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# Errata

**Title & Document Type:** 6227B Operating and Service Manual

**Manual Part Number:** 06227-90001

**Revision Date:** December 1970

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## HP References in this Manual

This manual may contain references to HP or Hewlett-Packard. Please note that Hewlett-Packard's former test and measurement, semiconductor products and chemical analysis businesses are now part of Agilent Technologies. We have made no changes to this manual copy. The HP XXXX referred to in this document is now the Agilent XXXX. For example, model number HP8648A is now model number Agilent 8648A.

## About this Manual

We've added this manual to the Agilent website in an effort to help you support your product. This manual provides the best information we could find. It may be incomplete or contain dated information, and the scan quality may not be ideal. If we find a better copy in the future, we will add it to the Agilent website.

## Support for Your Product

Agilent no longer sells or supports this product. You will find any other available product information on the Agilent Test & Measurement website:

www.tm.agilent.com

Search for the model number of this product, and the resulting product page will guide you to any available information. Our service centers may be able to perform calibration if no repair parts are needed, but no other support from Agilent is available.

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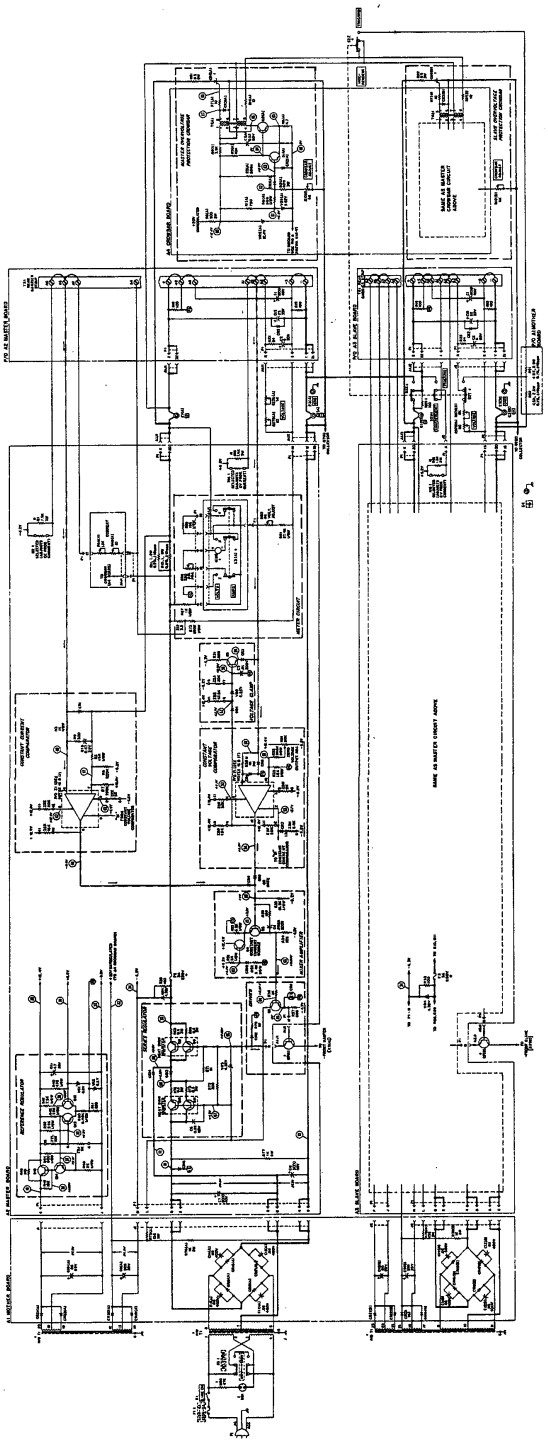
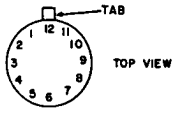


Figure 7-7. Model 62278, Schematic Diagram.

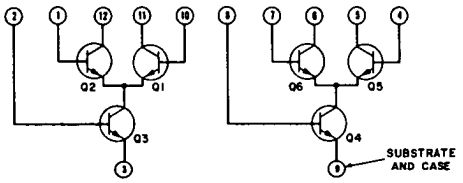
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## SCHEMATIC NOTES

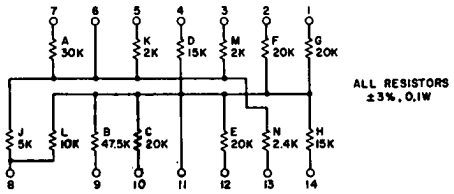
1. ALL RESISTORS ARE IN OHMS, 1/2W, ±5% UNLESS OTHERWISE NOTED.
2. ALL 1/4W AND 1/8W RESISTORS ARE ±1% UNLESS OTHERWISE NOTED.
3. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE NOTED.
4. REAR TERMINALS ARE SHOWN IN NORMAL STRAPPING FOR USE OF FRONT PANEL CONTROLS.
5. MODE SWITCH SHOWN IN INDEPENDENT POSITION; METER SWITCH SHOWN IN AMPS POSITION.
6. DC VOLTAGES WERE MEASURED UNDER THE FOLLOWING CONDITIONS:
   A. HEWLETT-PACKARD 427A OR EQUIVILENT.
   B. 115VAC INPUT.
   C. SUPPLY IN CONSTANT VOLTAGE OPERATION AT MAXIMUM RATED OUTPUT VOLTAGE WITH NO LOAD CONNECTED.
   D. CURRENT CONTROLS AND CROWBAR ADJUST CONTROLS TURNED FULLY CLOCKWISE; MODE SWITCH IN INDEPENDENT POSITION.
   E. VOLTAGES REFERENCED TO +S UNLESS OTHERWISE NOTED.
   F. VOLTAGES ARE TYPICAL ±10% UNLESS OTHERWISE NOTED.
7. †DENOTES NOMINAL VALUE COMPONENT SELECTED FOR OPTIMUM PERFORMANCE.
8. ◆DENOTES CHASSIS MOUNTED COMPONENTS.
9. MDENOTES ±20 PPM WIRE TEMPERATURE COEFFICIENT.
10. ▭ ENCLOSES FRONT PANEL MARKING.
11. ▭ ENCLOSES REAR PANEL MARKING.
12. ——▸—— DENOTES FORWARD SIGNAL PATH OF THE VOLTAGE FEEDBACK LOOP.
13. ——▸—— DENOTES FORWARD SIGNAL PATH OF THE CURRENT FEEDBACK LOOP.
14. —(7)— NUMBER OR LETTER REFERS TO PIN OF A1J1: NUMBER DESIGNATES CONTACT ON COMPONENT SIDE OF PLUG-IN BOARD; LETTER DESIGNATES CONTACT ON CIRCUIT SIDE OF PLUG-IN BOARD (SEE FIGURES 7-5 AND 7-6).
15. LETTERS (A) AND (B) ON A1 MOTHER BOARD AND A4 CROWBAR BOARD DESIGNATE COMPONENTS ASSOCIATED WITH MASTER AND SLAVE SUPPLIES, RESPECTIVELY.
16. PIN LOCATION DIAGRAM FOR INTEGRATED CIRCUIT Z1 IS SHOWN BELOW:




