null detector arranged as shown in Figure 5-1. The reference voltage source is adjusted so that the voltage difference between the supply being measured and the reference voltage will have the required resolution for the measurement being made. The voltage difference will be a function of the null detector that is used. Examples of satisfactory null detectors are: HP 419A null detector, a dc coupled oscilloscope utilizing differential input, or a 10 mV meter movement with a 100 division scale. For the latter, a 0.5mV change in voltage will result in a meter deflection of five divisions.

NOTE

Care must be exercised to avoid ground loops and circulating currents when using an electronic null detector for in which one input terminal is grounded.

CAUTION

RECOMMENDED MODEL	USI	REQUIRED CHARACTERISTICS	TYPE
---	Vary ac input for line regulation measurement.	Range: 103 to 127Vac. Recommended minimum output current: 5.5A.	Variable Voltage Transformer
See Figure 5-5.	Measure transient recovery time.	Switching rate: 60 to 400Hz. Rise time: 2µsec.	Repetitive Load Switch
---	Power supply load resistors.	Values: See Figures 5-2 and 5-11.	Resistive Loads
R10 and R11 (6227B); R10 (6228B); see Replaceable Parts List.	Measure output impedance; measure output current; calibrate ammeter.	Values: See Figures 5-7 and 5-11.	Current Sampling Resistors
---	Noise spike measurement.	Value: 50 ohms, 1/2 watt, ±5% non-inductive, 4 required.	Terminating Resistors
---	Noise spike measurement; output impedance measurement.	Values: 0.01µF, 100Vdc, 2 required; 100µF, 60Vdc, 1 required.	Blocking Capacitors

Table 5-1. Test Equipment Required (Continued)

With the exception of the tracking specification test (refer to Paragraph 5-42), all of the following measurements should be made on both of the independent power supplies contained in the instrument. If the correct result is not obtained for a particular check, do not adjust any internal controls; proceed to troubleshooting (Paragraph 5-56).

5-7 CONSTANT VOLTAGE TESTS

- 5-8 All measuring devices must be connected to the rear sensing terminals of the supply and not to the front output terminals (with the exception of the tracking specification, as noted in Paragraph 5-42), if maximum accuracy is to be obtained in the following measurements. In addition, the measuring devices must be connected as close to the sensing terminals as possible. This is particularly important when measuring the transient response, regulation, or ripple of the power supply. Note that under no circumstances should the measuring instruments be connected across the load. A measurement made across the load includes the impedance of the leads to the load and such lead lengths can easily have an impedance several orders of magnitude greater than the supply impedance, thus invalidating the measurement.
- 5-9 To avoid mutual coupling effects, each monitoring device must be connected to the sensing terminals by a separate pair of leads. Twisted pairs or shielded two-wire cables should be used to avoid pickup on the measuring leads. The load resistor should be connected across the output terminals as close to the supply as possible. When measuring the constant voltage performance specifications, the current controls should be set well above (at least 10%) the maximum output current which the supply will draw, since the onset of constant current action will cause a drop in output voltage, increased ripple, and other performance changes not properly ascribed to the constant voltage operation of the supply.
- 5-10 Voltage Output and Voltmeter Accuracy. To check the output voltage, proceed as follows:
- Connect load resistor (R_L) indicated in Figure 5-2 across output terminals of supply.
 - Connect differential voltmeter across +S and -S terminals of supply, observing correct polarity.
 - Turn CURRENT controls fully clockwise.
 - Turn on supply and adjust VOLTAGE controls until front panel meter indicates exactly maximum rated output voltage.
 - Differential voltmeter should indicate the following:

6227B	$25 \pm 0.6Vdc$
6228B	$50 \pm 1.2Vdc$
- 5-11 Load Regulation. Definition: The change ΔE_{OUT} in the
- Connect test setup shown in Figure 5-2.
 - Connect variable auto transformer
- 5-12 To check the constant voltage load regulation, proceed as follows:
- Connect test setup shown in Figure 5-2.
 - Turn CURRENT controls fully clockwise.
 - Turn on supply and adjust VOLTAGE controls until front panel meter indicates exactly maximum rated output current.
 - Read and record voltage indicated on differential voltmeter.
 - Disconnect load resistor.
 - Reading on differential voltmeter should not vary from reading recorded in Step (d) by more than the following:

6227B	3.5mV
6228B	6.0mV

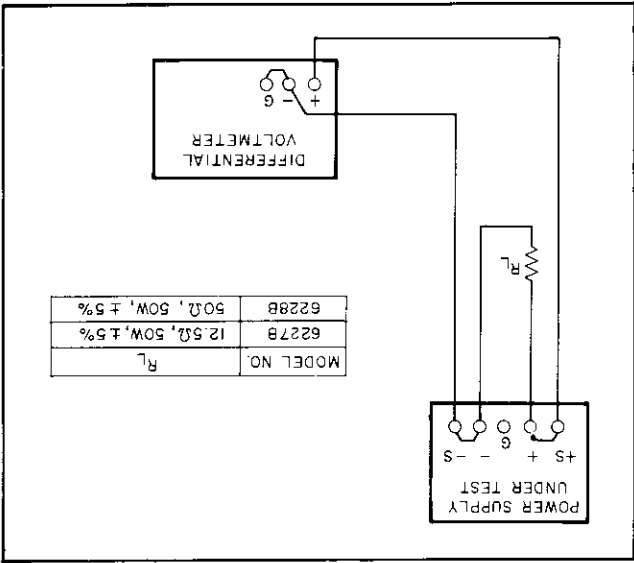


Figure 5-2. Constant Voltage Load Regulation Test Setup

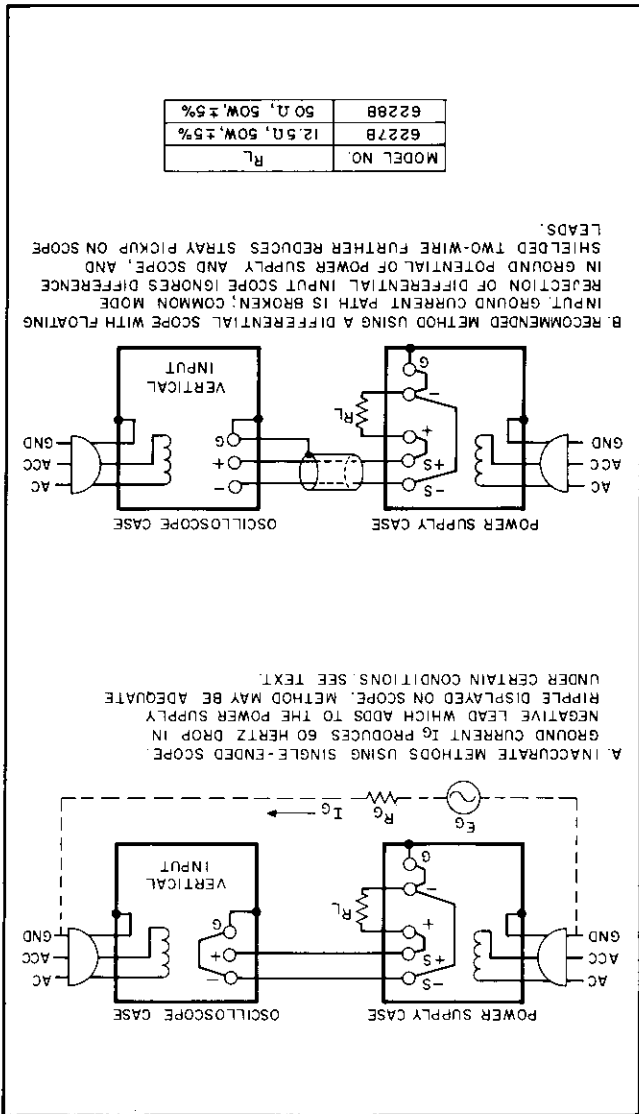
5-13 Line Regulation. Definition: The change ΔE_{OUT} in the static value of dc output voltage resulting from a change in load resistance (usually 103.5 volts) to high line (usually 126.5 volts), or from high line to low line.

5-14 To check the line regulation, proceed as follows:

- Connect test setup shown in Figure 5-2.
- Connect variable auto transformer

5-18 The same ground current and pickup problems can exist if an RMS voltmeter is substituted in place of the oscilloscope in Figure 5-3. However, the oscilloscope display, unlike the true RMS meter reading, tells the observer immediately whether the fundamental period of the signal displayed is 8.3 milliseconds (1/120Hz) or 16.7 milliseconds (1/60Hz). Since the fundamental ripple frequency present on the output of an HP supply is 120Hz (due to full-wave rectification), an oscilloscope display showing a 120Hz fundamental component is indicative of a "clean" measurement setup, while the presence of a 60Hz fundamental up, usually means that an improved setup will result in a more accurate (and lower) value of measured ripple.

Figure 5-3. Ripple Test Setup



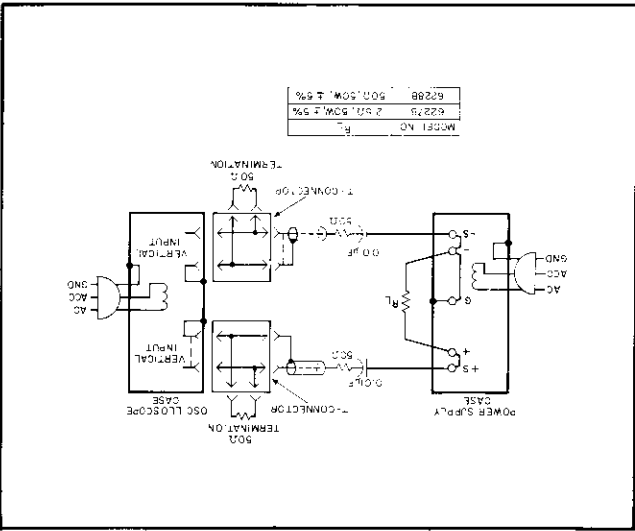
5-17 Ripple Measurements. Figure 5-3A shows an incorrect method of measuring p-p ripple. Note that a continuous ground loop exists from the third wire of the input power cord of the supply to the third wire of the input power cord of the oscilloscope via the grounded power supply case, the wire between the negative sensing terminal of the power supply and the vertical input of the scope, and the grounded scope case. Any ground current circulating in this loop as a result of the difference in potential E_G between the two ground points causes an IR drop which is in series with the scope input. This IR drop, normally having a 60Hz line frequency fundamental, plus any pickup on the unshielded leads interconnecting the power supply and scope, appears on the face of the CRT. The magnitude of this resulting noise signal can easily be much greater than the true ripple developed between the plus and minus sensing terminals of the power supply, and can completely invalidate the measurement.

5-16 The amount of ripple and noise that is present in the power supply output is measured either in terms of the RMS or (preferably) peak-to-peak value. The peak-to-peak measurement is particularly important for applications where noise spikes could be detrimental to a sensitive load, such as logic circuitry. The RMS measurement is not an ideal representation of the noise, since fairly high output noise spikes of short duration can be present in the ripple without appreciably increasing the RMS value.

5-15 Ripple and Noise. Definition: The residual ac voltage superimposed on the dc output of a regulated power supply. Ripple and noise may be specified and measured in terms of its RMS or (preferably) peak-to-peak value. Ripple and noise measurement can be made at any input ac line voltage combined with any dc output voltage and load current within the supply's rating.

- Adjust variable auto transformer for 103.5 volts ac input.
- Turn CURRENT controls fully clockwise.
- Turn on supply and adjust VOLTAGE controls until front panel meter indicates exactly maximum rated output voltage.
- Read and record voltage indicated on differential voltmeter.
- Adjust variable auto transformer for 126.5 volts ac input.
- Reading on differential voltmeter should not vary from reading recorded in Step (f) by more than 1mV.

Figure 5-4. Noise Spike Measurement Test Setup



ply end of the two coax cables are not connected

4. Notice that the shields of the power supply sensing terminals.

from the inner conductor of the cable to the power

matching resistor should be connected directly

able; the blocking capacitor and the impedance

coax is critical and must be kept as short as possible

3. The length of the test leads outside the

dc current path.

ing, and capacitors must be inserted to block the

cluded to eliminate standing waves and cable ring-

2. Impedance matching resistors must be in-

cluded to eliminate standing waves and cable ring-

1. As shown in Figure 5-4, two coax cables

must be substituted for the shielded two-wire cable.

achieved:

modified if accurate spike measurement is to be

the measurement concept of Figure 5-3B must be

5-25 The test setup illustrated in Figure 5-3A is

generally not acceptable for measuring spikes; a

5-24 Noise Spike Measurement. When a high fre-

quency spike measurement is being made, an in-

adequate. Measuring noise with an instrument that

has insufficient bandwidth may conceal high fre-

quency spikes detrimental to the load.

250µV rms and 4mV p-p.

d. The observed ripple should be less than

meter indicates maximum rated output voltage.

c. Adjust VOLTAGE controls until front panel

b. Turn CURRENT controls fully clockwise.

a. Connect oscilloscope or RMS voltmeter

as shown in Figures 5-3A or 5-3B.

5-23 To check the ripple output, proceed as fol-

lows:

not recommended for ripple measurements, it may

5-19 Although the method shown in Figure 5-3A is

tain precautionary measures are taken. One method

of minimizing the effects of ground current flow

(IT) is to ensure that both the supply and the test

instrument are plugged into the same ac power buss.

5-20 To minimize pick up, a twisted pair or (pre-

ferably) a shielded two-wire cable should be used

to connect the output terminals of the power supply

using a twisted pair, care must be taken that one

of the two wires is connected both to the grounded

terminal of the power supply and the grounded input

terminal of the oscilloscope. When using shielded

two-wire cable, it is essential for the shield to be

connected to ground at one end only to prevent any

ground current flowing through this shield from in-

ducing a signal in the shielded leads.

5-21 To verify that the oscilloscope is not dis-

playing ripple that is induced in the leads or pick-

ed up from the grounds, the (+) scope lead should

be shorted to the (-) scope lead at the power sup-

ply terminals. The ripple value obtained when the

leads are shorted should be subtracted from the

actual ripple measurement.

5-22 If the foregoing measures are used, the

single-ended scope of Figure 5-3A may be ade-

quate to eliminate non-real components of ripple

so that a satisfactory measurement can be obtained.

However, in stubborn cases or in measurement

situations where it is essential that both the pow-

er supply case and the oscilloscope case be con-

nected to ground (e.g., if both are rack-mounted),

it may be necessary to use a differential scope

with floating input as shown in Figure 5-3B. If de-

sired, two single-conductor shielded cables may

be substituted in place of the shielded two-wire

cable with equal success. Because of its common

mode rejection, a differential oscilloscope dis-

plays only the difference in signal between its two

vertical input terminals, thus ignoring the effects

of any common mode signal produced by the differ-

ence in the ac potential between the power supply

case and scope case. Before using a differential

input oscilloscope in this manner, however, it is

imperative that the common mode rejection capabil-

ity of the oscilloscope be verified by shorting to-

gether its two input leads at the power supply

sensing terminals and observing the trace on the

CRT. If this trace is a straight line, then the oscil-

loscope is properly ignoring any common mode sig-

nal present. If this trace is not a straight line,

then the scope is not rejecting the ground signal

and must be realigned in accordance with the manu-

facturer's instructions until proper common mode

rejection is attained.

a. Connect test setup shown in Figure 5-5. Turn CURRENT controls fully clockwise.

b. To check the transient recovery time, proceed as follows:

5-31 Starting from the major graticule division representative of time zero, count to the right 50µsec and vertically 10mV. Recovery should be within these tolerances as illustrated in Figure 5-6.

k. Adjust the horizontal positioning control so that the trace starts at a point coincident with a major graticule division. This point is then representative of time zero.

l. Increase the sweep rate so that a single transient spike can be examined in detail.

j. Adjust the sync controls separately for the positive and negative going transients so that the recovery waveshape but also as much as possible of the rise time of the transient is displayed.

g. Adjust the vertical centering on the scope so that the tail ends of the no load and full load waveforms are symmetrically displayed about the horizontal center line of the oscilloscope. This center line now represents the nominal output voltage defined in the specification.

h. Adjust the horizontal positioning control so that the trace starts at a point coincident with a major graticule division. This point is then representative of time zero.

i. Increase the sweep rate so that a single transient spike can be examined in detail.

f. Set vertical input of oscilloscope for ac coupling so that small dc level changes in power supply output voltage will not cause display to shift.

e. Set oscilloscope for internal sync and lock on either positive or negative load transient spike.

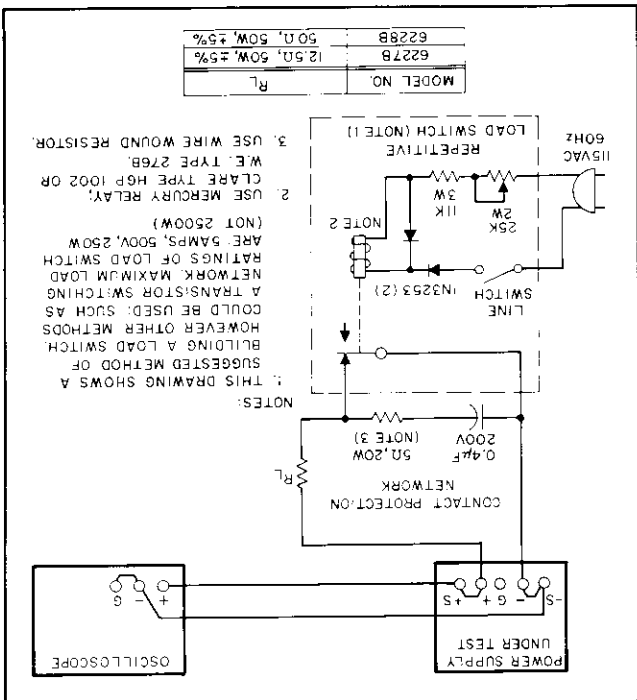
d. Close line switch on repetitive load switch setup.

c. Turn on supply and adjust VOLTAGE controls until front panel ammeter indicates maximum rated output current.

b. Close line switch on repetitive load switch setup.

a. Turn on supply and adjust VOLTAGE controls until front panel ammeter indicates maximum rated output current.

