PRECISION CONSTANT CURRENT SOURCE
MODEL 6186C

OPERATING AND SERVICE MANUAL

FOR SERIALS 1443A-00101 AND ABOVE*

*For Serials Above 1443A-00101
a change page may be included.

HP Part No. 06186-90005 Printed: January, 1975

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.

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.
⏚ or ⊥	Indicate earth (ground) terminal.
WARNING	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.
CAUTION	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.

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

SECTION I
GENERAL INFORMATION

1-1 DESCRIPTION

1-2 This power supply is designed for applications requiring a constant current source possessing a high degree of regulation and stability and very low ripple characteristics. Typical applications for this power supply include semiconductor device measurements such as transistor reverse breakdown voltage and current transfer ratio; four-terminal resistance measurements; testing components such as diodes and electrolytic capacitors; and various other applications in electrochemistry, electromagnetics, and other fields. For detailed applications information, refer to Application Note 128, Applications of a DC Constant Current Source, available at no charge from your local Hewlett-Packard sales office.

1-3 The supply is completely transistorized (all silicon) and is suitable for either bench or rack operation. It is of the constant current/voltage limit type that will furnish full rated output currant at the maximum rated output voltage or can be adjusted throughout the output range. The front panel CURRENT control is used to establish the output current level; the front panel VOLTAGE control is used to establish the output voltage limit (ceiling). Both the CURRENT and VOLTAGE controls are continuously variable throughout the entire output range of the supply.

1-4 Special attention has been given to circuit details in this power supply to allow well-regulated performance to be maintained down to very low output currents of the order of 1μA. The use of a three-position RANGE switch and a 10-turn output CURRENT control result in resolution down to 0.5μA.

1-5 Separate meters are used to measure output voltage and current. Output current can be measured in any of three ranges in accordance with the RANGE switch setting on the front panel. Output voltage is measured in one range.

1-6 The power supply has both front and rear terminals. Either the positive or negative output terminal may be grounded, or the power supply can be operated floating at up to a maximum of 300 volts above ground. (Adequate safety precautions must be taken to protect the operator when the supply is used in this mode.)

1-7 The supply incorporates an active guard that prevents leakage currents from degrading the output current regulation. Because the voltage at the positive output terminal is held equal to the guard voltage, the latter is also used to drive the front panel meter or an external high-accuracy voltmeter. This effectively isolates the voltmeter from the main supply and eliminates the usual output regulation degradation associated with connecting a voltmeter directly across the output of a constant current source.

1-8 Terminals at the rear of the unit allow access to various control points within the unit to expand the operating capabilities of the instrument. A brief description of these capabilities is given below:

a. Remote Programming: Both the output current and voltage limit can be programmed (controlled) from a remote location by means of an external voltage source or resistance. The output current can be rapidly programmed up and down using this facility; current programming speed is less than 10msec from zero to 99% of maximum rated output, with an accuracy of 1%.

b. External Voltage Monitoring. The output voltage of the supply can be externally monitored with an accurate differential or digital voltmeter connected to either front or rear meter terminals. Connecting the meter to the active guard in the supply prevents output performance degradation.

c. AC Modulation of Output. An external ac component can be superimposed on the dc output current of the supply. This feature allows dynamic measurements such as zener impedance and small-signal h-parameters to be made with a minimum of difficulty.

1-9 SPECIFICATIONS

1-10 Detailed specifications for the power supply are given in Table 1-1.

1-11 OPTIONS

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

Option No.	Description
014	Three Digit Graduated Decadial Current Control: A dial that replaces the 10-turn current control knob and allows accurate resetting of the output current to within 0.1%.

1-13 ACCESSORIES

1-14 The accessories listed in the following chart may be ordered with the instrument or separately from your local Hewlett-Packard field sales office (refer to list at rear of manual for addresses).

HP Part No.	Description
5060-8762	Rack Kit for mounting one or two units. (Refer to Section II for details.)
5060-8760	Filler panel to block unused half rack 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 part is the serial number prefix, consisting of a number-letter combination denoting the date of a significant design change and the country of manufacture. The first two digits indicate the year (10 = 1970, 11 = 1971, etc.); the second 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 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.

Table 1-1. Model 6186C Specifications

INPUT:
115/230Vac ±10%, single phase, 48-63Hz; 0.9 amp, 90 watts (nominal) @ 115Vac.

OUTPUT:
0-100mA @ 0-300Vdc. *

OUTPUT CURRENT RANGES:
0-1mA, 0-10mA, 0-100mA.

LOAD EFFECT (LOAD REGULATION):
The output current changes less than 25ppm of initial value plus 5ppm of current range switch setting for a load change which causes the output voltage to vary from zero to maximum when measured with the negative output terminal grounded. If the positive output is grounded, the load effect is less than ±100nA output current change for the same full-load change in output voltage. (The relative humidity must be less than 50% when measuring load effect in the 6186C.)

SOURCE EFFECT (LINE REGULATION):
The output current changes less than 25ppm of initial value plus 5ppm of range switch setting for any line voltage change within the input rating (104 to 127Vac, or 208 to 254Vac) and at any output current and voltage within rating.

PARD (RIPPLE AND NOISE):

Output Range (mA)	Ripple and Noise-rms/p-p (d~~c to 20MHz~~) 20Hz → UP
1	200nA rms/4μA p-p
10	2μA rms/50μA p-p
100	20μA rms/500μA p-p

TEMPERATURE RATING:
Operating: 0 to 55°C. Storage: -40 to +75°C.

TEMPERATURE COEFFICIENT:
Output change per degree Centigrade is less than 75ppm of output plus 5 ppm of range switch setting.

*In constant voltage operation, the minimum output voltage is 0.5V.

DRIFT (STABILITY):
Total output current drift is less than 100ppm of output plus 25ppm of range switch setting. Stability is measured for 8 hours at constant ambient, constant line voltage, and constant load after an initial warm-up of one hour.

INTERNAL IMPEDANCE AS A CONSTANT CURRENT SOURCE:

Output Range (mA)	Output Impedance (Typical) (R in parallel with C)*
1	R = 10, 000 Meg, C = 900pF
10	R = 1, 000 Meg, C = 700pF
100	R = 100 Meg, C = 1500pF

*The formula $Z = RX_C/\sqrt{R^2 + X_C^2}$ can be used for calculations up to 1MHz.

LOAD TRANSIENT RECOVERY TIME:
Less than 1msec for output current recovery to within 1% of the nominal output current on the 100mA range following a full-load change in output voltage; less than 1.6msec on the 10mA range; and less than 4msec on the 1mA range.

RESOLUTION:
0.02% of the range switch setting.

METER RANGES:
1.2, 12, 120mA; 360V. Accuracy: 2% of full scale.

OUTPUT CONTROLS:
Range switch selects desired output current range and selects meter range. Ten-turn current and single-turn voltage controls permit continuous adjustment over entire output span.

OUTPUT TERMINALS:
Positive and negative output, meter positive, and ground terminals are provided on the front panel. Two rear barrier strips include output, guard, and other terminals necessary for remote programming, ac modulation, and other control functions. Either the positive or the negative output terminal may be grounded or the supply may be floated at up to 300 volts above ground .

PROGRAMMING SPEED:
Less than 10msec is required to program from zero to 99% of the maximum rated output current of each range or from the maximum rated output current of each range to less than 1% of that current.

REMOTE PROGRAMMING, CONSTANT CURRENT:

Programming Source	Range (mA)		
	1	10	100
Resistance (Accuracy: 1% of output + 0.04% of range)	10KΩ/ mA	1KΩ/ mA	100Ω/ mA
Voltage (Accuracy: 0.5% of output + 0.04% of range)	10V/ mA	1V/ mA	100mV/ mA

REMOTE PROGRAMMING, VOLTAGE LIMIT:
Remote programming of the voltage limit at 1 volt per volt (accuracy 20%) or 820 ohms per volt (with an accuracy of 15% or 3V, whichever is greater) is available at the rear terminals.

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

SIZE:
6-17/32" (15, 76 cm) H x 12-3/8" (30, 87 cm) D x 7-3/4" (19, 7 cm) W.

WEIGHT:
13 lbs. (5, 9 Kg) net, 17 lbs. (7, 7Kg) shipping.

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 INSTALLATION DATA

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

2-9 LOCATION

2-10 This instrument is cooled by natural convection. Sufficient space should be allotted so that a free flow of cooling air can reach the sides and rear of the instrument when it is in operation. It should be used in an area where the ambient temperature remains between 0°C and +55°C.

2-11 OUTLINE DIAGRAM

2-12 Figure 2-1 illustrates the outline shape and dimensions of the 6186C supply.

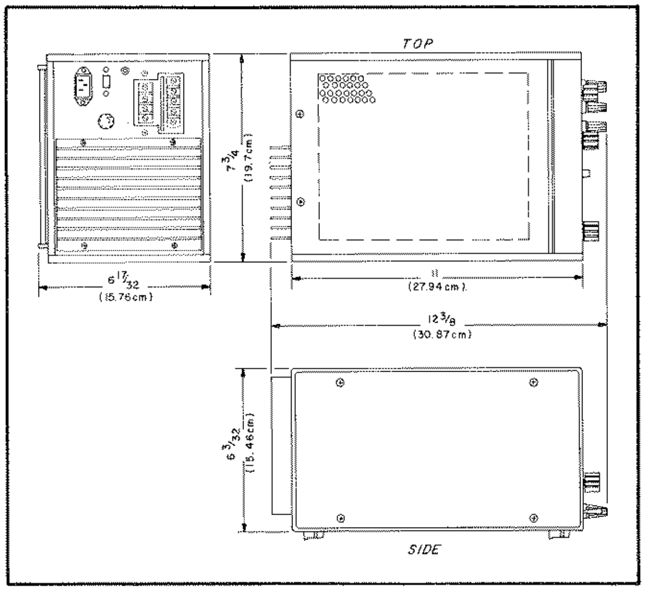


Figure 2-1. Outline Diagram

2-13 RACK MOUNTING

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

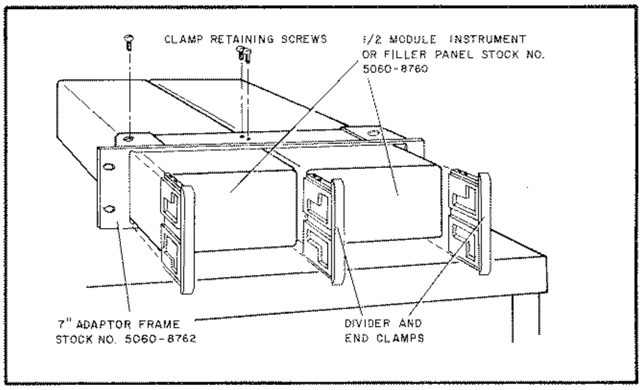


Figure 2-2. Rack Mounting One and Two Units

2-15 To mount one unit alone, or two units side-by-side, proceed as follows:

a. Place adaptor frame on bench.
b. Remove feet and tilt stand from

instrument(s). Place instrument(s) in frame.

c. Place divider clamp between instruments. If mounting one instrument alone, place blank panel in position that would be occupied by second instrument.

d. Place divider clamps in position on each end and push the instrument or instrument/blank panel combination into frame.

e. Insert screws on either side of frame and tighten.

2-16 INPUT POWER REQUIREMENTS

2-17 This power supply may be operated continuously from either a nominal 115 volt or 230 volt, 48-63Hz power source. The input power required when operating from a 115 volt, 60Hz power source at full load is 90 watts, 0.9 amperes.

2-18 115/230 VOLT OPERATION

2-19 A recessed, two-position slide switch located on the rear panel permits operation from either a 115 or 230 volt power source. Before 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.

2-20 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 power cord. Markings on the 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.

2-21 POWER CABLE

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

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

2-24 REPACKAGING FOR SHIPMENT

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

SECTION III
OPERATING INSTRUCTIONS

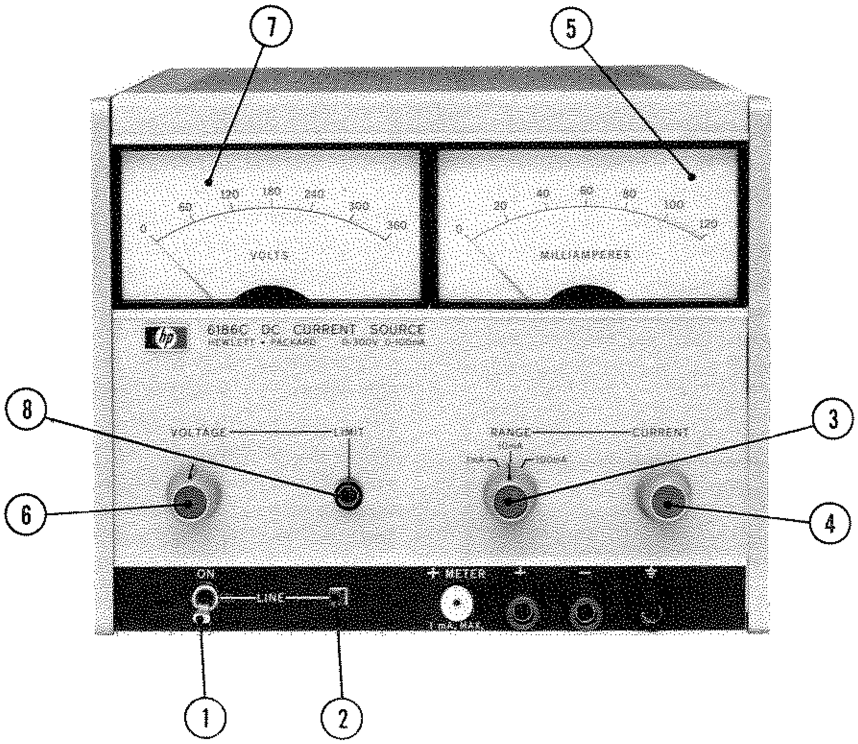


Figure 3-1. Operating Controls and Indicators

3-1 TURN-ON CHECKOUT PROCEDURE

3-2 The following checkout procedure describes the use of the front panel controls and indicators and ensures that the meter and programming circuits are operable. Actual output current should be checked with an external ammeter connected between the positive and negative output terminals before connecting delicate loads.

a. Set LINE switch ① to ON and observe that LINE light ② goes on.

b. Set RANGE switch ③ to desired current range.

c. Adjust CURRENT control ④ until front panel ammeter ⑤ indicates desired output current (no load connected).

d. Adjust VOLTAGE control ⑥ until front panel voltmeter ⑦ indicates desired voltage limit.

e. VOLTAGE LIMIT lamp ⑧ should be on with no load connected.

f. Connect load to front or rear output terminals.

3-3 OPERATING MODES

3-4 The power supply is designed so that its mode of operation can be selected by making strapping connections between particular terminals on the terminal strips at the rear of the power supply. The terminal designations are stenciled in black on the power supply above or below their respective terminals. The operator can ground either output terminal or, with added precautions to protect the user, operate the power supply up to 300Vdc above ground. The load may be connected to either the front or the rear terminals without any degradation of performance.

3-5 The following paragraphs describe the procedures for utilizing the various operational capabilities of the power supply. A more theoretical description of the operational features of this supply is contained in Application Note 90A, DC Power Supply Handbook, available at no charge from your local Hewlett-Packard sales office.

3-6 NORMAL OPERATING MODE

3-7 The power supply is normally shipped with its rear terminal strapping connections arranged for constant current/voltage limit, local programming, single unit mode of operation. This strapping pattern is illustrated in Figure 3-2. The operator merely selects a constant current output using the front panel controls as described in Paragraph 3-9.

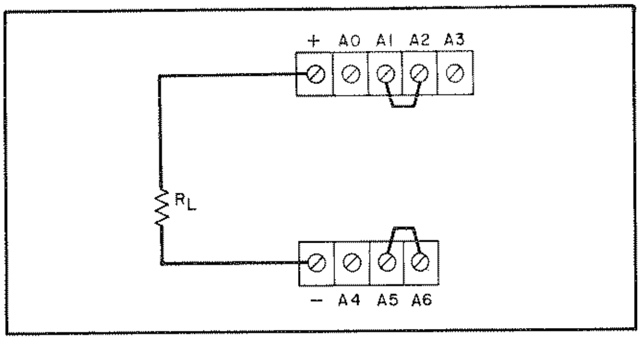


Figure 3-2. Normal Strapping Pattern

3-8 CONSTANT CURRENT

3-9 To select a constant current output, proceed as follows:

a. With output terminals open or shorted (see NOTE), adjust CURRENT and RANGE controls for desired output current.

b. With output terminals open, adjust VOLTAGE control for maximum output voltage allowable (voltage limit), as determined by load conditions. If a load change causes the voltage limit to be exceeded, the power supply will automatically crossover to voltage limited output at the preset voltage limit and the current supplied to the load will drop proportionately. When this occurs, the VOLTAGE LIMIT lamp on the front panel will light. In setting the voltage limit, allowance must be made for high peak voltages (corresponding to suddenly increased load resistance) which can cause unwanted crossover. (Refer to Paragraph 3-38.)

NOTE

Regardless of the supply's mode of operation (constant current or voltage limit), the front panel ammeter always indicates the programmed output current. This enables the operator to set the output current (using the front panel CURRENT and RANGE controls) without shorting the output terminals.

3-10 CONNECTING LOAD

3-11 Loads for a constant current source must be connected in series (not in parallel) if the desired output current is to be supplied to each load. Extreme care must be taken to avoid shunt paths external to the power supply. The presence of shunt paths will tend to degrade the performance of the supply. If the load is remotely located from the supply, shunt paths can be avoided by using shielded cable. If the supply is used as a positive source (negative terminal grounded) one end of the shield can be connected to the guard terminal (designated +METER on the front and terminal A0 on the rear) and the other end left unconnected. This effectively projects the internal guard voltage along the shield, affording absolute protection against leakage. If the supply is used as a negative source, the above method cannot be utilized. However, the use of a shielded cable will be sufficient to prevent shunt leakage in most applications.

CAUTION

Never connect the guard (+METER on the front panel and terminal A0 on the rear panel) to either the positive or the negative output terminal. Making this connection will result in loss of current control and will damage differential amplifiers Q1 and Q7.

3-12 OPERATION AS A CONSTANT VOLTAGE SOURCE

3-13 The instrument may be operated as a moderately well regulated constant voltage source by operating it in the voltage limit mode (VOLTAGE LIMIT light on). (When operating as a voltage source, the output voltage range is from 0.5 to 300Vdc.) In this situation, the output voltage will be held approximately constant at the limit level, and the output current will change to meet varying load conditions. For further information, please consult an HP sales engineer.

3-14 OPERATION BEYOND RATED OUTPUT

3-15 The maximum output voltage and current of the supply is internally limited to 315Vdc and 110-115mA in order to protect internal components. While the supply may be operated in the region between the rated output (300Vdc, 100mA) and the maximum output (315Vdc, 110-115mA) without being damaged, it cannot be guaranteed to meet all of its performance specifications.

3-16 OPTIONAL OPERATING MODES

3-17 REMOTE PROGRAMMING, CONSTANT CURRENT

3-18 Either a resistance or a voltage source can be used to control the constant current output of the supply. The CURRENT control on the front panel is automatically disabled when the supply is used in the remote programming mode. It is recommended that shielded cable (with the shield connected to terminal A3) be used to connect the programming resistance or voltage source to the supply.

3-19 Resistance Programming (Figure 3-3). In this mode, the output current varies at a linear rate determined by the remote resistance programming coefficient. This coefficient is different for each output current range, as shown in Table 1-1 of this manual. The programming coefficient is determined by the constant current programming current which is adjusted to 1mA ±0.25% at the factory. If greater programming accuracy is required, it can be achieved by adjusting resistor R32 as outlined in Paragraph 5-66.

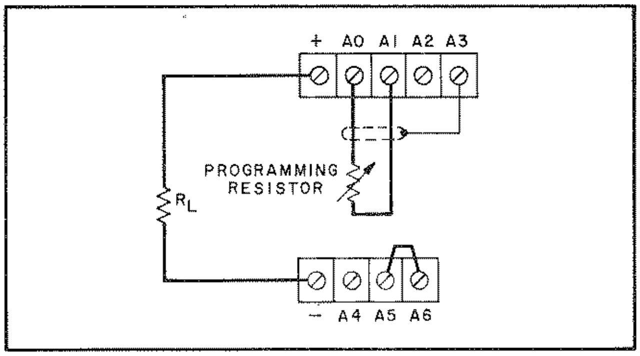


Figure 3-3. Remote Resistance Programming, Constant Current

3-20 Use stable, low noise, low temperature coefficient programming resistors to maintain the power supply's 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 (A0 and A1) 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 10K protection resistor be permanently connected across the programming terminals. Like the programming resistor, this resistor should be a low noise, low temperature coefficient type. Note, however, that when this resistor is used, the resistance value actually programming the supply is the parallel combination of the remote programming resistance and the protection resistor across the programming terminals.

3-21 If the negative output terminal of the supply is grounded, care must be taken to avoid leakage current paths from the programming source to the negative output terminal (ground). Shunt paths such as this will seriously degrade the performance of the supply.

3-22 Voltage Programming (Figure 3-4). In this mode, the output current varies at a linear rate determined by the voltage programming coefficient given in Table 1-1. The entire voltage span for the programming source is approximately 0-10 volts. The programming voltage should never be allowed to exceed 12 volts. Voltages in excess of this will result in excessive power dissipation in the instrument and possible damage.