17. SCHEMATIC DIAGRAM FOR INTEGRATED CIRCUIT Z1 IS SHOWN BELOW:



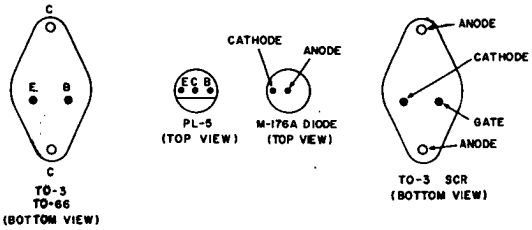

18. SCHEMATIC DIAGRAM FOR INTEGRATED CIRCUIT Z2 IS SHOWN BELOW:



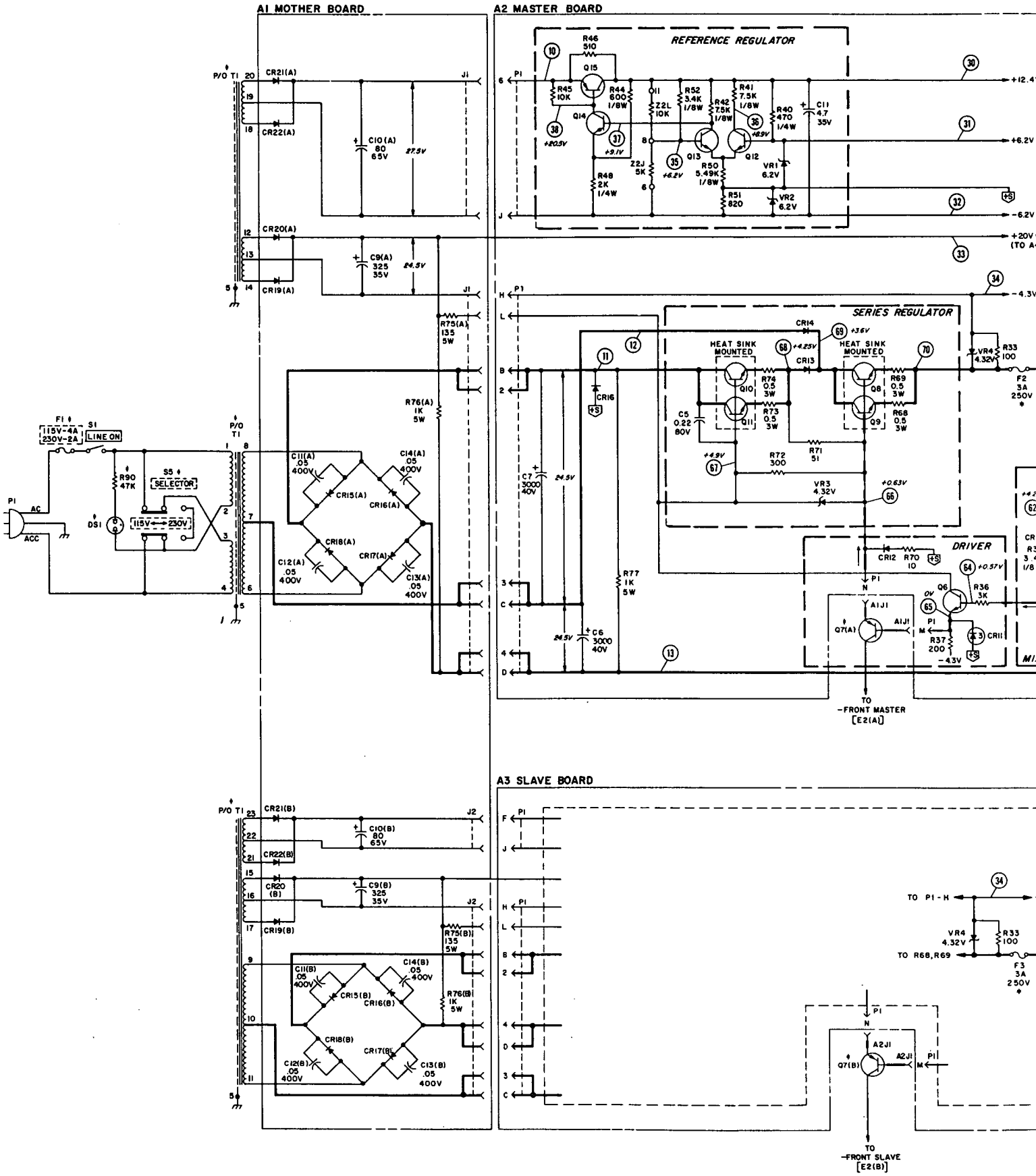

19. MODE SWITCH S2 AND METER SWITCH S3 AS VIEWED FROM REAR ARE SHOWN BELOW:



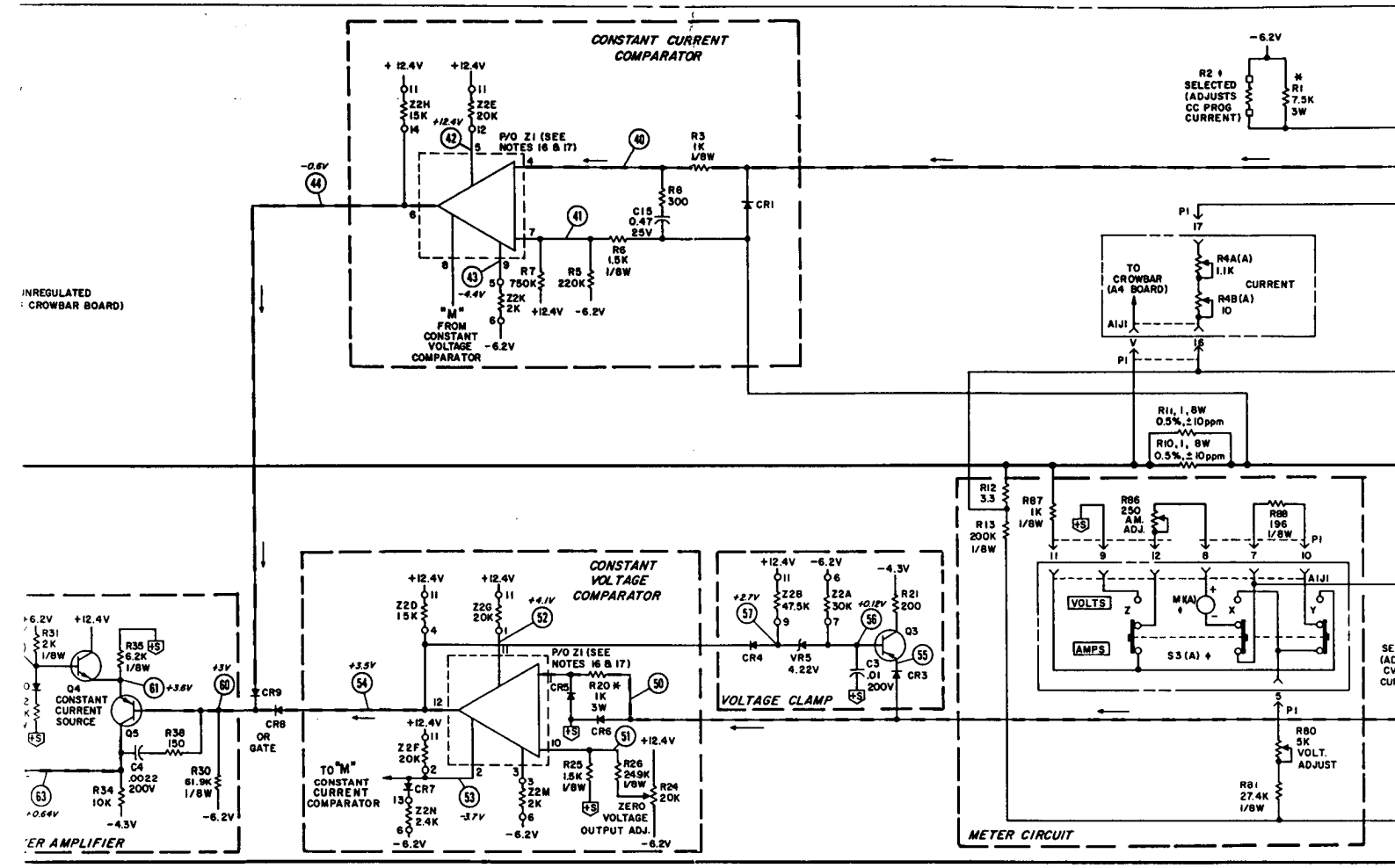

20. PIN LOCATIONS FOR TRANSISTORS, SCR, AND POWER DIODES ARE SHOWN BELOW:




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SAME AS MASTER CIRCUIT ABOVE