Figure 5-5. Transient Recovery Time Test Setup



5-27 Transient Recovery Time. Definition: The time "X" for the output voltage recovery to within "Y" millivolts of the nominal output voltage following a load current change of 5 amps or the full load current rating of the supply, whichever is less.

5-28 Transient recovery time may be measured at any input line voltage combined with any output voltage and load current within rating.

5-29 Reasonable care must be taken in switching the load resistance on and off. A hand-operated switch in series with the load is not adequate, since the resulting one-shot displays are difficult to observe on most oscilloscopes, and the arc energy occurring during switching action completely masks the display with a noise burst. Transistors for load switching devices are expensive if reasonably rapid load current changes are to be achieved.

5-30 A mercury-wetted relay, as connected in the load switching circuit of Figure 5-5 should be used for loading and unloading the supply. When this load switch is connected to a 60Hz ac input, the mercury-wetted relay will open and close 60 times per second. Adjustment of the 25K control permits adjustment of the duty cycle of the load current switching and reduction in jitter of the oscilloscope display.

5-31 To check the transient recovery time, proceed as follows:

a. Connect test setup shown in Figure 5-5. Turn CURRENT controls fully clockwise.

b. To check the transient recovery time, proceed as follows:

5-26 The setup of Figure 5-4 can also be used for the normal measurement of low frequency ripple; simply remove the four terminating resistors and the blocking capacitors and substitute a higher gain vertical plug-in in place of the wide-band plug-in required for spike measurements. Notice that with these changes, Figure 5-4 becomes a two-cable version of Figure 5-3C.

5. Since the impedance matching resistors constitute a 2-to-1 attenuator, the noise spikes observed on the oscilloscope should be less than 2mV p-p instead of 4mV p-p.

5-27 Transient Recovery Time. Definition: The time "X" for the output voltage recovery to within "Y" millivolts of the nominal output voltage following a load current change of 5 amps or the full load current rating of the supply, whichever is less.

5-28 Transient recovery time may be measured at any input line voltage combined with any output voltage and load current within rating.

5-29 Reasonable care must be taken in switching the load resistance on and off. A hand-operated switch in series with the load is not adequate, since the resulting one-shot displays are difficult to observe on most oscilloscopes, and the arc energy occurring during switching action completely masks the display with a noise burst. Transistors for load switching devices are expensive if reasonably rapid load current changes are to be achieved.

5-30 A mercury-wetted relay, as connected in the load switching circuit of Figure 5-5 should be used for loading and unloading the supply. When this load switch is connected to a 60Hz ac input, the mercury-wetted relay will open and close 60 times per second. Adjustment of the 25K control permits adjustment of the duty cycle of the load current switching and reduction in jitter of the oscilloscope display.

5-31 To check the transient recovery time, proceed as follows:

a. Connect test setup shown in Figure 5-5. Turn CURRENT controls fully clockwise.

b. To check the transient recovery time, proceed as follows:

5. Since the impedance matching resistors constitute a 2-to-1 attenuator, the noise spikes observed on the oscilloscope should be less than 2mV p-p instead of 4mV p-p.

e. Record differential voltmeter reading. Raise temperature to 40°C and allow 30 minutes warm-up.

g. Observe differential voltmeter reading. Difference in voltage reading between Step (e) and (g) should be less than the following:

6227B	5.2mV
6228B	10.2mV

5-36 Output Stability. Definition: The change in output voltage for the first eight hours following a 30-minute warm-up period. During the interval of measurement all parameters, such as load resistance, ambient temperature, and input line voltage are held constant.

5-37 This measurement is made by monitoring the output of the power supply on a differential voltmeter or digital voltmeter over the stated measurement interval; a strip chart recorder can be used to provide a permanent record. A thermometer should be placed near the supply to verify that the ambient temperature remains constant during the period of measurement. The supply should be put in a location immune from stray air currents (open doors or windows, air conditioning vents); if possible, the supply should be placed in an oven which is held at a constant temperature. Care must be taken that the measuring instrument has a stability over the eight hour interval which is at least an order of magnitude better than the stability specification of the power supply being measured. The supply will drift considerably less over the eight hour measurement interval than during the half-hour warm-up.

5-38 To check the output stability, proceed as follows:

- Connect load resistance and differential voltmeter as illustrated in Figure 5-2.
- Turn CURRENT controls fully clockwise.
- Adjust front panel VOLTAGE controls until differential voltmeter indicates maximum rated output voltage.
- Allow 30 minutes warm-up, then record differential voltmeter reading.
- After 8 hours, differential voltmeter should change from reading recorded in Step (d) by less than the following:

6227B	5.2mV
6228B	10.2mV

5-39 Output Impedance. Definition: At any given frequency of

load change, E_{OUT}/I_{OUT} . Strictly speaking the definition applies only for a sinusoidal load disturbance, unless, of course, the measurement is made at zero frequency (dc). The

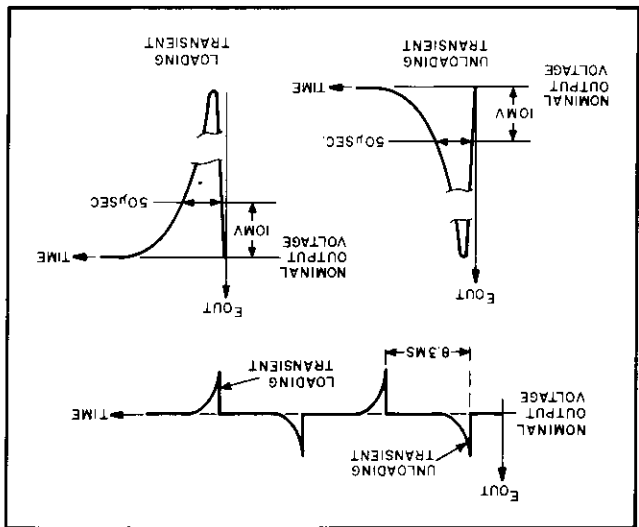


Figure 5-6. Transient Recovery Time Waveforms

5-32 Temperature Coefficient. Definition: The change in output voltage per degree Centigrade change in the ambient temperature under conditions of constant input ac line voltage, output voltage setting, and load resistance.

5-33 The temperature coefficient of a power supply is measured by placing the power supply in an oven and varying it over any temperature span within its rating. (Most HP power supplies are rated for operation from 0°C to 55°C.) The power supply must be allowed to thermally stabilize for a sufficient period of time at each measurement temperature.

5-34 The temperature coefficient given in the specifications is the maximum temperature-dependent output voltage change which will result over any one degree Centigrade interval. The differential voltmeter or digital voltmeter used to measure the output voltage change of the supply should be placed outside the oven and should have a long term stability adequate to insure that its drift will not affect the overall measurement accuracy.

5-35 To check the temperature coefficient, proceed as follows:

- Connect load resistance and differential voltmeter as illustrated in Figure 5-2.
- Turn CURRENT controls fully clockwise.
- Adjust front panel VOLTAGE controls until front panel voltmeter indicates maximum rated output voltage.
- Place power supply in temperature-controlled oven (differential voltmeter remains outside oven). Set temperature to 30°C and allow 30 minutes warm-up.

- e. Set oscillator frequency for 5Hz.
- f. Adjust amplitude controls of oscillator and amplifier for largest possible undistorted waveform on oscilloscope. Record reading on micro-voltmeter.
- g. Move switch S1 to position B (measure ac voltage drop across 1 ohm resistor, and therefore ac current delivered to power supply under test).
- h. Without changing amplitude controls on oscillator or amplifier, read and record voltage indicated on ac microvoltmeter.
- i. Output impedance (at 5Hz) is found by dividing the voltage reading from Step (f) by the voltage reading from Step (h); the value should not exceed 0.002 (ohms) for the 6227B and 0.006 (ohms) for the 6228B.
- j. Repeat Steps (d) through (i) for any other frequencies of interest up to 250KHz. (Note: Amplifier is not required at frequencies above 20KHz.) For any given frequency, the output impedance should be less than that indicated by the value of the curve in Figure 5-8. For example, at 1KHz the output impedance should be less than approximately 11 milliohms for the 6227B and 40 milliohms for the 6228B.

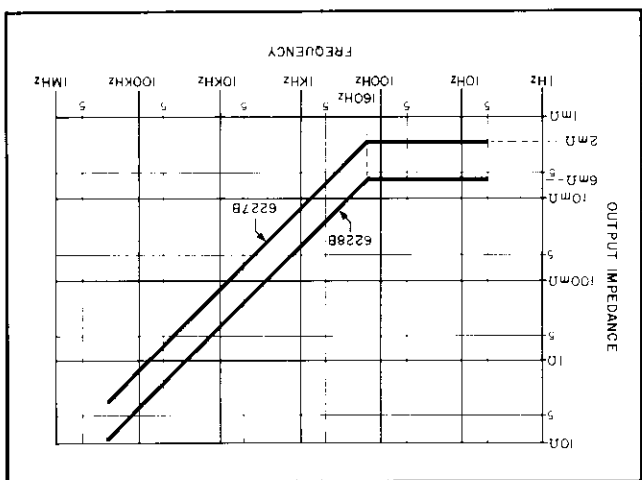


Figure 5-8. Output Impedance versus Frequency

5-42 Tracking Error. The tracking error is defined as the difference in percent between the output voltage of the master and slave supplies when the instrument is operated in the tracking mode. The error is measured once for the complete instrument, as opposed to the previous tests in which the test procedure was repeated for both supplies contained in the instrument. The test setup to be used is shown in Figure 5-9. Only the front output terminals should be used for this test; the rear output and sensing terminals cannot be used when the instrument is operated in the tracking mode. In addition, note that the minus output terminal of the master (left) supply must be used as the terminal

The output impedance of a power supply is normally not measured, since the measurement of transient recovery time reveals both the static and dynamic output characteristics with just one measurement. The output impedance of a power supply is commonly measured only in those cases where the exact value at a particular frequency is of engineering importance.

5-40 The test setup to be used is shown in Figure 5-7. It is important that the measuring instruments shown in the figure (oscilloscope and microvoltmeter) be connected directly across the power supply output terminals rather than at other points in the test setup. In addition, each instrument should be connected to the power supply with its own pair of leads in order to minimize mutual coupling effects. Monitoring resistor R_M (1 ohm, $\frac{1}{2}$ watt) must be a non-inductive resistor. The value shown for coupling capacitor C_C is the minimum required value; larger values of capacitance can be used without difficulty.

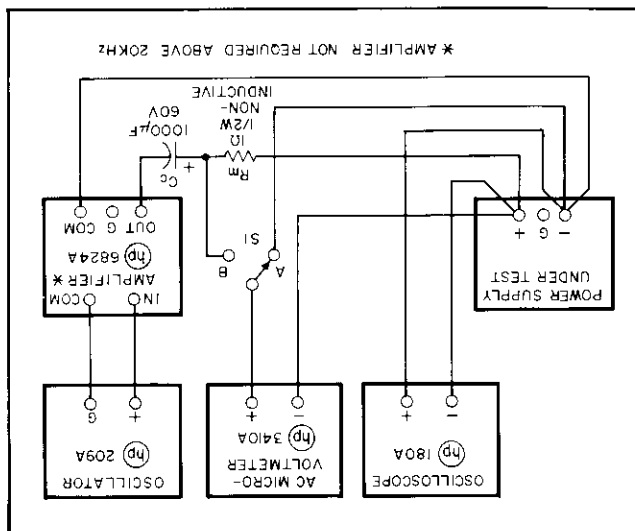


Figure 5-7. Output Impedance Test Setup

5-41 To check the output impedance of the power supply, proceed as follows:

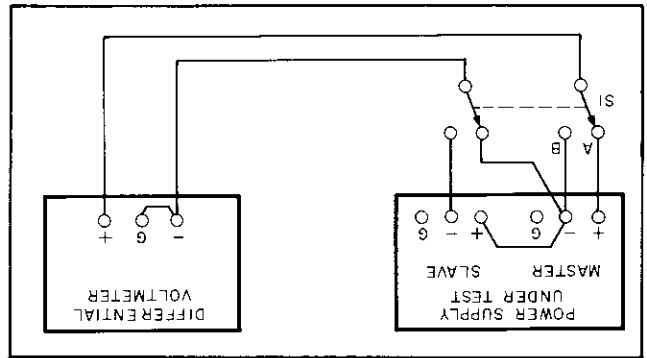
- a. Connect test setup shown in Figure 5-7.
- b. Turn CURRENT controls fully clockwise.
- c. Turn on supply and adjust VOLTAGE controls for maximum rated output voltage.
- d. Move switch S1 connected to ac microvoltmeter to position A (measure ac voltage impressed across power supply output terminals).

5-46 For all output current measurements the current sampling resistor must be treated as a four terminal device. In the manner of a meter shunt, the load current is fed to the extremes of the wire leading to the resistor while the sampling terminals are located as close as possible to the resistance portion itself (see Figure 5-10). Generally, any

5-45 The instruments, methods, and precautions for the proper measurement of constant current power supply characteristics are for the most part identical to those already described for the measurement of constant voltage power supplies. There are, however, two main differences: First, the power supply performance will be checked between short circuit and full load rather than open circuit and full load. Second, a current monitoring resistor is inserted between the output of the power supply and the load.

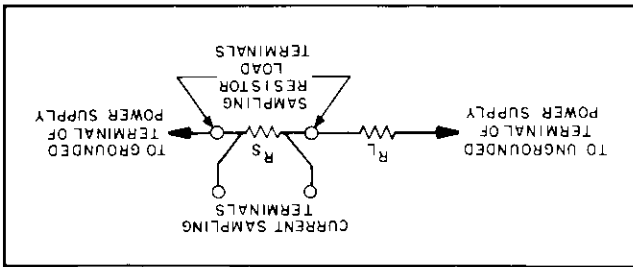
5-44 CONSTANT CURRENT TESTS

Figure 5-9. Tracking Error Test Setup



5-43 To check the tracking error, proceed as follows:
 a. Connect test setup shown in Figure 5-9. Set front panel mode switch to TRACK-ING, and connect jumper between minus output terminal of left supply and positive output terminal of right supply as shown on front panel and in Figure 5-9.
 c. Turn CURRENT controls fully clockwise and set switch S1 to position A (measure master supply output voltage).
 d. Turn on supply and adjust master VOLT-AGE controls until differential voltmeter reads actively maximum rated output voltage.
 e. Move switch S1 to position B (measure slave output voltage). Differential voltmeter reading should be within following tolerances:
 6227B 25V ± 52mV
 6228B 50V ± 102mV

Figure 5-10. Current Sampling Resistor Connections



current sampling resistor should be of the low noise, low temperature coefficient (less than 20ppm/°C) type and should be used at no more than 10% of its rated power so that its temperature rise will be minimized. If difficulty is experienced in obtaining a resistor suitable for current sampling, a duplicate of the sampling resistor used in this unit (R10 and R11 in the 6227B; R10 in the 6228B) may be obtained from the factory.

5-47 Rated Output and Meter Accuracy.
 a. Connect test setup shown in Figure 5-11.
 b. Turn VOLTAGE controls fully clockwise.
 c. Turn on supply and adjust CURRENT controls until front panel ammeter indicates maximum rated output current.
 d. Differential voltmeter should read 1.0 ± 0.024Vdc.

5-48 Load Regulation.
 Definition: The change ΔIOUT in the static value of the dc output current resulting from a change in load resistance from short circuit to a value which yields maximum rated output voltage.

5-49 To check the constant current load regulation, proceed as follows:
 a. Connect test setup shown in Figure 5-11.
 b. Turn VOLTAGE controls fully clockwise.
 c. Adjust CURRENT controls until front panel meter reads exactly maximum rated output voltage.
 d. Read and record voltage indicated on differential voltmeter.
 e. Short circuit load resistor (RL).
 f. Reading on differential voltmeter should not vary from reading recorded in Step (d) by more than the following:
 6227B 225µV
 6228B 350µV

5-50 Line Regulation.
 Definition: The change ΔIOUT in the static value of dc output current resulting from a change in ac input voltage over the specified range from low

line (usually 103.5 volts) to high line (usually 126.5 volts), or from high line to low line.