3-23 The 1mA programming current, flowing into terminal A1 from the reference supply (see schematic), imposes two restrictions in the voltage programming mode. The first restriction is that the voltage source must be capable of sinking (absorbing) this 1mA current; the second restriction is that if the programming terminals are opened, the 1mA programming current will cause the output current to rise to an excessive level (refer to CAUTION note of Paragraph 3-20). A protection resistor, previously mentioned in the CAUTION note, can be employed to limit the output current to a safe value under any conditions.

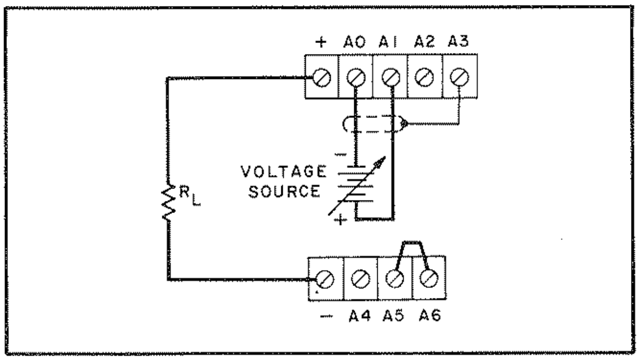


Figure 3-4. Remote Voltage Programming, Constant Current

3-24 If the user's voltage source cannot sink the 1mA programming current, the programming current path to terminal A1 can be opened by removing resistor R32 (mounted on standoffs) from the main printed circuit board. This does not detract from the voltage programming performance in any way but does eliminate the need for sinking the programming current. Opening R32 also eliminates the need for an open-terminal protection resistor. Opening the programming terminals when no programming current is flowing results in zero output current rather than an excessive output current.

3-25 The programming voltage source must always be floating (ungrounded). If the negative output terminal is grounded, shunt leakage paths from the floating programming source to the negative terminal must be avoided. To accomplish this, the <u>case</u> of the voltage source can be connected to the circuit common terminal (A3), thus affording protection against leakage. If this method is used, ensure that the case is not grounded by any means such as the power line.

3-26 REMOTE PROGRAMMING, VOLTAGE LIMIT

3-27 The voltage limit of the supply can be programmed with a remote resistance or voltage source if required. Note that the front panel VOLTAGE control is automatically disabled in the following procedures.

3-28 <u>Resistance Programming (Figure 3-5)</u>. The voltage limit of the supply is determined by the programming coefficient of 820 ohms per volt. The voltage programming current is 1mA and is factory adjusted to within 15%. Adjustment of the programming accuracy can be achieved by adjusting resistors R86 and R87 as described in Paragraphs 5-69 and 5-72.

3-29 A switch can be used in conjunction with various resistance values in order to obtain discrete voltages. The switch should have make-before-break contacts to avoid momentarily opening the programming terminals during the switching interval. Opening the programming terminals (A4 and A6) causes the output voltage to rise to an excessive level that may damage the load.

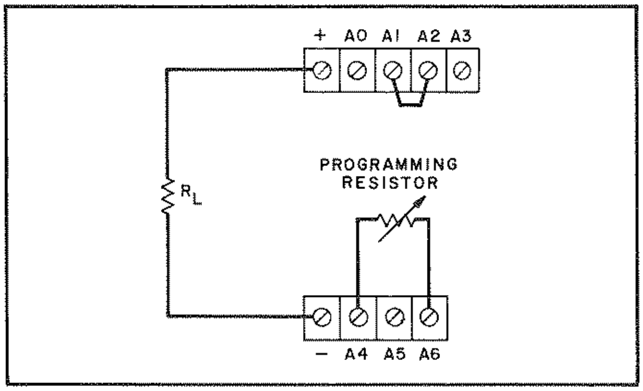


Figure 3-5. Remote Resistance Programming, Voltage Limit

3-30 <u>Voltage Programming (Figure 3-6)</u>. In this mode, the voltage limit will vary in a 1 to 1 ratio with the programming voltage (voltage source). The voltage source used must be capable of sinking the 1mA programming current flowing into terminal A6, and it must be floating with respect to the output terminals and earth ground.

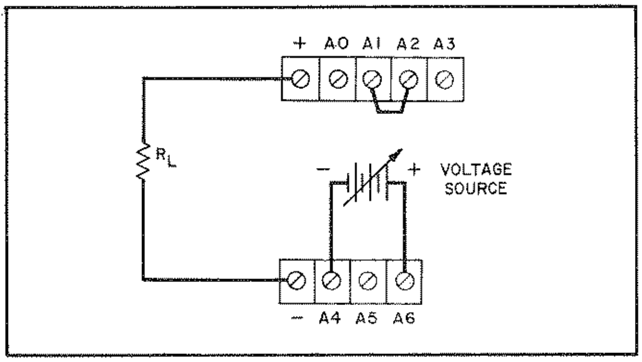


Figure 3-6. Remote Voltage Programming, Voltage Limit

3-31 EXTERNAL VOLTAGE MONITORING

3-32 If an accurate measurement of the output voltage is required, it can be obtained by connecting an external voltmeter between the front panel +METER and (-) terminals, or between the rear (A0) and (-) terminals as shown in Figure 3-7. When connected in this manner, the external voltmeter will indicate the actual output voltage with an accuracy of ±1 millivolt. Notice that the meter is connected between the guard and the negative terminal rather than the positive and the negative terminal. Connecting the meter to the guard supply effectively isolates the meter from the main power supply, preventing the performance degradation that would occur if the meter were connected directly across the positive and negative output terminals.

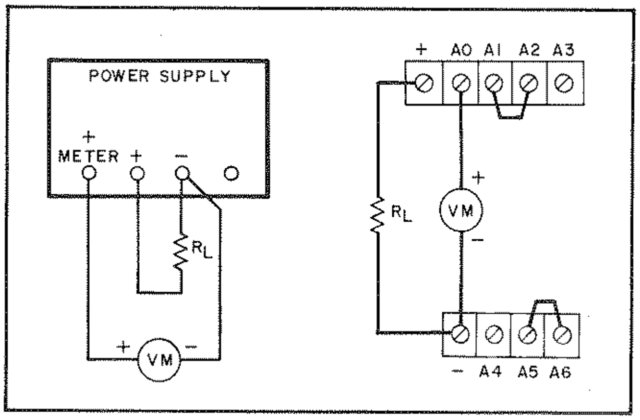


Figure 3-7. External Voltage Monitoring

NOTE

The external voltmeter must not draw more than 1mA from the programming/guard supply (the A0 or +METER terminal). A current drain in excess of 1mA will seriously impair the operation of the power supply.

3-33 EXTERNAL AC MODULATION

3-34 Figure 3-8 shows a method of superimposing an ac component on top of the adjustable dc output current of the supply. The dc current level is controlled in the normal fashion from the front panel, while the ac component of the output current is determined by the modulation percentage. The percentage of modulation is determined by the amplitude of the external voltage input and the value of the series resistance according to the following formula: % Modulation = 100 $[\frac{1}{2}E_{source}$ (p-p)/R_X (in KΩ)$]$. The programming voltage appearing across terminals A1 and A3 should be limited to 10V p-p and must not exceed 12 volts if damage to the instrument is to be avoided. Using the above formula, the user would require an external resistance of 2KΩ and a 4 volts peak-to-peak input signal from the external source to modulate a dc current level of 50mA by 100%. In this case, the output current would swing between 100mA and zero amperes. The output current should never be allowed to swing beyond the rating of the supply (100mA), or clipping of the output and possible internal damage will result.

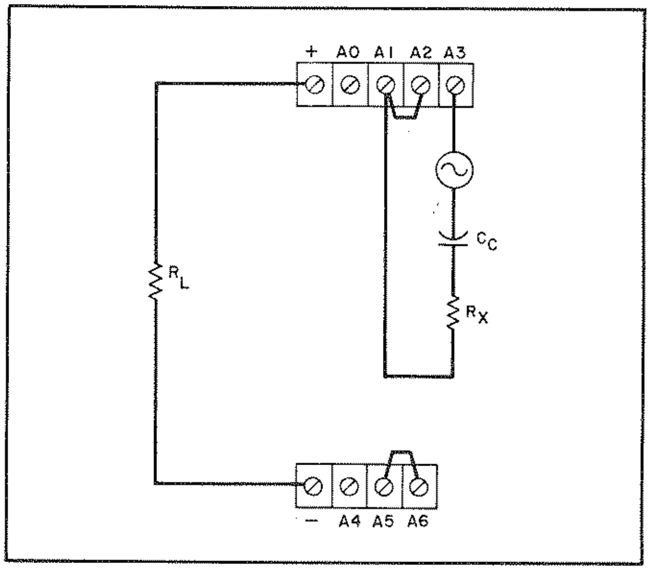


Figure 3-8. External AC Modulation

3-35 The coupling capacitor (C_C) should be chosen so that its reactance is at least ten times smaller than R_X at the frequency of interest. For input frequencies up to 50Hz, the output of the supply can be modulated 100%. Above 50Hz, the modulation capability decreases linearly to approximately 10% at 500Hz.

3-36 It is possible to simultaneously remote resistance program and externally modulate the dc current output simply by combining the strapping patterns of Figures 3-3 and 3-8 as follows:

a. Connect external modulation source, coupling capacitor, and series resistor between terminals A1 and A3 as shown in Figure 3-8.

b. Do not connect strap between terminals A1 and A2.

c. Connect remote programming resistance between terminals A0 and A1 as shown in Figure 3-3.

If it is desired to simultaneously remote voltage program and externally modulate the dc current output, please consult an HP sales engineer.

3-37 SPECIAL OPERATING CONSIDERATIONS

3-38 PULSE LOADING

3-39 The power supply will automatically cross over from constant current operation to voltage limited operation if the output voltage reaches the preset limit due to an increase in load resistance. Although the preset limit may be set higher than the average output voltage, high peak voltages due to pulse loading may reach the preset limit and cause crossover to occur. If this crossover limiting is not desired, the voltage limit should be set for the peak requirement and not the average.

3-40 REVERSE VOLTAGE LOADING

3-41 Diodes VR6 and CR43 are connected in series internally across the supply. Under normal operating conditions, the series combination of these diodes is reverse biased (anode connected to the negative output terminal). If a reverse voltage is applied to the output terminals (positive voltage applied to the negative output terminal), the diode combination will conduct, shunting current through it. These diodes protect the series regulator transistors.

SECTION IV
PRINCIPLES OF OPERATION

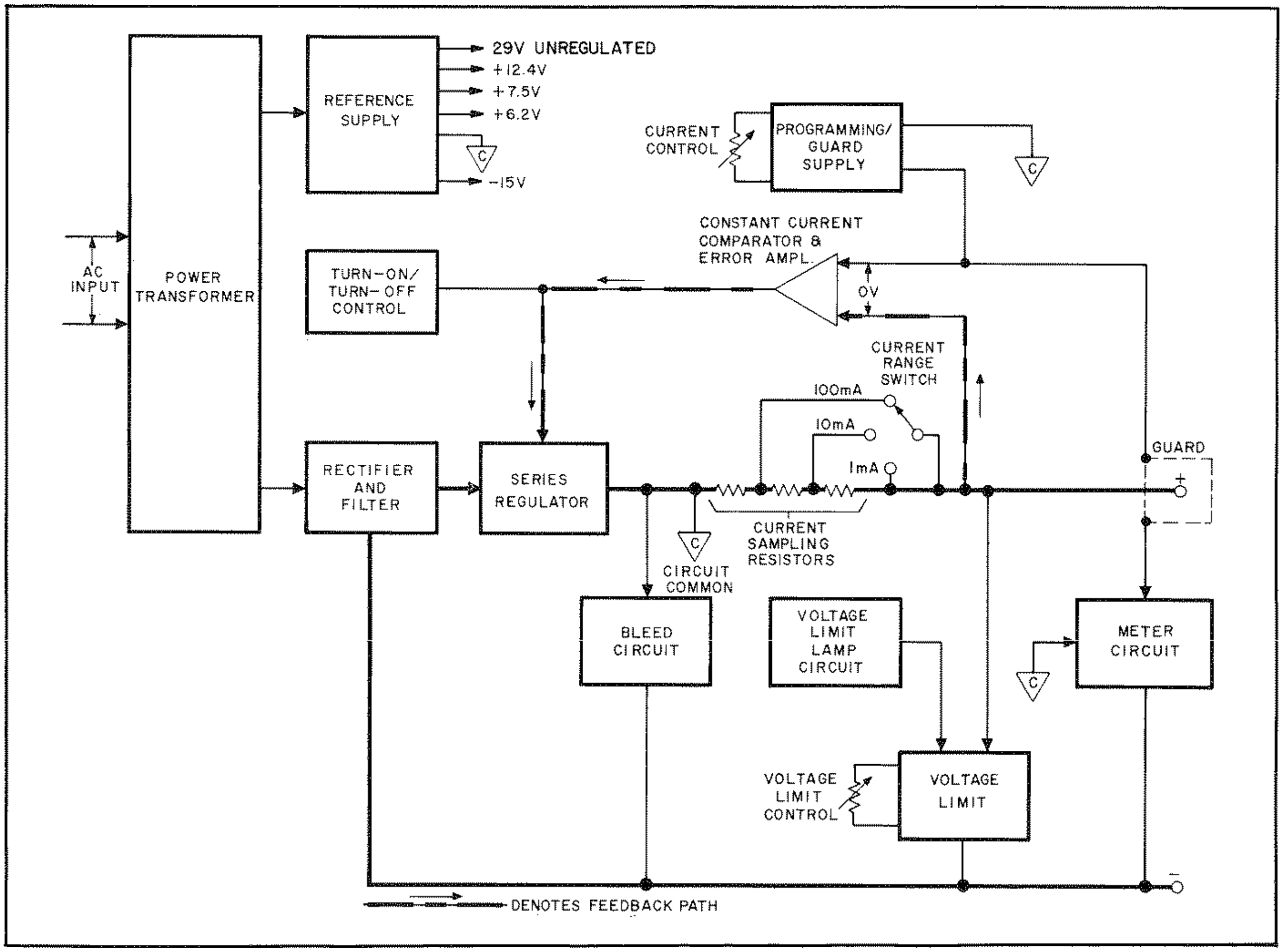


Figure 4-1. Overall Block Diagram

4-1 OVERALL BLOCK DIAGRAM DISCUSSION

4-2 The major circuits of the power supply are shown in Figure 4-1. The input ac line voltage passes through the power transformer and is converted by the rectifier and filter to "raw" or unregulated dc. This "raw" dc is applied to the series regulator, which varies its conduction in order to keep the output current at a constant level. The range of the output current is selected by the current RANGE switch; the position of the switch determines the value of current sampling resistance that is placed in series with the positive output terminal.

4-3 The series regulator is part of a feedback loop whose other components include the constant current comparator and the current sampling resistor(s). The purpose of this feedback loop is to maintain the current flowing through the series regulator at a constant, well regulated value. During normal constant current operation, the constant current comparator continuously compares the voltage drop across the current sampling resistor with the reference voltage from the programming/guard supply. If a difference between these two voltages exists, that is, if the IR drop across the current sampling resistor does not equal the programming/guard supply voltage, the constant current comparator sends an amplified error signal to the series regulator. The error signal alters the conduction of the series regulator until the voltage drop across the current sampling resistor once again equals the programming/guard supply voltage. Thus the actual output current is held constant at a level proportional to the programming/guard supply voltage.

4-4 The programming/guard supply is an independent, regulated, variable voltage supply that simultaneously performs two distinct functions. In its primary or programming function, its output voltage serves as a reference against which the drop across the sampling resistor is compared in order to maintain the output current at a constant level. In its guard function, its output is connected to a copper guard conductor surrounding the positive output terminal. Since the constant current comparator maintains the positive output terminal at the same potential as the output of the programming/guard supply, no leakage current flows from the positive output terminal. Instead, leakage current that would normally flow from the positive output terminal flows from the guard conductor via the low impedance programming/guard supply.

4-5 As mentioned above and shown in Figure 4-1, the circuit common point for the supply (C) is the <u>inboard</u> side of the current sampling resistor. This is a significant point because it insures that only the output current flows through the current sampling resistor. In this way, any leakage current flowing directly between the supply's two output terminals is eliminated, and precise load regulation is obtained. Note that the circuit common point is at a different potential than both the negative output terminal and the chassis ground.

4-6 The guard conductor also serves as a convenient connection point for the meter circuit. If the voltmeter were to be placed directly across the output of the supply, its relatively low resistance would degrade the load regulation and diminish the load current. Instead, the voltmeter is connected between the guard conductor and the negative output terminal (remember that the guard is maintained at the same potential as the positive output terminal). The meter drive current is thus supplied by the programming/guard supply and not by the main regulated current supply. The ammeter is connected between circuit common and the guard conductor, allowing it to indicate the output voltage of the programming/guard supply. As described in Paragraph 4-3, the IR drop across the current sampling resistance is held equal to the output voltage of the programming/guard supply; thus measuring this voltage produces an indication of the (output) current flowing through the current sampling resistor.

4-7 The turn-on/turn-off control consists of a pair of long-time-constant networks that allow the supply to achieve a gradual turn-on and turn-off characteristic, thus minimizing any current transients appearing in the output when the instrument is first turned on or when power is suddenly removed. At turn-on, the control circuit withholds drive current from the series regulator until all other circuits in the supply have stabilized. At turn-off, the control circuit immediately interrupts the drive current, thus preventing the series regulator from remaining on while its bias and control voltages are falling.

4-8 The bleed circuit maintains a continuous, small current flow through the series regulator. This current provides a path for leakage currents and keeps the series regulator on and in its active region at all times, even when little or no output current is being drawn from the supply. Maintaining this on-condition insures that the supply will maintain its regulation at very low output currents.

4-9 The voltage limit circuit provides an adjustable limit on the output voltage of the supply. If the output voltage exceeds the preset limit (set with the front panel VOLTAGE control), a shunt regulator gate diode is driven into conduction. The shunt regulator draws current away from the load, causing the output voltage of the supply to be clamped to the preset limit level.

4-10 The voltage limit lamp circuit drives the front panel LIMIT lamp; this circuit is activated by the shunt current that flows through the voltage limit circuit when the supply output voltage rises to the preset limit level. When lit, the lamp informs the supply operator that the full programmed output current is no longer being supplied to the load, and that the output voltage has reached the preselected limit.

4-11 The combination of the programming scheme and the voltage limit circuit used in the 6186C allow the output current to be set without shorting the output terminals. As noted in Paragraph 4-6, the front-panel ammeter indicates the programmed output current. If the supply is operating in the normal constant current mode, all the programmed output current is delivered to the load; if the supply is operating in the voltage limit mode, part of the programmed output current (or all of it, if no load is connected) is flowing through the shunt regulator. Thus the series regulator and the current sampling resistor are always conducting the programmed output current, and the ammeter, actually indicating the output voltage of the programming/guard supply, indicates the programmed output current regardless of the load connected to the supply.

4-12 The reference supply provides reference and

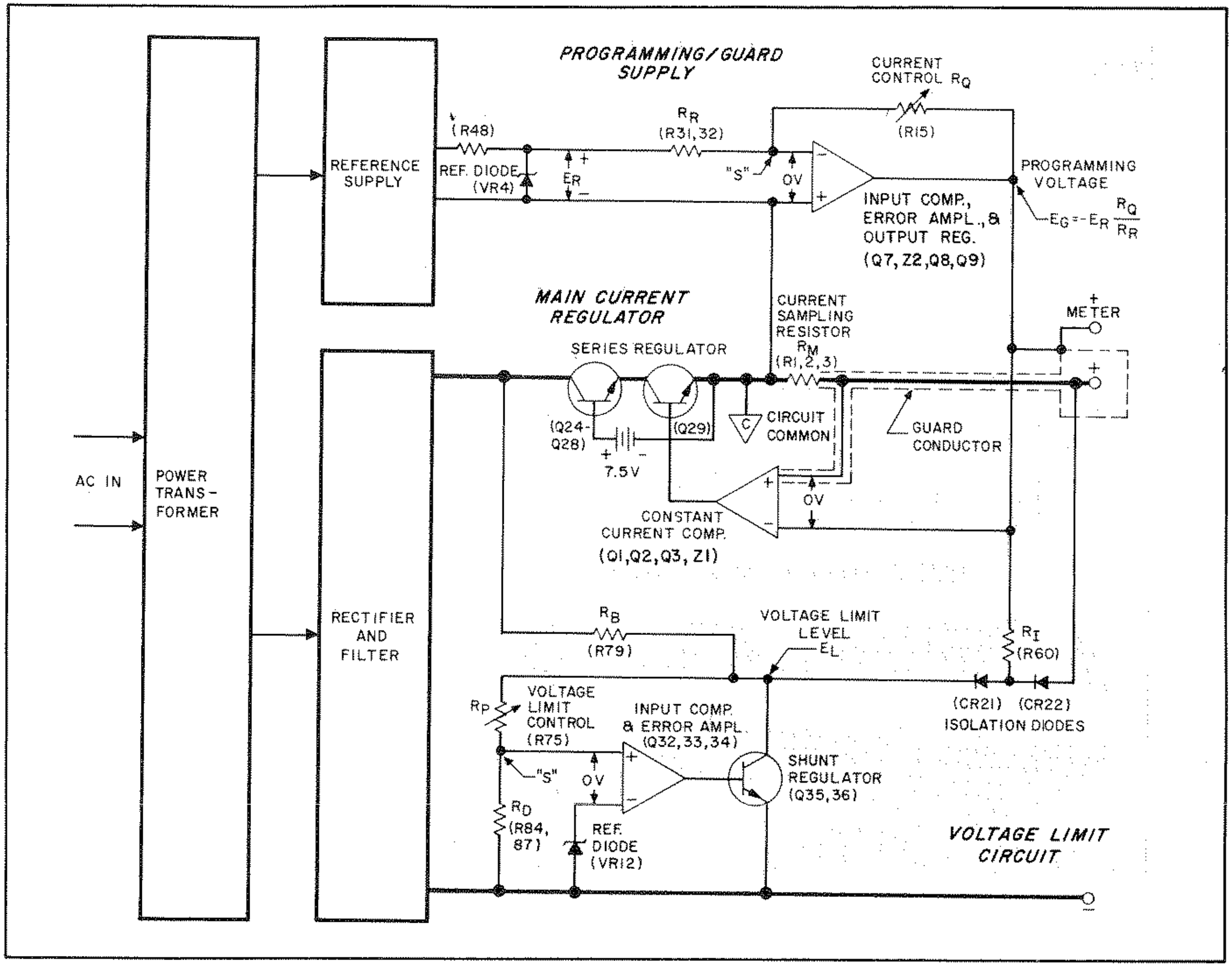


Figure 4-2. Simplified Schematic

bias voltages for the constant current section of the instrument. The supply has four regulated outputs (+12.4V, +7.5V, +6.2V, and -15V). An additional, unregulated output (+29V) is provided for use in the bleed circuit and the voltage limit lamp circuit.