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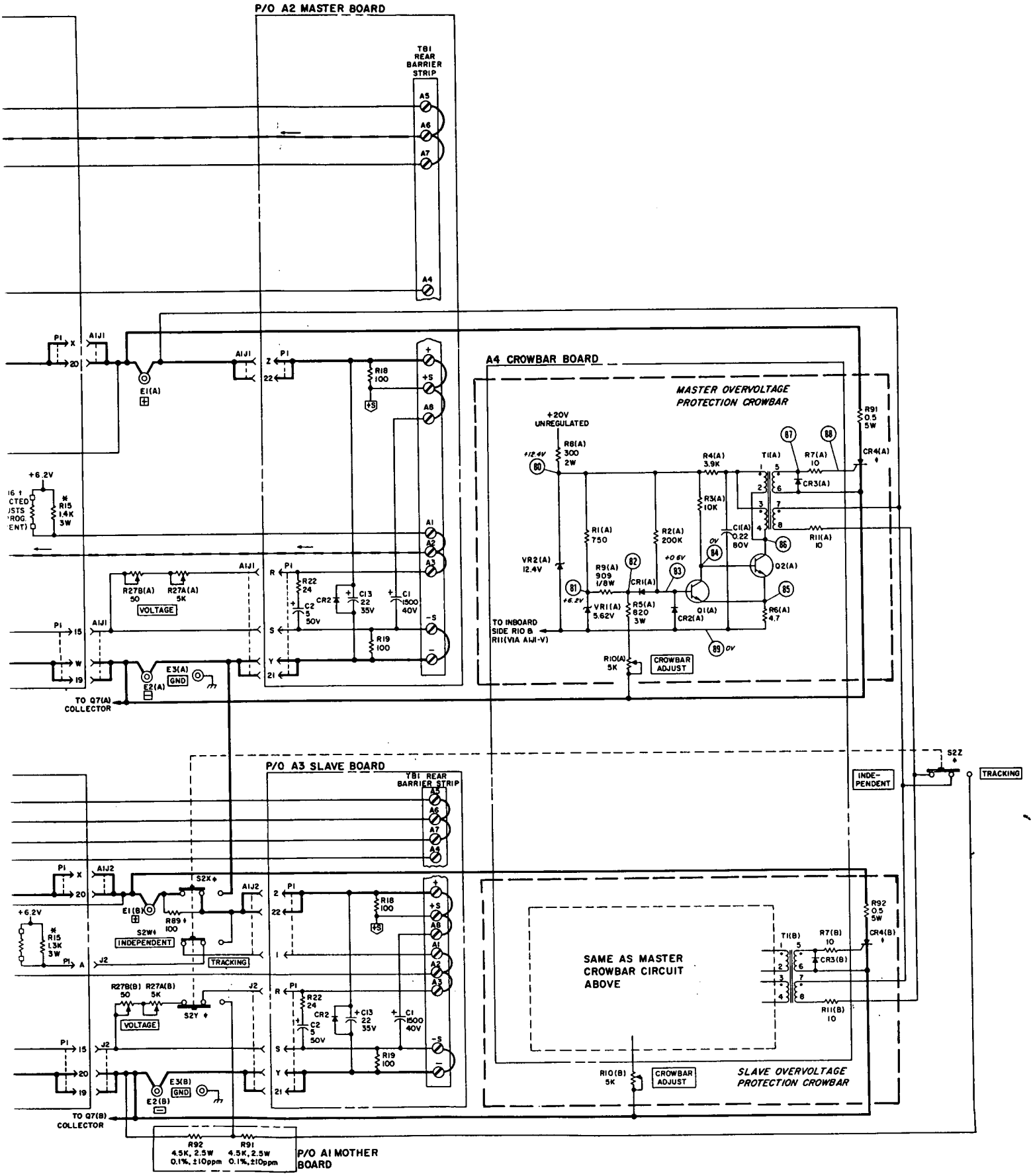



Figure 7-7. Model 6227B, Schematic Diagram.

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# *Operating and Service Manual*

# HP Model 6227B DC Power Supply

HP Part No. 06227-90001

HEWLETT PACKARD

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HEWLETT PACKARD

# *Operating and Service Manual*

# HP Model 6227B DC Power Supply

HP Part No. 06227-90001

For Serials 1019A-00141 and Above *

* For serials Above 1019A-00141 a Change Page may be included.

* For serials Below 1019A-00141 refer to Appendix A.

Printed: December, 1970

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## CERTIFICATION

*Hewlett-Packard Company certifies that this product met its published specifications at time of shipment from the factory. Hewlett-Packard further certifies that its calibration measurements are traceable to the United States National Bureau of Standards, to the extent allowed by the Bureau's calibration facility, and to the calibration facilities of other International Standards Organization members.*

## WARRANTY

This Hewlett-Packard hardware product is warranted against defects in material and workmanship for a period of one year from date of delivery. HP software and firmware products, which are designated by HP for use with a hardware product and when properly installed on that hardware product, are warranted not to fail to execute their programming instructions due to defects in material and workmanship for a period of 90 days from date of delivery. During the warranty period Hewlett-Packard Company will, at its option, either repair or replace products which prove to be defective. HP does not warrant that the operation for the software firmware, or hardware shall be uninterrupted or error free.

For warranty service, with the exception of warranty options, this product must be returned to a service facility designated by HP. Customer shall prepay shipping charges by (and shall pay all duty and taxes) for products returned to HP for warranty service. Except for products returned to Customer from another country, HP shall pay for return of products to Customer.

Warranty services outside the country of initial purchase are included in HP's product price only if Customer pays HP international prices (defined as destination local currency price, or U.S. or Geneva Export price).

If HP is unable, within a reasonable time, to repair or replace any product to a condition as warranted, the Customer shall be entitled to a refund of the purchase price upon return of the product to HP.

## LIMITATION OF WARRANTY

The foregoing warranty shall not apply to defects resulting from improper or inadequate maintenance by the Customer, Customer-supplied software or interfacing, unauthorized modification or misuse, operation outside of the environmental specifications for the product, or improper site preparation and maintenance. NO OTHER WARRANTY IS EXPRESSED OR IMPLIED. HP SPECIFCALLY DISCLAIMS THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

## EXCLUSIVE REMEDIES

THE REMEDIES PROVIDED HEREIN ARE THE CUSTOMER'S SOLE AND EXLCUSIVE REMEDIES. HP SHALL NOT BE LIABLE FOR ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES, WHETHER BASED ON CONTRACT, TORT, OR ANY OTHER LEGAL THEORY.

## ASSISTANCE

*The above statements apply only to the standard product warranty. Warranty options, extended support contracts, product maintenance agreements and customer assistance agreements are also available. Contact your nearest Hewlett-Packard Sales and Service office for further information on HP's full line of Support Programs.*

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# 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).

## FUSES

Only fuses with the required rated current, voltage, and specified type (normal blow, time delay, etc.) should be used. Do not use repaired fuses or short circuited fuseholders. To do so could cause a shock or fire hazard.

## 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.

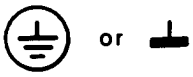
## SAFETY SYMBOLS.



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.



Indicate earth (ground) terminal.

WARNING

or



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

or

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.*

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**Herstellerbescheinigung**

Diese Information steht im Zusammenhang mit den Anforderungen der Maschinenlärminformationsverordnung vom 18 Januar 1991.

* Schalldruckpegel Lp < 70 dB(A) * Am Arbeitsplatz * Normaler Betrieb * Kein Ventilator eingebaut * Nach DIN 45635 T. 19 (Typprüfung)

**Manufacturer's Declaration**

This statement is provided to comply with the requirements of the German Sound Emission Directive, from 18 January 1991. This product has a sound pressure emission (at the operator position) < 70 dB.

* Sound Pressure Lp < 70 dB(A) * At Operator Position * Normal Operation * No fan installed * According to ISO 7779 (Type Test).

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# MANUAL CHANGES

Model 6227B DC Power Supply
Manual HP P/N 06227-90001
Manual Printing Date 12/70
Change Date 9/12/94

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

| SERIAL | | MAKE CHANGES |
|---|---|---|
| Prefix | Number | |
| All | --- | Errata |
| 1020A | 0161-0305 | 1 |
| 1113A | 0306-0595 | 1,2 |
| 1146A | 0596-0795 | 1-3 |
| 1146A | 0796-0845 | 1-4 |
| 1146A | 0846-1045 | 1-5 |
| 1146A | 1046-1245 | 1-6 |
| 1146A | 1246-1295 | 1-7 |
| 1146A | 1296-1895 | 1-8 |
| 1146A | 1896-2545 | 1-9 |
| 1607A | 2546-3345 | 1-10 |
| 1736A | 3346-3545 | 1-11 |
| 1750A | 3546-3825 | 1-12 |
| 1814A | 3826-4805 | 1-13 |
| 1927A | 4806-8495 | 1-14 |
| 2432A | 8495-8820 | 1-15 |
| 2451A | 8821-8970 | 1-16 |
| 2507A | 8971-10520 | 1-17 |
| 2507A | 10521-10522 | 1-18 |
| 2507A | 10523 | 1-17 |
| 2507A | 10524-10525 | 1-18 |
| 2507A | 10526-10528 | 1-17 |
| 2507A | 10529-10533 | 1-18 |
| 2507A | 10534-10535 | 1-17 |
| 2507A | 10536-10537 | 1-18 |
| 2507A | 10538 | 1-17 |
| 2507A | 10539-10540 | 1-18 |
| 2831A | 10541-11680 | 1-18 |
| 3314A | 11681-11830 | 1-19 |
| 3446A | 11831-up | 1-20 |

ERRATA:

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

CHANGE 1:

In the replaceable parts table and on the schematic diagram add new capacitors, A2C16 and A3C16: 1 uF, 35 V, HP P/N 0180-0291. C16 is connected in series with current sampling resistance R11 (across R10) in both the master and slave supplies.

CHANGE 2:

The Serial Prefix of this unit has been changed to 1113A. This is the only change.

CHANGE 3:

In the replaceable parts table and on the schematic diagram make the following changes: A2F2: Change to 3A, 250 V, HP P/N 2110-0003. F2 has been moved from Master Board (A2) to the chassis and is now in series with the master's negative output lead (from CR16A-CR17A).