5-51 To check the line regulation, proceed as follows:

- Utilize test setup shown in Figure 5-11.
- Connect variable auto transformer between input power source and power supply power input.
- Adjust auto transformer for 103.5Vac input.
- Adjust auto transformer for 103.5Vac input.
- Turn VOLTAGE controls fully clockwise.
- Adjust CURRENT controls until front panel ammeter reads exactly maximum rated output current.
- Read and record voltage indicated on differential voltmeter.
- Adjust variable auto transformer for 126.5Vac input.
- Reading on differential voltmeter should not vary from reading recorded in step (f) by more than the following:

6227B 50 μ V
6228B 100 μ V

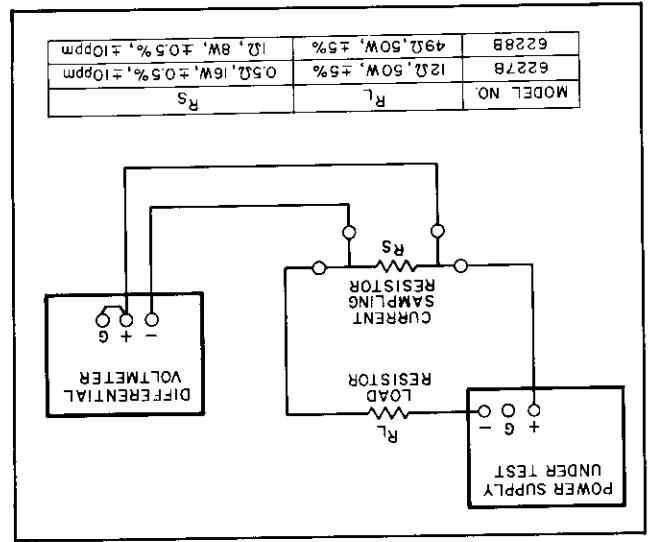


Figure 5-11. Constant Current Load Regulation Test Setup

5-52 Ripple and Noise. Definition: The residual ac current which is superimposed on the dc output current of a regulated power supply. Ripple and noise may be specified and measured in terms of its RMS or (preferably) peak-to-peak value.

5-53 Most of the instructions pertaining to the ground loop and pickup problems associated with

constant voltage ripple and noise measurements

also apply to the measurement of constant current ripple and noise. Figures 5-12 and 5-13 illustrate

the most important precautions to be observed

when measuring the ripple and noise of a constant

current supply. The presence of a 120Hz wave-

form on the oscilloscope is normally indicative of

a correct measurement method. A wavelshape hav-

ing 60Hz as its fundamental component is typical-

ly associated with an incorrect measurement setup.

5-54 Ripple Measurement. To check the ripple

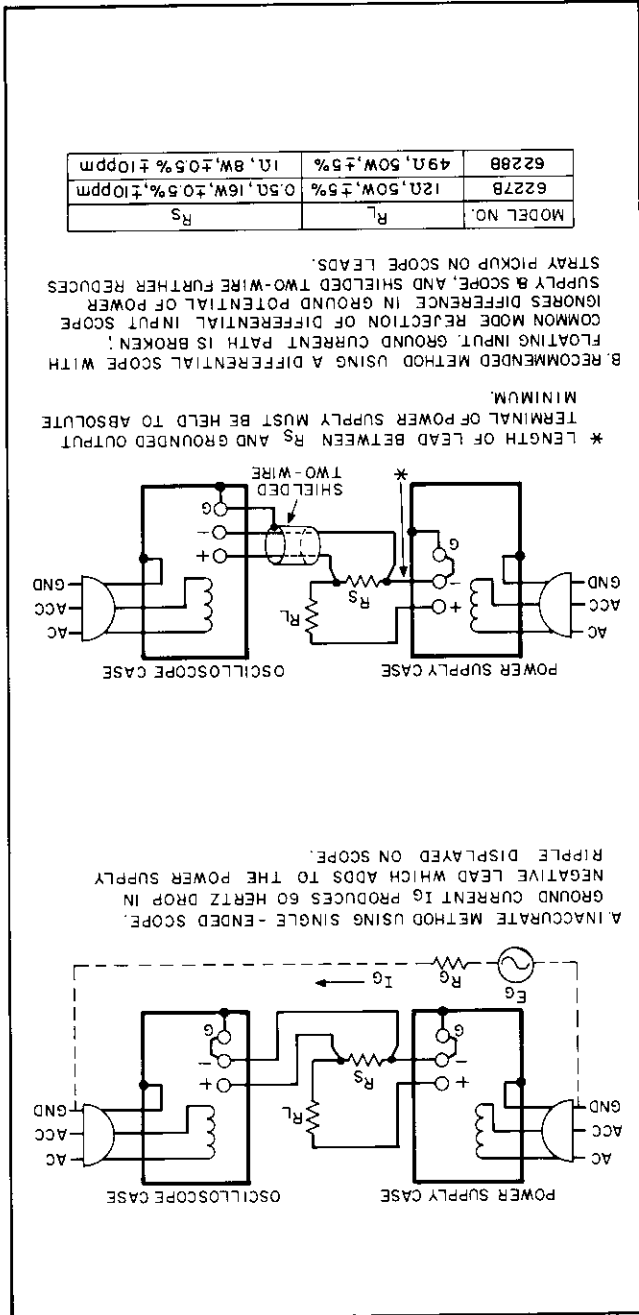


Figure 5-12. Constant Current Ripple Test Setup

of the manual before attempting to troubleshoot the instrument. Once the principles of operation are understood, refer to the overall troubleshooting procedure in Paragraph 5-61 to locate the symptom and its probable cause.

5-59 The schematic diagram at the rear of the manual (Figure 7-7) contains normal voltage readings taken at various points within the circuits. These voltages (in italics) are positioned adjacent to the applicable test points (identified by encircled numbers). The component location diagrams (Figures 7-1 through 7-6) at the rear of the manual should be consulted to determine the location of components and test points.

5-60 If a defective component is located, replace it and re-conduct the performance test. When a component is replaced, refer to the repair and replacement (Paragraph 5-71) and adjustment and calibration (Paragraph 5-73) sections of this manual.

5-61 OVERALL TROUBLESHOOTING PROCEDURE

5-62 The following procedure must be followed in sequence when initially troubleshooting the instrument.

a. Check for obvious troubles such as blown main fuse (F1), 115/230V line switch in wrong position, incorrect rear strapping pattern (refer to Figure 3-2), input power failure, or defective meter (check output voltage with external meter).

b. Remove top, bottom, and side covers (total 12 Phillips screws) and inspect for open connections, charred components, etc.

c. Check internal protection fuse F2; if blown, replace.

d. Isolate crowbar from supply by disconnecting anode of CR4 (see Figure 7-2).

NOTE

Because the troubleshooting procedures are based on driving the series regulator into saturation or cutoff by shorting or opening a previous stage, the crowbar must be disconnected from the supply in order to prevent tripping the crowbar and blowing fuse F2 every time the series regulator is driven into saturation.

e. Disconnect load, set mode switch to

output, proceed as follows:

- Connect oscilloscope or RMS voltmeter as shown in Figures 5-12A or 5-12B.
- Turn VOLTAGE controls fully clockwise.
- Adjust CURRENT controls until front panel ammeter reads exactly maximum rated output current.

d. The observed ripple should be less than: 6227B 125µV 6228B 250µV

5-55 Noise Spike Measurement. To check the noise spike output, proceed as follows:

- Connect test setup shown in Figure 5-13.
- Turn VOLTAGE controls fully clockwise.
- Adjust CURRENT controls until front panel ammeter indicates exactly rated output current.

d. The observed noise spikes should be less than 1.0mV p-p.

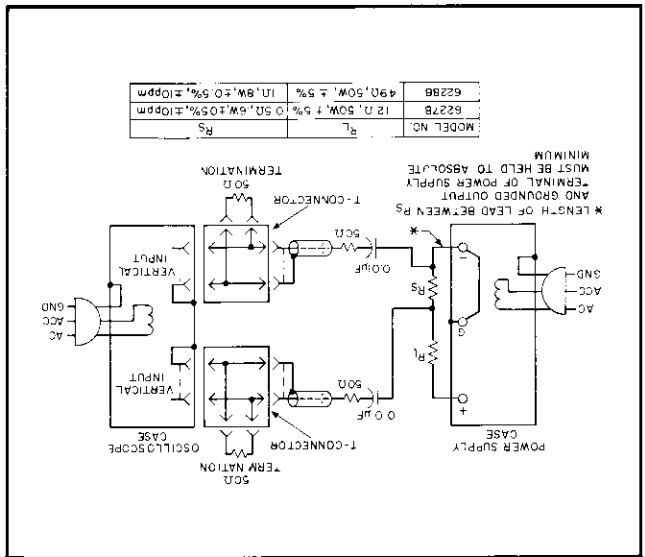


Figure 5-13. Constant Current Noise Spike Test Setup

5-56 TROUBLESHOOTING

5-57 Before attempting to troubleshoot this instrument, ensure that the fault is with the instrument and not with an associated circuit. The performance test (Paragraph 5-5) enables this to be determined without removing the instrument's covers.

5-58 A good understanding of the principles of operation is a helpful aid in troubleshooting, and it is recommended that the reader review Section IV

5-63 In many cases, trouble can be caused by incorrect dc bias voltages; thus it is good practice to check these voltages before proceeding with any troubleshooting a supply with multiple failures, in which curing one trouble often uncovers another, it is a good idea to check the reference voltages whenever a new symptom occurs. In many cases the reference voltages may be incorrect even though all the components in the reference regulator are functional; this may occur because a defective component or stage in the regulator feedback loop is drawing excessive current and loading down the reference voltages. In this situation the defective

f. Check the reference and bias voltages given in Table 5-2.

Never turn the VOLTAGE controls fully CCW when high output voltage is the trouble symptom; doing so may damage the potentiometer due to high current flowing from +OUT to -OUT through CR5, R20, and the pot.

CAUTION

INDEPENDENT and meter switch to VOLTS, turn VOLTAGE and CURRENT controls fully clockwise, and turn on supply.

STEP	METER COMMON	METER POSITIVE	NORMAL VDC	NORMAL RIPPLE (P-P)	CHECK IF PROPER INDICATION IS NOT OBTAINED
1	TP32	TP12	+27.5 ±5.5	2.5V	CR21, CR22
2	+S	TP30	+12.4 ±0.9	2.0mV	VR1, VR2, Q15, Q14, Q13, Q12
3	+S	TP31	+6.2 ±0.3	0.5mV	VR1, VR2
4	TP32	+S	+6.2 ±0.3	2.0mV	VR2, VR1
5	TP34	+S	+4.3 ±0.4	0.5V	VR4, CR19, CR20
6	+S	TP33	+20 ±4.0	2.0V	VR4, CR19, CR20

Table 5-2. Reference and Bias Voltages (Refer to Schematic and Figures 7-4 through 7-6 for test point locations)

5-64 After checking the reference and bias voltages, refer to Table 5-3, Initial Troubleshooting. This table lists the most common trouble symptoms (high output voltage, low output voltage, and defective crowbar) and their possible causes. For each symptom the reader is referred to another, more detailed, troubleshooting table (Tables 5-4 through 5-6).

5-65 Tables 5-4 and 5-5 provide troubleshooting procedures for the high and low voltage output symptoms, respectively. These tables contain instructions for driving each stage of the series regulator feedback loop into conduction or cutoff. By following these steps, the fault can be isolated to a particular circuit or component. Table 5-6 provides troubleshooting procedures for the crowbar; this table contains instructions for triggering the crowbar from two different points in the circuit and thus isolating the fault to a particular group of components.

5-66 Table 5-7 contains a list of less common troubles and their possible causes. The troubles in this table are less catastrophic than those listed in Table 5-3; for the most part these symptoms describe degraded performance rather than complete failure. The possible causes listed should be checked in the order they appear in the table.

Table 5-3. Initial Troubleshooting (Common Troubles)

PROBABLE CAUSE AND REMEDIAL ACTION	SYMPTOM									
<p>a. Fuse F2 blown. Replace fuse, isolate crowbar by disconnecting anode of CR4, and turn on supply. If output voltage is high, refer to "High Output Voltage" symptom below. If output voltage is low, refer to "Low or No Output Voltage" symptom below. If output voltage is normal, check constant current comparator by performing the following test:</p>	<p>No output voltage under loaded conditions; normal output voltage and slow up-programming under no-load conditions</p>									
<table border="1"> <thead> <tr> <th data-bbox="203 1564 462 1617">PROBABLE CAUSE</th> <th data-bbox="462 1564 787 1617">RESPONSE</th> <th data-bbox="787 1564 1356 1617">ACTION</th> </tr> </thead> <tbody> <tr> <td data-bbox="203 1501 462 1554">a. Z1 defective.</td> <td data-bbox="462 1501 787 1554">a. Output current remains constant.</td> <td data-bbox="787 1501 1356 1554">Turn off supply, and disconnect cathode of CR8. Connect 1/4-current load resistor across output terminals (100Ω, 25W for 6227B and 200Ω, 25W for 6228B). Set meter switch to AMPS and turn on supply. Ammeter will indicate approximately 0.5A on 6227B and 0.25A on 6228B. (If meter switch is set to VOLTS, meter will go off-scale.) Check turn-off of constant current comparator by shunting R5 with 10kΩ resistor.</td> </tr> <tr> <td data-bbox="203 1438 462 1491">b. R4A or R4B open; strap missing between terminals A6 and A7.</td> <td data-bbox="462 1438 787 1491">b. Output current decreases.</td> <td data-bbox="787 1438 1356 1491"></td> </tr> </tbody> </table>	PROBABLE CAUSE	RESPONSE	ACTION	a. Z1 defective.	a. Output current remains constant.	Turn off supply, and disconnect cathode of CR8. Connect 1/4-current load resistor across output terminals (100Ω, 25W for 6227B and 200Ω, 25W for 6228B). Set meter switch to AMPS and turn on supply. Ammeter will indicate approximately 0.5A on 6227B and 0.25A on 6228B. (If meter switch is set to VOLTS, meter will go off-scale.) Check turn-off of constant current comparator by shunting R5 with 10kΩ resistor.	b. R4A or R4B open; strap missing between terminals A6 and A7.	b. Output current decreases.		<p>High output voltage after replacing fuse F2 and isolating crowbar</p> <p>Low or no output voltage after replacing fuse F2 and isolating crowbar</p>
PROBABLE CAUSE	RESPONSE	ACTION								
a. Z1 defective.	a. Output current remains constant.	Turn off supply, and disconnect cathode of CR8. Connect 1/4-current load resistor across output terminals (100Ω, 25W for 6227B and 200Ω, 25W for 6228B). Set meter switch to AMPS and turn on supply. Ammeter will indicate approximately 0.5A on 6227B and 0.25A on 6228B. (If meter switch is set to VOLTS, meter will go off-scale.) Check turn-off of constant current comparator by shunting R5 with 10kΩ resistor.								
b. R4A or R4B open; strap missing between terminals A6 and A7.	b. Output current decreases.									
<p>a. Series regulator feedback loop in high voltage condition. Refer to Table 5-4.</p>	<p>Crowbar trips every time supply is turned on regardless of setting of CROWBAR ADJUST control</p>									
<p>a. Check voltage across main filter capacitors C6 and C7. If no voltage is present, check CR13 through CR18 and fuse F1. If correct voltage is present, series regulator feedback loop is in low voltage condition. Refer to Table 5-5.</p>	<p>Crowbar will not trip regardless of setting of CROWBAR ADJUST control; output voltage falls slowly when unloaded supply is turned off</p>									
<p>a. Regulator loop in high voltage condition. Isolate crowbar by disconnecting anode of CR4, and refer to Table 5-4.</p> <p>b. Defective crowbar. Check SCR CR4 for anode-to-cathode short, and check CROWBAR ADJUST control R10 for short.</p>	<p>NOTE</p> <p>Uncertainty over whether the crowbar has tripped and shorted the output of the supply, or the supply output has fallen to zero due to a regulating loop failure can be resolved by switching the meter switch to AMPS. If the crowbar is tripped, the ammeter will indicate the current flowing through the SCR (the level is determined by the setting of the CURRENT control); if the crowbar is not tripped, the ammeter will read zero.</p>									
<p>a. Defective crowbar. Refer to Table 5-6.</p>	<p>Crowbar will not trip regardless of setting of CROWBAR ADJUST control; output voltage falls slowly when unloaded supply is turned off</p>									

Table 5-4. Series Regulator Troubleshooting, High Voltage Condition

STEP	ACTION	RESPONSE	PROBABLE CAUSE
1	<p>Check turn-off of series regulator transistors Q8 through Q11 by turning off supply, shorting driver Q7 collector (-OUT terminal) to emitter (TP66), and turning supply on again.</p> <p>CAUTION</p> <p>Do not apply short circuit to Q7 when supply is on or severe component damage will result.</p>	<p>a. Output voltage remains high.</p> <p>b. Output voltage decreases.</p>	<p>a. One or more of Q8 through Q11 shorted.</p> <p>b. Remove short and proceed to Step 2.</p>
2	<p>Check turn-on of driver Q7 by shorting predriver Q6 base (TP64) to emitter (TP65).</p>	<p>a. Output voltage remains high.</p> <p>b. Output voltage decreases.</p>	<p>a. Q7 open.</p> <p>b. Remove short and proceed to Step 3.</p>
3	<p>Check turn-off of predriver Q6 by shorting mixer amplifier Q5 base (TP60) to emitter (TP61).</p>	<p>a. Output voltage remains high.</p> <p>b. Output voltage decreases.</p>	<p>a. Q6 shorted; Q4 shorted.</p> <p>b. Remove short and proceed to Step 4.</p>
4	<p>Check turn-off of mixer amplifier Q5 by connecting base (TP60) to +6.2V reference (TP31).</p>	<p>a. Output voltage remains high.</p> <p>b. Output voltage decreases.</p>	<p>a. Q5 shorted.</p> <p>b. Remove connection and proceed to Step 5.</p>
5	<p>Check turn-off of constant voltage comparator by connecting 10kΩ resistor from pin 10 of Z1 (TP51) to +12.4V reference (TP30).</p>	<p>a. Output voltage remains high.</p> <p>b. Output voltage decreases.</p>	<p>a. Z1 defective.</p> <p>b. R27A or R27B open; open strap between terminals A2 and A3.</p>

Table 5-5. Series Regulator Troubleshooting, Low Voltage Condition

STEP	ACTION	RESPONSE	PROBABLE CAUSE
1	<p>Check conduction of series regulator transistors Q8 through Q11 by shorting driver Q7 base (TP65) to emitter (TP66).</p>	<p>a. Output voltage remains low.</p> <p>b. Output voltage rises.</p>	<p>a. Q8 through Q11 open and/or R68, R69, R73, and R74 open; VR3 shorted.</p> <p>b. Remove short and proceed to Step 2.</p>

Table 5-5. Series Regulator Troubleshooting. Low Voltage Condition (Continued)

STEP	ACTION	RESPONSE	PROBABLE CAUSE
2	Check turn-off of driver Q7 by shorting predriver Q6 collector (TP67) to emitter (TP65).	a. Output voltage remains low. b. Output voltage rises.	a. Q7 shorted. b. Remove short and proceed to Step 3.
3	Check conduction of predriver Q6 by shorting Q5 collector (TP63) to emitter (TP61).	a. Output voltage remains low. b. Output voltage rises.	a. Q6 open; Q4 open. b. Remove short and proceed to Step 4.
4	Check conduction of mixer amplifier Q5 by shunting resistor R30 with 10k Ω resistor.	a. Output voltage remains low. b. Output voltage rises.	a. Q5 open. b. Remove 10k Ω resistor and proceed to Step 5.
5	Isolate fault to either constant voltage comparator or constant current comparator by opening cathode of CR9.	a. Output voltage remains low. b. Output voltage rises.	a. Reconnect lead and proceed to Step 7. b. Reconnect lead and proceed to Step 6.
6	Check conduction of constant current comparator Z1 by shunting R7 with a 10k Ω resistor.	a. Output voltage remains low. b. Output voltage rises.	a. Z1 defective. b. R4A and R4B shorted; CR1 shorted; open strap between terminals A6 and A5.
7	Check conduction of constant voltage comparator by connecting 10k Ω resistor from pin 10 of Z1 (TP51) to -6.2V reference (TP32).	a. Output voltage remains low. b. Output voltage rises.	a. Z1 defective. b. R27A and R27B shorted; CR5 or CR6 shorted; C2 shorted; open strap between terminals A1 and A2.