4-13 SIMPLIFIED SCHEMATIC DISCUSSION

4-14 The simplified schematic of Figure 4-2 illustrates the three main circuits in the power supply. These circuits (the programming/guard supply, the main current regulator, and the voltage limit circuit) are delineated by separate shaded areas in the figure. The following paragraphs discuss the functional details of each circuit and the feedback loops formed by the interconnection of the three circuits.

4-15 PROGRAMMING/GUARD SUPPLY

4-16 The programming/guard supply is an independent, regulated, variable voltage supply. The operation of this supply is most easily understood when it is drawn in the standard operational amplifier configuration shown in the top third of Figure 4-2. An input voltage E_R (derived from the reference supply and reference diode) is applied to summing point "S" via resistor R_R. The output voltage E_G is fed back to this same summing point through resistor R_Q (the front-panel CURRENT control). Because the input impedance of the amplifier is high, the input current to the amplifier can be considered negligibly small, and all of the input current flows through both resistors R_R and R_Q. The feedback and the very high gain of the amplifier holds the two inputs to the amplifier equal; therefore, since one input is connected to circuit common (C), summing point "S" is held at zero potential (virtual ground). From the above statements, the standard gain expression for an operational amplifier is easily derived as

$$E_G = -E_R (R_Q/R_R)$$

This equation indicates that the output voltage E_G of the programming/guard supply is linearly dependent upon the setting of the current control, R_Q (doubling the value of R_Q doubles the output voltage). Thus linear control of the regulated output current is assured.

4-17 MAIN CURRENT REGULATOR

4-18 As discussed in Paragraph 4-3, the output of the programming/guard supply provides the programming voltage (E_G) for the main current regulator. This dc voltage, negative with respect to circuit common, is applied to one of the inputs of the constant current comparator. The other input is connected to the current sampling resistor R_M. The constant current comparator continuously compares the voltage drop across the current monitoring resistor ($I_{OUT}R_M$) with the programming voltage (E_G). If these voltages are momentarily unequal due to a load disturbance or change in the output current control setting, the error voltage is amplified and applied to the series regulator transistors, altering the current conducted through them and forcing the voltage drop $I_{OUT}R_M$ to once again equal E_G.

4-19 The output current is thus related to the programming voltage and the reference voltage by the relationship

$$I_{OUT} = E_G/R_M = E_R R_Q/R_R R_M$$

As this equation suggests, current sampling resistor R_M is a critical component and is selected to have low noise, low temperature coefficient, and low inductance. Its ohmic value is large enough to give an adequate current monitoring voltage, yet small enough to minimize its temperature rise and the resulting resistance change caused by its own power dissipation. Note that the same programming voltage is used on all three output current ranges, and that the range is changed by switching the value of the current sampling resistors (see Figure 4-1).

4-20 The high output impedance of the power supply is a result of several factors, both electrical and mechanical. First, the series regulator transistors are in a cascode configuration (see Paragraph 4-50), which has an inherently high output impedance. Second, the high open-loop gain of the constant current comparator and error amplifier provides greatly increased closed-loop output impedance when feedback is introduced. Third, there is no physical output capacitor placed across the output terminals. Although the output impedance falls off with frequency due to the necessary gain and phase compensation in the amplifier circuits, it is much higher than it would be if a capacitor were connected across the output terminals. Finally, the impedances of internal leakage paths have been made as high as possible by careful mechanical design. For example, the series regulator transistors are electrostatically isolated from the chassis by a copper-clad mylar shield connected to circuit common; the transistors are insulated from the shield with a layer of boron nitride which has an extremely high insulation resistance.

4-21 Further reduction in leakage, both internal and external, is achieved through active guarding. The operation of the active guard depends on the fact that the unwanted leakage currents are flowing through some impedance to get into or out of the sensitive circuit. By carefully surrounding the sensitive circuit with a conducting surface or guard, each of the impedances between the sensitive circuit and the outside world can be split into two parts, one between the guard and the sensitive circuit and one between the guard and the rest of the world. When the voltage between the guard and the sensitive circuit is kept at zero, the guard accomplishes its purpose of eliminating unwanted currents flowing into or out of the sensitive circuit. The guard is not connected directly to the sensitive circuit; if it were, then no improvement would result.

4-22 As discussed in Paragraph 4-4 and shown in Figure 4-2 by a dotted line, the positive output terminal, the current sampling resistor, and the non-inverting input to the constant current comparator are all surrounded by a guard conductor connected to the output of the programming/guard supply. The constant current comparator keeps the positive output terminal and the guard conductor within one millivolt of each other for any load or output setting. Any leakage impedance connected to the positive output terminal thus has nearly zero volts across it, and leakage currents are forced to flow through the guard instead of the positive output terminal.

4-23 VOLTAGE LIMIT CIRCUIT

4-24 The basic function of the voltage limit circuit is to provide an adjustable limit on the power supply output voltage. This limit is necessary to prevent the output voltage from rising to the "raw" supply voltage of more than 400 volts when the load is removed; such prevention is necessary for the protection of both load and operator.

4-25 The voltage limit circuit is an independent, regulated, variable voltage supply with output voltage E_L. The voltage divider formed by the voltage limit control R_P and resistor R_D allows a fraction of this output voltage to be applied to one input of a comparator. A zener diode connected to the other input of the comparator establishes a reference voltage. If a difference exists between the reference voltage and the fraction of the output voltage, an error signal is produced by the comparator and applied to the shunt regulator, which varies its conduction until the output voltage E_L is at the level required by the setting of the voltage limit control.

4-26 When voltage limiting action is not occuring, the setting of the voltage limit control establishes across the shunt regulator (as described in Paragraph 4-25) a preset voltage limit E_L which is higher than the positive output voltage and its twin, the guard voltage. Since there is zero volts across the series combination of isolation diode CR22 and resistor R_I, no current flows through them. Potential E_G is thus present at their junction, back-biasing isolation diode CR21. Any small reverse leakage current flowing through CR21 flows through R_I and into circuit common via the programming/guard supply, but does not flow into CR22 or the positive output terminal. The shunt regulator conducts a "standby" current through bias resistor R_B; this current insures that the shunt voltage regulator is operating in its linear region, ready to react quickly when voltage limiting action is required, thus minimizing crossover transients.

4-27 If the output voltage exceeds the preset voltage limit value, CR22 and CR21 conduct, momentarily placing a potential higher than E_L on the collector of the shunt regulator. This unbalances the voltage limit comparator, which causes the shunt regulator to increase its conduction, diverting a portion of the current that would otherwise flow to the load. Since the load receives less current, the output voltage of the supply drops until it reaches the preset voltage limit (E_L), at which point it is clamped by the regulating action of the voltage limit circuit.

4-28 When CR22 and CR21 are conducting, the programming/guard supply provides a current through R_I and CR21 of such magnitude that the voltage drop across R_I exactly equals the forward voltage drop across CR22. This insures the continuing fullfillment of the primary condition required by the main current regulating feedback loop (zero potential between the positive output terminal and the guard conductor). The voltage drop across resistor R_I is also used to trigger the voltage limit light circuit, since the voltage drop is present only when the voltage limit circuit is activated. Note that even during voltage limiting action, the output of the programming/guard supply (E_G) is maintained at a value equal to the potential at the positive output terminal. Both guarding action and the normal control action of the main current regulator continue, minimizing any output current transients which might tend to occur during transfer from voltage limit mode to normal output current mode. Output voltage transients are also minimized, since the voltage limit circuit goes into operation in as little time as it takes to turn on the two isolation diodes.

4-29 DETAILED CIRCUIT ANALYSIS
(See Figure 7-4)

4-30 REFERENCE SUPPLY

4-31 The reference supply is an independent, regulated voltage supply that provides stable bias and reference voltages used throughout the instrument. All the references voltages are derived from raw dc obtained from full wave rectifier CR35-CR38 and filter capacitor C35; all the voltages are measured with respect to the circuit common point (C).

4-32 The regulating circuit consists of differential amplifier Q11-Q12, driver Q14, and series regulator Q15-Q16. Temperature-compensated zener diode VR4, connected to the base of Q12 and biased by resistor R48, provides a stable reference voltage (+6.2 volts with respect to circuit common) for one input of the differential amplifier. The voltage divider formed by resistors R45 and R46 applies half of the +12.4V regulated output (+6.2V) to the other input (Q11 base). The feedback loop functions to maintain the difference between these two inputs at zero. For example, if the +12.4V output momentarily increases, Q11 increases its conduction, which decreases the conduction of Q14 and therefore lowers the base current flowing out of series regulator Q15-Q16. The +12.4V output thus decreases from its higher-than-normal value back to +12.4V.

4-33 Triple-junction diode CR12 sets the operating level for Q14. Note that the output of the differential amplifier is taken from both collectors; this has the effect of doubling the voltage gain of the stage, when compared with the customary single-collector-output differential amplifier configuration. Resistors R41 and R42 in the emitters of series regulating transistors Q15 and Q16 cause the current through the two transistors to be shared equally; R40 is a bleed resistor that allows turn-on of the reference supply by providing a current path into the output of the regulator. Diode CR14 is one of many turn-on/turn-off didoes used throughout this instrument. In general, the function of these diodes is to eliminate output current and voltage transients when the unit is first turned on or when input power is suddenly removed. Specifically, CR14 blocks series regulator bias and bleed current flow through VR3, VR5, and C15 to circuit common (and thus to the output of the unit) at turn-off.

4-34 Zener diode VR7, biased from the +12.4V output through CR16 and R68, provides a regulated +7.5V output; VR3 and VR5 provide a regulated -15V output. An additional unregulated +29V output (used in the voltage limit lamp circuit and the bleed circuit) is drawn from the positive end of C35.

4-35 PROGRAMMING/GUARD SUPPLY

4-36 The programming/guard supply is an independent, regulated, variable voltage supply. As described in Paragraph 4-4, it provides the programming voltage for the constant current comparator, and also provides a guard potential that eliminates leakage currents flowing between the instrument's output terminals. Paragraph 4-16 describes the operation of the programming/guard supply in operational amplifier terms; the following paragraphs describe the supply's operation on a stage-by-stage basis.

4-37 The programming/guard supply consists of a differential amplifier and associated constant current source (Q7A-Q7B and Q5), an error amplifier (Z2), and an output regulator (Q8 and Q9). The differential amplifier consists of two matched silicon transistors housed in a single package; this configuration minimizes thermal differential drift since both transistors operate at the same temperature. Transistor Q5, connected as a constant current source, biases the emitters of both transistors in the package. Q5 is biased with the combination of VR1 and R34; these components are shared with Q4 in the constant current comparator. One input of the differential amplifier (Q7A base) is connected to the circuit common point through resistor R30. The other input (Q7B base) is connected to a summing point (terminal A1) at the junction of programming resistor R15 and current pullout resistors R31 and R32. Diodes CR7, CR8, and CR49 form a limiting network that protects the input from overvoltage. Potentiometer R29 (GUARD ZERO ADJUST) allows the differential amplifier base-to-base voltage to be balanced by varying the ratio of the differential amplifier's collector currents.

4-38 Instantaneous changes in the output of the programming/guard supply (terminal A0) result in an increase or decrease in the summing point potential; this unbalances the differential amplifier and produces an error signal. The error signal is amplified and fed to the programming/guard supply's output regulator, which alters its conduction sufficiently to return the output voltage to its former level (selected by the setting of CURRENT control R15) and thus balance the differential amplifier. Because the summing point is held at a virtual ground by the high gain of the supply's feedback loop, a constant current flows from the +6.2V reference through R31 and R32; this produces a constant current through the programming potentiometer, which insures linear programming. Resistor R33, connected in parallel with R31 and R32, provides an extra current that allows for the tolerance of R15; this insures full-range programming.

4-39 Amplifier Z2 is a high-gain, bipolar output, IC operational amplifier. Components C7, C9 C10, C11, R25, and R36 provide gain and phase compensation for the stage; CR9 and CR10 form a limiting network that protects the input from overvoltage.

4-40 The programming/guard supply output regulator is a push-pull emitter follower. Its function is to maintain the programming/guard voltage (variable between 0 and minus 10 volts with respect to circuit common) at the level set by the CURRENT control. If a change in the CURRENT control setting requires the voltage to decrease (become less negative), the positive error signal produced by Z2 drives Q9 into greater conduction and decreases the conduction of Q8, pulling the output voltage towards +12.4V. If the voltage is required to increase (become more negative), the negative error signal produced by Z2 drives Q8 into greater conduction and decreases the conduction of Q9, pushing the output voltage towards -15V. This push-pull action results in much faster programming than if a single-ended stage were used. Zener diode VR6, connected across load resistor R19 and output filter capacitor C1, prevents the programming/guard supply output voltage from going positive at turn-off or from exceeding -12.4V. The combination of VR6 and CR43, connected in series from the minus output terminal to circuit common, also provides reverse voltage protection for the entire instrument.

4-41 CONSTANT CURRENT COMPARATOR

4-42 The constant current comparator is a differential amplifier whose function is to compare the voltage drop across the current sampling resistor with the output voltage of the programming/guard supply, and to produce an error signal proportional to the difference. As discussed in Paragraph 4-18, the error signal is applied to the series regulator, which alters its conduction until the IR drop across the sampling resistor equals the programming/guard supply voltage, thus keeping the output current constant at the desired level.

4-43 The constant current comparator consists of a differential amplifier and associated constant current source (Q1A-Q1B and Q4), a differential driver amplifier (Q2-Q3) and an output amplifier (Z1). As in the guard supply, the differential amplifier consists of two matched silicon transistors in a single package. The emitters of the differential amplifier are biased by constant current source Q4; as mentioned in Paragraph 4-37, the biasing components for Q4 (VR1 and R34) are shared with Q5 in the programming/guard supply. One input of the differential amplifier (Q1B base) is connected to the output of the programming/guard supply (terminal A0) through jumper J1 (used in the troubleshooting procedure); the other input (Q1A base) is connected to the outboard side of the appropriate current sampling resistor (R1, R2, and/or R3) through R16 and current RANGE switch S2. Diodes CR3, CR4 and CR48 form a limiting network that protects the input from overvoltage. R16 limits the peak current that output transients can inject into the programming/guard supply through CR3 (and also acts as a fuse). Potentiometer R11 (CONSTANT CURRENT COMPARATOR ZERO ADJUST) allows the differential amplifier base-to-base voltage to be balanced by varying the collector voltage on Q1A.

4-44 Differential driver amplifier Q2-Q3 is an emitter follower; its primary function is to match the relatively high output impedance of differential amplifier Q1A-Q1B to the relatively low input impedance of amplifier Z1. CR1 and CR2 form a limiting network similar in purpose to CR3 and CR4.

4-45 Output amplifier Z1 is a high-gain, bipolar output, IC operational amplifier. Components C2, C4, C5, C33, and R4, provide gain and phase compensation for the stage. At turn-on, diodes CR50 and CR51 clamp the output of amplifier Z1 until the series regulator is turned on and the current feedback loop stabilizes. This prevents C2 from charging up to +12.4 volts and delaying the start of regulation until it discharges. The amplifier acts as a variable current sink for the drive current supplied to the series regulator through transistor Q22 in the turn-on/turn-off control (see Paragraph 4-47). For example, if the sampling resistor voltage drop is momentarily higher than the output voltage of the programming/guard supply, amplifier Z1 increases its conduction and diverts more drive current away from the series regulator, causing a corresponding decrease in the regulated output current. This decrease causes the sampling resistor voltage to drop, returning the differential amplifier to a balanced condition. Diode CR17, connected in the error amplifier's output line, prevents the amplifier output from reversing and driving current into the series regulator (such current would generate an unwanted turn-on signal).

4-46 TURN-ON/TURN-OFF CONTROL

4-47 The turn-on/turn-off control consists of a pair of long-time-constant networks that allow the supply to achieve a gradual turn-on and turn-off characteristic by controlling the drive current to the series regulator. The source of the drive current is the +12.4V reference voltage; the path the current follows during normal operation is through CR16 into the emitter of Q22 (saturated during normal operation), out the collector through R69 and CR45, and into Q29 and Z1. At turn-on, capacitor C18 initially couples -15V to the base of Q29, keeping it in cutoff. The series regulator drive current is thus diverted through CR34 into C18. As C18 charges, CR34 becomes back-biased and CR45 becomes forward biased, switching the drive current into the series regulator. Capacitor C18 then continues charging through R65, insuring that CR34 remains back-biased. Diode CR6 provides a discharge path for C18 at turn-off, resetting the circuit for another turn-on cycle.

4-48 At turn-off, the voltage on capacitor C21 (discharging through R66) falls slowly compared to the +12.4V reference. This reverse biases the base-emitter junction of Q22, immediately turning it off and interrupting the series regulator drive current. The series regulator is thus prevented from remaining on while its bias voltages are falling (such a condition could result in uncontrolled output current transients).

4-49 SERIES REGULATOR

4-50 The series regulator is the heart of the constant current supply; it regulates the output current by altering its conduction in accordance with the feedback signal from the constant current comparator and the main error amplifier. Reduced to its basic form (see "Main Current Regulator" block in Figure 4-2), the circuit consists of a common emitter stage in series with a common base stage. This configuration, called "cascode" in technical literature, effectively combines the advantages and eliminates the disadvantages of each of the two types of circuits. A common base stage has high output impedance (very desirable in a constant current source), but is difficult to drive because all the drive current must go through the collector bias source. A common emitter stage, while easy to drive, has a relatively low output impedance. Combining these two circuits in a cascode configuration results in an amplifier that is both easy to drive _and_ has a high output impedance.

4-51 Referring to the schematic diagram (Figure 7-4), it can be seen that transistor Q29 is the common emitter stage (emitter connected to circuit common through R50); and that Q24 through Q28, when taken as a unit, form the common base stage (base connected to circuit common through the reference supply). Transistors Q24 and Q26 form a Darlington pair, as do transistors Q25 and Q27 (leakage resistors R62 and R63 can be considered as having negligible effect upon the Darlington action). Viewing each pair as a single transistor, it can be seen that Q24-Q26, Q25-Q27, and Q28 form a string of three equally-biased, common-base stages (R73, R72, R71, VR2, and R51 form the bias network). Three series stages are required due to the high power dissipation involved. Zener diodes VR101 through VR106 protect each of these three series stages from excessive voltage due to the unequal voltage division that might occur during a transient caused by shorting the output. Note that the use of Darlington pairs in this circuit reduces the power dissipation in the bias network, since the drive current of Q26 and Q27 flows through Q24 and Q25 instead of R73 and R72.

4-52 Diode CR18 limits the reverse bias on the base-emitter junction of Q29. CR19 provides a path for the series regulator bleed current at turn-on (through the +29V unregulated reference supply voltage to circuit common). C20 and R70 shape the frequency response of the series regulator.

4-53 BLEED CIRCUIT

4-54 The bleed circuit maintains a continuous current flow through the series regulator, keeping it on and in its active region at all times. The circuit has two internal current paths—an "active" path and a "passive" path. Resistors R100 and R101, connected from +29V to the negative output bus (and thus effectively from circuit common to the negative output bus), form the "passive" path. These resistors draw a current through the series regulator whose magnitude is proportional to the supply output voltage.

4-55 In order to maintain the bleed current at a relatively constant value over the complete range from no load to full load, another current path ("active") is provided by transistors Q37 and Q39. These transistors form a variable current sink whose conduction is controlled by driver Q38. The base of Q38 senses a portion of the output voltage at the guard conductor through voltage divider R98-R99. As the output voltage decreases, Q38 increases its conduction, thus increasing Q37's conduction. This increase in current approximately balances the decrease in the current flowing through R100 and R101; thus the total current drawn through the series regulator by the bleed circuit is maintained at a relatively constant level.