A3F2: Change to same fuse as A2F2 and designate "F3." This fuse has also been moved to the chassis from the Slave Board and is in series with slave's negative output led (CR16B-CR17B). Add fuse blocks (2) for above fuses: HP P/N 2110-0247.

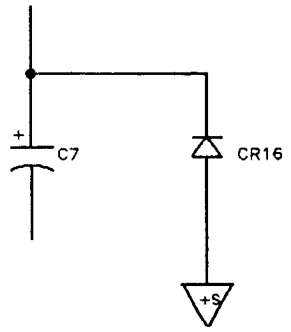
A2, A3R85: Delete (short-out) R85 in the two meter circuits.

CHANGE 4:

In the replaceable parts table and on the schematic (as applicable), make the following changes:

F1 (230 V): Change F1 (230 V) to 2A slow blow, HP P/N 2110-0303.

CR16: Add diode CR16, HP P/N 1901-0416 as shown below:




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

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| DESCRIPTION | STANDARD | HP PART NO. OPTION A85 | OPTION X95 |
|---|---|---|---|
| Front Panel | 06227-60004 | 06227-60003 | < -------- |
| Meter Trim | 5020-8061 | 5020-5770 | <--------- |
| Upper rear panel | 5000-9462 | 5000-6263 | <--------- |
| Lower rear panel | 5000-9463 | 5000-6264 | <--------- |
| Left/Right Side Covers | 5000-9432 | <--------- | 5000-6145 |
| Rear Barrier Cover | 5000-9450 | <--------- | 5000-6275 |
| Heat Sink | 5020-8069 | <--------- | 5020-5774 |
| Top Cover | 5060-8585 | <--------- | 5060-0724 |
| Bottom Cover | 5000-9444 | <--------- | 5000-6261 |

CHANGE 5

In the replaceable parts table under Chassis-Electrical, and on the schematic, make the following changes:
Terminal Board: Add Terminal Board, HP P/N 0360-0401.
Terminal Board: Add Terminal Board, HP P/N 0360-0393.
R91, R92: Add resistors R91 and R92, .5 ohm +/-10%, 5w, HP P/N 0811-1848. R91 is placed in series with the anode of CR4(A) and + out. The resistors provide current limit when the crowbars are activated by a capacitive load or battery on the output.

CHANGE 6

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

CHANGE 7:

In the parts list and on the schematic for both the A2 master board and the A3 slave board, change R36 to 3 k 1/2 W, HP P/N 0686-3025; and change R15 to 1.4 k 5% 3 W 30ppm, HP P/N 0811-1804.

CHANGE 8:

In the parts list under Front Panel-Electrical, change toggle switch S1 to HP P/N 3101-1055.

CHANGE 9:

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

CHANGE 10:

In parts list under A4 Crowbar Board-Electrical, add cable assembly W1, HP P/N 8120-2085. The cable assembly connects the A4 board to Mother board A1 and replaces 10 individual wires which were previously used. This change does not affect the schematic diagram.

ERRATA:

For all instruments delivered on or after July 1, 1978, change the HP P/N for fuseholder from 1400-0084 to fuseholder body 2110-0564 and fuseholder carrier 2110-0565. Change the HP P/N for fuseholder nut from 2950-0038 to 2110-0569. I fuseholder must be replaced for any reasons, replace complete fuseholder and with new fuseholder parts. Do not replace new parts with old parts.

Under Section IV in the Table of Contents, delete the words "To be supplied with final manual.

Add the following notice to paragraph 1-18: "Effective December 1, 1975, extra manuals may be obtained by ordering Option 910 when ordering your instrument. The number of extra manuals depends on the number of Option 910s ordered.

Effective January 1st, 1977, Options 007 (10-turn voltage control) and 008 (10-turn current control) are no longer available individually, but they are still available combined as Option 009. Likewise, Options 013 (10-turn voltage control with decadial) and Option 014 (10 -turn current control with decadial) are no longer available individually, but they are available combined into a single new option designated Option 015. Make these changes wherever Option 007, 008, 013, or 014 is mentioned in the manual.

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Delete the posts listed on page 6-9 of the parts list and add: black binding post, HP P/N 1510-0114 (qty. 4); and red binding post, HP P/N 1510-0115 (qty. 2).

On Figures 7-5 and 7-6, change the circled test point numbers as follows:
64 change to 66
65 change to 67
66 change to 68
67 change to 69
68 change to 70

In the parts list, page 6-10, change: Bottom cover to HP P/N 5000-9368 qty. 1. Top cover to HP P/N 5000-9367 qty. 1.

In the parts list, page 6-10, under BOARDS MECHANICAL, change jumper to HP P/N 0360-2186 and change Barrier Block to HP P/N 0360-2197.

In the Operating and Service manual, change Section 2-23 to read as follows:

"The power supply may be operated from either a nominal 115 volt or 230 volt 48-63 Hz power source. When the instrument leaves the factory, the proper internal/external voltage selection, line cord plug, and fuse have been installed to operate with the mains voltage, frequency, and outlet receptacle of the country of destination.

Make sure that the correct fuse is installed if the mains voltage is changed."

For units with Option 040, add the following note.

NOTE

When calibrated for Option 040, units may not meet full output voltage or current specification when used with the front panel potentiometer. This is due to the resistance tolerance of the potentiometer and the programming coefficient accuracy required for Option 040.

In the parts list on page 6-8, change Q1A,B to 2N3904, HP p/n 1854-0215.

CHANGE 11:

Zero voltage output adjust A2R24 and A3R24 in the constant voltage comparator circuits of the master and slave boards have been changed to 20 k, 10%, HP P/N 2100-0558. Correct the Figure 7-7 schematic and the parts list.

CHANGE 12:

In the parts list and the above table, delete rear heat sink 5020-8069 and add the following:

Heat Sink, Left: HP P/N 5020-2587.
Heat Sink, Right: HP P/N 5020-2588

CHANGE 13:

In parts list, A4 crowbar board, change resistors R10A, B to 5k ohm, 5%, 1/2W, HP P/N 2100-3708.

CHANGE 14:

In the parts list, change the HP P/N for the binding posts and associated hardware to the following:

Red binding post, qty. 4: 1510-0094
Terminal lug, qty. 4: 0360-0375
Lockwasher, qty. 4: 2190-0016
Nut, qty. 4: 2500-0001
Black binding post, qty 2: 1510-0522
Terminal lug, qty. 2: 0360-1190
Nut, qty. 6: 2950-0144

CHANGE 15:

In the replaceable parts list, page 6-9, under Front Panel-Electrical, delete DS1, R90, and S1. On next page, Front Panel-Mechanical, change Front-Panel, Control Section Insert to HP P/N 5020-2663, TQ 1. Change Front-Panel, Output Section Insert to HP P/N 5001-6704, TQ 1. Delete Lampholder-base, DS1 and Lampholder-clear,DS1. Add terminal strip, HP P/N 0360-0393, TQ 1. Add S1, switch,dpst, HP P/N 3101-2443, TQ1. On the schematic, figure 7-7, in the line voltage section, delete R90 and DS1. Replace S1 with a double-pole single-throw switch.(One section of S1 breaks the AC line and the opposite side breaks the ACC line).

CHANGE 16:

In the parts list, page 6-9, change R10A, 10B to HP P/N 2100-4102, TQ is 2.

CHANGE 17:

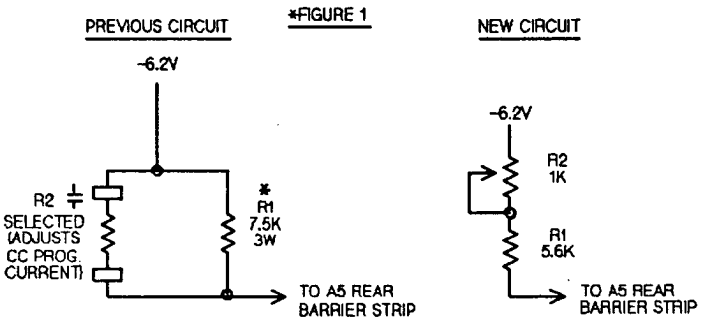
On page 5-20, paragraph 5-84 delete steps c. and g. and change in step f, "decade resistance box" to "potentiometer R16". On the following page, 5-21, in paragraph 5-88 delete steps d. and g. and change in step f, "decade resistance box" to "potentiometer R2".