Table 5-6. Crowbar Troubleshooting: Non-Tripping Crowbar (Refer to Paragraph 5-70 for A4 Crowbar Board removal procedure)

STEP	ACTION	RESPONSE	PROBABLE CAUSE
1	Attempt to trigger crowbar by shorting Q2 collector (TP86) to emitter (TP85).	a. Crowbar does not trip. b. Crowbar trips.	a. CR4 open; Q2 shorted; Q1 open; CR3 shorted; VR2 shorted. b. Reset crowbar by turning unit off and then on again, and proceed to Step 2.

PROBABLE CAUSE AND REMEDIAL ACTION	SYMPTOM
<p>a. Tracking jumper missing (should be connected between -OUT of master and +OUT of slave as indicated on front panel).</p> <p>b. Defective tracking switch. Check pole "W".</p> <p>c. Defective voltage divider resistors. Check R91 and R92 (on A1 Mother board).</p>	<p>Improper operation in tracking mode (Excessive voltage difference between master and slave or slow up-programming of slave supply)</p>
<p>a. Q10-Q11 and/or R73-R74 open.</p> <p>b. VR3 and/or Q6 shorted.</p>	<p>Cannot reach maximum output voltage under loaded conditions; output voltage may be normal under no-load conditions</p>
<p>a. Noisy zener diodes in reference circuit. Check VR1, VR2.</p>	<p>High frequency noise ("grass") in output</p>
<p>a. Ground loops in operating setup or improper measurement technique. Refer to Paragraph 5-17 and/or section on ground loops in AN-90A, <u>Power Supply Handbook</u>.</p> <p>b. Supply crossing over to constant current operation under loaded conditions. Check CURRENT control setting or constant current comparator (Z1 and associated components).</p> <p>c. Excessive ripple in reference voltages. Refer to Table 5-2.</p> <p>d. Mixer amplifier current source (Q4) shorted; capacitor C5 leaky.</p>	<p>High ripple in output</p>
<p>a. Improper measurement technique. Refer to Paragraph 5-11.</p> <p>b. Supply current limiting. Check constant current comparator (Z1 and associated components).</p> <p>c. Reference regulator not regulating +6.2V reference voltage. Refer to Table 5-2.</p> <p>d. Defect in constant voltage comparator bias circuit. Check voltage at TP53 (Point "M").</p>	<p>Poor load regulation (Constant voltage)</p>

Table 5-7. Less Common Troubles

PROBABLE CAUSE	RESPONSE	ACTION	STFP
<p>a. Q2 open; Q1 shorted; CR2 shorted.</p> <p>b. CR1 open; VR1 shorted; R10 open.</p>	<p>a. Crowbar does not trip.</p> <p>b. Crowbar trips.</p>	<p>Attempt to trigger crowbar by connecting base of Q1 (TP83) to -4.3V reference (TP34) through 100Ω resistor.</p>	<p>2</p>

Table 5-6. Crowbar Troubleshooting: Non-Tripping Crowbar (Continued)
(Refer to Paragraph 5-70 for A4 Crowbar Board removal procedure)

Table 5-7. Less Common Troubles (Continued)

PROBABLE CAUSE AND REMEDIAL ACTION	SYMPTOM
<p>a. Improper measurement technique. See Paragraph 5-48. b. Supply voltage limiting. Check constant voltage compa- rator (Z1 and associated components). c. Reference regulator not regulating -6.2V reference volt- age. Refer to Table 5-2. d. Voltage clamp circuit defective. Check CR3, 4; Q3; VR5. e. Leaky output capacitors. Check C1 and C13. f. Defective mixer amplifier current source. Check CR10. g. Defective "meter replacement" resistors. Check R87 and R88 and meter switch.</p>	<p>Poor load regulation (Constant current)</p>
<p>a. Improper measurement technique. See Paragraph 5-13. b. Reference regulator not regulating +12.4V reference volt- age. Refer to Table 5-2.</p>	<p>Poor line regulation</p>
<p>a. C4, C15 leaky. b. C1, C5, C13 open.</p>	<p>Oscillates (Constant voltage/constant cur- rent)</p>
<p>a. Incorrect reference voltages. Refer to Table 5-2. b. Dirty contact fingers on circuit board edge-connectors. Clean fingers with "Pink Pearl" eraser. c. Noisy VOLTAGE or CURRENT controls. Check R4,R24,R27. d. Defective integrated circuits Z1 or Z2. e. CR1, CR5, CR6, or C5 leaky.</p>	<p>Instability (Constant voltage/constant cur- rent)</p>

5-67 DISASSEMBLY PROCEDURES

5-68 The following paragraphs describe proce-
 dures for removing or providing access to the four
 subassemblies in this supply (A1 mother circuit
 board, A2 master circuit board, A3 slave circuit
 board, and A4 crowbar circuit board). Reference to
 these procedures should only be necessary when a
 component must be replaced; essentially all of the
 troubleshooting procedures given in this section
 can be performed without any disassembly other
 than simply removing the instrument's four covers.

5-69 Master and Slave Circuit Board (A2 and A3)
 Removal. To remove the master and slave print-
 ed circuit boards, proceed as follows:
 a. Remove top, bottom, and side covers
 (total 12 Phillips screws).
 b. Remove 4 Phillips screws holding rear
 aluminum frame to main side frames.
 c. Exerting gentle rearward pressure on
 heatsink and rear aluminum frame, unplug entire
 assembly (consisting of heatsink and both circuit

boards) from connectors on A1 mother board.
 d. With master/slave board assembly com-
 pletely removed, A1 mother board and chassis-
 mounted components may now be easily accessed.
 5-70 Crowbar Circuit Board (A4) Removal. To re-
 move the A4 crowbar circuit board, proceed as fol-
 lows:
 a. Remove top, bottom, and side covers
 (total 12 Phillips screws).
 b. Turn unit upside down and remove 2 Phil-
 lips screws holding bracing rod to main side frames
 at bottom front of unit.
 c. Remove 6 Phillips screws holding internal
 aluminum tray chassis to main side frames.
 d. Remove 2 Phillips screws holding top
 front trim (aluminum extrusion) to main side frames.
 e. Using $\frac{3}{8}$ " Allen wrench and working from
 front panel, remove two bushings holding CROW-
 BAR ADJUST potentiometers to front panel.
 f. While spreading main side frames slightly
 apart, pull lower (control) portion of front panel
 away from unit.

9. Crowbar board may now be maneuvered up and out of unit. Board can be folded back on its connecting wires for better access.

5-71 REPAIR AND REPLACEMENT

5-72 Section VI of this manual contains a list of replaceable parts. If the part to be replaced does not have a standard manufacturers' part number, it

Table 5-8. Checks and Adjustments After Replacement of Semiconductor Devices

REFERENCE	FUNCTION OR CIRCUIT	CHECK	ADJUST
Z1	Constant voltage and constant current comparator.	CV/CC load regulation, and zero output voltage and current.	R24, and R5 or R7
A4Q1, A4Q2	Crowbar.	Crowbar action.	---
Q3	Voltage clamp.	CC load regulation.	---
Q4, Q5	Mixer amplifier.	CV/CC load regulation, output ripple.	---
Q6, Q7 (*)	Driver amplifiers.	CV/CC load regulation.	---
Q8, Q9, Q10, Q11	Series regulator.	CV/CC load regulation, output voltage over full range.	---
Q12, Q13, Q14, Q15	Reference regulator.	+12.4V, +6.2V, and -6.2V reference voltages.	---
A4CR1, A4CR2, A4CR3, CR4 (*)	Crowbar.	Crowbar action.	---
CR1	Constant current comparator	CV/CC load regulation.	---
CR2	Reverse voltage protection.	Output voltage.	---
CR3, CR4	Voltage clamp.	CC load regulation.	---
CR5, CR6	Constant voltage comparator	CV load regulation.	---
CR7	Constant voltage/constant current comparator	Temperature coefficient.	---
CR8, CR9	OR-gate.	Crossover between constant voltage and constant current operation.	---
CR10	Mixer amplifier current source	Temperature coefficient, CC load regulation.	---

ADJUST	ADJUSTMENT PARAGRAPH	PRINCIPLES OF OPERATION PARAGRAPH	ADJUSTMENT OR CALIBRATION
Pointer	5-75	----	Ammeter/Volmeter Zero
R86	5-79	4-59	Ammeter Calibration
R80	5-80	4-58	Volmeter Calibration
R24	5-82	4-30	Constant Voltage Zero Output Voltage
R16	5-84	4-32	Constant Voltage Programming Accuracy
R5 or R7	5-86	4-37	Constant Current Zero Output Current
R2	5-88	4-38	Constant Current Programming Accuracy

Table 5-9. Adjustment and Calibration Summary

ADJUST	CHECK	FUNCTION OR CIRCUIT	REFERENCE
---	Output voltage.	Driver amplifier protection.	CR1, CR2
---	Output voltage over full range.	Series regulator switching diodes.	CR3, CR4
---	Output voltage.	Main rectifier diodes.	A1CR5, A1CR6, A1CR7, A1CR8
---	+20V and -4.3V bias voltages.	Bias supply rectifier diodes.	A1CR9, A1CR20
---	+12.4V, +6.2V, and -6.2V reference voltages.	Reference regulator rectifier diodes.	A1CR21, A1CR22
R10	Crowbar action, trip voltage range.	Crowbar.	A4VR1, A4VR2
R2 and R16.	+6.2V and -6.2V reference voltages.	Reference regulator.	VR1, VR2
---	Output voltage over full range.	Series regulator.	VR3
---	-4.3V reference voltage.	Bias supply.	VR4
---	CC load regulation.	Voltage clamp.	VR5

Table 5-8. Checks and Adjustments After Replacement of Semiconductor Devices (Continued)

5-73 ADJUSTMENT AND CALIBRATION

5-74 Adjustment and calibration may be required after performance testing, troubleshooting, or repair and replacement. Perform only those adjustments that affect the operation of the faulty circuit and no others. Except where otherwise indicated, all of the following adjustments must be performed twice—once for each of the two independent power supplies contained in the instrument.

5-75 METER ZERO

5-76 The meter pointer must rest on the zero calibration mark on the meter scale when the instrument is at normal operating temperature, resting in its normal operating position, and turned off. To zero set the meter proceed as follows:

- Turn on instrument and allow it to come up to normal operating temperature (about 30 minutes).
- Turn instrument off. Wait one minute for power supply capacitors to discharge completely.
- Insert sharp pointed object (pen point orawl) into small indentation near top of round black plastic disc located directly below meter face.
- Rotate plastic disc clockwise until meter reads zero, then rotate counterclockwise slightly in order to free adjustment screw from meter suspension. Pointer should not move during latter part of adjustment.

5-77 METER CALIBRATION

5-78 Because of interaction between the ammeter and voltmeter calibration potentiometers, the ammeter must be calibrated before the voltmeter.

5-79 Ammeter Calibration. To calibrate the ammeter, proceed as follows:

- Connect test setup shown in Figure 5-11. Turn VOLTAGE controls fully clockwise and set meter switch to AMPS.
- Turn on supply and adjust CURRENT controls until differential voltmeter reads 1.0 volts.
- Adjust potentiometer R86 until front panel meter indicates exactly maximum rated output current.

5-80 Voltmeter Calibration. To calibrate the voltmeter, proceed as follows:

- Connect test setup shown in Figure 5-2. Turn CURRENT controls fully clockwise and set meter switch to VOLTS.
- Turn on supply and adjust VOLTAGE controls until differential voltmeter reads exactly maximum rated output voltage.
- Adjust potentiometer R80 until front panel meter also reads exactly maximum rated output voltage.

5-81 CONSTANT VOLTAGE PROGRAMMING CURRENT

5-82 Zero Output Voltage. In order for the instrument to meet the tracking error specification, the slave supply's zero output voltage adjustment must be made with the instrument in the TRACKING mode. Because of this requirement, when operated in the INDEPENDENT mode and programmed for zero output with the front panel pot, the slave's output voltage may be a maximum of 60mV above zero. If the slave supply is adjusted in the INDEPENDENT mode to remove this positive voltage, the instrument will not meet the tracking specification. The master supply's zero output voltage adjustment may be made with the instrument operating in either the TRACKING or the INDEPENDENT mode, though adjustment in the TRACKING mode is somewhat more convenient due to the restriction that the slave be adjusted in the TRACKING mode. Note that since the master supply is the reference against which the slave supply tracks, the master supply's zero output voltage adjustment must be made before the slave supply is adjusted.

5-83 To calibrate the zero voltage programming accuracy, proceed as follows:

- Connect test setup shown in Figure 5-9, and set switch S1 to position "A".
- Set front panel mode switch to TRACKING, and connect jumper between minus output terminal of left supply and positive output terminal of right supply as shown on front panel and in Figure 5-9.
- If instrument is to be locally programmed, turn master VOLTAGE controls fully counterclockwise. If instrument is to be remote programmed, connect remote programming setup (Figures 3-3, 3-4, or 3-5) to master supply, and adjust remote resistance or voltage to zero (minimum). Rotate both sets of CURRENT controls fully clockwise and turn on supply.
- Adjust potentiometer R24 in master supply until differential voltmeter reads exactly zero.
- Move switch S1 to position "B".
- Adjust potentiometer R24 in slave supply until differential voltmeter reads exactly zero.

5-84 CV Programming Accuracy. The voltage programming accuracy is determined by the voltage programming current flowing through both the pull-out resistors (R15, R16) and the voltage controls (R27A, R27B); this current determines the programming coefficient. The following procedure adjusts the voltage programming current to obtain a coefficient of exactly 200 ohms per volt:

- Connect a 0.1%, 1/8 watt resistor of value shown below between terminals -S and A2 on rear barrier strip.

6227B 5K Ω
6228B 10K Ω

d. Observe reading on differential voltmeter. If it is more positive than 0 volts, shunt resistor R5 with decade resistance box.

e. Adjust decade resistance until differential voltmeter reads zero, then shunt R5 with resistance value equal to that of decade resistance box.

f. If reading of Step (d) is more negative than 0 volts, shunt resistor R7 with decade resistance box.

g. Adjust decade resistance until differential voltmeter reads zero, then shunt resistor R7 with resistance value equal to that of decade box.

5-88 CC Programming Accuracy. To calibrate the constant current programming current, proceed as follows:

a. Connect test setup shown in Figure 5-11.

b. Remove strap between terminals A6 and A7 on rear barrier strips.

c. Connect a 1K Ω , 0.1%, 1/8 watt resistor between terminals A4 and A6.

d. Connect decade resistance box in place of resistor R2.

e. Rotate VOLTAGE controls fully clockwise and turn on supply.

f. Adjust decade resistance until differential voltmeter reads 1.0V.

g. Replace decade resistance with appropriate value resistor in R2 position.

5-89 CROWBAR DISABLEMENT

5-90 To disable the overvoltage protection crowbars completely, disconnect the anodes of SCR's CR4(A) and CR4(B). The SCR's are mounted on the chassis (see Figure 7-2); their connecting wires are easily accessed by removing the bottom cover of the instrument.

b. Remove strap between terminals A2 and A3 on rear barrier strip.

c. Connect decade resistance box in place of resistor R16.

d. Connect differential voltmeter across rear output terminals of supply.

e. Turn CURRENT controls fully clockwise and turn on supply.

f. Adjust decade resistance box until differential voltmeter indicates exactly maximum rated output voltage.

g. Replace decade resistance box with resistor of appropriate value in R16 position.