4-56 Driver stage Q38 is biased from the lower end of R115B in the voltage limit circuit. This point, maintained at approximately +11.2V by VR12 and VR13, serves as a bias voltage source for Q32, Q33, and Q34 in the voltage limit circuit as well as Q38 in the bleed circuit. Sink transistor Q39 is biased by R100 and R101; R94 is a "power sharing" resistor that reduces the power dissipation in Q37 and Q39. Diodes CR39 and CR40 are base-emitter junction protection diodes. Diode CR25 prevents reverse current flow from the +11.2V bias voltage source into the guard conductor. Diodes CR30 and CR44 are turn-on/turn-off diodes; CR30 (normally off) and CR44 (normally on) allow current to flow from the 11.2V bias voltage supply point through R100 and R101 at turn-off, thus keeping transistors Q37 and Q39 biased on as the +29V reference supply voltage is falling.

4-57 VOLTAGE LIMIT CIRCUIT

4-58 The operation of the voltage limit circuit is explained functionally in Paragraphs 4-24 through 4-28. In summary, the voltage limit circuit is an independent, regulated, variable voltage supply that establishes a preset voltage limit across the shunt regulator. When the output voltage is less than the limit voltage, isolation diode CR22 has zero volts across it, and CR21 is reverse biased. When the output voltage slightly exceeds the preset limit voltage, CR22 and CR21 conduct, allowing a portion of the output current to be diverted away from the load and through the shunt regulator.

4-59 The voltage limit circuit consists of a differential amplifier (Q33-Q34), an error amplifier (Q32), and a shunt regulator (Q35-Q36). One input of the differential amplifier (Q34 base) senses a fraction of the voltage limit circuit output voltage via the variable voltage divider formed by R84-R87 and R85-R86 in series with VOLTAGE control R75. The other input (Q33 base) is connected to zener diode VR12. This diode, connected in series with VR13 and biased through R115A-R115B, establishes a +5.6V reference against which the fraction of the limit voltage appearing at the other input is compared. The combination of VR12 and VR13 also establish a +11.2V bias voltage source for Q32, Q33, and Q34 in the voltage limit circuit as well as Q38 in the bleed circuit. Diodes CR27 and CR29 form a limiting network which protects against breakdown from overvoltage. Selected resistor R87 adjusts the value of the current (supplied by the voltage limit programming current source; see Paragraph 4-64) required to flow through R84-R87 to produce a voltage drop exactly equal to that produced by VR12. Since this current is also flowing through programming potentiometer R75, adjusting the current adjusts the voltage limit programming coefficient. Selected resistor R86 compensates for tolerance variations in VR8. By making the sum of the voltage drops across VR12, R85-R86, and the end resistance of R75 equal to the sum of the voltage drops across VR8 and CR20, the voltage limit can be adjusted to approximately zero when programmed to zero.

4-60 The feedback loop functions to maintain the difference between the two inputs to the differential amplifier at zero. For example, if the voltage limit level (appearing at the collector of Q35) suddenly increases, Q34 increases its conduction, driving error amplifier Q32 and shunt regulator

Q35-Q36 into greater conduction. The voltage limit level thus decreases from its higher-than-desired level back to the level at which the differential amplifier is balanced. The function of Q32 is thus to amplify the error signal produced by the differential amplifier to a level sufficient to drive the shunt regulator. Diode CR31 protects Q32 in the event of a collector-base short in either Q35 or Q36; zener diode VR19 limits the maximum current flow through Q35 and Q36.

4-61 The shunt regulator must dissipate power over a relatively wide range of voltages and currents. Over most of this range, Q35 functions as a driver for Q36 while Q36 shunts the necessary current and shares the power dissipation with collector load resistors R117, R118, and R119. If the shunt regulator must shunt a relatively high current while a relatively low voltage limit is programmed, however, the ability of Q36 to conduct sufficient current is limited by these collector resistors. Under these circumstances, Q36 goes into saturation and Q35 shunts the additional current required to maintain the programmed voltage limit. This additional current flows through the base-emitter junction of Q36. Capacitor C25 catches the initial voltage limit transient that occurs each time the circuit goes into voltage limit; resistor R91 discharges C25 at turn-off. Bias resistor R79 allows the shunt regulator to conduct a "standby" current and allows C25 to be charged to the desired level; this insures that the regulator is always operating in its linear region, ready to react quickly when voltage limiting action is required. Diodes VR9, VR10, VR11, VR14, VR15, and CR42, connected in series from the negative output bus to the collector of the shunt regulator transistors, protect the transistors by preventing the voltage across them from exceeding approximately 360 volts (such protection becomes necessary if the supply is inadvertently operated without the strap connecting rear terminals A5 and A6).

4-62 The zener diode string discussed in Paragraph 4-61 also provides protection for the series regulator. If the output voltage of the supply exceeds approximately 345 volts (as would happen when the strap between A5 and A6 was removed under no-load conditions), diode CR41 conducts. This action diverts most of the series regulator drive current (supplied from Q22) through the zener string and thus limits the voltage applied to the series regulator to less than 345 volts. Under this condition, zener diode VR15 holds the voltage limit approximately 16 volts higher than the voltage on the series regulator.

4-63 Zener diodes VR16 and VR17 provide a bias voltage that allows the output of the supply to be set completely to zero. Without these diodes, the minimum output voltage appearing between the output terminals would be the sum of the forward drops of CR21 and CR22, the minimum V_{CE} (collector-emitter voltage) of Q35 and Q36, and the drop across emitter resistors R116 and R93, minus the forward drop of CR26. With these diodes connected between the shunt regulator transistors and the negative output terminal, the effect of these voltage drops is neutralized and the minimum output voltage appearing between the output terminals becomes zero. Resistor R114, connected across the diodes, limits the maximum resistance of the circuit. Diode CR46, connected from the junction of the voltage doubler filter capacitors to the junction of R115A-R115B, is another turn-on/turn-off diode; it allows C32 to charge up rapidly when the supply is first turned on, thus allowing the voltage limit circuit to take effect <u>before</u> the series regulator is activated.

4-64 VOLTAGE LIMIT PROGRAMMING CURRENT SOURCE

4-65 The voltage limit programming current source provides the programming current that flows through VOLTAGE control R75 and resistors R85-R86 and R84-R87. This current produces a voltage drop across R84-R87 exactly equal to the voltage drop across VR12. The output of the programming current source is always greater than the current value required to satisfy the above condition; any additional current flows through VR8 and CR20 into the shunt regulator. Note that this "excess" current is actually necessary to maintain the voltage limit circuit's regulation, since the current through the shunt regulator must be variable in order to allow the feedback loop to reach a stable regulating condition. During rapid down-programming, diode CR20 becomes back-biased (because the voltage at the top of R75 is falling faster than C25 can discharge through the shunt regulator), allowing the "excess" current to flow through the programming potentiometer and R84-R87. The programming current source thus limits the maximum current that can flow through R75, R85-R86, and R84-R87. If CR20 were not present in the circuit, C25 would discharge through these components, possibly damaging R75.

4-66 The current source is comprised of two series stages, Q30 and Q31. Functionally, these two transistors (and R78) can be considered as one transistor (two series transistors are required only because of the high voltages involved). Base bias for Q30 and Q31 is provided by R77, R78, and CR23; note that the voltage across these components varies from approximately 100 volts to over 400 volts as the voltage limit setting is varied. Thus the total output current of the programming current source is variable and depends on the voltage limit setting; the difference between the current flowing through R84-R87 and the total current is the "excess" current mentioned in Paragraph 4-65. Zener diode VR8 adds an extra bias voltage to the output of the voltage limit circuit. By allowing the voltage limit circuit output to be depressed below the reference voltage at the summing point (+5.6V), the voltage limit can be set to approximately zero.

4-67 VOLTAGE LIMIT LIGHT CIRCUIT

4-68 The voltage limit lamp circuit energizes the front-panel LIMIT lamp whenever the voltage limit circuit is activated. As mentioned in Paragraph 4-28, a voltage drop equal tothe forward drop across CR22 is developed across R60 (R_I) whenever the voltage limit circuit is triggered; this voltage, appearing on the base of Q20, is the turn-on signal for the limit light circuit.

4-69 Transistors Q20 and Q21 form the voltage limit sensing switch. When the limit light is not on, Q21 is on and Q20 is off. Emitter current for Q20 is supplied by constant current source Q19. Components R57, R58, R59, and CR13 provide base bias for Q21 and allows the switch to function properly in the presence of a varying common mode voltage (the 0 to -10V output of the programming/guard supply appears between the guard and circuit common). When the circuit is activated, Q20 turns on and Q21 turns off, driving Q17 into conduction. Current thus flows from +29V through R55, LIMIT light DS2, and Q17 to -15V. VR18 keeps a constant 5.6V across the light, preventing lamp burnout from overvoltage.

4-70 METER CIRCUIT

4-71 The ammeter (M2), connected between circuit common and the guard, measures the output voltage of the programming/guard supply. As explained in Paragraphs 4-3 and 4-11, the constant current comparator holds the drop across the current sampling resistor equal to this output (reference) voltage; the ammeter thus indicates the programmed output current. Potentiometer R106 allows calibration of the ammeter. The voltmeter (M1) is connected between the guard and the negative output terminal. As explained in Paragraph 4-22, the guard conductor is maintained at the same potential as the positive output terminal; the voltmeter thus indicates the output voltage of the supply. Potentiometer R110 allows calibration of the voltmeter.

4-72 VOLTAGE DOUBLER

4-73 The voltage doubler circuit is comprised of diodes CR32 and CR33, and capacitors C30 and C31. The circuit operates as follows: during the negative half-cycle of the input voltage, C31 is charged through CR33 to one half the peak-to-peak voltage appearing across the secondary of transformer T1. During the positive half-cycle of the input voltage, capacitor C30 is charged through CR32 to the same level. Thus the output voltage, appearing across the series combination of C30 and C31, is double the value it would be for a full wave bridge circuit.

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 5-38). After repair and replacement (Paragraph 5-47), perform any necessary adjustments and calibrations (Paragraph 5-51). 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 one 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: 1mV full scale (min.). Input impedance: 10 megohms (min.). Resolution: 1 ppm of range.	Measure dc voltages; calibration procedures.	HP 3420A/B (See Note)
Variable Voltage Transformer	Range: 90-130 volts. Output current: 2 amperes (min.). Equipped with voltmeter accurate within 1 volt.	Vary ac input.	---
AC Voltmeter	True rms. Sensitivity: 0.1mV full scale deflection (min.). Accuracy: 2%.	Measure ac voltages and rms ripple.	HP 3400A
Oscilloscope	Differential input. Sensitivity and bandwidth: 100μV/cm and 500kHz for general measurements; 5mV sensitivity and 50MHz bandwidth for noise spike measurement or to check for high frequency oscillation.	Measure ripple; display transient response waveforms; measure noise spikes.	HP 180A with 1821A time base and 1806A vertical plug-in; 1801A plug-in for measurements requiring a wide bandwidth.
DC Volt-Ammeter	Voltage sensitivity: 1mV full scale (min.). Current sensitivity: 1mA full scale (min.). Accuracy: 2%.	Measure dc voltages and currents.	HP 412A
Repetitive Load Switch	Switching Rate: 60 — 400Hz. Rise time: 2μsec.	Measure transient response and programming speed.	See Figures 5-5 and 5-7
Resistive Loads	Values: See Figure 5-3. 30W, 3, 0. 3W ($R_{L1, 2, 3}$) (must be noninductive) 1%	Power supply load resistors.	---

Table 5-1. Test Equipment Required (Continued)

TYPE	REQUIRED CHARACTERISTICS	USE	RECOMMENDED MODEL
Current Sampling Resistors	Values: See Figure 5-3. 0.5%, 5ppm, 4-Terminal, 10W, 1/2W, 1/2W ($R_{S1, 2, 3}$) (Must be non-inductive)	Measure output current; calibrate ammeter.	R1, R2 and R3; see parts table
Decade Resistance Box	Range: 0-100K. Accuracy: 0.1% plus 1 ohm. Make-before-break contacts.	Adjust programming accuracy.	---

NOTE

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 50mV meter movement with a 100 division scale. For the latter, a 2mV change in voltage will result in a meter deflection of four divisions..

CAUTION

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

5-5 PERFORMANCE TEST

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 115Vac, 60Hz, single phase input power source. If the correct result is not obtained for a particular check, do not adjust any internal controls; proceed to troubleshooting (Paragraph 5-38).

5-7 CONSTANT CURRENT TESTS

5-8 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 5-2). In addition, the resistors should be of the precision, low noise, low temperature coefficient (less than 5ppm/°C) type and should be used at no more than 10% of their rated power so that their temperature rise will be minimized.

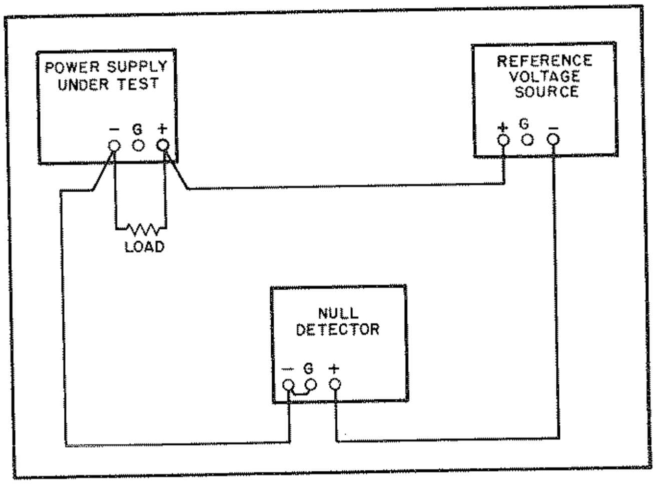


Figure 5-1. Differential Voltmeter Substitute Test Setup

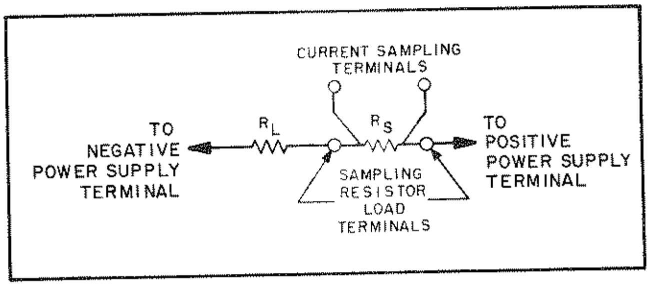


Figure 5-2. Current Sampling Resistor Connections

NOTE

If difficulty is experienced in obtaining adequate sampling resistors, it is recommended that duplicates of the sampling resistors (R1, R2, and R3) used in the unit be obtained from the factory.

5-9 The monitoring device should be connected across the current sampling resistors as shown in Figure 5-3. As indicated in this illustration, neither output terminal of the power supply is grounded and the measuring device case is connected to the junction of the load and sampling resistors. This arrangement prevents ground loop paths and minimizes shunt current paths. The external range switch must have a high insulation resistance (100000MΩ or greater) to avoid significant leakage that would degrade the performance of the supply

5-10 RATED OUTPUT AND METER ACCURACY

5-11 Current. To check the output current on all three ranges, proceed as follows:

a. Connect test setup shown in Figure 5-3, leaving switch S2 open throughout test.

b. Turn VOLTAGE control fully clockwise.

c. Set front panel RANGE switch to 100mA position, set external test setup range switch S1 to high position, connect + terminal of differential voltmeter to R_{S1}, and turn on supply.

d. Adjust CURRENT control until front panel ammeter indicates exactly 100.

e. Differential voltmeter should read 10 ±0.24Vdc. If it does not, refer to ammeter calibration procedure in Paragraph 5-55.

f. Repeat Steps (d) and (e) with front panel RANGE switch set to 10mA position, external test setup range switch S1 set to medium position, and differential voltmeter connected to R_{S2}.

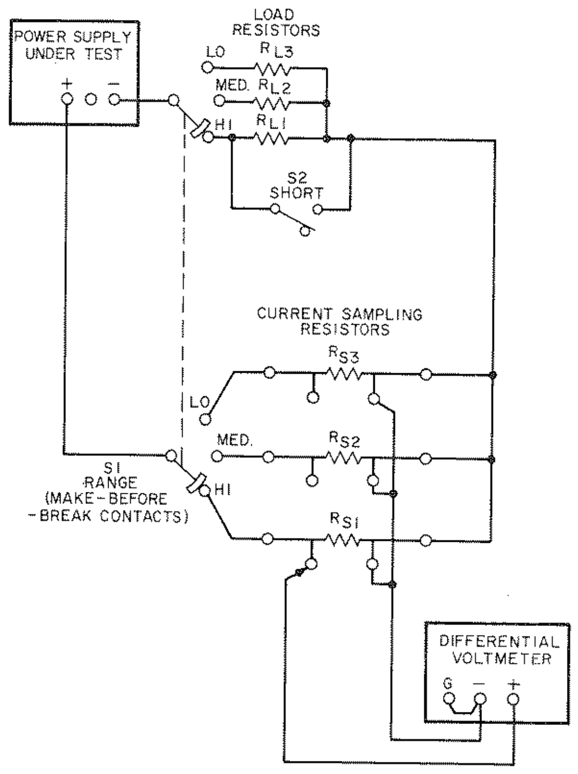
g. Repeat Steps (d) and (e) with front panel RANGE switch set to 1mA position, external test setup range switch S1 set to low position, and differential voltmeter connected to R_{S3}.

5-12 Voltage. To check the output voltage, proceed as follows:

a. Connect test setup shown in Figure 5-3, except connect differential voltmeter between +METER and (-) output terminals or between A0 and (-) output terminals (see Figure 3-7). Leave switch S2 open throughout test.

b. Set front panel RANGE switch to 100mA position and set external test setup range switch S1 to high position.

c. Turn VOLTAGE control fully clockwise



MODEL NO.	HIGH RANGE		MEDIUM RANGE		LOW RANGE	
	R_{S1}	R_{L1}	R_{S2}	R_{L2}	R_{S3}	R_{L3}
6177C	2Ω	98Ω	20Ω	980Ω	200Ω	9.8K
6181C	10Ω	390Ω	100Ω	3.9K	1K	39K
6186C	100Ω	2.9K	1K	2.9K	10K	290K

Figure 5-3. Output Current Test Setup

and turn on supply.

d. Adjust CURRENT control until front panel voltmeter indicates exactly 300Vdc.

e. Differential voltmeter should read 300 ±7.2Vdc. If it does not, refer to voltmeter calibration procedure in Paragraph 5-57.

5-13 Load Effect (Load Regulation)

Definition: The change ΔI_{OUT} 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.

5-14 To check the constant current load regulation on all three output current ranges, proceed as follows:

a. Connect test setup shown in Figure 5-3.

b. Turn VOLTAGE control fully clockwise.

c. Set both range switches (front panel

RANGE switch and external test setup range switch S1) to highest current position (100mA and "HI", respectively), connect + terminal of differential voltmeter to R_{S1}, and turn on supply.

d. Adjust current control until front panel ammeter reads exactly 100.

e. Read and record voltage indicated on differential voltmeter.

f. Short out load resistor R_{L1} by closing switch S2.

g. Reading on differential voltmeter should not vary from reading recorded in Step (e) by more than 300µVdc.

h. Repeat Steps (d) through (g) with both range switches set to middle current range (10mA and "MED") and differential voltmeter connected to R_{S2}.

i. Repeat Steps (d) through (g) with both range switches set to lowest current range (1mA and "LO") and differential voltmeter connected to R_{S3}.

5-15 Source Effect (Line Regulation)

Definition: The change ΔI_{OUT} in the static value of dc output current resulting from a change in ac input voltage over the specified range from low line (104 or 208 volts) to high line 127 or 254 volts), or from high line to low line.

5-16 To check the constant current line regulation on all three current ranges, proceed as follows:

a. Connect test setup shown in Figure 5-3. In addition, connect variable autotransformer between input power source and power supply power input.

b. Turn VOLTAGE control fully clockwise.

c. Set both range switches to highest current position, connect differential voltmeter to R_{S1}, and turn on supply.

d. Adjust autotransformer for a low line input.

e. Adjust CURRENT control until front panel ammeter reads exactly 100.

f. Read and record voltage indicated on differential voltmeter.

g. Adjust autotransformer for a high line input.

h. Reading on differential voltmeter should not vary from reading recorded in Step (f) by more than 300µVdc.

i. Repeat Steps (d) through (h) with both range switches set to middle current range and differential voltmeter connected to R_{S2}.

j. Repeat Steps (d) through (h) with both range switches set to lowest current range and differential voltmeter connected to R_{S3}.

5-17 PARD (Ripple and Noise)

Definition: The residual ac current which is superimposed on the dc output current of a regulated supply. Ripple and noise is specified and measured in terms of both its rms and peak-to-peak value.

5-18 RMS Measurement. To check the rms ripple and noise on all three current ranges, proceed as follows:

a. Connect test setup shown in Figure 5-3, substituting true rms ac voltmeter for differential voltmeter (neither terminal grounded) and connecting positive terminal of supply to ground.

NOTE

To prevent extraneous 60Hz pickup, the external range switch (S1) and load resistors (R_L and R_S) should be enclosed in a shielded box. In addition, the leads connecting the sampling resistor to the ac voltmeter should be twisted or shielded.

b. Turn VOLTAGE control fully clockwise.

c. Set both range switches to the highest current range, connect + side of ac voltmeter to R_{S1}, and turn on supply.

d. Adjust CURRENT control until front panel meter indicates exactly 100.

e. AC voltmeter should read less than 2mV rms. If it does not, refer to Paragraph 5-59.

f. Repeat Steps (d) and (e) with both range switches set to middle current range and ac voltmeter connected to R_{S2}.

g. Repeat Steps (d) and (e) with both range switches set to lowest current range and ac voltmeter connected to R_{S3}.