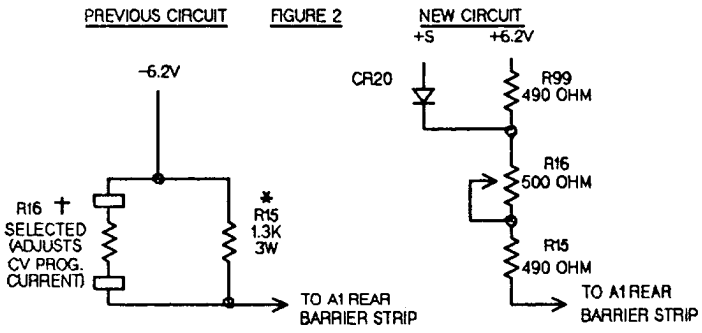
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In the replaceable parts list make the following changes to the A2 Master Board and the A3 Slave Board. Change R1 to 5.6K, 3%, 3W, HP P/N 0812-0091, R2 to var., 1K, 10%, HP P/N 2100-3352, R15 to 490 ohms, 5%, 3W, HP P/N 0811-1801, R16 to var., 500, 10%, HP P/N 2100-3351, R80 to var., 5K, 10%, HP P/N 2100-3252 and R86 to var., 250 ohms, 10%, HP P/N 2100-3531.

In the replaceable parts list, add the following parts to the A2 Master Board and the A3 Slave Board. Resistor R99, 490 ohms, 5%, 3W, HP P/N 0811-1801, TQ 1, and Diode CR20 HP P/N 1901-0033, TQ 1.

On Figure 7-7 change the circuits on the A2 Master Board and A3 Slave Board to appear as shown below. *Because common circuits are not repeated, Figure 1 only appears in Figure 7-7 on the A2 Master Board, electrically the changes that are made to the A2 Master Board were also made to the A3 Slave Board.




CHANGE 18:

In the replaceable parts list (and on the schematic) for the A2 Master Board, and the A3 Slave board, change R46 from 470 ohms (HP P/N 0686-4715) to 510 ohms (HP P/N 0686-5115) - (qty of 1 for each board).

CHANGE 19:

In the parts list on pages 6-8 and 6-9, change R4 A&B to var. ww 2k 5% 10-turn, HP p/n 2100-2029. Change R27 A&B to var. ww 5k 5% 10-turn, HP p/n 2100-1865. Add R200 fxd 2.6k 5% 3W, TQ2, HP p/n 0811-1808.

On page 6-10 under the Front Panel - Mechanical, delete Knob TQ4 p/n 0370-0179 and Knob TQ4 p/n 0370-0101. Add Knob base rnd, TQ4, HP p/n 0370-1091.

On the schematic diagram, indicate that dual-control potentiometers R27 A&B and R4 A&B (located in the voltage and current control circuits) are replaced with the single 10-turn potentiometers as previously described. In the Current Control circuit, add R200 (previously described) in parallel with R4 A&B across terminals A7 and A4.

If either one of the older controls must be replaced, it is recommended that both controls be changed to the new part numbers. The following service kits are available for replacing these controls in the field:

| Control | Service Kit |
|---|---|
| Current (R4 A&B) | 5060-3548 |
| Voltage (R27 A&B) | 06227-60006 |

ERRATA:

On page 1-3, categorize the specifications in Table 1-1 as follows:

Performance specifications that are guaranteed through the warranty of the product:
AC Input Voltage and Frequency
DC Output Ranges -- Voltage and Current
Load Effect (Load Regulation)
Source Effect (Line Regulation)
Ripple and Noise (PARD)
Transient Recovery Time

Supplemental characteristics that are type-tested or typical values: (Supplemental characteristics are based on a product sample and, while representative, are not guaranteed.)
AC Input Current and Power
Temperature Ratings
Temperature Coefficient
Stability (Drift)
Output Impedance
Weight
Meters
Output Controls
Slave Tracking Error
Remote Voltage Programming
Remote Resistance Programming
Overvoltage Protection Crowbar
Cooling, Size, Finish

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CHANGE 20:

In the parts list on the A1 board, change CR15A-18A, 15B-18B to HP p/n 1901-1130. Note that when changing any of these diodes, all FOUR diodes must be replaced as a set.

On the A2 and the A3 boards, change CR2, CR13,14, and CR16 (added in change 3) to HP p/n 1901-1130. Note that CR13 and CR14 must be replaced as a set.

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## TABLE OF CONTENTS


| Section | | Page No. |
|---|---|---|
| I | GENERAL INFORMATION | 1-1 |
| | 1-1 Description | 1-1 |
| | 1-9 Specifications | 1-2 |
| | 1-11 Options | 1-2 |
| | 1-13 Accessories | 1-2 |
| | 1-15 Instrument Identification | 1-2 |
| | 1-18 Ordering Additional Manuals | 1-2 |
| II | INSTALLATION | 2-1 |
| | 2-1 Initial Inspection | 2-1 |
| | 2-3 Mechanical Check | 2-1 |
| | 2-5 Electrical Check | 2-1 |
| | 2-7 Repackaging for Shipment | 2-1 |
| | 2-9 Installation Data | 2-1 |
| | 2-11 Location | 2-1 |
| | 2-13 Outline Diagram | 2-1 |
| | 2-15 Rack Mounting | 2-1 |
| | 2-19 Input Power Requirements | 2-2 |
| | 2-21 115/230 Volt Operation | 2-2 |
| | 2-24 Power Cable | 2-2 |
| III | OPERATING INSTRUCTIONS | 3-1 |
| | 3-1 Turn-On Checkout Procedure | 3-1 |
| | 3-3 Basic Operating Modes | 3-2 |
| | 3-5 Independent Operation | 3-2 |
| | 3-8 Constant Voltage | 3-2 |
| | 3-10 Constant Current | 3-2 |
| | 3-12 Overvoltage Crowbar Operation | 3-3 |
| | 3-17 Connecting Load | 3-3 |
| | 3-21 Operation Beyond Rated Output | 3-3 |
| | 3-23 Tracking Operation | 3-3 |
| | 3-25 Constant Voltage | 3-3 |
| | 3-28 Connecting Load | 3-4 |
| | 3-35 Overvoltage Crowbar Operation | 3-5 |
| | 3-39 Optional Operating Modes (Tracking or Independent) | 3-5 |
| | 3-41 Remote Programming, Constant Voltage | 3-5 |

| Section | | Page No. |
|---|---|---|
| III | OPERATING INSTRUCTIONS (Continued) | |
| | 3-50 Optional Operating Modes (Independent Only) | 3-6 |
| | 3-52 Remote Programming, Constant Current | 3-6 |
| | 3-61 Remote Sensing | 3-8 |
| | 3-66 Auto-Parallel Operation | 3-8 |
| | 3-70 Auto-Series Operation | 3-9 |
| | 3-74 Auto-Tracking Operation | 3-10 |
| | 3-78 Special Operating Considerations | 3-10 |
| | 3-79 Pulse Loading | 3-10 |
| | 3-81 Output Capacitance | 3-10 |
| | 3-84 Reverse Voltage Loading | 3-11 |
| | 3-86 Reverse Current Loading | 3-11 |
| IV | PRINCIPLES OF OPERATION (To Be Supplied With Final Manual) | 4-1 |
| V | MAINTENANCE | 5-1 |
| | 5-1 Introduction | 5-1 |
| | 5-3 Test Equipment Required | 5-1 |
| | 5-5 Performance Test | 5-2 |
| | 5-7 Constant Voltage Tests | 5-3 |
| | 5-44 Constant Current Tests | 5-9 |
| | 5-56 Adjustment and Calibration | 5-11 |
| | 5-58 Meter Zero | 5-11 |
| | 5-60 Meter Calibration | 5-12 |
| | 5-64 Constant Voltage Programming Current | 5-12 |
| | 5-68 Constant Current Programming Current | 5-12 |
| | 5-72 Crowbar Disablement | 5-13 |
| VI | REPLACEABLE PARTS | 6-1 |
| | 6-1 Introduction | 6-1 |
| | 6-4 Ordering Information | 6-1 |
| VII | SCHEMATIC DIAGRAM AND COMPONENT LOCATION DIAGRAMS | 7-1 |