5-85 CONSTANT CURRENT PROGRAMMING CURRENT

5-86 Zero Current Output. Since constant current operation is not possible when the instrument is operated in the TRACKING mode, the zero current output adjustment for both supplies must be made separately with the instrument operating in the INDEPENDENT mode. The adjustment procedure varies the bias voltage on the base of one side of the constant current comparator differential amplifier.

5-87 To calibrate the zero current programming accuracy, proceed as follows:

a. Connect test setup shown in Figure 5-11.

b. If supply is to be locally programmed, turn CURRENT controls fully counterclockwise. If supply is to be remote programmed, connect remote programming setup (Figure 3-6, 3-7, or 3-8) and adjust remote resistance or voltage to zero (minimum).

c. Rotate CURRENT controls fully clockwise and turn on supply.

SECTION VI REPLACEABLE PARTS

6-1 INTRODUCTION

6-2 This section contains information for ordering replacement parts. Table 6-4 lists parts in alpha-numeric order by reference designators and provides the following information:

- a. Reference Designators. Refer to Table 6-1.
- b. Description. Refer to Table 6-2 for abbreviations.
- c. Total Quantity (TQ). Given only the first time the part number is listed except in instruments containing many sub-modular assemblies, in which case the TQ appears the first time the part number is listed in each assembly.
- d. Manufacturer's Part Number or Type.
- e. Manufacturer's Federal Supply Code Number. Refer to Table 6-3 for manufacturer's name and address.
- f. Hewlett-Packard Part Number.
- g. Recommended Spare Parts Quantity (RS)
- h. For complete maintenance of one instrument during one year of isolated service.
- i. Parts not identified by a reference designator are listed at the end of Table 6-4 under Miscellaneous and/or Miscellaneous. The former consists of parts belonging to and grouped by individual assemblies; the latter consists of all parts not immediately associated with an assembly.

6-3 ORDERING INFORMATION

6-4 To order a replacement part, address order or inquiry to your local Hewlett-Packard sales office (see lists at rear of this manual for addresses). Specify the following information for each part: Model, complete serial number, and any Option or special modification (O) numbers of the instrument; Hewlett-Packard part number; circuit reference designator and description. To order a part not listed in Table 6-4, give a complete description of the part, its function, and its location.

A	= assembly	E	= miscellaneous electronic part
B	= blower (fan)	F	= fuse
CB	= circuit breaker	J	= jack, jumper
CR	= diode	K	= relay
DS	= device, signaling (lamp)	L	= inductor
		M	= meter

Table 6-1. Reference Designators

Table 6-1. Reference Designators (Continued)

V	= vacuum tube,	P	= plug
VR	= neon bulb, photocell, etc.	Q	= transistor
X	= zener diode	R	= resistor
	= socket	S	= switch
Z	= integrated circuit or network	I	= transformer
		TB	= terminal block
		TS	= thermal switch

Table 6-2. Description Abbreviations

mfr	= manufacturer	A	= ampere
mod.	= modular or modified	ac	= alternating current
mtg	= mounting	assy.	= assembly
n	= nano = 10 ⁻⁹	bd	= board
NC	= normally closed	bkt	= bracket
NO	= normally open	OC	= degree
NP	= nickel-plated	Centigrade	
r	= ohm	cd	= card
obd	= order by description	coef	= coefficient
OD	= outside diameter	comp	= composition
P	= pico = 10 ⁻¹²	CRT	= cathode-ray tube
P.C.	= printed circuit	CT	= center-tapped
pot.	= potentiometer	dc	= direct current
p-p	= peak-to-peak	DPDT	= double pole, double throw
ppm	= parts per million	DPST	= double pole, single throw
pvr	= peak reverse voltage	elect	= electrolytic
rect	= rectifier	encap	= encapsulated
rms	= root mean square	F	= farad
SI	= silicon	of	= degree
SPDT	= single pole, double throw	fxd	= fixed
SPST	= single pole, single throw	Ge	= germanium
SS	= small signal	H	= Henry
T	= slow-blow	Hz	= Hertz
Tan.	= titanium	IC	= integrated circuit
Ti	= titanium	incnd	= incandescent
V	= volt	ID	= inside diameter
var	= variable	incnd	= incandescent
vw	= wirewound	incnd	= incandescent
W	= Watt	incnd	= incandescent
		met.	= metal
		μ	= micro = 10 ⁻⁶
		M	= mega = 10 ⁶
		m	= milli = 10 ⁻³
		k	= kilo = 10 ³

Table 6-3. Code List of Manufacturers

CODE NO.	MANUFACTURER ADDRESS	CODE NO.	MANUFACTURER ADDRESS
00629	EBY Sales Co., Inc. Jamaica, N. Y.	07138	Westinghouse Electric Corp. Electronic Tube Div. Elmira, N. Y.
00656	Aerovox Corp. New Bedford, Mass.	07263	Patrichild Camera and Instrument Corp. Semiconductor Div. Mountain View, Calif.
00853	Sangamo Electric Co. S. Carolina Div. Pickens, S. C.	07263	Patrichild Camera and Instrument Corp. Semiconductor Div. Mountain View, Calif.
01121	Allen Bradley Co. Milwaukee, Wis.	07387	Bircher Corp., The Los Angeles, Calif.
01255	Litton Industries, Inc. Beverly Hills, Calif.	07397	Sylvania Electric Prod. Inc. Sylvania Electronic Systems Mountain View, Calif.
01281	TRW Semiconductors, Inc. Lawndale, Calif.	07716	IRC Div. of TRW Inc. Burlington Plant Burlington, Iowa
01295	Texas Instruments, Inc. Semiconductor-Components Div. Dallas, Texas	07910	Continental Device Corp. Hawthorne, Calif.
01686	RGL Electronics, Inc. Manchester, N. H.	07930	Raytheon Co. Components Div. Semiconductor Operation Mountain View, Calif.
01930	Amerock Corp. Rockford, Ill.	08484	Breeze Corporations, Inc. Union, N. J.
02107	Sparta Mfg. Co. Dover, Ohio	08530	Reliance Mica Corp. Brooklyn, N. Y.
02114	Ferroxube Corp. Saugerties, N. Y.	08717	Sloan Company, The Sun Valley, Calif.
02606	Fenwal Laboratories Morton Grove, Ill.	08730	Vemaline Products Co. Inc. Wyckoff, N. J.
02660	Amphenol Corp. Broadview, Ill.	08806	General Elect. Co. Minia- ture Lamp Dept. Cleveland, Ohio
02735	Radio Corp. of America, Solid State and Receiving Tube Div. Somerville, N. J.	08863	Nylomatic Corp. Northville, Pa.
03508	G. E. Semiconductor Products Dept. Syracuse, N. Y.	08919	RCH Supply Co. Vernon, Calif.
03797	Eldema Corp. Compton, Calif.	09021	Airco Speer Electronic Components Bradford, Pa.
03877	Transitron Electronic Corp. Wakefield, Mass.	09182	*Hewlett-Packard Co. New Jersey Div. Berkeley Heights, N. J.
03888	Pyrofilm Resistor Co. Inc. Cedar Knolls, N. J.	09213	General Elect. Co. Semiconductor Prod. Dept. Buffalo, N. Y.
04009	Arrow, Hart and Hegeman Electric Co. Hartford, Conn.	09214	General Elect. Co. Semiconductor Prod. Dept. Auburn, N. Y.
04072	ADC Electronics, Inc. Harbor City, Calif.	09353	C & K Components Inc. Newton, Mass.
04213	Caddell & Burns Mfg. Co. Inc. Mineola, N. Y.	09922	Burndy Corp. Norwalk, Conn.
04404	*Hewlett-Packard Co. Palo Alto Div. Palo Alto, Calif.	11115	Wagner Electric Corp. Tung-Sol Div. Bloomfield, N. J.
04713	Motorola Semiconductor Prod. Inc. Phoenix, Arizona	11236	CTS of Berne, Inc. Chicago Telephone of Cal. Inc. So. Pasadena, Calif.
04713	Motorola Semiconductor Prod. Inc. Phoenix, Arizona	11237	Chicago Telephone of Cal. Inc. So. Pasadena, Calif.
05277	Westinghouse Electric Corp. Semiconductor Dept. Youngwood, Pa.	11711	General Instrument Corp. Rectifier Div. Newark, N. J.
05347	Ultronix, Inc. Grand Junction, Colo.	11711	General Instrument Corp. Rectifier Div. Newark, N. J.
05820	Wakefield Engr. Inc. Wakefield, Mass.	11502	IRC Div. of TRW Inc. Boone Plant Boone, N. C.
05820	Wakefield Engr. Inc. Wakefield, Mass.	11502	IRC Div. of TRW Inc. Boone Plant Boone, N. C.
06001	General Elect. Co. Electronic Capacitor & Battery Dept. Irmo, S. C.	12136	Philadelphia Handle Co. Inc. Camden, N. J.
06004	Basisk Div. Stewart-Warner Corp. Bridgeport, Conn.	12136	Philadelphia Handle Co. Inc. Camden, N. J.
06486	IRC Div. of TRW Inc. Semiconductor Plant Lynn, Mass.	12615	U. S. Terminals, Inc. Cincinnati, Ohio
06540	Amatom Electronic Hardware Co. Inc. New Rochelle, N. Y.	12617	Hamlin Inc. Lake Mills, Wisconsin
06555	Beede Electrical Instrument Co. Penacook, N. H.	12697	Clarostat Mfg. Co. Inc. Dover, N. H.
06666	General Devices Co. Inc. Indianapolis, Ind.	13103	Thermalloy Cg. Dallas, Texas
06751	Semcor Div. Components, Inc. Phoenix, Arizona	14493	*Hewlett-Packard Co. Loveland Div. Loveland, Colo.
06776	Robinson Nugent, Inc. New Albany, Ind.	14655	Cornell-Dubilier Electronics Div. Federal Pacific Electric Co. Newark, N. J.
06812	Torrington Mfg. Co., West Div. Van Nuys, Calif.	14936	General Instrument Corp. Semicon- ductor Prod. Group Hicksville, N. Y.
07137	Transistor Electronics Corp. Minneapolis, Minn.	15801	Fenwal Elect. Framingham, Mass.

*Use Code 28480 assigned to Hewlett-Packard Co., Palo Alto, California

Table 6-3. Code List of Manufacturers (Continued)

CODE NO.	MANUFACTURER	ADDRESS
70563	Amperite Co. Inc.	Union City, N.J.
70901	Beemer Engrg. Co.	Fort Washington, Pa.
70903	Belden Corp.	Chicago, Ill.
71218	Bud Radio, Inc.	Willoughby, Ohio
71279	Cambridge Thermionic Corp.	Cambridge, Mass.
71400	Bussmann Mfg. Div. of McGraw & Edison Co.	St. Louis, Mo.
71450	GTS Corp.	Eikhart, Ind.
71468	I. T. I. Cannon Electric Inc.	Los Angeles, Calif.
71590	Globe-Union Inc.	Milwaukee, Wis.
71700	General Cable Corp. Cornish Centralab Div.	Milwaukee, Wis.
71707	Wire Co. Div. Williamstown, Mass.	Williamstown, Mass.
71744	Coto Coil Co. Inc.	Providence, R.I.
71785	Cinch Mfg. Co. and Howard	Chicago, Ill.
71984	Dow Corning Corp.	Midland, Mich.
72136	Electro Motive Mfg. Co. Inc.	Chicago, Ill.
72619	Dialight Corp.	Brooklyn, N.Y.
72699	General Instrument Corp.	Newark, N.J.
72765	Drake Mfg. Co.	Harwood Heights, Ill.
72962	Elastic Stop Nut Div. of Amerace Esna Corp.	Union, N.J.
72982	Erie Technological Products Inc.	Erie, Pa.
73096	Hart Mfg. Co.	Hartford, Conn.
73138	Beckman Instruments Inc.	Fullerton, Calif.
73168	Helipot Div. Fenwal, Inc.	Ashland, Mass.
73293	Hughes Aircraft Co. Electron Dynamics Div.	Torrance, Calif.
73445	Amperex Electronic Corp.	Hicksville, N.Y.
73506	Bradley Semiconductor Corp.	New Haven, Conn.
73559	Carling Electric, Inc.	Hartford, Conn.
73734	Federal Screw Products, Inc.	Chicago, Ill.
74193	Heinemann Electric Co.	Trenton, N.J.
74545	Hubbell Harvey Inc.	Bridgport, Conn.
74688	Amphenol Corp. Amphenol RF Div.	Danbury, Conn.
74970	E. F. Johnson Co.	Waseca, Minn.
75042	IRC Div. of TRW, Inc.	Philadelphia, Pa.
75183	*Howard B. Jones Div. of Cinch Mfg. Corp.	New York, N.Y.
75376	Kurz and Kasch, Inc.	Dayton, Ohio
75382	Kilka Electric Corp.	Mt. Vernon, N.Y.
75915	Littelfuse, Inc.	Des Plaines, Ill.
76381	Minnesota Mining and Mfg. Co.	St. Paul, Minn.
76385	Minor Rubber Co. Inc.	Bloomfield, N.J.
76487	James Millen Mfg. Co. Inc.	Malden, Mass.
76493	J. W. Miller Co.	Compton, Calif.

CODE NO.	MANUFACTURER	ADDRESS
16758	Delco Radio Div. of General Motors Corp.	Kokomo, Ind.
17545	Atlantic Semiconductors, Inc.	Asbury Park, N.J.
17803	Fairchild Camera and Instrument Corp	Mountain View, Calif.
17870	Daven Div. Thomas A. Edison Industries	Orange, N.J.
18324	Signetics Corp.	Sunnyvale, Calif.
19315	Bendix Corp. The Navigation and Control Div.	Teterboro, N.J.
19701	Electra/Midland Corp.	Mineral Wells, Texas
21520	Fansteel Metallurgical Corp.	No. Chicago, Ill.
22229	Union Carbide Corp. Electronics Div.	Mountain View, Calif.
22753	UID Electronics Corp.	Hollywood, Fla.
23936	Pamotor, Inc.	Pampa, Texas
24446	General Electric Co. Schenectady, N.Y.	Schenectady, N.Y.
24455	General Electric Co. Lamp Div. of Con-sumer Prod. Group	Cleveland, Ohio
24655	General Radio Co. West Concord, Mass.	West Concord, Mass.
24681	LTV ElectroSystems Inc Memcor/Com-ponents Operations	Huntington, Ind.
26982	Dynacool Mfg. Co. Inc. Saugerties, N.Y.	Saugerties, N.Y.
27014	National Semiconductor Corp.	Santa Clara, Calif.
28480	Hewlett-Packard Co.	Palo Alto, Calif.
28520	Heyman Mfg. Co.	Kenilworth, N.J.
28875	IMC Magnetics Corp.	Rochester, N.H.
31514	SAE Advance Packaging, Inc.	Santa Ana, Calif.
31827	Budwig Mfg. Co.	Ramona, Calif.
33173	G. E. Co. Tube Dept.	Owensboro, Ky.
35434	Lectrom, Inc.	Chicago, Ill.
37942	P. R. Mallory & Co. Inc.	Indianapolis, Ind.
42190	Muter Co.	Chicago, Ill.
43334	New Departure-Hyatt Bearings Div.	Sandusky, Ohio
44655	General Motors Corp.	Sandusky, Ohio
44655	Omrite Manufacturing Co.	Skokie, Ill.
46384	Penn Engr. and Mfg. Corp.	Doylestown, Pa.
47904	Polaroid Corp.	Cambridge, Mass.
49956	Raytheon Co.	Lexington, Mass.
55026	Simpson Electric Co. Div. of American Gage and Machine Co.	Chicago, Ill.
56289	Sprague Electric Co.	North Adams, Mass.
58474	Superior Electric Co.	Bristol, Conn.
58849	Syntron Div. of FMC Corp.	Homer City, Pa.
59730	Thomas and Betts Co.	Philadelphia, Pa.
61637	Union Carbide Corp.	New York, N.Y.
63743	Ward Leonard Electric Co.	Mt. Vernon, N.Y.

*Use Code 71785 assigned to Cinch Mfg. Co., Chicago, Ill.