5-19 High Frequency Noise Measurement. When measuring high frequency noise, an oscilloscope of sufficient bandwidth (20MHz or more) must be used. Figure 5-4A shows the correct method of measuring the output ripple of a constant current supply using a single-ended scope. Ground loop paths are broken by floating the oscilloscope case with a 3-to-2 adapter.

5-20 Either a twisted pair or (preferably) a shielded two-wire cable should be used to connect the output terminals of the power supply to the vertical input terminals of the scope. When using shielded two-wire, it is essential for the shield to be connected to ground at one end only to prevent ground current from flowing through this shield and inducing a noise signal in the shielded leads.

5-21 To verify that the oscilloscope is not displaying ripple induced in the leads or picked up from the grounds, the (+) scope lead should be shorted to the (-) scope lead at the power supply terminals. The ripple value obtained when the leads are shorted should be subtracted from the actual ripple measurement.

5-22 In most cases, the single-ended scope method of Figure 5-4A will eliminate non-real components of ripple and noise well enough to allow a satisfactory measurement to be obtained. However, in more stubborn cases or in measurement situations where it is essential that both the power supply case and the oscilloscope case be connected 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 5-4B. 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 displays only the difference in signal between its two vertical input terminals, thus ignoring the effects of any common mode signal produced by the difference in the ac potential between the power supply case and scope case. Before using a differential input scope in this manner, however, it is imperative that the common mode rejection capability of the scope be verified by shorting together its two input leads at the power supply and observing the trace on the CRT. If this trace is a straight line, then the scope is properly ignoring any common mode signal 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 manufacturer's instructions until proper common mode rejection is attained.

5-23 To check the high frequency noise output on all three ranges, proceed as follows:

a. Connect test setup shown in Figure 5-4A or 5-4B.

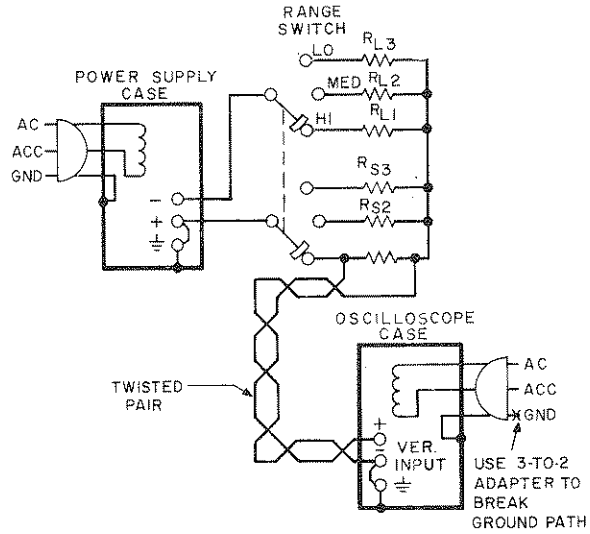
b. Set both range switches to highest current range, turn VOLTAGE control fully clockwise, and turn on supply.

c. Adjust CURRENT control until front panel ammeter indicates exactly 100.

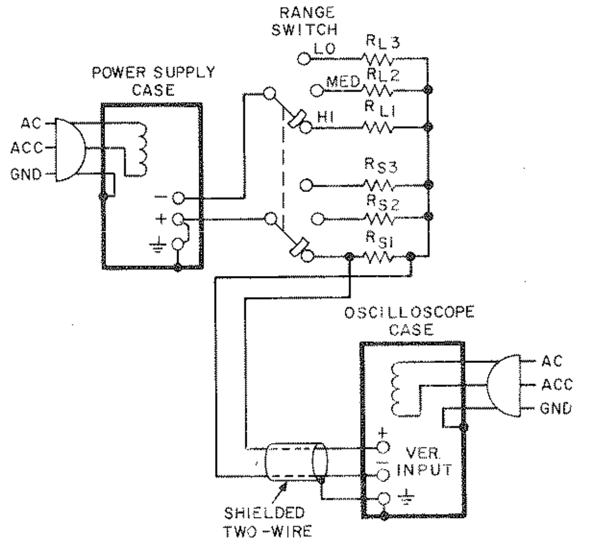
d. Noise reading on oscilloscope should be less than 50mV p-p.

e. Repeat Steps (b) and (c) with both range switches set to middle current range. Noise reading should be less than 50mV p-p.

f. Repeat Steps (b) and (c) with both range switches set to lowest current range. Noise reading should be less than 40mV p-p.



A. MEASUREMENT METHOD USING A SINGLE-ENDED SCOPE. 3-TO-2 ADAPTER BREAKS GROUND CURRENT LOOP; TWISTED PAIR REDUCES STRAY PICKUP ON SCOPE LEADS



B. BETTER METHOD USING DIFFERENTIAL SCOPE WITH FLOATING INPUT. GROUND CURRENT PATH IS BROKEN; COMMON MODE REJECTION OF DIFFERENTIAL INPUT SCOPE IGNORES LIKE POLARITY INPUTS; SHIELDED WIRE FURTHER REDUCES STRAY PICKUP ON SCOPE LEADS.

NOTES:
FOR VALUES OF LOAD RESISTORS (R_L AND R_S) SEE FIGURE 5-3 AND TABLE 5-1 FOR HIGH FREQUENCY MEASUREMENTS, LOW INDUCTANCE RESISTORS SHOULD BE USED.

Figure 5-4. High Frequency Ripple and Noise Test Setup

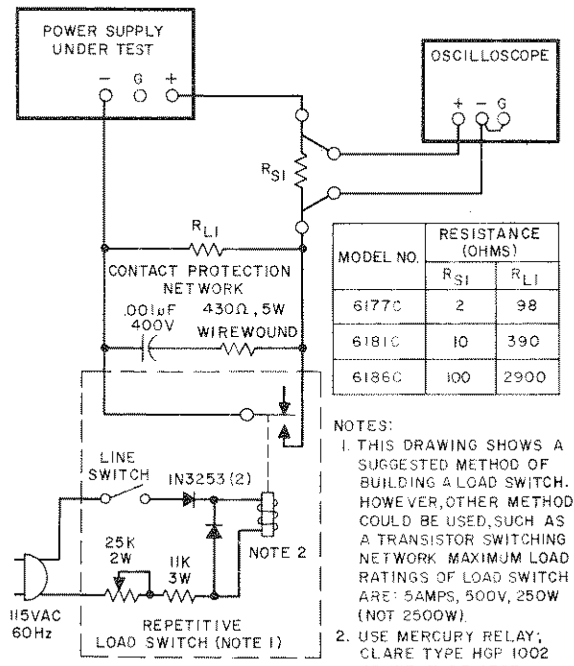
5-24 Load Transient Recovery Time

Definition: The time "X" for output current recovery to within "Y"

milliamps of the nominal output current following a "Z" amp step change in load voltage, where:
"Y" is generally of the same order as the load regulation specification;
the nominal output current is defined as the dc level halfway between the static output current before and after the imposed load change; and "Z" is the specified load voltage change, normally equal to the full load voltage rating of the supply.

5-25 Transient recovery time may be measured at any input line voltage combined with any output voltage and load current within rating.

5-26 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 the switching action completely masks the display with a noise burst. Transistor load switching devices are expensive if reasonably rapid load current changes are to be achieved.



MODEL NO.	RESISTANCE (OHMS)	
	R_{S1}	R_{L1}
6177C	2	98
6181C	10	390
6186C	100	2900

NOTES:
1. THIS DRAWING SHOWS A SUGGESTED METHOD OF BUILDING A LOAD SWITCH. HOWEVER, OTHER METHODS COULD BE USED, SUCH AS A TRANSISTOR SWITCHING NETWORK. MAXIMUM LOAD RATINGS OF LOAD SWITCH ARE: 5AMPS, 500V, 250W (NOT 2500W).
2. USE MERCURY RELAY; CLARE TYPE HGP 1002 OR W.E. TYPE 2768

Figure 5-5. Load Transient Recovery Time, Test Setup

5-27 A mercury-wetted relay, 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.

5-28 To check the load transient recovery time of the supply, proceed as follows:

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

b. Turn VOLTAGE control fully clockwise.

c. Set front panel RANGE switch to 100mA position and turn on supply.

d. Adjust CURRENT control until front panel ammeter indicates exactly 100mA.

e. Close line switch on repetitive load switch setup.

f. Adjust 25K potentiometer until stable display is obtained on oscilloscope. Recovery waveform should be within tolerances shown in Figure 5-6. Output should return to within ±100mV of nominal value in less than 1 millisecond.

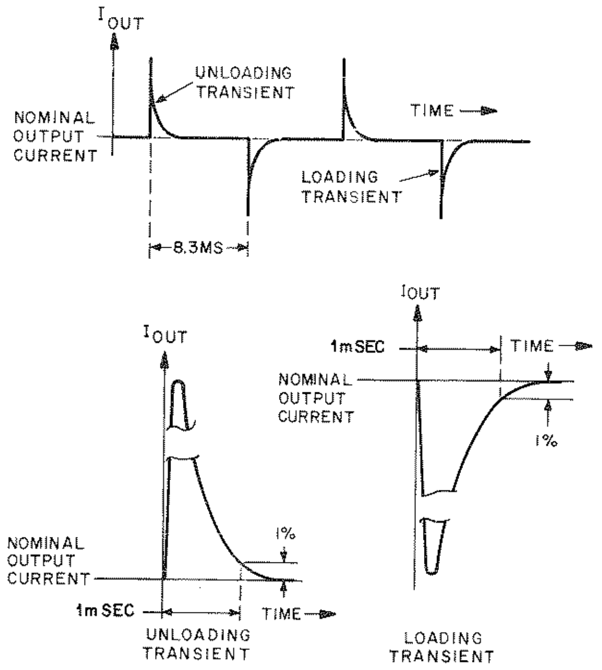


Figure 5-6. Load Transient Recovery Time, Waveforms

5-29 Programming Speed

Definition: The time (µsecs) required for the output current to change from zero amps to within "X" milliamps of the maximum rated output, or from maximum rated output to within "X" millamps of zero. "X" is generally of the same order as the load regulation specification.

5-30 To check the constant current remote programming speed, proceed as follows:

a. Connect test setup shown in Figure 5-7.

b. Turn VOLTAGE control fully clockwise.

c. Set RANGE switch to 100mA position and turn on supply.

d. Adjust CURRENT control until front panel meter indicates exactly 100mA.

e. Close line switch on mercury wetted relay and observe waveform on oscilloscope. Rise time indicates up-programming speed and fall time indicates down-programming speed.

f. Programming speed should be within tolerances of Figure 5-8. Output should rise from zero to 297 volts within 10 milliseconds. Fall time (down programming) should be almost identical to rise time shown in Figure 5-8 except for inversion.

5-31 Drift (Stability) [illegible]

Definition: The change in output current for the first 8 hours following a one hour warm-up period. During the interval of measurement all parameters such as load resistance, output setting, ambient temperature, and input line voltage are held constant.

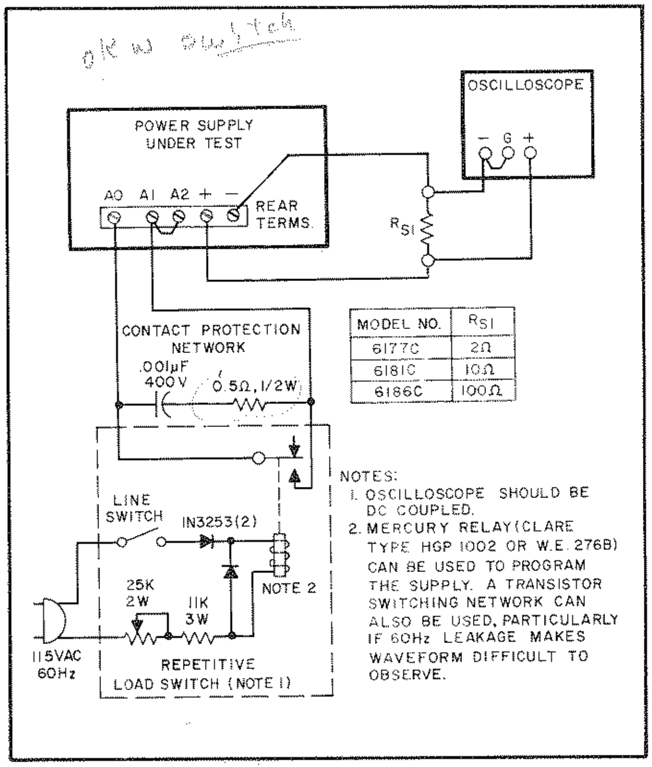
5-32 The stability of the supply in constant current operation must be measured while holding the temperature of the power supply and the external current sampling resistor (R_S) as constant as possible. A thermometer should be placed near the supply to verify that the ambient temperature remains constant during the measurement period. The supply should be placed in a location immune from stray air currents; 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 hour warm-up.

5-33 To check the output stability on all three ranges, proceed as follows:

a. Connect test setup shown in Figure 5-3. Strip chart recorder can be substituted for differential voltmeter to obtain permanent record.

b. Turn VOLTAGE control fully clockwise.

c. Set front panel RANGE switch and external test setup range switch S1 to highest current position, connect + lead of differential voltmeter to R_{S1}, and turn on supply.



MODEL NO.	R_{S1}
6177C	2Ω
6181C	10Ω
6186C	100Ω

NOTES:
1. OSCILLOSCOPE SHOULD BE DC COUPLED.
2. MERCURY RELAY (CLARE TYPE HGP 1002 OR W.E. 276B) CAN BE USED TO PROGRAM THE SUPPLY. A TRANSISTOR SWITCHING NETWORK CAN ALSO BE USED, PARTICULARLY IF 60Hz LEAKAGE MAKES WAVEFORM DIFFICULT TO OBSERVE.

Figure 5-7. Programming Speed, Test Setup

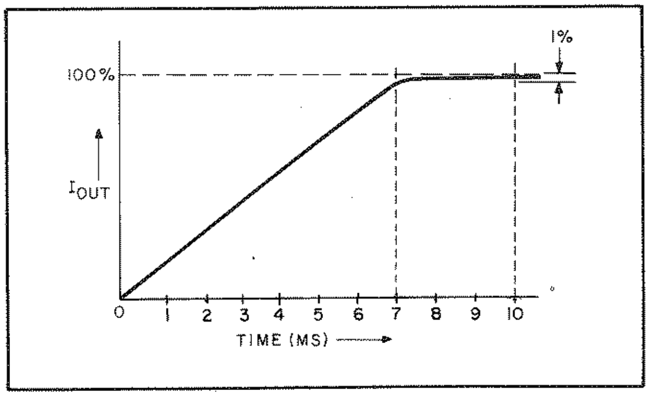


Figure 5-8. Up-Programming Speed Waveform

d. Allow one hour warm-up, adjust CURRENT control to obtain front panel ammeter reading of exactly 100, and then record differential voltmeter reading.

e. Over 8 hours, differential voltmeter reading should not vary by more than 1.25mV.

f. Repeat Steps (d) and (e) with both range switches set to middle current position and differential voltmeter connected to R_{S2}.

g. Repeat Steps (d) and (e) with both range switches set to lowest current position and differential voltmeter connected to R_{S3}.

5-34 Temperature Coefficient.

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

5-35 The temperature coefficient of the supply is measured by placing the supply in an oven and varying it over any temperature span within the operating range of 0 to 55°C. The external test setup current sampling resistors (R_{S1}, R_{S2}, and R_{S3}) should not be placed in the oven, but instead must be held at a constant temperature while this measurement is made.

5-36 The differential voltmeter used to measure the output current 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.

5-37 To check the temperature coefficient on all three current ranges, proceed as follows:

a. Connect test setup shown in Figure 5-3. Strip chart recorder can be substituted for differential voltmeter to obtain permanent record.

b. Turn VOLTAGE control fully clockwise.

c. Set front panel RANGE switch and external test setup range switch S1 to highest current position, connect + lead of differential voltmeter to R_{S1}, and turn on supply.

d. Adjust CURRENT control to obtain front panel ammeter reading of exactly 100.

e. Insert supply into temperature-controlled oven (voltmeter and load resistors remain outside oven). Set temperature to 30°C and allow one hour warm-up.

f. Record differential voltmeter indication.

g. Raise oven temperature to 40°C and allow one hour warm-up.

h. Reading on differential voltmeter should not vary from reading recorded in Step (f) by more than 8mV.

i. Repeat Steps (d) through (h) with both range switches set to middle current position and differential voltmeter connected to R_{S2}.

j. Repeat Steps (d) through (h) with both range switches set to lowest current position and differential voltmeter connected to R_{S3}.

5-38 TROUBLESHOOTING

5-39 Before attempting to troubleshoot this instrument, insure 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.

5-40 A good understanding of the principles of operation is essential for effective troubleshooting; it is recommended that the reader study at least Paragraphs 4-1 through 4-28 of Section IV, if not the entire section. Once the principles of operation are understood, refer to the overall troubleshooting procedures in Paragraph 5-43 to locate the symptom and its probable cause.

5-41 The schematic diagram at the rear of the manual (Figure 7-4) contains normal voltage readings taken at various points within the instrument; Note 12 on the Schematic gives the measurement conditions. These voltages (in italics) are positioned adjacent to the applicable test points (identified by encircled numbers). The component location diagrams (Figure 7-1 through 7-3) at the rear of the manual should be consulted to determine the location of components and test points.

5-42 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 5-47) and Adjustment and Calibration (Paragraph 5-51) sections of this manual.

5-43 OVERALL TROUBLESHOOTING PROCEDURE

5-44 To locate the cause of trouble, follow Steps (1), (2), and (3) in sequence:

(1) Check for obvious troubles such as open fuse, defective power cord, input power failure, 115/230V switch in wrong position, incorrect strapping pattern (refer to Figure 3-2), or defective meter (check output current with external ammeter). Next, remove top and bottom covers (2 retaining screws each) and inspect for open connections, charred components, etc. If the trouble source cannot be detected by visual inspection, proceed to Step (2).

(2) Disconnect load, and connect short circuit across output terminals of supply. Shorting the output terminals is an extremely important step; failure to short the output terminals may result in the destruction of the shunt regulator transistors.

(3) Examine Table 5-2 for your symptom and its probable cause. The symptoms listed in Table 5-2 are of two kinds, the first of which is symptoms due to easily-corrected trouble sources such as a single defective component or an incorrect internal adjustment. For these symptoms, direct troubleshooting procedures are given in the table. The second kind of symptom includes primarily those resulting from failure of a feedback loop. For these symptoms, the table refers the reader to one or more of Tables 5-3 through 5-7.

5-45 Table 5-3 presents a sequenced isolation and initial troubleshooting procedure for the series regulator, programming/guard supply, and constant current comparator. This table is referenced in Table 5-2. At various points in Table 5-3, instructions direct the reader to one of Tables 5-4, 5-5, or 5-6, depending upon the results of tests in Table 5-3. After completing the procedures in Tables 5-4, 5-5, or 5-6, the reader is directed to re-enter Table 5-3 at the former exit point. This is suggested because following the procedures in Table 5-3 through to the end of the table (Step 10) even after locating and replacing a defective component provides a rapid and effective method of testing all the circuits in the instrument.

5-46 In some special circumstances it may be desirable to go directly to Tables 5-4, 5-5, or 5-6 without first going through at least a portion of Table 5-3. Instructions at the beginning of each of the three tables provide for this possibility. Table 5-7 (voltage LIMIT light troubleshooting) is referenced in Table 5-2 only; however, instructions are provided at the beginning of Table 5-7 relating it to Table 5-3.

NOTE

While troubleshooting this instrument, keep in mind that the front panel milliammeter does not indicate output current directly, but instead provides a reading proportional to the output voltage of the programming/guard supply. Ordinarily this voltage is proportional to the output current but this cannot be depended on if the instrument is in need of repair. If the front panel milliammeter responds appropriately when the current control is adjusted, the programming/guard supply is functioning. Use an external milliammeter in series with the output to monitor the output current directly while troubleshooting to avoid misinterpreting trouble symptoms.

CAUTION

The RANGE switch must be kept on the 100mA position at all times while troubleshooting this instrument. Switching to a lower range may cause the destruction of current sampling resistors R2 or R3.

Table 5-2. Overall Troubleshooting

SYMPTOM	PROBABLE CAUSE
Blows fuses.	**CAUTION** Do not operate the supply without a short across the output terminals. If a shorted series regulator is the trouble source, operating the supply without a short across the output terminals will result in the destruction of transistors Q35 and/or Q36. a. Shorted series regulator. Check Q24, 25, 26, 27, 28, 29, and VR2. b. Shorted series regulator and shorted voltage limit transistors. See (a) above, and check Q35 and Q36. Also check VR19 and isolation diode CR22. c. Short on printed circuit board. Check for loose pieces of wire, etc. d. External current path between common (A3) and negative output terminal. Check strapping pattern and instrumentation connections. e. Defective rectifier diodes in main supply and/or reference supply. Check CR32, 33, 35-38.
Output current locked up, or not controllable throughout entire range.	a. Series regulator, programming/guard supply, or constant current comparator defective. Refer to Table 5-3.