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## LIST OF ILLUSTRATIONS


| Figure | | Page No. |
|---|---|---|
| 2-1 | Outline Diagram | 2-1 |
| 2-2 | Procedure for Installing Instrument(s) in HP Combining Case | 2-2 |
| 3-1 | Operating Controls and Indicators | 3-1 |
| 3-2 | Normal Strapping Pattern | 3-2 |
| 3-3 | Remote Resistance Programming, Constant Voltage | 3-5 |
| 3-4 | Remote Voltage Programming, Constant Voltage (Unity Gain) | 3-6 |
| 3-5 | Remote Voltage Programming, Constant Voltage (Variable Gain) | 3-6 |
| 3-6 | Remote Resistance Programming, Constant Current | 3-7 |
| 3-7 | Remote Voltage Programming, Constant Current (Unity Gain) | 3-7 |
| 3-8 | Remote Voltage Programming, Constant Current (Variable Gain) | 3-7 |
| 3-9 | Remote Sensing | 3-8 |
| 3-10 | Auto-Parallel Operation, Two Units | 3-9 |
| 3-11 | Auto-Series Operation, Two and Three Units | 3-9 |
| 3-12 | Auto-Tracking Operation, Two and Three Units | 3-10 |
| 5-1 | Differential Voltmeter Substitute Test Setup | 5-2 |
| 5-2 | Constant Voltage Load Regulation Test Setup | 5-3 |
| 5-3 | Ripple Test Setup | 5-4 |
| 5-4 | Noise Spike Measurement Test Setup | 5-5 |
| 5-5 | Transient Recovery Time Test Setup | 5-6 |
| 5-6 | Transient Recovery Time Waveforms | 5-7 |
| 5-7 | Output Impedance Test Setup | 5-8 |
| 5-8 | Output Impedance versus Frequency | 5-8 |
| 5-9 | Tracking Error Test Setup | 5-9 |
| 5-10 | Current Sampling Resistor Connections | 5-9 |
| 5-11 | Constant Current Load Regulation Test Setup | 5-10 |
| 5-12 | Constant Current Ripple Test Setup | 5-10 |
| 5-13 | Constant Current Noise Spike Test Setup | 5-11 |
| 7-1 | Main Chassis Component Location Diagram, Top View | 7-2 |
| 7-2 | Main Chassis Component Location Diagram, Bottom View | 7-3 |
| 7-3 | A4 Crowbar Printed Circuit Board Component Location Diagram | 7-4 |
| 7-4 | A1 Mother Printed Circuit Board Component Location Diagram | 7-4 |
| 7-5 | A3 Slave Printed Circuit Board Component Location Diagram | 7-5 |
| 7-6 | A2 Master Printed Circuit Board Component Location Diagram | 7-6 |
| 7-7 | Schematic Diagram | Foldout |


## LIST OF TABLES


| Table | | Page No. |
|---|---|---|
| 1-1 | Specifications | 1-3 |
| 5-1 | Test Equipment Required | 5-2 |
| 5-2 | Calibration and Adjustment Summary | 5-11 |
| 6-1 | Reference Designators | 6-1 |
| 6-2 | Description Abbreviations | 6-1 |
| 6-3 | Code List of Manufacturers | 6-2 |
| 6-4 | Replaceable Parts | 6-5 |




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# SECTION I
# GENERAL INFORMATION

## 1-1 DESCRIPTION

1-2 This instrument is designed to be used in applications such as powering operational amplifiers, push-pull stages, and deflection systems where plus and minus voltages are required to track with an insignificant error, and in any application where two independent power supplies housed in a single package represent an operating convenience.

1-3 The instruments consists of two identical, independently adjustable dc power supplies in a half-rack case. A front panel switch selects one of two modes of operation: independent or tracking. In the independent mode, the output voltage and current of each supply are controlled separately, and each supply is isolated up to 300V from output to chassis or output to output. In the tracking mode, both outputs are automatically connected in series, and the controls of the left supply adjust the magnitudes of both the positive and negative output voltages. Because the outputs are connected in a tracking configuration, any internal disturbance in the master supply (such as drift or ripple) will cause an equal percentage change in the outputs of both the supplies.

1-4 Each power supply is a completely transistorized, well-regulated, constant voltage/constant current supply that will furnish full rated output voltage at the maximum output current or can be continuously adjusted throughout the output range. The front panel CURRENT controls can be used to establish the output current limit (overload or short circuit) when the supply is used as a constant voltage source (independent or tracking modes), and the VOLTAGE controls can be used to establish the voltage limit (ceiling) when the supply is used as a constant current source (independent mode only). The supply will automatically cross over from constant voltage to constant current operation (current limited operation in the tracking mode) and vice versa if the output current or voltage exceeds these preset limits.

1-5 Each supply has its own front panel meter that can measure output voltage or current. The front panel METER switch on each supply selects either of the two functions.

1-6 Each supply has a built in overvoltage protection crowbar for the protection of delicate loads. The crowbar sets a limit (adjustable from the front panel) on the output voltage. If this limit is exceeded, a short circuit is applied across the output of the supply.

1-7 Both front and rear output terminals are provided on each supply. Either set of terminals can be used in the independent mode; only the front terminals can be used when the instrument is operated in the tracking mode. Either the positive or negative output terminals can be connected to the chassis through a separate ground terminal located adjacent to the output terminals, or the supply can be operated floating at up to a maximum of 300 volts above ground.

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

a. Remote Programming. In the independent mode, the output voltage or current of each supply may be programmed (controlled) from a remote location by means of an external voltage source or resistance connected to each supply. In the tracking mode, the output voltage of both supplies may be programmed from a remote location by means of an external voltage source or resistance connected to the left (master) supply.

b. Remote Sensing. The degradation in regulation which occurs at the load due to voltage drop in the load leads can be reduced by employing remote sensing. This is possible with the instrument in the independent mode of operation only.

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

d. Auto-Parallel Operation. Each individual power supply may be operated in parallel with one or more similar units when greater output current capability is required. Auto-Parallel operation permits one-knob control of the total output current from a master supply.

e. Auto-Tracking Operation. One power supply may be used as a master supply controlling one or more slave supplies furnishing various voltages for a system. When operated with the



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

## 1-9 SPECIFICATIONS

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

## 1-11 OPTIONS

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

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

## 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 sales office (refer to list at rear of manual for addresses).

| HP Part or Model No. | Description |
|---|---|
| 1052A | Combining Case for mounting one or two units in standard 19" rack (refer to Section II for details). |
| 5060-0789 | Cooling kit for above combining case, 115Vac, 50-60Hz. |
| 5060-0796 | Cooling kit for above combining case, 230Vac, 50-60Hz. |
| 5060-0794 | Filler panel to block unused half of above combining case when mounting only one unit. |

## 1-15 INSTRUMENT IDENTIFICATION

1-16 Hewlett-Packard power supplies are identified by a three-part serial number. The first part is the power supply model number. The second 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, 20 = 1980, 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 or manual backdating changes in Appendix A define the differences between your instrument and the instrument described by this manual.

## 1-18 ORDERING ADDITIONAL MANUALS

1-19 One manual is shipped with each instrument. Additional manuals may be purchased from your local Hewlett-Packard field office (see list at rear of this manual for addresses). Specify the model number, serial number prefix, and HP part number shown on the title page.



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Table 1-1. Specifications

INPUT:
115/230Vac ±10%, single phase, 48-66Hz, 2.7A, 260W @ 115V.

OUTPUT:
Independent Mode - Two independent outputs, each of which can be set from 0-25 volts at 0-2 amperes.
Tracking Mode - Tracking outputs of 0 to ±25 volts at 2 amperes each.

LOAD REGULATION:
Constant Voltage - Less than 0.01% plus 1mV for a load current change equal to the current rating of the supply.
Constant Current - Less than 0.01% plus 250μA for a load voltage change equal to the voltage rating of the supply.

LINE REGULATION:
Constant Voltage - Less than 1mV for a change in line voltage from 103.5 to 126.5V at any output voltage and current within rating.
Constant Current - Less than 100μA for a line voltage change from 103.5 to 126.5V at any output voltage and current within rating.

RIPPLE AND NOISE:
Constant Voltage - Less than 250μV rms, 4mV p-p (dc to 20MHz).
Constant Current - Less than 250μA rms, 2mA p-p (dc to 20MHz).

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

TEMPERATURE COEFFICIENT:
Constant Voltage - Less than 0.02% plus 200μV change per degree Centigrade change in ambient following 30 minutes warm-up.
Constant Current - Less than 0.02% plus 300μA change per degree Centigrade change in ambient following 30 minutes warm-up.

STABILITY:
Constant Voltage - Less than 0.2% plus 2mV total drift for 8 hours following 30 minutes warm-up under constant ambient conditions.
Constant Current - Less than 0.2% plus 3mA total drift for 8 hours following 30 minutes warm-up under constant ambient conditions.

OUTPUT IMPEDANCE:
A 2mΩ resistor in series with a 2μH inductor.

WEIGHT:
24 lbs. (11 Kg) net. 28 lbs. (12,9 Kg) shipping.

TRANSIENT RECOVERY TIME:
Less than 50μsec is required for output voltage recovery (in constant voltage operation) to within 10mV of the nominal output voltage following a 2 ampere change in output current.

METERS:
Each front panel meter can be used as either a 0-30V voltmeter or a 0-2.4A ammeter. Meters are accurate within 2% of full scale; meter switch selects voltage or current readings.

OUTPUT CONTROLS:
Single-turn concentric coarse and fine voltage and current controls are included on the front panel. Mode switch selects one of two modes of operation: either two independent, isolated outputs; or the two outputs connected in series and referred to a common bus for tracking.