CODE NO.	MANUFACTURER	ADDRESS
76530	Cinch	City of Industry, Calif.
76854	Oak Mfg. Co. Div. of Oak	Crystal Lake, Ill.
77068	Bendix Corp., Electrodynamics Div.	No. Hollywood, Calif.
77122	Palmat Co.	Mountainside, N.J.
77147	Patton-MacGuver Co.	Providence, R.I.
77221	Phaoston Instrument and Electronic Co.	South Pasadena, Calif.
77252	Philadelphia Steel and Wire Corp.	Philadelphia, Pa.
77342	American Machine and Foundry Co.	Philadelphia, Pa.
77342	Potter and Brumfield Div.	Princeton, Ind.
77630	TRW Electronic Components Div.	Camden, N.J.
77764	Resistance Products Co.	Harrisburg, Pa.
78189	Illinois Tool Works Inc. Shakeproof Div.	Elgin, Ill.
78452	Everlock Chicago, Inc.	Chicago, Ill.
78488	Stackpole Carbon Co.	St. Marys, Pa.
78526	Stanwyck Winding Div. San Fernando	San Fernando
78553	Tinnerman Products, Inc.	Cleveland, Ohio
78584	Stewart Stamping Corp.	Yonkers, N.Y.
79136	Waldes Kohinor, Inc.	L.I.C., N.Y.
79307	Whitehead Metals Inc.	New York, N.Y.
79727	Continental-Wirt Electronics Corp.	Philadelphia, Pa.
79963	Zierick Mfg. Co.	Mt. Kisco, N.Y.
80031	Mepco Div. of Sessions Clock Co.	Morristown, N.J.
80294	Bourns, Inc.	Riverside, Calif.
81042	Howard Industries Div. of Msl Ind. Inc.	Racine, Wisc.
81073	Grayhill, Inc.	La Grange, Ill.
81483	International Rectifier Corp.	El Segundo, Calif.
81751	Columbus Electronics Corp.	Yonkers, N.Y.
82099	Goodyear Sundries & Mechanical Co. Inc.	New York, N.Y.
82142	Airco Speer Electronic Components	Du Bois, Pa.
82219	Sylvania Electric Products Inc.	Electronic Tube Div. Receiving Tube Operations Emporium, Pa.
82389	Switchcraft, Inc.	Chicago, Ill.
82647	Metals and Controls Inc. Control	Attleboro, Mass.
82866	Research Products Corp.	Madison, Wis.
82877	Rotron Inc.	Woodstock, N.Y.
83058	Carr Fastener Co.	Cambridge, Mass.
83186	Victory Engineering Corp.	Springfield, N.J.
83298	Bendix Corp. Electric Power Div.	Fatontown, N.J.
83330	Herman H. Smith, Inc.	Brooklyn, N.Y.
83385	Central Screw Co.	Chicago, Ill.
83501	Gavitt Wire and Cable Div. of	Amerace Esna Corp. Brookfield, Mass.
83508	Grant Pulley and Hardware Co.	West Nyack, N.Y.
83594	Burroughs Corp. Electronic	Plainfield, N.J.
83835	U.S. Radium Corp.	Morristown, N.J.
83877	Yardeny Laboratories, Inc.	New York, N.Y.
84171	Arco Electronics, Inc.	Great Neck, N.Y.
84411	TRW Capacitor Div.	Ogallala, Neb.
86684	RCA Corp. Electronic Components	Harrison, N.J.
86838	Rummel Fibre Co.	Newark, N.J.
87034	Marco & Oak Industries a Div. of Oak	Anaheim, Calif.
87216	Phico Corp. Lansdale Div.	Lansdale, Pa.
87585	Stockwell Rubber Co. Inc.	Philadelphia, Pa.
87929	Tower-Olschan Corp.	Bridgeport, Conn.
88140	Cutler-Hammer Inc. Power Distribution	and Control Div. Lincoln Plant Lincoln, Ill.
88245	Liton Precision Products Inc. USECO	Div. Liton Industries Van Nuys, Calif.
90634	Gulton Industries Inc.	Metuchen, N.J.
90763	United-Car Inc.	Chicago, Ill.
91345	Miller Dial and Nameplate Co.	El Monte, Calif.
91418	Radio Materials Co.	Chicago, Ill.
91506	Augat, Inc.	Attleboro, Mass.
91637	Date Electronics, Inc.	Columbus, Neb.
91662	Eico Corp.	Willow Grove, Pa.
91929	Honeywell Inc. Div. Micro Switch	Freeport, Ill.
92825	Whitso, Inc.	Schiller Pk., Ill.
93332	Sylvania Electric Prod. Inc. Semi-	conductor Prod. Div. Woburn, Mass.
93410	Essex Wire Corp. Stemco	Controls Div. Mansfield, Ohio
94144	Raytheon Co. Components Div.	Ind. Components Oper. Quincy, Mass.
94154	Wagner Electric Corp.	Tung-Sol Div. Livingston, N.J.
94222	Southco Inc.	Lester, Pa.
95263	Leecraft Mfg. Co. Inc.	L.I.C., N.Y.
95354	Method Mfg. Co. Rolling Meadows, Ill.	Bendix Corp. Microwave Devices Div. Franklin, Ind.
95987	Wackesser Co. Inc.	Chicago, Ill.
96791	Amphenol Corp. Amphenol	Controls Div. Janesville, Wis.
97464	Industrial Retaining Ring Co.	Irvington, N.J.
97702	IMC Magnetics Corp. Eastern Div.	Westbury, N.Y.
98291	Sealectro Corp.	Mamaroneck, N.Y.
98410	ETC Inc.	Cleveland, Ohio
98978	International Electronic Research Corp.	Burbank, Calif.
99934	Renbrandt, Inc.	Boston, Mass.

Table 6-3. Code List of Manufacturers (Continued)

Table 6-4. Replaceable Parts

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
A1	Printed Circuit Board, Mother	1	28480	062228-60020	062228-60020	1
C9A, 9B	fxd, elect 325µF 35Vdc	2	28480	0180-0332	0180-0332	1
C10A, 10B	fxd, elect 80µF 65Vdc	2	72D1005	56289	0180-2258	1
C11A-14A, 11B-14B	fxd, ceramic .05µF 500V	8	33C17A	56289	0150-0052	2
CR15A-18A, 15B-18B	Rect. SI. 3A 200prv	8	MR1032B	04713	1901-0416	6
CR19A, 19B, 20A, 20B, 21A, 21B, 22A, 22B	Rect. SI. 200mA 180V	8	1N5059	03508	1901-0327	6
J1, J2	Connector, PC Board edge	2	252-22-30-340	71785	1251-1887	2
R75A, 75B	fxd, ww 250Ω ±5% 5W	2	Type 5XM	63743	0811-1856	1
R76A, 76B	fxd, ww 2kΩ ±5% 5W	2	Type 5XM	63743	0812-0100	1
R91, 92	fxd, ww 4.5kΩ ±1% ±10ppm 2½W	2	Type T2C	01686	0811-1993	1
T1	Transformer, Power	1	28480	062228-80091	062228-80091	1
A2	Printed Circuit Board, Master	1	28480	062228-60021	062228-60021	1
C1	fxd, elect 750µF 75Vdc	1	28480	0180-1891	0180-1891	1
C2	fxd, elect 5µF 65Vdc	2	28480	0180-1836	0180-1836	1
C3	fxd, mylar .01µF 200V	1	192P10392	56289	0160-0161	1
C4	fxd, mylar .001µF 200Vdc	1	192P22292	56289	0160-0153	1
C5	fxd, mylar .1µF 200Vdc	1	192P10492	56289	0160-0168	1
C6, 7	fxd, elect 1600µF 85Vdc	2	28480	0180-1986	0180-1986	1
C11	fxd, elect 4.7µF 35Vdc	1	150D475X9035B2	56289	0180-0100	1
C13	fxd, elect 5µF 65Vdc	1	5C11B75	56289	0180-1836	1
C15	fxd, mylar .47µF 25V	1	5C11B75	56289	0160-0174	1
CR1	Diode, SI. 250mW 200V	5	28480	1901-0033	1901-0033	5
CR2	Rect. SI. 3A 200prv	3	MR1032B	04713	1901-0416	3
CR3	Diode, SI. 250mA 75V	1	28480	1901-0050	1901-0050	1
CR4	Diode, SI. 400mW 15V	3	28480	1901-0461	1901-0461	3
CR5-7	Diode, SI. 250mW 200V	3	28480	1901-0033	1901-0033	3
CR8, 9	Diode, SI. 400mW 15V	2	28480	1901-0461	1901-0461	2
CR10	Diode, SI. 250mW 200V	1	28480	1901-0033	1901-0033	1
CR11	Diode, SI. 400mW 10V	1	28480	1901-0460	1901-0460	1
CR12	Rect. SI. 1A 200prv	1	1N5059	03508	1901-0327	1
CR13, 14	Rect. SI. 3A 200prv	1	MR1032B	04713	1901-0416	1
F2	Fuse Cartridge, 2A 250V 3AG Normal Blow Pigtail	1	28480	2110-0262	2110-0262	5
Q1, 2, 7-11	NOT ASSIGNED	-	-	-	-	-
Q3	SS PNP SI.	3	28480	1853-0099	1853-0099	3
Q4	SS NPN SI.	5	28480	1854-0071	1854-0071	5
Q5	SS PNP SI.	5	28480	1853-0099	1853-0099	5
Q6, 12-14	SS NPN SI.	5	28480	1854-0071	1854-0071	5
Q15	SS PNP SI.	1	28480	1853-0099	1853-0099	1
R1	fxd, ww 7.5kΩ ±5% 3W	1	Type 24ZE	56289	0811-1815	1
R2	fxd, comp (Selected) ±5% ½W	2	Type EB (obd)	01121	0757-0280	1
R3	fxd, met. film 1kΩ ±1% 1/8W	2	Type CEA T-0	07716	0757-0280	1

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
R5	fxd, comp 220k \pm 5% $\frac{1}{2}$ W	1	EB-2245	01121	0686-2245	1
R6	fxd, met, film 1.5k \pm 1% 1/8W	2	Type CEA T-0	07716	0757-0427	1
R7	fxd, comp 750k \pm 5% $\frac{1}{2}$ W	1	EB-7545	01121	0686-7545	1
R8	fxd, comp 75 \pm 5% $\frac{1}{2}$ W	2	EB-7505	01121	0686-7505	1
R9, 11, 14,						
17, 23,						
27-29, 39,						
43, 47, 49,						
53-67, 78,						
79, 82, 83						
R10	fxd, w 1 \pm 0.5% 8W	1	Type T-7A	01686	0811-2133	1
R12	fxd, comp 3.3 \pm 5% $\frac{1}{2}$ W	1	EB-0335	01121	0686-0335	1
R13	fxd, met, film 200k \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0472	1
R15	fxd, w 1.3k \pm 5% 3W	1	Type 242E	56289	0811-1803	1
R16	fxd, comp (Selected) \pm 5% $\frac{1}{2}$ W	3	Type EB (obd)	01121	0686-1015	1
R18, 19	fxd, comp 100 \pm 5% $\frac{1}{2}$ W	3	EB-1015	01121	0686-1015	1
R20	fxd, w 1k \pm 5% 3W	1	Type 242I	56289	0813-0001	1
R21	fxd, comp 200 \pm 5% $\frac{1}{2}$ W	2	EB-2015	01121	0686-2015	1
R22	fxd, comp 24 \pm 5% $\frac{1}{2}$ W	1	EB-2405	01121	0686-2405	1
R24	var. comp 25k \pm 30%	1		28480	2100-1534	1
R25	fxd, met, film 1.5k \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0427	1
R26	fxd, met, film 249k \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0270	1
R30	fxd, met, film 61.9k \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0460	1
R31	fxd, met, film 2k \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0283	1
R32	fxd, met, film 3.4k \pm 1% 1/8W	2	Type CEA T-0	07716	0698-4440	1
R33	fxd, comp 390 \pm 5% $\frac{1}{2}$ W	2	EB-3915	01121	0686-3915	1
R34	fxd, comp 10k \pm 5% $\frac{1}{2}$ W	2	EB-1035	01121	0686-1035	1
R35	fxd, met, film 6.2k \pm 1% 1/8W	1	Type CEA T-0	07716	0698-5087	1
R36	fxd, comp 2k \pm 5% $\frac{1}{2}$ W	1	EB-2025	01121	0686-2025	1
R37	fxd, comp 470 \pm 5% $\frac{1}{2}$ W	1	EB-4715	01121	0686-4715	1
R38	fxd, comp 150 \pm 5% $\frac{1}{2}$ W	1	EB-1515	01121	0686-1515	1
R40	fxd, met, film 470 \pm 1% $\frac{1}{2}$ W	1	Type CEB T-0	07716	0698-3506	1
R41, 42	fxd, met, film 7.5k \pm 1% 1/8W	2	Type CEA T-0	07716	0757-0440	1
R44	fxd, met, film 600 \pm 1% 1/8W	1	Type CEA T-0	07716	0757-1100	1
R45	fxd, comp 10k \pm 5% $\frac{1}{2}$ W	1	EB-1035	01121	0686-1035	1
R46	fxd, comp 470 \pm 5% $\frac{1}{2}$ W	1	EB-4715	01121	0686-4715	1
R48	fxd, met, film 2k \pm 1% $\frac{1}{2}$ W	1	Type CEB T-0	07716	0757-0739	1
R50	fxd, met, film 5.49k \pm 1% 1/8W	1	Type CEA T-0	07716	0698-3382	1
R51	fxd, comp 820 \pm 5% $\frac{1}{2}$ W	1	EB-8215	01121	0686-8215	1
R52	fxd, met, film 3.4k \pm 1% 1/8W	4	Type CEA T-0	07716	0698-4440	1
R68, 69	fxd, w 1 \pm 5% 3W 20ppm	4		28480	0811-1732	1
R70	fxd, comp 10 \pm 5% $\frac{1}{2}$ W	1	EB-1005	01121	0686-1005	1
R71	fxd, comp 91 \pm 5% $\frac{1}{2}$ W	1	EB-9105	01121	0686-9105	1
R72	fxd, comp 200 \pm 5% $\frac{1}{2}$ W	1	EB-2015	01121	0686-2015	1
R73, 74	fxd, w 1 \pm 5% 3W 20ppm	1		28480	0811-1732	1
R77	fxd, w 2k \pm 5% 5W	1	Type 5XM	63743	0812-0100	1
R80	var. w 3k \pm 20%	1		28480	1902-0797	2
R81	(Voltmeter Adjust)	1	Type 110-F4	11236	2100-1824	1
R85	fxd, met, film 57.6k \pm 1% $\frac{1}{2}$ W	1	Type CEB T-0	07716	0757-0114	1
R86	var. w 250 \pm 20%	1	Type CEA T-0	07716	0757-0316	1
R87	fxd, met, film 1k \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0280	1
R88	fxd, met, film 196 \pm 1% 1/8W	1	Type CEA T-0	07716	0698-3440	1
VR1, 2	Diode, zener 6.2V 250mW	2		28480	1902-1221	2
VR3, 4	Diode, zener 4.32V 1W	2		28480	1902-0797	2

RF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
VR5	Diode, zener 4.22V 400mW	1	CA3026	28480	1902-3070	1
Z1	Dual Independent Diff. Amp	1		02735	1820-0240	1
Z2	Resistor Network	1		28480	1810-0042	1
A3	Printed Circuit Board, Slave	1		28480	06228-60022	1
C1	fxd, elect 750µF 75Vdc	1		28480	0180-1891	1
C2	fxd, elect 5µF 65Vdc	1		28480	0180-1836	1
C3	fxd, mylar .01µF 200V	1	192P10392	56289	0160-0161	1
C4	fxd, mylar .001µF 200Vdc	1	192P22292	56289	0160-0153	1
C5	fxd, mylar .1µF 200Vdc	1	192P10492	56289	0160-0168	1
C6, 7	fxd, elect 1600µF 85Vdc	2		28480	0180-1986	1
C11	fxd, elect 4.7µF 35Vdc	1	150D475X9035B2	56289	0180-0100	1
C13	fxd, elect 5µF 65Vdc	1		28480	0180-1836	1
C15	fxd, mylar .47µF 25V	1	5C11B75	56289	0160-0174	1
CR1	Diode, SI, 250mW 200V	5		28480	1901-0033	5
CR2	Rect. SI, 3A 200prv	3	MR1032B	04713	1901-0416	3
CR3	Diode, SI, 250mA 75V	1		28480	1901-0050	1
CR4	Diode, SI, 400mW 15V	3		28480	1901-0461	3
CR5-7	Diode, SI, 250mW 200V			28480	1901-0033	
CR8, 9	Diode, SI, 400mW 15V			28480	1901-0461	
CR10	Diode, SI, 250mW 200V			28480	1901-0033	
CR11	Diode, SI, 400mW 10V	1		28480	1901-0460	1
CR12	Rect. SI, 1A 200prv	1	IN5059	03508	1901-0327	1
CR13, 14	Rect. SI, 3A 200prv		MR1032B	04713	1901-0416	
F2	Fuse Cartridge, 2A 250V Normal Blow Pigtail 3AG	1		28480	2110-0262	5
Q1, 2, 7-11	NOT ASSIGNED	-		-	-	-
Q3	SS PNP SI.	3		28480	1853-0099	3
Q4	SS NPN SI.	5		28480	1854-0071	5
Q5	SS PNP SI.			28480	1853-0099	
Q6, 12-14	SS PNP SI.			28480	1854-0071	
Q15	SS PNP SI.			28480	1853-0099	
R1	fxd, ww 7.5kΩ ±5% 3W	1	Type 242E	56289	0811-1815	1
R2	fxd, comp (Selected) ±5% ½W	2	Type EB (obd)	01121	0757-0280	1
R3	fxd, met. film 1kΩ ±1% 1/8W	2	Type CEA T-0	07716	0686-2245	1
R5	fxd, comp 220kΩ ±5% ½W	1	EB-2245	01121	0686-2245	1
R6	fxd, met. film 1.5kΩ ±1% 1/8W	2	Type CEA T-0	07716	0757-0427	1
R7	fxd, comp 750kΩ ±5% ½W	1	EB-7545	01121	0686-7545	1
R8	fxd, comp 75Ω ±5% ½W	1	EB-7505	01121	0686-7505	1
R9, 11, 14,						
R10	fxd, ww 1kΩ ±0.5% 8W	1	Type T-7A	01686	0811-2133	1
R12	fxd, comp 3.3kΩ ±5% ½W	1	EB-0335	01121	0686-0335	1
R13	fxd, met. film 200kΩ ±1% 1/8W	1	Type CEA T-0	07716	0757-0472	1
R15	fxd, ww 1.3kΩ ±5% 3W	1	Type 242E	56289	0811-1803	1
R16	fxd, comp (Selected) ±5% ½W		Type EB (obd)	01121		
R18, 19	fxd, comp 100Ω ±5% ½W	3	EB-1015	01121	0686-1015	1
R20	fxd, ww 1kΩ ±5% 3W	1	Type 242E	56289	0813-0001	1