Table 5-2. Overall Troubleshooting (Continued)

SYMPTOM	PROBABLE CAUSE
Measured output current zero, LIMIT light on continuously.	a. Voltage limit circuit defective. Refer to Table 5-5.
Measured output current zero, LIMIT light not on.	a. Series regulator, programming/guard supply, or constant current comparator defective. Refer to Table 5-3. b. Voltage limit circuit defective and limit light circuit defective. Refer to Tables 5-3 and 5-7.
Voltage limit fails to operate (VOLTAGE control has no effect); LIMIT light not on.	a. Voltage limit circuit defective. Refer to Table 5-5.
Voltage limit will not go to zero.	a. Zener diodes VR16, VR17, or VR8 shorted.
LIMIT light not functioning at all, though voltage limit operation and supply output current are normal.	a. Voltage limit light circuit defective. Refer to Table 5-7.
LIMIT light will not operate at low output current levels.	a. Isolation diode CR22 shorted.
Poor load regulation.	a. Improper measurement technique. Refer to Paragraph 5-13. b. Differential amplifiers Q1 or Q7 defective. c. Defect in reference supply. Refer to Table 5-4. d. Dirt on printed circuit board. e. Internal or external current leakage path between terminal A1 and negative output terminal. To verify that this is the trouble, connect a DVM between terminals A0 and A3. Set the CURRENT control for 100mA, and open-circuit the output terminals. Vary the VOLTAGE control; if the DVM reading varies, the programming/guard amplifier is eliminated as a possible source of trouble. f. Internal or external current leakage path between positive and negative output terminals.
Poor line regulation.	a. Improper measurement technique. Refer to Paragraph 5-15. b. Defect in reference supply. Refer to Table 5-4.
High ripple.	a. Improper measurement technique. Refer to Paragraph 5-17. b. Ground loops in operating setup. c. Ripple Adjust control R119 set incorrectly. Refer to Paragraph 5-59. d. Differential amplifier Q1 defective. e. Leaky filter capacitors C30 and/or C31.

Table 5-2. Overall Troubleshooting (Continued)

SYMPTOM	PROBABLE CAUSE
Oscillation.	a. Operational amplifiers Z1 or Z2 defective.
Instability.	a. Differential amplifiers Q1 or Q7 defective.

Table 5-3. Series Regulator, Programming/Guard Supply, and Constant Current Comparator Isolation and Initial Troubleshooting

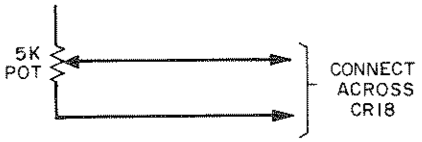
STEP	ACTION	RESPONSE	REACTION
1	Isolate series regulator as follows: a. Set RANGE switch to 100mA, and VOLTAGE control fully clockwise. b. Connect ammeter (or short circuit with clip-on probe, or 100Ω, 10W resistor and voltmeter) across output terminals. c. Remove Z1 from socket. d. Connect a 5KΩ pot across CR18 as shown in sketch at right. Set the pot for minimum resistance. e. Short Q22 collector to emitter.		
2	Increase the resistance of the 5kΩ pot gradually while observing the external ammeter. (If the meter does not respond, turn the pot back to zero resistance.) **CAUTION** Do not allow the output current to exceed 100mA.	a. Output current (as indicated on external ammeter) does not change. b. Output current (as indicated on external ammeter) varies from zero to approximately 100mA.	a. Series regulator is defective. Check Q26, 27, 28, VR2, Q24, 25, Q29. After establishing proper operation of series regulator (Response b), proceed to Step 3. b. Series regulator is operative. Proceed to Step 3.
3	Set the resistance of the 5KΩ pot for a reading on the external ammeter of about 50mA, then remove short across Q22.	a. Output current (as indicated on external ammeter) drops to zero. b. Output current essentially unchanged.	a. Q22 defective. Replace Q22 and proceed to Step 4. b. Q22 operative. Proceed to Step 4.

Table 5-3. Series Regulator, Programming/Guard Supply, and Constant Current Comparator Isolation and Initial Troubleshooting (Continued)

STEP	ACTION	RESPONSE	REACTION
4	Check all reference voltages listed in Table 5-4.	a. One or more reference voltages zero or much higher than correct value.	a. Troubleshoot reference circuit as directed in Table 5-4 under particular reference voltage. After establishing proper reference voltages, proceed to Step 5.
		b. One or more reference voltages slightly low.	b. Slightly low voltages are usually caused by loading due to a defect in a circuit other than the reference supply. Proceed to Step 5.
		c. All reference voltages correct within given tolerances.	c. Proceed to Step 5.
5	To check voltage limit circuit, leave supply connected as in previous step and connect external voltmeter between test point 21 and negative output terminal. Vary VOLTAGE control. (If desired, the voltage limit circuit can be completely isolated by lifting the cathode of CR21).	a. Voltage at test point 21 does not change.	a. Voltage limit circuit is defective. Perform troubleshooting procedures given in Table 5-5. After establishing proper operation (Response b), proceed to Step 6.
		b. Voltage at test point 21 varies from zero to approximately 315Vdc.	b. Voltage limit circuit is operative. Proceed to Step 6.
6	Isolate programming/guard supply by lifting one end each of jumper J1 and diode CR43.	----	----
7	Check operation of programming/guard supply by connecting external voltmeter between terminal A0 (+) and terminal A3 (-). Vary front panel CURRENT control.	a. Voltage indicated on external voltmeter does not change.	a. Programming/guard supply is defective. Perform troubleshooting procedures given in Table 5-6. After establishing proper operation (Response b), proceed to Step 8.
		b. Voltage indicated on external voltmeter varies from approximately +0.7 to -10.5V dc. (Front panel ammeter should follow external voltmeter.)	b. Programming/guard supply is operative. Proceed to Step 8.

Table 5-3. Series Regulator, Programming/Guard Supply, and Constant Current Comparator Isolation and Initial Troubleshooting (Continued)

STEP	ACTION	RESPONSE	REACTION
8	Plug Z1 (originally in constant current comparator) into Z2 socket, and re-perform Step 7.	a. Voltage indicated on external voltmeter does not change. b. Voltage indicated on external voltmeter varies from approximately +0.7 to -10.5V dc.	a. Z1 is defective. Install new Z1 in constant current comparator, and re-install Z2 in programming/guard supply. Proceed to Step 9. b. Z1 is operative. Return Z1 to its original socket (in constant current comparator) and re-install Z2 in programming/guard supply. Proceed to Step 9.
9	Test constant current comparator as follows: a. Reconnect jumper J1 and diode CR43. b. Remove the 5KΩ pot connected across CR18. c. Attempt to control output current with front panel CURRENT control.	a. Output current (as indicated on external ammeter) does not change. b. Output current (as indicated on external ammeter) varies over full range.	a. Defect in constant current comparator circuit. Proceed to Step 10. b. Constant current comparator is operative; supply should be functioning properly. Verify proper operation of supply.
10	Isolate trouble in constant current comparator to either driver amplifiers Q2-Q3 or input comparator Q1 as follows: a. If output current is locked up, short Q1A collector to emitter. b. If output current is locked down, short Q1B collector to emitter.	a. Output current does not change. b. Output current decreases if locked up, or increases if locked down.	a. Check for defective Q2, 3, or 4. After replacement, supply should function normally. Verify proper operation of supply. b. Defect in Q1 or Q4 stage. After replacement, supply should function normally. Verify proper operation of supply.

Table 5-4. Reference and Bias Voltages. (Refer to Schematic and Figure 7-3 for test point locations.)

NOTE

The measurements in this table are designed to be performed after Steps (1) through (3) of Table 5-3 (verification of operation of the series regulator) have been performed. If the instrument is operating correctly, the correct results will be achieved for these measurements regardless of the performance or non-performance of these three steps. However, if the instrument is not functioning correctly, correct measurement results cannot be guaranteed unless these three steps are performed, since a defective series regulator will usually affect one or more of the reference voltages.

Table 5-4. Reference and Bias Voltages (Continued)

STEP	METER COMMON	METER POSITIVE	NORMAL VDC	NORMAL RIPPLE (P-P)	CHECK IF PROPER INDICATION IS NOT OBTAINED
1	A3	9	+29.0 ± 25%	2.0V	CR35, 36, 37, 38
2	A3	58	+6.2 ± 5%	2.0mV	VR4
3	A3	57	+12.4 ± 5%	2.0mV	Q11, 12, 14, 15, 16
4	A3	19	+7.5 ±5%	2.0mV	VR7
5	A3	10	-15.0 ±5%	2.0mV	VR3, 5. NOTE: If the -15V reference voltage is much more negative than normal (VR3 and/or VR5 open), also check Q1, Q7, Z1, and Z2 for possible damage due to over-voltage.
6	11	13	+11.2 ±5%	2.0mV	VR12, 13
7	11	47	+19.9 ±5%	2.0V	Q37, 38, 39

Table 5-5. Voltage Limit Circuit Troubleshooting

NOTE

The procedures in this table are designed to be performed after Steps (1) through (5) of Table 5-3 have been performed. If it is necessary to independently perform the procedures given in this table, first connect a short circuit across the output terminals of the supply, and then perform Step (5) of Table 5-3.

STEP	ACTION	RESPONSE	PROBABLE CAUSE
PART A. VOLTAGE LIMIT LOCKED UP (LIMIT LIGHT OFF).			
1	Attempt to turn on shunt regulator transistors Q35-Q36 by shorting Q32 collector to emitter.	a. Voltage at test point 21 (measured from TP11) does not change. b. Voltage at test point 21 decreases.	a. Check Q35 and Q36 for open; also check CR31 for open. b. Proceed to Step 2.
2	Attempt to turn on error amplifier Q32 by shorting Q34 collector to emitter.	a. Voltage at test point 21 does not change. b. Voltage at test point 21 decreases.	a. Check Q32 for open. b. Check Q34 for open, Q33 for short, R75 for open, Q30-Q31 for open, or missing strap between terminals A5 and A6.

Table 5-5. Voltage Limit Circuit Troubleshooting (Continued)

STEP	ACTION	RESPONSE	PROBABLE CAUSE
	PART B. VOLTAGE LIMIT LOCKED DOWN (LIMIT LIGHT ON).		
1	Attempt to turn off shunt regulator Q35-Q36 by shorting Q32 base to emitter.	a. Voltage at test point 21 (measured from TP11) does not change. b. Voltage at test point 21 increases.	a. Check Q35 and Q36 for short, and VR9-10-11-14-15 for short. b. Proceed to Step 2.
2	Attempt to turn off error amplifier Q32 by shorting Q34 base to emitter.	a. Voltage at test point 21 does not change. b. Voltage at test point 21 increases.	a. Check Q32 for short. b. Check Q34 for short, Q33 for open, R75 for short.

Table 5-6. Programming/Guard Supply Troubleshooting

STEP	ACTION	RESPONSE	PROBABLE CAUSE
	CAUTION The procedures in this table should only be performed after at least Steps (1), (4), and (6) of Table 5-3 have been performed.		
1	Check output regulator transistors Q8 and Q9 as follows: a. Connect external voltmeter between terminals A0 (+) and A3 (-). b. Remove Z2 from socket. c. Connect one end of a 10kΩ pot to test point 10 (-15V), the other end to terminal A3, and the wiper to pin 6 of Z2 socket. d. Vary pot over full range.	a. Voltage indicated on external voltmeter does not change. b. Voltage indicated on external voltmeter varies from approximately +0.7 to -12V.	a. Q8 or Q9 defective. b. Q8 and Q9 operative. Proceed to Step 2.
2	Re-install Z2, and remove 10kΩ pot connected in Step (1). Check operation of Z2 as follows: a. If voltage on external voltmeter is negative, short Q7A collector to emitter. b. If voltage on external voltmeter is approximately zero, short Q7B collector to emitter.	a. Voltage indicated on external voltmeter does not change. b. Voltage goes from negative value towards zero. c. Voltage goes from zero towards negative value.	a. Z2 or Q5 defective. b. Check for defective Q5, Q7, open R15, or missing strap between terminals A1 and A2. c. Check for defective Q5, Q7, or shorted R15

Table 5-7. Voltage Limit Light Circuit Troubleshooting

STEP	ACTION	RESPONSE	PROBABLE CAUSE
	NOTE The procedures in this table are based on the assumption that the voltage limit circuit and the programming/guard supply are operating correctly. Check-out procedures for these circuits are given in Steps (5) through (7) of Table 5-3.		
1	Attempt to turn on light by shorting Q17 collector to emitter.	a. Light does not go on.	a. Check +29V and -15V reference voltages, light bulb, and VR18.
		b. Light goes on.	b. Proceed to Step 2.
2	Attempt to turn on lamp driver Q17 by shorting Q20 collector to emitter.	a. Light does not go on.	a. Check Q17 and Q19 for open.
		b. Light goes on.	b. Proceed to Step 3.
3	Attempt to turn on light by shorting Q21 base to emitter.	a. Light does not go on.	a. Check Q20 for open, Q21 for short.
		b. Light goes on.	b. Check CR22.

Table 5-8. Adjustments Necessary After Replacement of Semiconductor Devices

REFERENCE	CIRCUIT	ADJUST	ADJUSTMENT PARAGRAPH
CR20	Voltage limit programming current source.	R86, R87	5-69, 5-72
Q1	Constant current comparator.	R11 (Constant current comparator zero adjust)	5-63
Q7	Programming/guard supply.	R29 (Guard zero adjust)	5-61
VR4	Reference supply (+6.2V reference).	R32 (Adjustment of R11 and R29 must be checked before R32 is adjusted.)	5-66
VR8	Voltage limit programming current source.	R86, R87	5-69, 5-72
VR12	Voltage limit.	R87	5-69

5-47 REPAIR AND REPLACEMENT

5-48 Section VI of this manual contains a list of replaceable parts. If the part to be replaced does not have a standard manufacturer's part number, it is a "special" part and must be obtained directly from Hewlett-Packard. After replacing a semiconductor device, refer to Table 5-8 for necessary checks and adjustments.

5-49 It is recommended that a low power soldering iron (50 watts maximum) be used on this instrument. The use of a "solder sucker" greatly simplifies component replacement, especially where multi-lead parts are concerned. In addition, only high quality rosin-core solder should be used when repairing the printed circuit boards.

5-50 To facilitate repair, the main (A2) printed circuit board in this instrument can be placed vertically (on edge) to allow easy access to both sides. To accomplish this, remove the two hold-down screws, and slide the board towards the front of the unit and out of its plastic guide channels. Sufficient lead length is provided to allow the board to be placed vertically.

5-51 ADJUSTMENT AND CALIBRATION

5-52 Adjustment and calibration may be required after performance testing, troubleshooting, or repair and replacement. If more than one adjustment must be performed, the sequence of adjustments presented in the following paragraphs should be followed.

5-53 VOLTMETER AND AMMETER ZERO

5-54 The meter pointers 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 meters, proceed as follows:

a. Turn on instrument and allow it to come up to normal operating temperature (about one hour).

b. Turn instrument off. Wait one minute for power supply capacitors to discharge completely.

c. Insert sharp pointed object (pen point or awl) into small indentation near top of round black plastic disc located directly below meter face.

d. 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.

5-55 AMMETER CALIBRATION

5-56 To calibrate the ammeter, proceed as follows:

a. Connect test setup shown in Figure 5-3 (external range switch and medium and low range load resistors can be eliminated if desired).

b. Turn VOLTAGE control fully clockwise, set front panel RANGE switch to 100mA position, and connect differential voltmeter to $R_{S}1$.

c. Turn on supply and adjust CURRENT control for reading of 10.0Vdc on differential voltmeter.

d. Adjust potentiometer R106 (see Figure 7-3) until front panel ammeter indicates exactly 100mA.

5-57 VOLTMETER CALIBRATION

5-58 To calibrate the voltmeter, proceed as follows:

a. Connect test setup shown in Figure 5-3, except connect differential voltmeter between +METER and (-) output terminal or between A0 and (-) output terminal (see Figure 3-7). External range switch and medium and low range load resistors can be eliminated if desired.

b. Set front panel RANGE switch to 100mA position, turn on supply, and adjust CURRENT control until front panel ammeter reads exactly 100mA.

c. Adjust VOLTAGE control until differential voltmeter reads exactly 300Vdc.

d. Adjust potentiometer R110 (see Figure 7-3) until front panel voltmeter reads exactly 300Vdc.

5-59 RIPPLE MINIMIZATION

5-60 To adjust the supply for minimum output current ripple, proceed as follows:

a. Connect test setup shown in Figure 5-4B. External range switch and high and medium range load resistors can be eliminated if desired.

b. Turn VOLTAGE control fully clockwise, set front panel RANGE switch to 1mA position, turn CURRENT control fully counterclockwise, and turn on supply.

c. Adjust R119 (see Figure 7-3) for minimum 60Hz ripple displayed on oscilloscope. Note that both 60Hz and 120Hz ripple as well as spikes and harmonics are displayed on scope; R119 is to be adjusted until combined amplitude of spikes, harmonics, and 60Hz ripple is minimum.

5-61 GUARD AMPLIFIER ZERO

5-62 This adjustment minimizes the offset between the bases of the guard input amplifier, Q7. The offset should be checked and adjusted, if necessary, whenever Q7 is replaced. Proceed as follows to perform this adjustment:

a. Place short across output terminals of supply and allow supply to warm up for a half hour.

b. Connect differential voltmeter across diode CR8 on main circuit board (see Figure 7-3).

c. Set RANGE switch to 100mA position, turn VOLTAGE control fully clockwise, and turn on supply.

d. Adjust CURRENT control until front panel ammeter indicates exactly 100mA.

e. Adjust potentiometer R29 (see Figure 7-3) to obtain reading of 0 ± 200μVdc on differential voltmeter.

5-63 CONSTANT CURRENT COMPARATOR ZERO

5-64 This adjustment minimizes the offset between the bases of the constant current comparator input amplifier, Q1. The offset should be checked and adjusted, if necessary, whenever Q1 is replaced. Proceed as follows to perform this adjustment:

a. Perform Steps (a) through (d) in Paragraph 5-62 above, except connect differential voltmeter across diode CR4 (see Figure 7-3).

b. Adjust potentiometer R11 (see Figure 7-3) to obtain reading of 0 ± 200μVdc on differential voltmeter.

5-65 This adjustment can also be used to set the zero current programming accuracy when the supply is remote resistance programmed. However, the adjustment should not be made if the total minimum resistance of the remote programming device (potentiometer, switched-resistor setup, etc.) and its connecting wires exceeds approximately 10 ohms. Using the constant current comparator zero adjustment to set the output current to zero under this condition may result in the supply not meeting its temperature coefficient specification. Proceed as follows to perform this adjustment:

a. Connect test setup shown in Figure 7-3.

b. Set both range switches to highest current range, turn VOLTAGE control fully clockwise, and connect + lead of differential voltmeter to R_{S1}.

c. Connect remote resistance programming setup (see Figure 3-3) and adjust remote resistance to zero (minimum).

d. Turn on supply and adjust potentiometer R11 (see Figure 7-3) for reading of exactly zero on differential voltmeter.

5-66 CONSTANT CURRENT PROGRAMMING CURRENT

5-67 This procedure adjusts the constant current programming current within the supply. The programming current is factory set to within 0.25% of 1mA and should not need adjustment thereafter unless 100mA range current sampling resistor R1 or reference supply zener diode VR4 is replaced. The programming current (and thus the programming coefficient) can also be checked and adjusted, if necessary, before remote resistance programming the supply.

NOTE

> To obtain an accurate adjustment, always zero the constant current comparator and guard amplifier (Paragraphs 5-61 and 5-63) before making this adjustment.

5-68 To adjust the constant current programming current, proceed as follows:

a. Connect test setup shown in Figure 5-3.

b. Set both range switches to highest current range, connect + lead of differential voltmeter to R_{S1}, and turn VOLTAGE control fully clockwise.

c. Remove strap between terminals A1 and A2 and connect precision programming resistor (10kΩ, 0.1%) between terminals A0 and A1.

d. Connect decade resistance box in place of R32 (mounted on standoffs on main circuit board; see Figure 7-3).

e. Turn on supply and adjust decade resistance box for reading of 10 ± 0.025Vdc on differential voltmeter.

f. Turn off supply and replace decade resistance box with appropriate value, 5%, 3W wirewound resistor in R32 position.

NOTE

> Due to the limited range of 3 watt resistor values available, it may be necessary to select a resistor value that gives an output voltage of slightly less than 9.975Vdc and then trim the voltage to within 10 ± 0.025Vdc by adding a 1/8 watt, ±100ppm metal film resistor in parallel with the 3 watt resistor.

5-69 VOLTAGE LIMIT PROGRAMMING CURRENT

5-70 This procedure adjusts the voltage limit programming current to within 15% of 1mA. It allows the supply to provide 105% of the maximum rated output voltage despite the 15% total tolerance of the VOLTAGE control (R75) and the differential amplifier reference zener diode (VR12). This adjustment is necessary if either of these components are replaced; it can also be performed as an accuracy check before remote resistance programming the voltage limit.

5-71 To adjust the voltage limit programming current, proceed as follows:

a. Set RANGE switch to 100mA position, and turn VOLTAGE control fully clockwise.

b. Set CURRENT control for front panel ammeter reading of 100mA (no load).

c. Connect high impedance differential voltmeter across output terminals of supply.