SLAVE TRACKING ERROR:
During tracking operation, the slave supply is matched to within 0.2% ±2mV of the master supply.

REMOTE VOLTAGE PROGRAMMING:
All programming terminals on rear barrier strips.
Constant Voltage - 1V/volt.
Constant Current - 0.5V/ampere.

REMOTE RESISTANCE PROGRAMMING:
All programming terminals on rear barrier strips.
Constant Voltage - 200 ohms/volt.
Constant Current - 500 ohms/ampere.

OVERVOLTAGE PROTECTION CROWBAR:
During independent operation, each supply is protected by its own crowbar. In the tracking mode, an overvoltage in either supply results in firing both crowbars. The minimum crowbar trip setting above the desired operating output voltage to prevent false crowbar tripping is 7% of output voltage setting plus 1.5 volt. Nominal trip voltage range is 5 to 28Vdc.

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

SIZE:
6-17/32" (16,59cm) H x 12-3/8" (31,43cm) D x 7-3/4" (19,69cm) W.

FINISH:
Light gray panel with dark gray case.



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# SECTION II
# INSTALLATION

## 2-1 INITIAL INSPECTION

2-2 Before shipment, this instrument was inspected and found to be free of mechanical and electrical defects. As soon as the instrument is received, proceed as instructed in the following paragraphs.

2-3 MECHANICAL CHECK

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

2-5 ELECTRICAL CHECK

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

## 2-7 REPACKAGING FOR SHIPMENT

2-8 To insure safe shipment of the instrument, it is recommended that the package designed for the instrument be used. The original packaging material is reusable. If it is not available, contact your local Hewlett-Packard field office to obtain the materials. This office will also furnish the address of the nearest service office to which the instrument can be shipped. Be sure to attach a tag to the instrument specifying the owner, model number, full serial number, and service required, or a brief description of the trouble.

## 2-9 INSTALLATION DATA

2-10 The instrument is shipped ready for bench operation. It is necessary only to connect the instrument to a source of power and it is ready for operation.

2-11 LOCATION

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

2-13 OUTLINE DIAGRAM

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

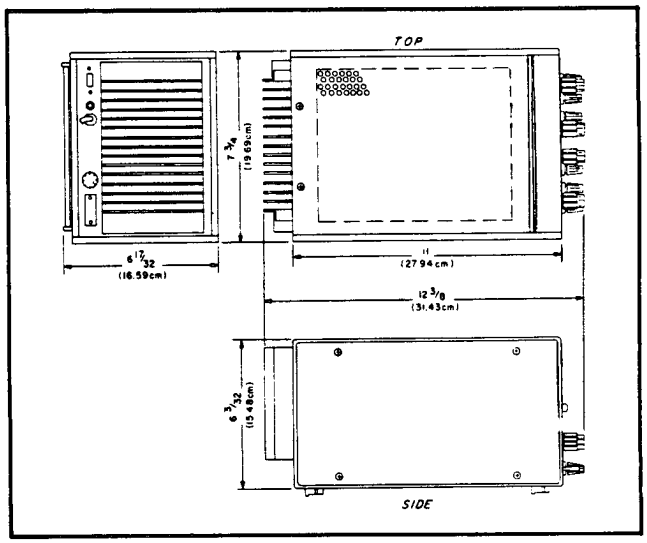



Figure 2-1. Outline Diagram

2-15 RACK MOUNTING

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

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



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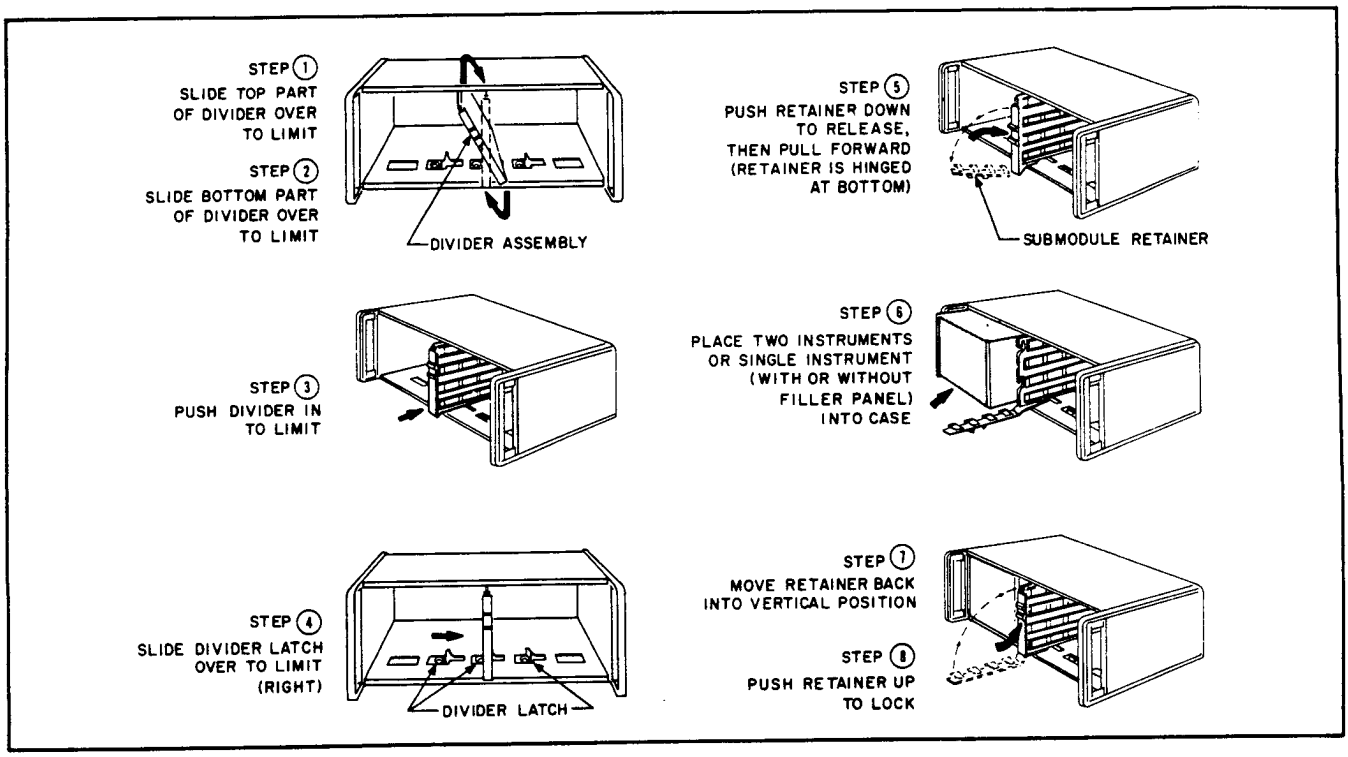



Figure 2-2. Procedure for Installing Instrument(s) in HP Combining Case

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

2-18 To rack mount the combining case in a standard rack, proceed as follows:

a. Remove gray plastic trim strips (glued on) at each side of case by inserting thin screwdriver at edge or top of strip and prying gently away from case.

b. Attach rack ears (furnished with each combining case) to side of case using screws supplied with ears.

c. Mount unit in rack, using standard mounting screws.

## 2-19 INPUT POWER REQUIREMENTS

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

2-21 115/230 VOLT OPERATION

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

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

2-24 POWER CABLE

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

2-26 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.