REF. DESIG.	DESCRIPTION	TO	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
R21	fxd, comp 200 Ω \pm 5% $\frac{1}{2}$ W	2	EB-2015	01121	0686-2015	1
R22	fxd, comp 24 Ω \pm 5% $\frac{1}{2}$ W	1	EB-2405	01121	0686-2405	1
R24	var, comp 25k Ω \pm 30% (Zero Volt Adj.)	1		28480	2100-1534	1
R25	fxd, met, film 1.5k Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0427	1
R26	fxd, met, film 249k Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0270	1
R30	fxd, met, film 61.9k Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0460	1
R31	fxd, met, film 2k Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0283	1
R32	fxd, met, film 3.4k Ω \pm 1% 1/8W	2	Type CEA T-0	07716	0698-4440	1
R33	fxd, comp 390 Ω \pm 5% $\frac{1}{2}$ W	1	EB-3915	01121	0686-3915	1
R34	fxd, comp 10k Ω \pm 5% $\frac{1}{2}$ W	2	EB-1035	01121	0686-1035	1
R45	fxd, comp 10k Ω \pm 5% $\frac{1}{2}$ W	1	EB-1035	01121	0686-1035	1
R46	fxd, comp 470 Ω \pm 5% $\frac{1}{2}$ W	1	EB-4715	01121	0686-4715	1
R48	fxd, met, film 2k Ω \pm 1% $\frac{1}{2}$ W	1	Type CEB T-0	07716	0757-0739	1
R50	fxd, met, film 5.49k Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0698-3382	1
R51	fxd, comp 820 Ω \pm 5% $\frac{1}{2}$ W	1	EB-8215	01121	0686-8215	1
R52	fxd, met, film 3.4k Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0698-4440	1
R68, 69	fxd, w 1 Ω \pm 5% 3W \pm 20ppm	4		28480	0811-1732	1
R70	fxd, comp 10 Ω \pm 5% $\frac{1}{2}$ W	1	EB-1005	01121	0686-1005	1
R71	fxd, comp 91 Ω \pm 5% $\frac{1}{2}$ W	1	EB-9105	01121	0686-9105	1
R72	fxd, comp 200 Ω \pm 5% $\frac{1}{2}$ W	1	EB-2015	01121	0686-2015	1
R73, 74	fxd, w 1 Ω \pm 5% 3W \pm 20ppm	1		28480	0811-1732	1
R77	fxd, w 2k Ω \pm 5% 5W	1	Type 5XM	63743	0812-0100	1
R80	var, w 5k Ω \pm 20% (Voltmeter Adj.)	1	Type 110-F4	11236	2100-1824	1
R81	fxd, met, film 57.6k Ω \pm 1% $\frac{1}{2}$ W	1	Type CEB T-0	07716	0757-0114	1
R85	fxd, met, film 42.2 Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0316	1
R86	var, w 250 Ω \pm 20%	1		11236	2100-0439	1
R87	fxd, met, film 1k Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0757-0280	1
R88	fxd, met, film 196 Ω \pm 1% 1/8W	1	Type CEA T-0	07716	0698-3440	1
VR1, 2	Diode, zener 6.2V 250mW	2		28480	1902-1221	2
VR3, 4	Diode, zener 4.32V	2		28480	1902-0797	2
VR5	Diode, zener 4.22V 400mW	1		28480	1902-3070	1
Z1	Dual Independent Diff. Amp.	1	CA3026	02735	1820-0240	1
Z2	Resistor Network	1		28480	1810-0042	1
A4	V4 CROWBAR BOARD - ELECTRICAL	1		28480	06228-60023	1
C1A, 1B	Printed Circuit Board, Crowbar	1	192P2249R8	56289	0160-2453	1
C1A-3A, 1B-3B	Diode, Si, 200mA 200prv	6		28480	1901-0033	6
Q1A, 1B	SS NPN SI.	2		28480	1854-0027	2
Q2A, 2B	SS NPN SI.	2	2N3417	03508	1854-0087	2
R1A, 1B	fxd, comp 430 Ω \pm 5% $\frac{1}{2}$ W	2	EB-4315	01121	0686-4315	1
R2A, 2B	fxd, comp 200k Ω \pm 5% $\frac{1}{2}$ W	2	EB-2045	01121	0686-2045	1
R3A, 3B	fxd, comp 10k Ω \pm 5% $\frac{1}{2}$ W	2	EB-1035	01121	0686-1035	1
R4A, 4B	fxd, comp 3.9k Ω \pm 5% $\frac{1}{2}$ W	2	EB-3925	01121	0686-3925	1
R5A, 5B	fxd, w 390 Ω \pm 5% 3W	2	Type 242E	56289	0811-1799	1

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
R6A, 6B R7A, 7B R8A, 8B R9A, 9B R10A, 10B	fxd, comp 4.7 μ \pm 5% $\frac{1}{2}$ W fxd, comp 10 μ \pm 5% $\frac{1}{2}$ W fxd, met. oxide 180 μ \pm 5% 2W fxd, met. film 471 μ \pm 1% 1/8W var. comp 5k Ω \pm 20% $\frac{1}{2}$ W (Crowbar Adjust) fxd, comp 10 μ \pm 5% $\frac{1}{2}$ W	2 2 2 2 2 2	EB-47G5 EB-1005 Type G42S Type CEA T-0	01121 01121 16299 07716 28480 01121 01121	0698-0001 0686-1005 0698-3626 0698-5514 2100-0011 0686-1005 9100-2160	1 1 1 1 1 1 1
T1A, 1B R11A, 11B	Transformer, Pulse fxd, comp 10 μ \pm 5% $\frac{1}{2}$ W	2 2	EB-1005	28480 01121	2100-0011 0686-1005	1 1
VR1A, 1B VR2A, 2B	Diode, zener 6.19V 400mW Diode, zener 12.4V 400mW	2 2		28480 28480	1902-0049 1902-3185	2 2
D51 E1A, 1B E2A, 2B E3A, 3B M1A, 1B	Front Panel Assembly (Loaded, excluding M1) Indicator Lamp, Neon (Line On) 5 Way Binding Post, Maroon 5 Way Binding Post, Green 5 Way Binding Post, Black Meter, 0-60V and 0-1.2A	1 1 2 2 2 2	AIC DF21MRN DF21GNC DF21BLK	28480 58474 58474 58474 28480	06228-60001 2140-0047 1510-0040 1510-0066 1510-0039 1120-1242	1 1 1 1 1 1
R4A(A), 4B(A); R4A(B), 4B(B) R27A(A), R27A(B); R27B(A), R27B(B) R89 R90	var. ww 1.1k Ω -10 Dual Concentric, (Current, Fine and Coarse) var. ww 10k Ω -100 Dual Concentric, (Voltage, Fine and Coarse) fxd, comp 100 μ \pm 5% $\frac{1}{2}$ W fxd, comp 47k Ω \pm 5% $\frac{1}{2}$ W	2 2 1 1 1 1	EB-1015 EB-4735	28480 01121 01121 0686-1015 0686-4735	2100-2526 0686-1015 0686-4735 3101-1296 3101-1293 3101-1288	1 1 1 1 1 1
S1 S2 S3A, 3B	Switch, Toggle, SPST 15A (Line On) Switch, Slide, 4PDT 3A (Mode Tracking/Independent) Switch, Slide, 3PDT 3A (Meter: Volts/Amperes)	1 1 2		28480 28480 28480		1 1 1
E4 F1 (115V) F1 (230V) P1 Q8A-9A, 8B-9B Q10A-11A Q10B-11B S5	REAR PANEL - ELECTRICAL 5 Way Binding Post (GND) Fuse Cartridge, 4A 250V 3AG Fuse Cartridge, 2A 250V 3AG Power Cord, AC Line Power NPN SI. Power NPN SI. Switch, Slide, DPDT (115/230V Line Selector)	1 1 1 1 4 4 1	312.004 312.002 KH-4096	28480 75915 75915 70903 28480 28480 28480	1510-0044 2110-0055 2110-0002 8120-0050 1854-0225 1854-0239 3101-1234	1 5 5 1 4 4 1
CR4A, 4B Q7A, 7B	CHASSIS - ELECTRICAL SCR, 12.5A 600prv Power PNP SI.	2 2	2N3669	02735 28480	1884-0019 1850-0277	2 2

REF. DESIG.	DESCRIPTION	QTY	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
	P.C. BOARDS - MECHANICAL	2	28480	28480	2950-0334	
	Hex Nut Bushing	2	28480	28480	1410-0052	
	Bushing	2	28480	28480	0360-1573	
	Jumper	14	28480	28480	0360-1143	
	FRONT PANEL - MECHANICAL	1	28480	28480	5020-5770	
	Meter Trim, Top	1	28480	28480	4040-0483	
	Bezel, Meter, 3 1/2"	2	28480	28480	1480-0181	
	Meter Combining Pin	1	28480	28480	5020-5773	
	Front Panel, Basic	1	28480	28480	5000-6265	
	Front Panel, Control Section Insert	1	28480	28480	5000-6266	
	Front Panel, Output Section Insert	1	28480	28480	7120-1254	
	Knob	4	28480	28480	0370-0179	
	Knob	4	28480	28480	0370-0101	
	Knurled Nut (R4A, R4B, R27A, R27B)	4	76320NP	73734	0590-0856	
	Lampholder, Clear, DSI	1	28480	28480	5040-0234	
	Lampholder, Base, DSI	1	28480	28480	5040-0305	
	Stand, Tilt, Foot Assembly	1	28480	28480	1490-0032	
	Hinge, Foot Assembly	2	28480	28480	5040-0700	
	Foot Assembly	1	28480	28480	5060-0728	
	REAR PANEL - MECHANICAL	1	28480	28480	5020-5774	
	Heat Sink, Rear Panel, Q8-11(A & B)	1	28480	28480	5000-6264	
	Rear Panel - Lower	1	28480	28480	5000-6263	
	Rear Panel - Upper	1	28480	28480	5000-6275	
	Cover, Rear Barrier Strips	2	28480	28480	2190-0491	
	Shoulder Washer (CR4A, 4B; Q7A, 7B)	8	28480	28480	0340-0171	
	Bushing, Insulator (Q7A, 7B)	2	28480	28480	0340-0180	
	Insulator, Mica (Q7A, 7B)	2	28480	28480	0340-0174	
	Insulator, Mica (CR4A, 4B; Q8-11A, Q8-11B)	10	28480	28480	7120-1111	
	Serial Plate	1	28480	28480	0340-0166	
	Bushing, Insulator, Emitter-Base, Q8-11(A & B), CR4A, CR4B	20	28480	28480	0340-0168	
	Screws, Q8-11(A & B)	16	28480	28480	0340-0168	
	Fuseholder, FI	1	75915	75915	1400-0084	
	Hex Nut, Fuseholder	1	28480	28480	2950-0038	
	Lockwasher, Fuseholder	1	28480	28480	2190-0037	
	Flat Neoprene Washer, Fuseholder	1	28480	28480	1400-0090	
	Spacer	4	28480	28480	0380-0912	
	Strain Relief Bushing	1	28480	28480	0400-0013	
	CHASSIS ASSEMBLY - MECHANICAL	1	28480	28480	5000-6262	
	Chassis, Center	1	28480	28480	5000-6145	
	Cover, Side	2	28480	28480	5060-0724	
	Cover, Top	1	28480	28480	5000-6261	
	Cover, Bottom	1	28480	28480	0590-0052	
	Fastener, Top and Bottom Covers	4	28480	28480	5060-0703	
	Side Frame Assembly	2	28480	28480	1400-0116	
	Cable Clamp	4	28480	28480	0403-0150	
	Guide, Printed Circuit Boards	4	28480	28480	0380-0951	
	Bracing Rod, Insulated	1	28480	28480		

REF. DESIG.	DESCRIPTION	QTY	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
	MISCELLANEOUS Manual Carton, Packing Floater Pad, Packing Fuse Envelope, FI (230V)	1 1 2 1		28480 28480 28480 28480	06227-90001 9211-1183 9220-1404 9320-0234	
R27 (A), 27 (B)	OPTION 007: 10-Turn Voltage Control var. w 10k Ω \pm 5% 2W, 10-Turn Knob, Black	2 2		28480	2100-1866 0370-0846	1 1
R4 (A), 4 (B)	OPTION 008: 10-Turn Current Control var. w 1k Ω \pm 5% 2W, 10-Turn Knob, Black	2 2		28480	2100-1864 0370-0846	1 1
R4 (A), 4 (B) R27 (A), 27 (B)	OPTION 009: 10-Turn Current & Voltage Controls var. w 1k Ω \pm 5% 2W, 10-Turn var. w 10k Ω \pm 5% 2W, 10-Turn Knob, Black	2 2 4		28480 28480 28480	2100-1864 2100-1866 0370-0846	1 1 1 1
R27 (A), 27 (B)	OPTION 013: 3 Digit Decadal Voltage Control 3-Digit Decadal var. w 10k Ω \pm 5% 2W, 10-Turn	2 2	RD-411	28480	2100-1866 1140-0020	1 2
R4 (A), 4 (B)	OPTION 014: 3 Digit Decadal Current Control 3-Digit Decadal var. w 1k Ω \pm 5% 2W, 10-Turn	2 2	RD-411	28480	2100-1864 1140-0020	1 2

SECTION VII SCHEMATIC DIAGRAM AND COMPONENT LOCATION DIAGRAMS

b. The schematic diagram (Figure 7-7), illustrating the circuitry for the entire power supply. Test points (encircled numbers) are given on the schematic. These points coincide with the test points on the component location diagrams and are referred to throughout the text. Voltages are given in italics adjacent to the test points.

This section contains the diagrams necessary for the operation and maintenance of this power supply. Included are:

a. Component location diagrams (Figures 7-1 through 7-6), showing the physical location and reference designators of parts mounted on the printed circuit boards and chassis.