NOTE

> Do not let voltage on differential voltmeter exceed 317 volts. Voltages in excess of this level will damage the shunt regulator transistors in the voltage limit circuit.

d. Connect decade resistance box set for 50kΩ in place of R87 (mounted on standoffs on main circuit board; see Figure 7-3).

e. Turn on supply and adjust decade resistance until differential voltmeter reads 315 ± 2Vdc.

f. Turn off supply and replace decade resistance box with appropriate value, 5%, 1/2W resistor in R87 position.

5-72 VOLTAGE LIMIT ZERO

5-73 To adjust the voltage limit zero voltage programming accuracy, proceed as follows:

a. Set RANGE switch to 100mA position, adjust CURRENT control for front panel ammeter reading of 100mA (no load), and turn VOLTAGE control fully counterclockwise.

b. Connect high impedance differential voltmeter across output terminals of supply.

c. Connect decade resistance box set for 10kΩ in place of R86 (mounted on standoffs on main circuit board; see Figure 7-3).

d. Turn on supply and adjust decade resistance box until differential voltmeter reads 0 ± 50mVdc.

e. Turn off supply and replace decade resistance box with appropriate value, 5%, 1/2W, resistor in R86 position.

SECTION VI
REPLACEABLE PARTS

6-1 INTRODUCTION

6-2 This section contains information for ordering replacement parts. Table 6-4 lists parts in alphanumeric 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) for complete maintenance of one instrument during one year of isolated service.

h. Parts not identified by a reference designator are listed at the end of Table 6-4 under Mechanical 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 (J) 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.

Table 6-1. Reference Designators

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

Table 6-1. Reference Designators (Continued)

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

Table 6-2. Description Abbreviations

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

Table 6-3. Code List of Manufacturers

CODE NO.	MANUFACTURER	ADDRESS
00629	EBY Sales Co., Inc.	Jamaica, N.Y.
00656	Aerovox Corp.	New Bedford, Mass.
00853	Sangamo Electric Co. S. Carolina Div.	Pickens, S.C.
01121	Allen Bradley Co.	Milwaukee, Wis.
01255	Litton Industries, Inc.	Beverly Hills, Calif.
01281	TRW Semiconductors, Inc.	Lawndale, Calif.
01295	Texas Instruments, Inc. Semiconductor-Components Div.	Dallas, Texas
01686	RCL Electronics, Inc.	Manchester, N.H.
01930	Amerock Corp.	Rockford, Ill.
02107	Sparta Mfg. Co.	Dover, Ohio
02114	Ferroxcube Corp.	Saugerties, N.Y.
02606	Fenwal Laboratories	Morton Grove, Ill.
02660	Amphenol Corp.	Broadview, Ill.
02735	Radio Corp. of America, Solid State and Receiving Tube Div.	Somerville, N.J.
03508	G.E. Semiconductor Products Dept.	Syracuse, N.Y.
03797	Eldema Corp.	Compton, Calif.
03877	Transitron Electronic Corp.	Wakefield, Mass.
03888	Pyrofilm Resistor Co. Inc.	Cedar Knolls, N.J.
04009	Arrow, Hart and Hegeman Electric Co.	Hartford, Conn.
04072	ADC Electronics, Inc.	Harbor City, Calif.
04213	Caddell & Burns Mfg. Co. Inc.	Mineola, N.Y.
04404	*Hewlett-Packard Co. Palo Alto Div.	Palo Alto, Calif.
04713	Motorola Semiconductor Prod. Inc.	Phoenix, Arizona
05277	Westinghouse Electric Corp. Semiconductor Dept.	Youngwood, Pa.
05347	Ultronix, Inc.	Grand Junction, Colo.
05820	Wakefield Engr. Inc.	Wakefield, Mass.
06001	General Elect. Co. Electronic Capacitor & Battery Dept.	Irmo, S.C.
06004	Bassik Div. Stewart-Warner Corp.	Bridgeport, Conn.
06486	IRC Div. of TRW Inc. Semiconductor Plant	Lynn, Mass.
06540	Amatom Electronic Hardware Co. Inc.	New Rochelle, N.Y.
06555	Beede Electrical Instrument Co.	Penacook, N.H.
06666	General Devices Co. Inc.	Indianapolis, Ind.
06751	Semcor Div. Components, Inc.	Phoenix, Arizona
06776	Robinson Nugent, Inc.	New Albany, Ind.
06812	Torrington Mfg. Co., West Div.	Van Nuys, Calif.
07137	Transistor Electronics Corp.	Minneapolis, Minn.
07138	Westinghouse Electric Corp. Electronic Tube Div.	Elmira, N.Y.
07263	Fairchild Camera and Instrument Corp. Semiconductor Div.	Mountain View, Calif.
07387	Birtcher Corp., The	Los Angeles, Calif.
07397	Sylvania Electric Prod. Inc. Sylvania Electronic Systems Western Div.	Mountain View, Calif.
07716	IRC Div. of TRW Inc. Burlington Plant	Burlington, Iowa
07910	Continental Device Corp.	Hawthorne, Calif.
07933	Raytheon Co. Components Div. Semiconductor Operation	Mountain View, Calif.
08484	Breeze Corporations, Inc.	Union, N.J.
08530	Reliance Mica Corp.	Brooklyn, N.Y.
08717	Sloan Company, The	Sun Valley, Calif.
08730	Vemaline Products Co. Inc.	Wyckoff, N.J.
08806	General Elect. Co. Miniature Lamp Dept.	Cleveland, Ohio
08863	Nylomatic Corp.	Norrisville, Pa.
08919	RCH Supply Co.	Vernon, Calif.
09021	Airco Speer Electronic Components	Bradford, Pa.
09182	*Hewlett-Packard Co. New Jersey Div.	Rockaway, N.J.
09213	General Elect. Co. Semiconductor Prod. Dept.	Buffalo, N.Y.
09214	General Elect. Co. Semiconductor Prod. Dept.	Auburn, N.Y.
09353	C & K Components Inc.	Newton, Mass.
09922	Burndy Corp.	Norwalk, Conn.
11115	Wagner Electric Corp. Tung-Sol Div.	Bloomfield, N.J.
11236	CTS of Berne, Inc.	Berne, Ind.
11237	Chicago Telephone of Cal. Inc.	So. Pasadena, Calif.
11502	IRC Div. of TRW Inc. Boone Plant	Boone, N.C.
11711	General Instrument Corp Rectifier Div.	Newark, N.J.
12136	Philadelphia Handle Co. Inc.	Camden, N.J.
12615	U.S. Terminals, Inc.	Cincinnati, Ohio
12617	Hamlin Inc.	Lake Mills, Wisconsin
12697	Clarostat Mfg. Co. Inc.	Dover, N.H.
13103	Thermalloy Co.	Dallas, Texas
14493	*Hewlett-Packard Co. Loveland Div.	Loveland, Colo.
14655	Cornell-Dubilier Electronics Div. Federal Pacific Electric Co.	Newark, N.J.
14936	General Instrument Corp. Semiconductor Prod. Group	Hicksville, N.Y.
15801	Fenwal Elect.	Framingham, Mass.
16299	Corning Glass Works, Electronic Components Div.	Raleigh, N.C.

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

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

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 Semiconductor Div. Transducer Plant	Mountain View, Calif.
17870	Daven Div. Thomas A. Edison Industries McGraw-Edison Co.	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.
24455	General Electric Co. Lamp Div. of Consumer Prod. Group	Nela Park, Cleveland, Ohio
24655	General Radio Co.	West Concord, Mass.
24681	LTV Electrosystems Inc Memcor/Components Operations	Huntington, Ind.
26982	Dynacool Mfg. Co. Inc.	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. New Hampshire Div.	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	Lectrohm, Inc.	Chicago, Ill.
37942	P.R. Mallory & Co. Inc.	Indianapolis, Ind.
42190	Muter Co.	Chicago, Ill.
43334	New Departure-Hyatt Bearings Div. General Motors Corp.	Sandusky, Ohio
44655	Ohmite 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.

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	CTS Corp.	Elkhart, Ind.
71468	I.T.T. Cannon Electric Inc.	Los Angeles, Calif.
71590	Globe-Union Inc. Centralab Div.	Milwaukee, Wis.
71700	General Cable Corp. Cornish Wire Co. Div.	Williamstown, Mass.
71707	Coto Coil Co. Inc.	Providence, R.I.
71744	Chicago Miniature Lamp Works	Chicago, Ill.
71785	Cinch Mfg. Co. and Howard B. Jones Div.	Chicago, Ill.
71984	Dow Corning Corp.	Midland, Mich.
72136	Electro Motive Mfg. Co. Inc.	Willimantic, Conn.
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. Helipot Div.	Fullerton, Calif.
73168	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.	Bridgeport, Conn.
74868	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	Littlefuse, 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.

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

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

CODE NO.	MANUFACTURER	ADDRESS
76530	Cinch	City of Industry, Calif.
76854	Oak Mfg. Co. Div. of Oak Electro/Netics Corp.	Crystal Lake, Ill.
77068	Bendix Corp., Electrodynamics Div.	No. Hollywood, Calif.
77122	Palnut Co.	Mountainside, N.J.
77147	Patton-MacGuyer Co.	Providence, R.I.
77221	Phaostron Instrument and Electronic Co.	South Pasadena, Calif.
77252	Philadelphia Steel and Wire Corp.	Philadelphia, Pa.
77342	American Machine and Foundry Co. 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 Electric Mfg. Co. Inc.	Newburgh, N.Y.
78553	Tinnerman Products, Inc.	Cleveland, Ohio
78584	Stewart Stamping Corp.	Yonkers, N.Y.
79136	Waldes Kohinoor, 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 Products Group	Attleboro, Mass.
82866	Research Products Corp.	Madison, Wis.
82877	Rotron Inc.	Woodstock, N.Y.
82893	Vector Electronic Co.	Glendale, Calif.
83058	Carr Fastener Co.	Cambridge, Mass.
83186	Victory Engineering Corp.	Springfield, N.J.
83298	Bendix Corp. Electric Power Div.	Eatontown, 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 Components Div.	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 Electro/netics Corp.	Anaheim, Calif.
87216	Philco 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	Litton Precision Products Inc, USECO Div. Litton 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	Dale Electronics, Inc.	Columbus, Neb.
91662	Elco Corp.	Willow Grove, Pa.
91929	Honeywell Inc. Div. Micro Switch	Freeport, Ill.
92825	Whitso, Inc.	Schiller Pk., Ill.
93332	Sylvania Electric Prod. Inc. Semiconductor 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	Methode Mfg. Co.	Rolling Meadows, Ill.
95712	Bendix Corp. Microwave Devices Div.	Franklin, Ind.
95987	Weckesser 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 6-4. Replaceable Parts

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
	A1 INPUT BOARD					
C25	fxd, elect 10µF 450Vdc	1		28480	0180-2365	1
C29	fxd, ceramic 1.0µF 220Vac	1		28480	0160-3679	1
C30, 31	fxd, elect 300µF 250Vdc	2		28480	0180-1886	1
C32	fxd, elect 80µF 300Vdc	1		28480	0180-1851	1
C34	fxd, ceramic .01µF 500V	1		28480	0150-0081	1
C35	fxd, elect 490µF 85Vdc	1		28480	0180-1888	1
C36	fxd, elect 68µF 15Vdc	1	150D686X0015R2	56289	0180-1835	1
C37	fxd, film .1µF 500Vdc	1		28480	0160-0269	1
CR32, 33	Rect. Si. 700mA 800prv	3	A14N	03508	1901-0330	3
CR35-38	Rect. Si. 1A 200prv	4	A14B	03508	1901-0327	4
CR46	Rect. Si. 700mA 800prv		A14N	03508	1901-0330	
R91	fxd, met. ox. 150kΩ ±5% 2W	1	Type C-42S	16299	0764-0049	1
R112, 113	fxd, comp 10Ω ±5% 1/2W	2	EB-1005	01121	0686-1005	1
R114	fxd, comp 270Ω ±5% 1/2W	1	EB-2715	01121	0686-2715	1
R117	fxd, comp 100Ω ±5% 3W	1	242E1015	56289	0813-0050	1
R119	var. ww 100Ω ±20% (Ripple Adj.)	1	Type 110-F4	11236	2100-0281	1
VR16, 17	Diode, zener 4.22V 400mW	2	SZ10939-74	04713	1902-3070	2
	A2 MAIN BOARD					
C1	fxd, mylar .1µF 200V	2	192P10492	56289	0160-0168	1
C2	fxd, cer .05µF 400V	1	33C17A3-CDH	56289	0150-0052	1
C4	fxd, mica 18pF 300V	1		28480	0160-0356	1
C5	fxd, mylar .068µF 200V	2	292P68392-PTS	56289	0160-0166	1
C7	fxd, mylar .1µF 200V		192P10492	56289	0160-0168	
C9	fxd, mylar .01µF 200V	1	192P10392	56289	0160-0161	1
C10	fxd, mica 33pF 300V	1		28480	0160-2150	1
C11	fxd, mylar .068µF 200V		292P68392-PTS	56289	0160-0166	
C14	fxd, mica 100pF 500V	1	RCM15E101J	00853	0140-0041	1
C15	fxd, elect 22µF 35Vdc	3	150D226X0035R2	56289	0180-0160	1
C16	fxd, elect 4.7µF 35Vdc	2	150D475X9035B2	56289	0180-0100	1
C17, 18	fxd, elect 22µF 35Vdc		150D226X0035R2	56289	0180-0160	
C20	fxd, ceramic 1µF 25V	1	5C13C-CML	56289	0160-0127	1
C21	fxd, elect 1µF 35Vdc	1	150D105X9035A2	56289	0180-0291	1
C22	fxd, elect 4.7µF 35Vdc		150D475X9035B2	56289	0180-0100	
C23	fxd, ceramic 0.47µF 25V	2		28480	0160-0174	1
C26	fxd, ceramic .01 100V	1	obd	91418	0150-0093	1
C28	fxd, ceramic 0.47µF 25V			28480	0160-0174	
C33	fxd, mica 20pF 500V	1		28480	0160-0370	
CR1, 2	Diode, Si. 200mA 180V	21	SG3396	03877	1901-0033	8
CR3-5	Diode, Si. 50mA 75V	7	DA2050	03508	1901-0642	5
CR6	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR7, 8	Diode, Si. 50mA 75V		DA2050	03508	1901-0642	
CR9, 10	Diode, Si. 200mA 180V	6	SG3396	03877	1901-0033	
CR11, 12	Diode, Si. 150mA 15V	4	STB523	03508	1901-0460	1
CR13-16	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
CR17	Diode, Si. 200mA 10V	1	SG9309	03877	1901-0461	1
CR18, 19	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR20, 21	Rect. Si. 1A 800V	9	A14N	03508	1901-0330	6
CR22	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR23	Diode, Si. 150mA 15V		STB523	03508	1901-0460	
CR24, 25	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR26	Rect. Si. 1A 800V		A14N	03508	1901-0330	
CR27	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR29	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR30, 31	Rect. Si. 1A 800V		A14N	03508	1901-0330	
CR34, 39, 40	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR41-43	Rect. Si. 1A 800V		A14N	03508	1901-0330	
CR44	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR45	Diode, Si. 1A 800V		A14N	03508	1901-0330	
CR48, 49	Diode, Si. 50mA 75V		DA2050	03508	1901-0642	
CR50	Diode, Si. 200mA 180V		SG3396	03877	1901-0033	
CR51	Diode, Si. 150mA 15V		STB523	03508	1901-0460	
CR52, 53	Rect. Si. 1A 200V	2	A14B	03508	1901-0327	
CR55, 56	Diode, Si. 200mA 80V	2	FDH6308	07263	1901-0050	
L1, 2, 3	Ferrite Bead, Q17, 20, 21 emitter	3		28480	9170-0894	1
Q1	SS NPN dual Si.	2	2N5416		1854-0221	2
Q2-5	SS NPN Si.	10	TZ1200	56289	1854-0071	6
Q7	SS NPN dual Si.		2N5416		1854-0221	
Q8	SS PNP Si.	7	TZ173	56289	1853-0099	6
Q9, 11, 12, 14	SS NPN Si.		TZ1200	56289	1854-0071	
Q15, 16	SS PNP Si., T0-5	2	38640	02735	1853-0041	2
Q17	SS NPN Si.	1	40346	02735	1854-0095	1
Q19-22	SS PNP Si.		TZ173	56289	1853-0099	
Q24, 25	SS NPN Si., T0-66	2	2N4240		1854-0311	2
Q29	SS NPN Si.		2N1711A		1854-0244	
Q30, 31	SS NPN Si.	4	40327		1854-0232	4
Q32	SS PNP Si.		TZ173	56289	1853-0099	
Q33, 34	SS NPN Si.		TZ1200	56289	1854-0071	
Q37	SS NPN Si.		40327		1854-0232	
Q38	SS PNP Si.		TZ173	56289	1853-0099	
Q39	SS NPN Si.		40327		1854-0232	
R1	fxd, ww 100Ω ±0.5% 10W 5ppm	1	Type T10	01686	0811-2859	1
R2	fxd, ww 900Ω ±0.5% 1/2W 5ppm	1	Type E30	01686	0811-2112	1
R3	fxd, ww 9kΩ ±0.5% 1/2W 5ppm	1	Type E30	01686	0811-2858	1
R4	fxd, comp 4.3kΩ ±5% 1/2W	1	EB-4325	01121	0686-4325	1
R5	fxd, met. film 196Ω ±1% 1/8W	2	Type CEA T-O	07716	0698-3440	1
R7, 8	fxd, met. film 23kΩ ±1% 1/8W	2	Type CEA T-O	07716	0698-3269	1
R9	fxd, met. film 3.57kΩ ±1% 1/8W	1	Type CEA T-O	07716	0698-3496	1
R10	fxd, met. film 390kΩ ±1% 1/8W	1	Type CEA T-O	07716	0698-5093	1
R11	var. ww 2kΩ ±5% (CC Comp. Zero)	1	CT-100-4	84048	2100-1774	1
R12	fxd, met. film 3kΩ ±1% 1/8W	2	Type CEA T-O	07716	0757-1093	1
R13	fxd, met. film 249kΩ ±1% 1/8W	1	Type CEA T-O	07716	0757-0270	1
R14	fxd, met. film 68.1kΩ ±1% 1/8W	1	Type CEA T-O	07716	0757-0461	1
R16	fxd, met. film 196Ω ±1% 1/8W		Type CEA T-O	07716	0698-3440	
R19	fxd, comp 5.1kΩ ±5% 1/2W	2	EB-5125	01121	0686-5125	1
R20	fxd, comp 12kΩ ±5% 1/2W	2	EB-1235	01121	0686-1235	1
R21	fxd, comp 51Ω ±5% 1/2W	4	EB-5105	01121	0686-5105	1