Figure 7-1. Main Chassis Component Location Diagram, Top View

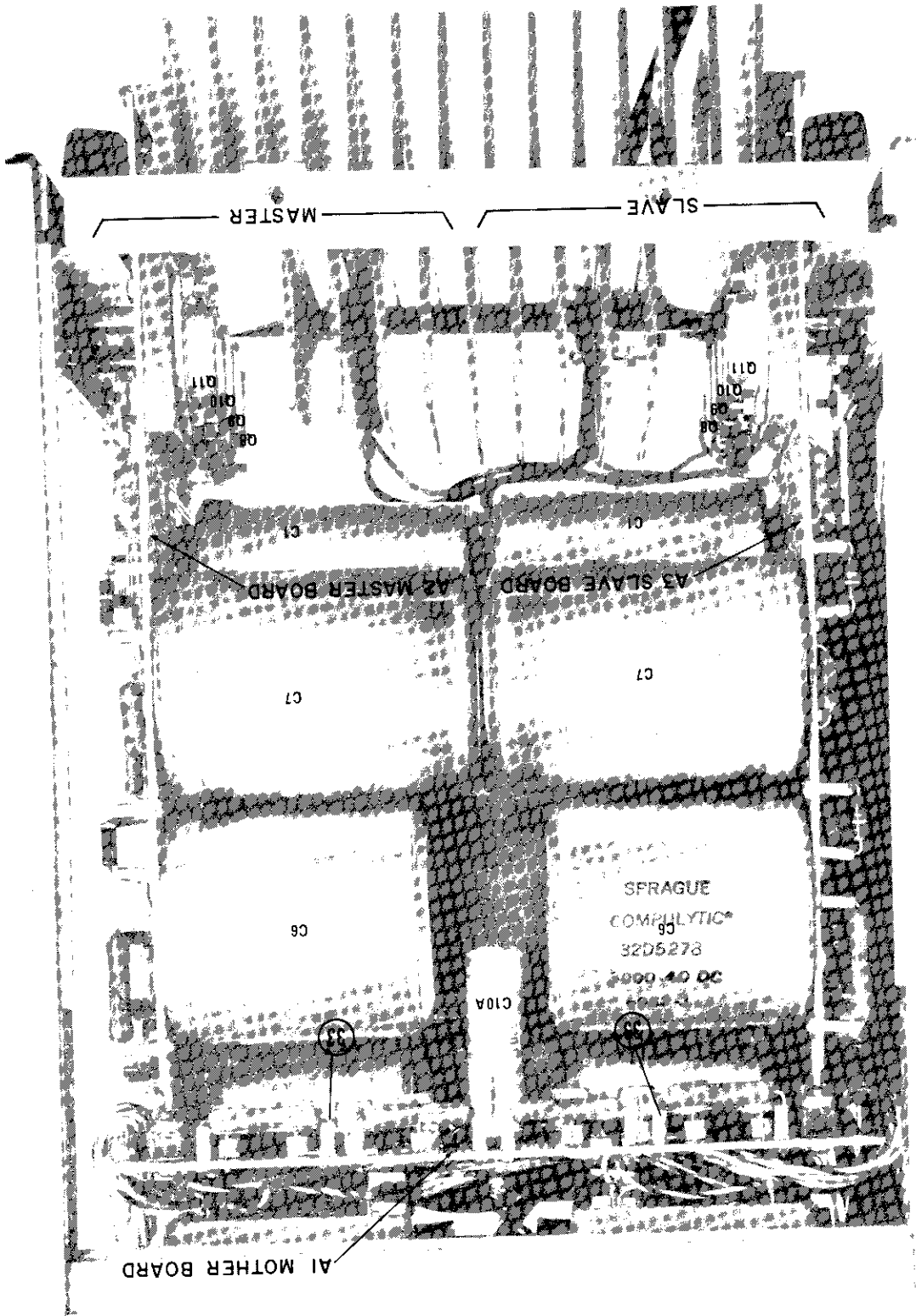


Figure 7-4. A1 Mother Printed Circuit Board
Component Location Diagram

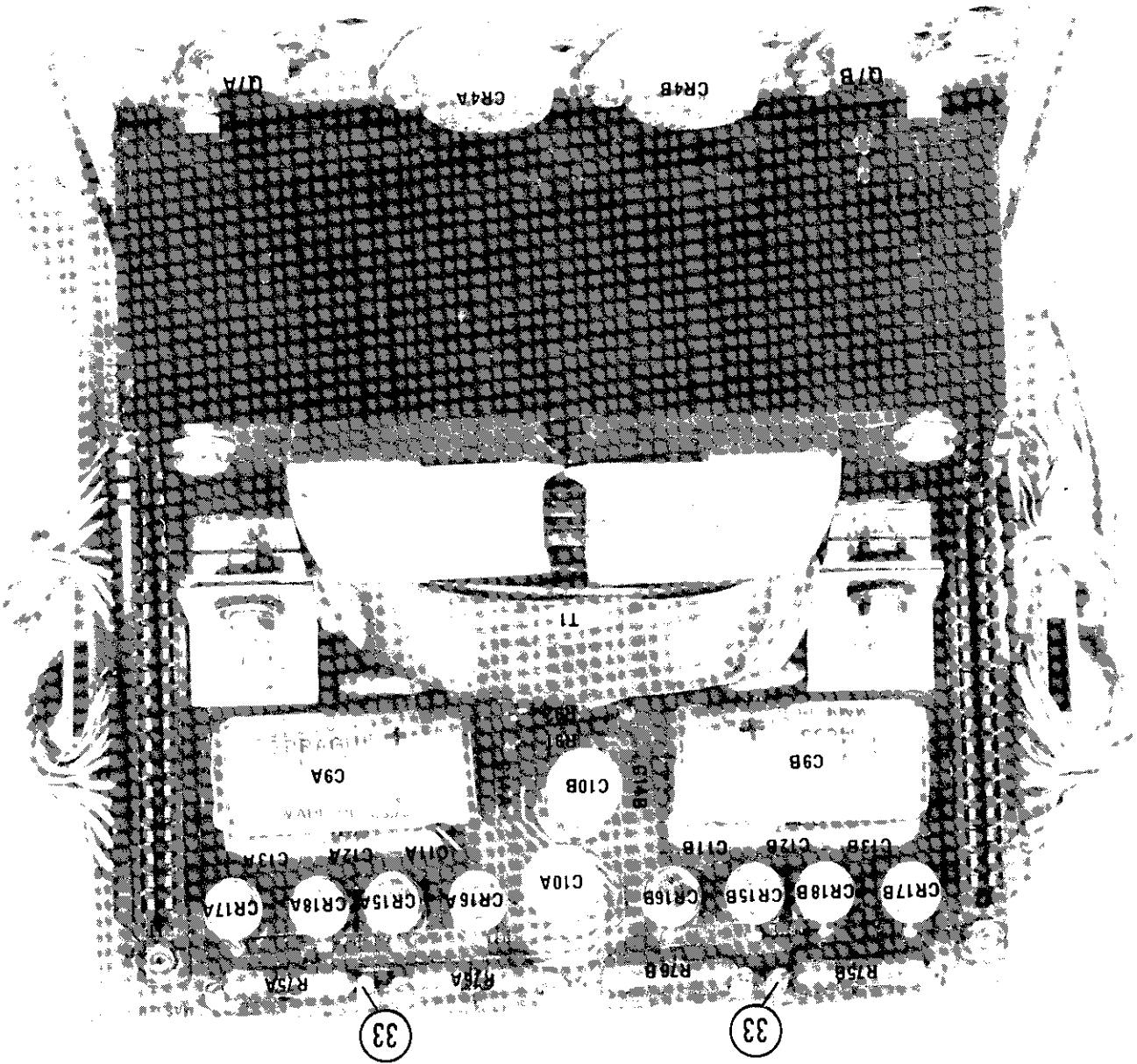


Figure 7-3. A4 Crowbar Printed Circuit Board
Component Location Diagram

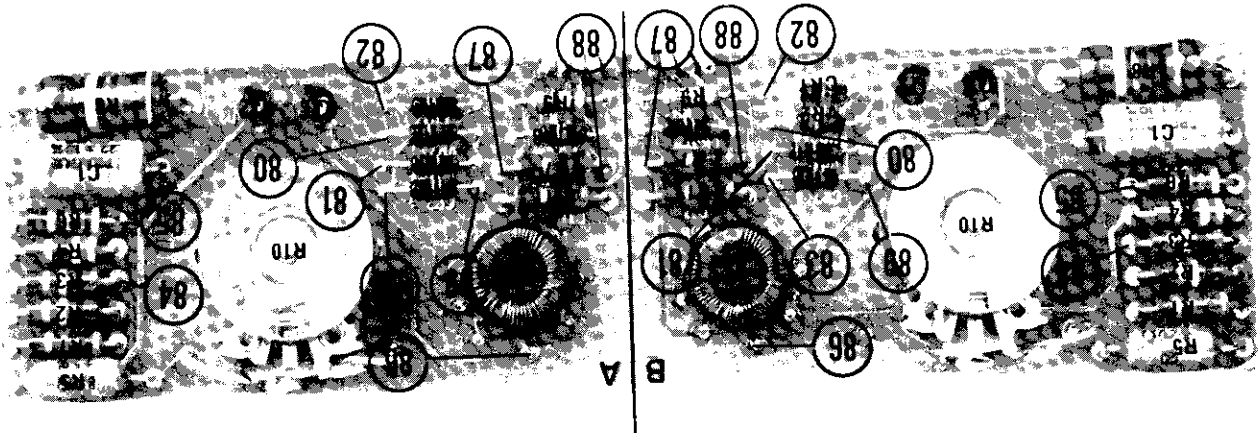
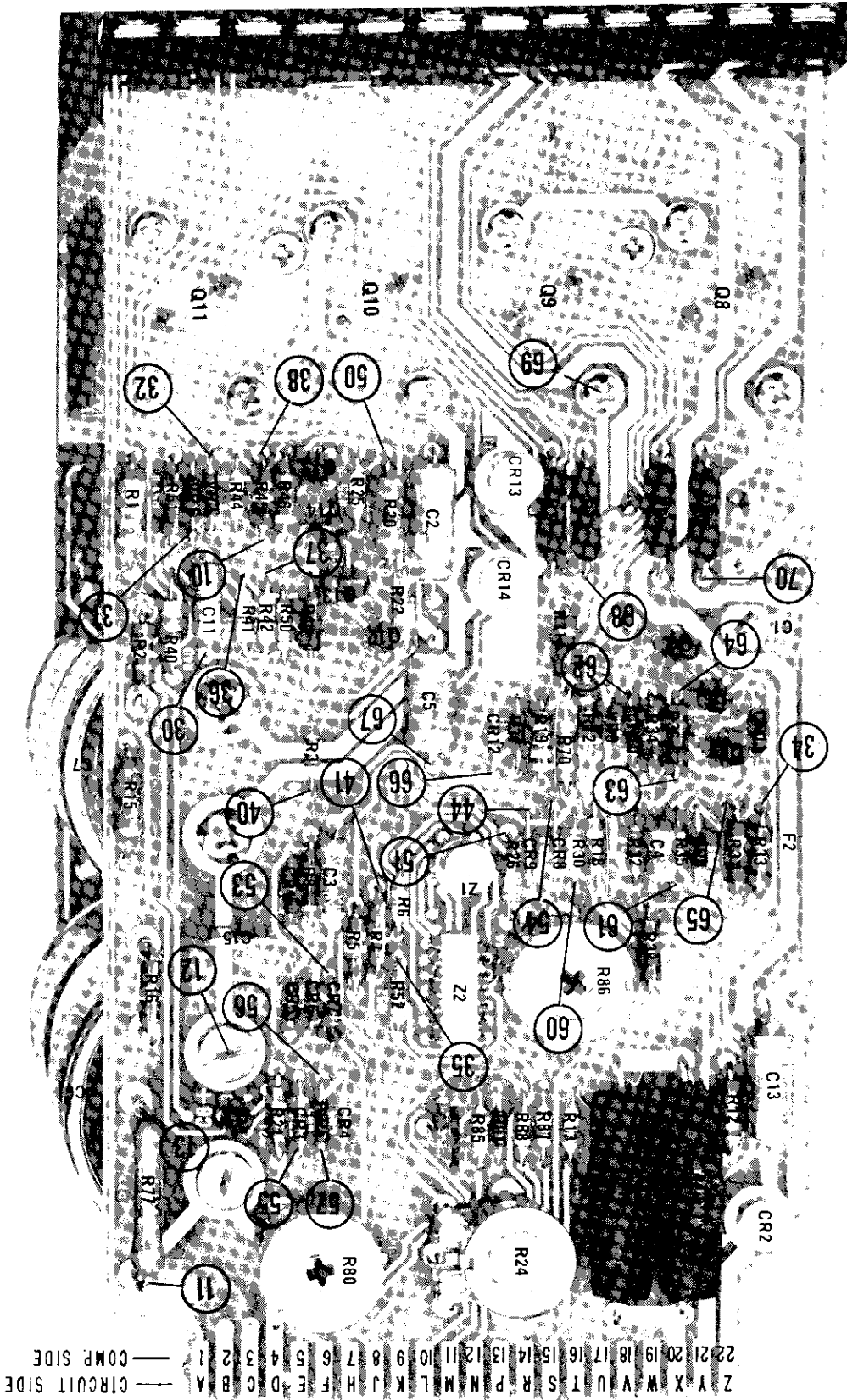


Figure 7-5. A3 Slave Printed Circuit Board
Component Location Diagram

*-NOT USED ON 6228B



MANUAL CHANGES

Model 6228B DC Power Supply
Manual HP Part No. 06228-90001

Make all corrections in the manual according to errata below, then check the following table for your power supply serial number and enter any listed change(s) in the manual.

MAKE	SERIAL	
	Prefix	Number
CHANGES	ALL	-
	1020A	0161 - 0340
	1145A	0341 - 0466
	1145A	0467 - 0495
	1145A	0496 - 0575
	1145A	0576 - 0695
	1145A	0696 - 0735
	1145A	0736 - 0975
	1145A	0976 - 1315
	1604A	1316 - 1735
	1723A	1736 - 1855
	1752	1856 - 1995
	1815A	1996 - 2315
	1918A	2316 - 2355
	1924A	2356-up
	Errata	1
		1, 2
		1, 2, 3
		1 thru 4
		1 thru 5
		1 thru 6
		1 thru 7
		1 thru 8
	1 thru 9	
	1 thru 10	
	1 thru 11	
	1 thru 12	
	1 thru 13	
	1 thru 14	

ERRATA:

Page 5-21, Paragraph 5-87, Step C: Change "CURRENT controls" to "VOLTAGE controls."

CHANGE 1:

In the replaceable parts table and on the schematic diagram add new capacitors, A2C16 and A3C16; 1µF, 35V, HP Part No. 0180-0291. C16 is connected across the current sampling resistance (R10) in both the master and slave supplies.

CHANGE 2:

In the replaceable parts table and on the schematic diagram, make the following changes: A2F2: Change to 2A 250V, HP Part No. 2110-0002. F2 has been moved from Master Board (A2) to the chassis and is now in series with the Master's negative output lead (from CR16A-CR17A).

A3F2: Change to same fuse as A2F2 and designate F3. This fuse has also been moved to the chassis from the Slave Board and is in series with the Slave's negative output lead (CR16B-CR17B). A2, A3R85: Delete (short-out) R85 in the two meter circuits.

CHANGE 3:

In the replaceable parts table and on the schematic (as applicable), make the following changes: F1 (230V): Change F1 (230V) to 2A slow blow, HP Part No. 2110-0303. CR16: Add diode CR16, HP Part No. 1901-0416 as shown below:

CHANGE 5:

In the replaceable parts table and on the schematic, change F1 (115V) to 4A, 250V, slow blow, 2110-0365. In the replacement parts table under Rear Panel-Mechanical, add transistor insulator 0340-0503 (quantity, 2).

In the replaceable parts table under Chassis-Electrical, and on the schematic, make the following changes:

Terminal Board: Add Terminal Board, HP Part No. 0360-0401.

Terminal Board: Add Terminal Board, HP Part No. 0360-0393.

R91, R92: Add resistors R91 and R92, 0.75a ±10%, 5W, HP Part No. 0811-1849.

R91 is placed in series with the anode of CR4(A) and + out. R92 is placed in series with the anode of CR4(B) and + out. The resistors provide current limit when the crowbars are activated by a capacitive load or battery on the output.

CHANGE 4:

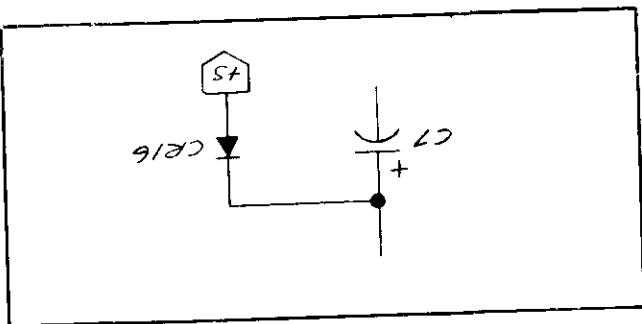
In the replaceable parts table, make the following changes:

R4: Change R4 (dual variable resistor, CUR-RENT control) to HP Part No. 2100-2942

R27: Change R27 (dual variable resistor, VOLTAGE control) to HP Part No. 2100-2527.

ERRATA:

The standard colors for this instrument are now mint gray (for front panel and rear panels) and olive gray (for all top, bottom, side, and other external surfaces). Option X95 designates use of the former color scheme of light gray and blue gray. Option A85 designates use of a lightgray front panel with olive gray used for all other external surfaces. New part numbers are shown on back.



CHANGE 10:
Zero voltage output adjust A2R24 and A3R24 in the constant voltage comparator circuits of the master and slave boards have been changed to 20k, 10%, HP Part No. 2100-0058. Correct the Fig. 7-7 schematic and the parts list.

CHANGE 11:
In the parts list and the above table, delete rear heat sink 5020-8069 and add the following:
Heat Sink, Left: No. 5020-2587
Heat Sink, Right: No. 5020-2588

CHANGE 12:
In parts list, A4 crowbar board, change resistors R10A, B to 5k Ω , 5%, 1/2W, HP Part No. 2100-3708.

CHANGE 13:
In parts list and on schematic add ferrite bead inductor, L1, HP Part No. 9170-0894, to emitter lead of Q7A.

ERRATA:

CHANGE 6:
In the parts list and on the schematic for both the A2 master board and the A3 slave board, change R36 to 3K 1/2W, HP Part No. 0686-3025; and change R15 to 1.4K 5% 3W 30ppm, HP Part No. 0811-1804.

CHANGE 7:
In the parts list under Front Panel-Electrical, change toggle switch S1 to HP Part No. 3101-1055.

CHANGE 8:
In parts list under Rear Panel-Mechanical:
Delete: Shoulder washer, qty 4, 2190-0491
Bushings, qty 2, 0340-0171
Add: Transistor insulator, qty 2, 0340-0547

CHANGE 9:
In parts list under A4 Crowbar Board - Electrical, add cable assembly W1, HP Part No. 8120-2085. The cable assembly connects the A4 Board to Mother Board A1 and replaces the 10 individual wires which were previously used. This change does not affect the schematic diagram.

ERRATA:

Add the following notice to paragraph 1-18:
"Effective December 1, 1975, extra manuals may be obtained by ordering Option 910 when ordering your instrument. The number of extra manuals depends on the number of Option 910s ordered."
Effective January 1st, 1977, Options 007 (10-turn voltage control) and 008 (10-turn current control) are no longer available individually, but they are still available combined as Option 009. Likewise, Options 013 (10-turn voltage control with decadal) and 014 (10-turn current control with decadal) are no longer available individually, but they are available combined into a single new option designated Option 015. Make these changes wherever Option 007, 008, 013, or 014 is mentioned in the manual.

CHANGE 14:
On page 6-9, change the HP Part No. for the front-panel + and - binding posts to 1510-0094, red, qty 4. Change the HP Part No. for the front-panel GND binding posts to 1510-0522, black, qty 2. Add the HP Part No. for solder lugs mounted behind GND binding posts: 0360-1190 qty 2. Add the HP Part No. for nylon nuts for mounting binding posts: 2950-0144, qty 6. Add the HP Part No. for items mounted on + and - binding posts: solder lug 0360-0372, qty 4; flat washer 3050-0066, qty 4; split washer 2190-0079, qty 4; 6-32 nut 2500-0001, qty 4.

5-31-79

HP PART NO.		DESCRIPTION	
06228-60003	OPTION A85	STANDARD	Front Panel
5020-5770			Meter Trim
5000-6263			Upper rear panel
5000-9432			Left & Right Side Covers
5000-9450			Rear Barrier Strip Covers
5020-8069			Heat Sink
5060-8585			Top Cover
5000-9444			Bottom Cover
06228-60004			Front Panel
5020-8061			Meter Trim
5000-9462			Upper rear panel
5000-9432			Left & Right Side Covers
5000-9450			Rear Barrier Strip Covers
5020-8069			Heat Sink
5060-8585			Top Cover
5000-9444			Bottom Cover
OPTION X95			