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
R22	fxd, comp 150Ω ±5% 1/2W	2	EB-1515	01121	0686-1515	1
R23	fxd, comp 51Ω ±5% 1/2W		EB-5105	01121	0686-5105	
R24	fxd, comp 510Ω ±5% 1/2W	3	EB-5115	01121	0686-5115	1
R25	fxd, comp 10kΩ ±5% 1/2W	3	EB-1035	01121	0686-1035	1
R27, 28	fxd, met. film 64kΩ 1% 1/8W 25ppm	2	Type CEA T-O	07716	0698-6275	1
R29	var. ww 15kΩ ±5% (Guard Zero Adj.)	1	Type CT-100-4	07716	2100-0896	1
R30	fxd, met. film 2kΩ ±1% 1/8W	3	Type CEA T-O	07716	0757-0283	1
R31	fxd, ww 5.9kΩ ±1% 1/4W	1		28480	0811-1978	1
R32	fxd, ww (Selected) ±5% 3W	1	(obd)	28480		
R33	fxd, met. film 118kΩ ±1% 1/8W	1	Type CEA T-O	07716	0698-3265	1
R34	fxd, comp 3kΩ ±5% 1/2W	4	EB-3025	01121	0686-3025	1
R35	fxd, met. film 5.49kΩ ±1% 1/8W	2	Type CEA T-O	07716	0698-3382	1
R36	fxd, comp 30Ω ±5% 1/2W	1	EB-3005	01121	0686-3005	1
R37	fxd, comp 150Ω ±5% 1/2W		EB-1515	01121	0686-1515	
R40	fxd, comp 2kΩ ±5% 1/2W	2	EB-2025	01121	0686-2025	1
R41, 42	fxd, comp 51Ω ±5% 1/2W		EB-5105	01121	0686-5105	
R43	fxd, comp 20kΩ ±5% 1/2W	2	EB-2035	01121	0686-2035	1
R44	fxd, comp 5.1kΩ ±5% 1/2W		EB-5125	01121	0686-5125	
R45, 46	fxd, met. film 1.5kΩ ±1% 1/8W	2	Type CEA T-O	07716	0757-0427	1
R47	fxd, comp 1.8kΩ ±5% 1/2W	1	EB-1825	01121	0686-1825	1
R48	fxd, met. film 750Ω ±1% 1/8W	1	Type CEA T-O	07716	0757-0420	1
R50	fxd, comp 20Ω ±5% 1/2W	1	EB-2005	01121	0686-2005	
R51	fxd, met. ox. 820Ω ±5% 3W	1	242E8215	56289	0813-0010	1
R52	fxd, comp 2.7kΩ ±5% 1/2W	1	EB-2725	01121	0686-2725	1
R53	fxd, comp 750Ω ±5% 1/4W	1	CB-7515	01121	0683-7515	
R54	fxd, comp 1kΩ ±5% 1/2W	2	EB-1025	01121	0686-1025	1
R55	fxd, met. ox. 750Ω ±5% 5W	1	243E7515	56289	0811-1861	1
R56	fxd, comp 10kΩ ±5% 1/2W		EB-1035	01121	0686-1035	
R57	fxd, comp 3kΩ ±5% 1/2W		EB-3025	01121	0686-3025	
R58	fxd, comp 12kΩ ±5% 1/2W		EB-1235	01121	0686-1235	
R59	fxd, comp 3kΩ ±5% 1/2W		EB-3025	01121	0686-3025	
R60	fxd, comp 750Ω ±5% 1/2W	1	EB-7515	01121	0686-7515	1
R61	fxd, comp 1.3kΩ ±5% 1/2W	1	EB-1325	01121	0686-1325	1
R62, 63	fxd, comp 510Ω ±5% 1/2W		EB-5115	01121	0686-5115	
R64	fxd, comp 3kΩ ±5% 1/2W		EB-3025	01121	0686-3025	
R65	fxd, comp 1Meg ±5% 1/2W	1	EB-1055	01121	0686-1055	1
R66	fxd, comp 510kΩ ±5% 1/2W	2	EB-5145	01121	0686-5145	1
R67	fxd, comp 20kΩ ±5% 1/2W		EB-2035	01121	0686-2035	
R68	fxd, comp 360Ω ±5% 1/2W	1	EB-3615	01121	0686-3615	1
R69	fxd, film 2kΩ ±1% 1/8W		Type CEA T-O	07716	0757-0283	
R70	fxd, film 21.5Ω ±1% 1/8W	1	Type MF4C1	19701	0698-3430	1
R71-73	fxd, met. ox. 33kΩ ±5% 2W	3	Type C-42S	16299	0764-0046	1
R76	fxd, comp 1kΩ ±5% 1/2W		EB-1025	01121	0686-1025	
R77, 78	fxd, met. ox. 47kΩ ±5% 2W	2	Type C-42S	16299	0764-0031	1
R79	fxd, ww 30kΩ ±5% 10W	1	247E3035	63743	0811-1918	1
R80	fxd, comp 200Ω ±5% 1/2W	2	EB-2015	01121	0686-2015	1
R81, 82	fxd, comp 5.6kΩ ±5% 1/2W	2	EB-5625	01121	0686-5625	1
R83	fxd, comp 10kΩ ±5% 1/2W		EB-1035	01121	0686-1035	
R84	fxd, met. film 5.49kΩ ±1% 1/8W		Type CEA T-O	07716	0698-3382	
R85	fxd, met. film 2kΩ ±1% 1/8W		Type CEA T-O	07716	0757-0283	
R86, 87	fxd, comp (Selected) ±5% 1/2W	2	Type EB (obd)	01121		
R88	fxd, met. ox. 68K, ±5%, 1W	1	RG-32	11502	0761-0083	1
R90	fxd, comp 200Ω ±5% 1/2W		EB-2015	01121	0686-2015	
R93	fxd, comp 5.1Ω ±5% 1/2W	1	EB-51G5	01121	0686-0515	1
R94	fxd, met. ox. 100kΩ ±5% 2W	1	Type FP42	27167	0764-0028	1

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
R95	fxd, comp 470Ω ±5% 1/2W	2	EB-4715	01121	0686-4715	1
R96	fxd, comp 390Ω ±5% 1/2W	1	EB-3915	01121	0686-3915	1
R97	fxd, comp 470Ω ±5% 1/2W		EB-4715	01121	0686-4715	
R98	fxd, comp 510kΩ ±5% 1/2W		EB-5145	01121	0686-5145	
R99	fxd, comp 24kΩ ±5% 1/2W	1	EB-2435	01121	0686-2435	1
R100, 101	fxd, ww 10kΩ ±5% 10W	2	247E1035	56289	0811-2702	1
R105	fxd, met. film 9.09kΩ ±1% 1/8W	1	Type CEA T-O	07716	0757-0288	1
R106	var. ww 5kΩ ±20% (Ammeter Adj.)	2	Type 110-F4	11236	2100-1824	1
R107	fxd, met. film 11kΩ ±1% 1/8W	1	Type CEA T-O	07716	0757-0443	1
R108	fxd, met. ox. 150kΩ ±5% 2W	1	Type C-42S	16299	0764-0049	1
R109	fxd, met. film 6.2kΩ ±1% 1/8W	1	Type CEA T-O	07716	0698-5087	1
R110	var. ww 5kΩ ±20% (Voltmeter Adj.)		Type 110-F4	11236	2100-1824	
TB1	Rear Barrier Block, 5 Terminals	1		28480	0360-1550	
TB2	Rear Barrier Block, 4 Terminals	1		28480	0360-1551	
VR1	Diode, zener 2.37V 400mW	1	SZ10939-2	04713	1902-3002	1
VR2	Diode, zener 7.5V 400mW	3	SZ10939-146	04713	1902-0064	3
VR3	Diode, zener 7.5V 1W	2	SZ11213-104	04713	1902-0799	
VR4	Diode, zener 6.2V 400mW 20ppm	1	1N825	28480	1902-1221	1
VR5	Diode, zener 7.5V 1W		SZ11213-104	04713	1902-0799	
VR6	Diode, zener 12.4V 400mW	1			1902-3185	1
VR7, 8	Diode, zener 7.5V 400mW		SZ10939-146	04713	1902-0064	
VR9, 10	Diode, zener 150V 1 watt	2	SZ11213-440	04713	1902-0586	2
VR11	Diode, zener 16.2V 400mW	2		28480	1902-0184	2
VR12, 13	Diode, zener 5.62V 400mW	3		28480	1902-3104	3
VR14	Diode, zener 28.7V 1 watt	1	SZ11213-272	04713	1902-0572	1
VR15	Diode, zener 16.2V 400mW			28480	1902-0184	
VR18	Diode, zener 5.62V 400mW			28480	1902-3104	
VR19	Diode, zener 4.99V 1W	1	SZ11213-54	04713	1902-0533	1
Z1, 2	Integrated Circuit, Operational Amplifier	2	LM301AH	27014	1820-0223	1
	A3 HEAT SINK BOARD					
CR54	Rect. Si. 1A 800V	1	A14N	03508	1901-0330	
R74	fxd, comp 510Ω ±5% 1/2W	1	EB-5115	01121	0686-5115	
VR101, 103, 105	Diode, zener 150V 1W	2	SZ11213-440	04713	1902-0586	
VR102, 104, 106	Diode, zener 75V 1W	3	SZ11213-392	04713	1902-0661	
	A4 HEAT SINK BOARD					
R92	fxd, comp 100Ω ±5% 1/2W	1	EB-1015	01121	0686-1015	1
R116	fxd, comp 10Ω ±5% 1/2W	1	EB-1005	01121	0686-1005	1
	FRONT PANEL ASSEMBLY-ELECTRICAL					
DS1	Line Indicator Lamp, Neon	1	A1C	08806	2140-0047	1
DS2	Voltage Limit Indicator Lamp, Incand. (Amber)	1	MCL-A3-1730	07137	1450-0305	1
E1	Tip Jack, Panel Mount, White (+ Meter)	1	105-601	74970	1251-2440	1

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
E2	5 Way Binding Post, Red (+)	1		28480	1510-0094	1
E3, 4	5 Way Binding Post, Black (-)	2		28480	1510-0522	1
M1	Voltmeter, 3 1/2", 0-360V	1		28480	1120-1151	1
M2	Ammeter, 3 1/2", 0-120mA	1		28480	1120-1157	1
P2	Tip plug, white (+ Meter)	1	105-301	74970	1251-2441	1
R15	var. ww 10kΩ ±5% 10-Turn 2W (Current Control)	1		28480	2100-1866	1
R75	mold, car. 250kΩ ±10% (Voltage Control)	1		28480	2100-2909	1
R118	fxd, comp 47kΩ ±5% 1/2W	1	EB-4735	01121	0686-4735	1
S1	Line switch, SPDT Toggle	1	7101PYZ1	09353	3101-1605	1
S2	Current Range Switch, Rotary	1		28480	3100-1935	1
	REAR PANEL ASSEMBLY-ELECTRICAL					
E5	5 Way Binding Post, N. P. Brass (Ground)	1	137	83330	1510-0044	1
F1 (115V)	Fuse Cartridge 1A, 125V (Slow Blow)	1	Type 3AG 313.001S	75915	2110-0007	5
F1 (230V)	Fuse Cartridge 0.5A, 250V (Slow Blow)	1	Type 3AG 313.500S	75915	2110-0202	5
J2	Receptable, Input Power	1		28480	1251-2357	
P1	Power Cord	1		28480	8120-1348	
Q26-28	Power NPN Si., TO-3	3	64494	02735	1854-0631	3
Q35, 36	Power NPN Si., TO-3	2	(See Note On Page 6-11)		1854-0690	2
S3	115/230V Line Switch, Recessed DPDT Slide	1		28480	3101-1234	1
	CHASSIS ASSEMBLY-ELECTRICAL					
R115A/R115B	fxd, ww 20kΩ ±5% 40W, Center Tapped	1	Type HLT-35	91637	0811-3236	1
R117, 118, 119	fxd, ww 400Ω ±5% 40W	3	Type V8ZT	12697	0818-0011	1
T1	Transformer, Power (includes Standoffs)	1		28480	06186-80091	1
	A2 BOARD-MECHANICAL					
	Jumper, Rear Barrier Blocks	3	422-13-11-013	71785	0360-1143	1
	Socket, Integrated Circuit Z1 and Z2	2	133-98-92-061	71785	1200-0763	1
	Standoff, Q24, 25, 1/4" Hex	4	2300	83330	0380-0716	4
	Heat Dissipator, TO-5 (Q37, Q39)	2	TXBE 032-031B	98978	1205-0030	
	Insulator, Transistor, TO-5	8		28480	0340-0166	

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
	FRONT PANEL MECHANICAL					
	Meter Trim	1		28480	5020-8061	
	Bezel Meter, 3 1/2"	2		28480	4040-0483	1
	Meter Combining Pin	1		28480	1480-0181	1
	Front Panel, Basic	1		28480	06186-20006	
	Front Panel, Control Section Insert	1		28480	06186-00011	
	Front Panel, Output Section Insert	1		28480	06186-00012	
	Insulated Strip, Nylon, Terminals E1, 2, 3	1		28480	5020-5754	1
	Corporate Logo	1		28480	7120-1254	
	Knob Assembly, R15	1		28480	0370-1091	1
	Knob Assembly, S2 and R75	2		28480	0370-1099	1
	Shoulder Washer, (+), (-), and GND Binding Posts	3		28480	2190-0494	3
	Lampholder, Clear, DS1	1		28480	5040-0234	1
	Lampholder, Base, DS1	1		28480	5040-0305	1
	Fastener, DS2, .312" Dia.	1	C-17373-102-24D	78553	0510-0123	1
	Stand, Tilt, Foot Assembly	1		28480	1490-0032	
	Hinge, Foot Assembly	2		28480	5040-0700	
	REAR PANEL-MECHANICAL					
	Panel, Rear	1		28480	06186-00010	
	Heat Sink Rear Panel, (Q26, 27, 28, 35, 36)	1		28480	06186-20005	
	Cover, Rear Barrier Strips	1		28480	06186-00007	
	Insulating Strip, Mylar, Copper-Clad Q26, 27, 28	1		28480	06186-20023	1
	Shoulder Washer, Double, Heat Sink and T1 Bracket	6		28480	0340-0172	6
	Serial Plate	1		28480	7120-1111	
	Insulator, Transistor Q26, 27, 28, 35, 36	5		28480	0340-0795	
	Fuseholder, F1	1	342014	75915	1400-0084	1
	Hex Nut. Fuseholder	1	903-12	75915	2950-0038	1
	Lockwahser, Fuseholder	1		28480	2190-0054	1
	Flat Neoprene Washer, Fuseholder	1	901-129	75915	1400-0090	1
	Insulator, Boron Nitride Q26, 27, 28, 35, 36	5	H-4001	61637	0340-0411	5
	CHASSIS ASSEMBLY-MECHANICAL					
	Chassis, Internal	1		28480	06186-00001	
	Bracket, Transformer T1	1		28480	06186-00003	
	Cover, Side	2		28480	5000-8565	
	Cover, Top	1		28480	5060-8585	
	Cover, Bottom	1		28480	5000-9444	
	Fastener, Top and Bottom Covers	4	C-8020-632-24B	78553	0590-0052	
	Side Frame Assembly	2		28480	5060-0703	
	Foot Assembly	2		28480	5060-0728	
	Spacer, Side Frame Assembly	1		28480	5020-0701	
	Shoulder Washer, Double, T1 Mounting	4		28480	0340-0492	
	Cable Clamp	2	3-4-1	31827	1400-0116	1

REF. DESIG.	DESCRIPTION	TQ	MFR. PART NO.	MFR. CODE	HP PART NO.	RS
	CHASSIS ASSEMBLY-MECHANICAL					
	Standoff, 6-32 x 1/2W, A2 Board	2	1951E	00866	0380-0093	
	Guide, Printed Circuit Boards	4		28480	0403-0150	
	MISCELLANEOUS					
	Manual	1		28480	06186-90005	
	Carton, Packing	1		28480	9211-1347	
	Floater Pad, Packing	2		28480	9220-1545	
	Fuse Envelope, F1 (230V)	1		28480	9320-0234	
	OPTION 14					
	3 Digit Decadial Current Control					
	3 Digit Decadial	1	RD411	07716	1140-0020	

NOTE:

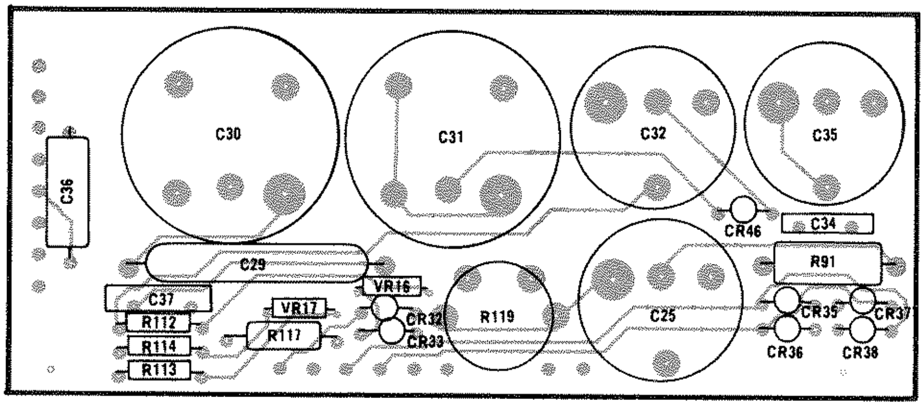
There is no direct commercial replacement for transistors Q35 and Q36. For these transistors, the 6186C uses RCA 2N5240's that are selected for BV_{CEO}, I_{CER}, and $I_{S/b}$ (second breakdown). The specifications and test conditions for these characteristics are tabulated below.

Characteristic	Specification	Test Conditions
BV_{CEO}	375V min.	I_C = 100mA, pulse loading
I_{CER}	1mA max.	V_{CE} = 375V, R_{EB} = 200Ω, case temp = 125°
$I_{S/b}$	25mA min.	V_{CE} = 300V, T = 1 sec, case temp 0°C to 125°C

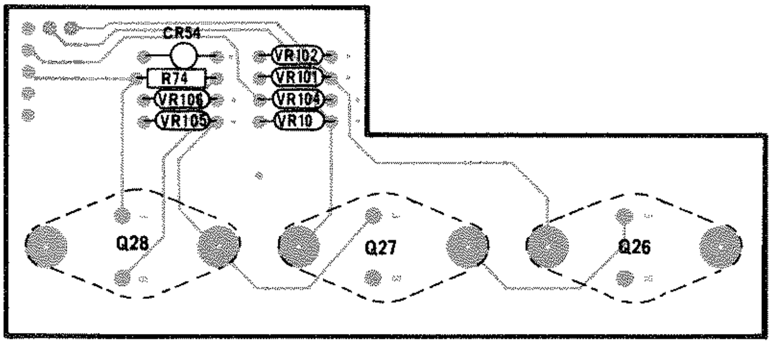
SECTION VII
CIRCUIT DIAGRAMS

This section contains component location diagrams and a schematic diagram of the power supply. The component location diagrams show the physical locations and reference designators of parts mounted on the printed circuit boards and chassis.

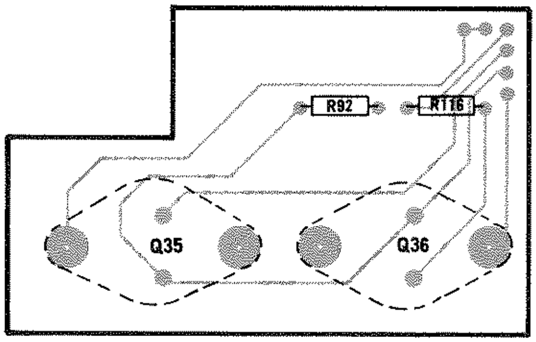
The schematic diagram illustrates the circuitry of the entire power supply. Voltages are given in italics adjacent to test points, which are identified by circled numbers both on the schematic and on the component location diagrams.



A1 Input Board



A3 Heatsink Board



A4 Heatsink Board

Figure 7-1. Component Location Diagrams

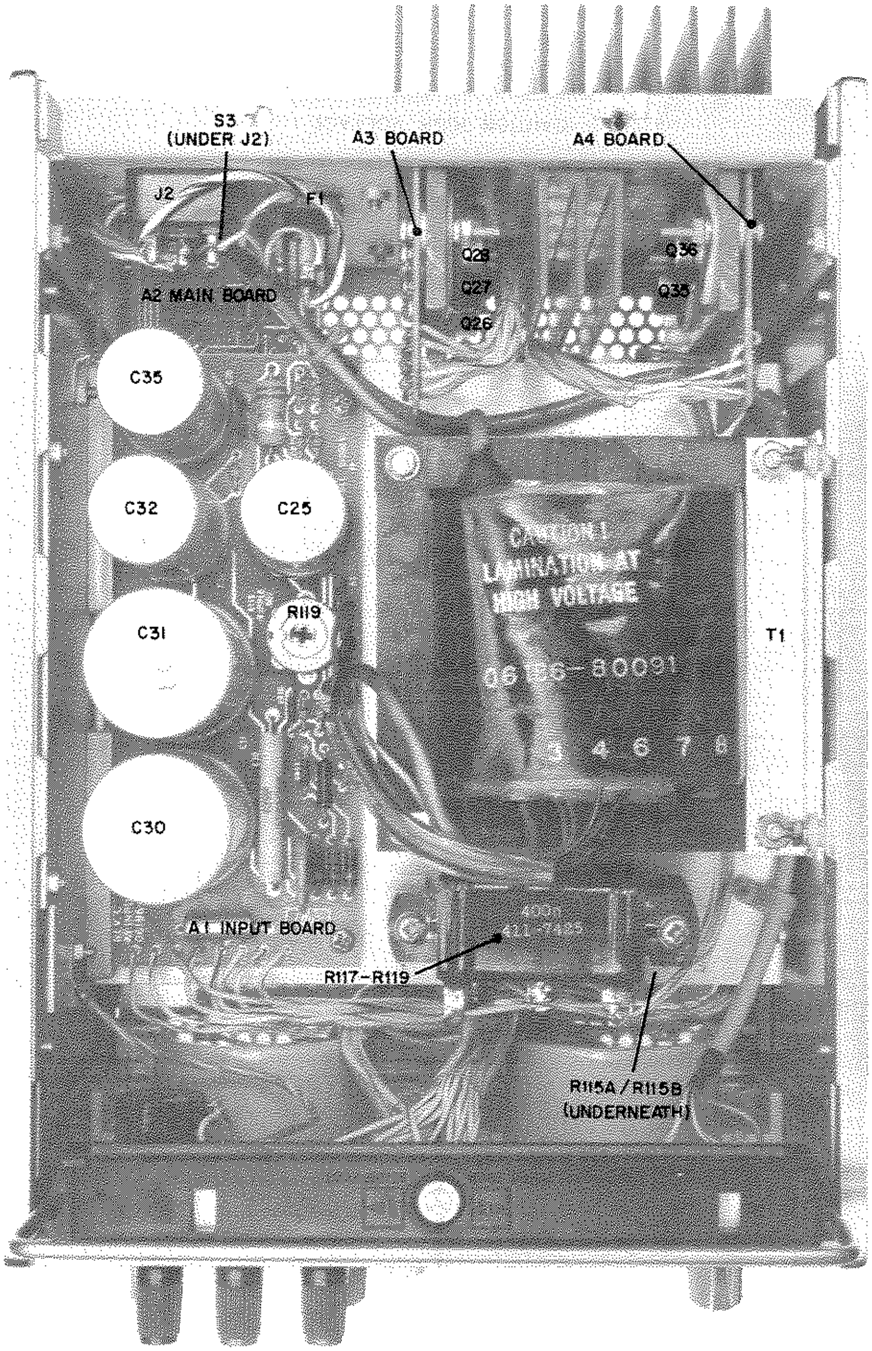


Figure 7-2. Chassis Component Location Diagram