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# SECTION III
# OPERATING INSTRUCTIONS

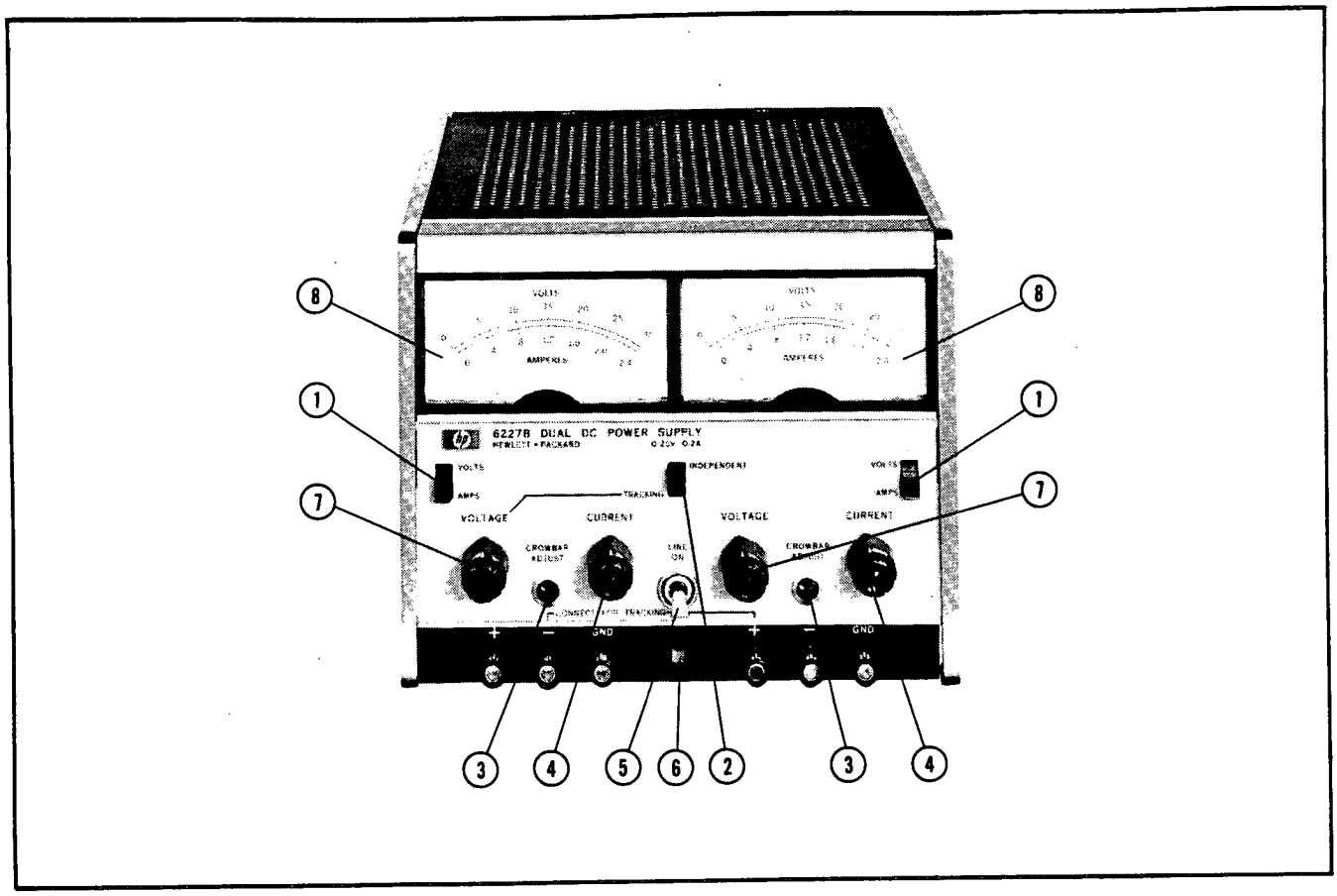



Figure 3-1. Operating Controls and Indicators

## 3-1 TURN-ON CHECKOUT PROCEDURE

3-2 The following checkout procedure describes the use of the front panel controls and indicators (Figure 3-1) and ensures that the supply is operational. This procedure should be performed with no load connected to the supply.

a. Set both meter switches (1) to VOLTS, set mode switch (2) to INDEPENDENT, rotate both CROWBAR ADJUST controls (3) (screwdriver adjust) fully clockwise, and rotate both sets of CURRENT controls (4) to middle of range (black knobs are coarse controls, red knobs are fine controls).

b. Set LINE switch (5) to ON, and observe that pilot lamp (6) lights.

c. Adjust both sets of VOLTAGE controls (7) (black knobs are coarse controls, red knobs are fine controls) until desired output voltages are indicated on meters (8)

d. To ensure that overvoltage crowbar circuit is operational, rotate each OVERVOLTAGE ADJUST control counterclockwise until associated supply crowbars. Output voltage of each supply will fall to approximately one volt.

e. To deactivate each crowbar, return its OVERVOLTAGE ADJUST control to maximum clockwise position and turn off supply. Turn supply back on and output voltages should again be value obtained in Step (c).

f. To check out constant current circuit, turn off supply. Short circuit both sets of front panel output terminals (plus to minus), rotate both sets of VOLTAGE controls to middle of range, set both meter switches to AMPS, and turn on supply.

g. Adjust both sets of CURRENT controls until desired output currents are indicated on meters.

h. To check out tracking mode of operation,



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

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

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

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

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

## 3-3 BASIC OPERATING MODES

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

## 3-5 INDEPENDENT OPERATION

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

3-7 The instrument is normally shipped with each supply's rear terminal strapping connections arranged for constant voltage/constant current, local sensing, local programming, single unit mode of operation. This strapping pattern is illustrated in Figure 3-2. The operator selects either a constant voltage or a constant current output using the front panel controls (local programming; no strapping changes are necessary).

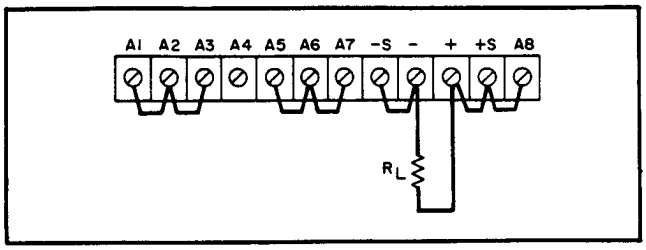



Figure 3-2. Normal Strapping Pattern

3-8 CONSTANT VOLTAGE

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

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

b. Short circuit output terminals and adjust CURRENT controls (with meter switch in AMPS position) for maximum output current allowable (current limit), as determined by load conditions. If a load change causes the current limit to be exceeded, the power supply will automatically cross over to constant current output at the preset current limit and the output voltage will drop proportionately. In setting the current limit, allowance must be made for high peak currents which can cause unwanted crossover. (Refer to Paragraph 3-79.)

3-10 CONSTANT CURRENT

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

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

b. Open circuit output terminals and adjust VOLTAGE controls (with meter switch in VOLTS position) for maximum output voltage allowable (voltage limit), as determined by load conditions. If a load change causes the voltage limit to be exceeded, the power supply will automatically cross over to constant voltage output at the preset voltage limit and the output current will drop proportionately. In setting the voltage limit, allowance must be made for high peak voltages which can cause unwanted crossover. (Refer to Paragraph 3-79.)



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3-12 OVERVOLTAGE CROWBAR OPERATION

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

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

To adjust the trip point, proceed as follows:

a. Turn CROWBAR ADJUST control fully clockwise and turn on supply.

b. Set output voltage to desired trip voltage.

c. Turn CROWBAR ADJUST control slowly counterclockwise until crowbar is tripped (voltmeter falls to one volt or less).

d. Turn off supply and turn down output voltage.

e. Turn on supply and set desired operating output voltage.

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

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

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

3-17 CONNECTING LOAD

3-18 Each load should be connected to the power supply output terminals (front or rear) using separate pairs of connecting wires. This will minimize mutual coupling effects between loads and will retain full advantage of the low output impedance of the power supply. Each pair of connecting wires should be as short as possible and twisted or shielded to reduce noise pickup. (If a shielded pair is used, connect the shield to ground at the power supply and leave the other end unconnected.)

3-19 If load considerations require that the output power distribution terminals be remotely located from the power supply, then the power supply output terminals should be connected to the remote distribution terminals via a pair of twisted or shielded wires and each load should be separately connected to the remote distribution terminals. For this case, remote sensing should be used. (Refer to Paragraph 3-61.)

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

3-21 OPERATION BEYOND RATED OUTPUT

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

## 3-23 TRACKING OPERATION

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

3-25 CONSTANT VOLTAGE

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



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

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

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

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

3-28 CONNECTING LOAD

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

**CAUTION**

Tracking operation is not possible with loads connected to the rear terminals. Do not switch from independent to tracking mode when loads are connected to the rear output terminals. Changing the mode switch position under these circumstances may result in damage to the switch.

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

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

3-32 If load considerations require that the output power distribution terminals be remotely located from the power supply, then the power supply output terminals should be connected to the remote distribution terminals via three twisted wires or a three-conductor shielded cable and each load should be separately connected to the remote distribution terminals. Note, however, that since remote sensing cannot be used when the instrument is operated in the tracking mode, the leads to the distribution terminals should be relatively short if degradation of the regulation specification is to be avoided.

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

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



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mode (connect the load between the master positive terminal and the slave negative terminal). In this mode, the 6227B will supply 0-50 volts at 2 amps, and the 6228B will supply 0-100 volts at 1 amp. It is possible to set the meter switch on the master to volts and the meter switch on the slave to to amps and thereby achieve simultaneous monitoring of the output voltage and current. Note that in this configuration, the voltage reading on the master's meter must be doubled to give the actual output voltage.

3-35 OVERVOLTAGE CROWBAR OPERATION

3-36 The two crowbars are automatically connected for tandem operation when the mode switch is in the TRACKING position. In this operating mode, an overvoltage in either the master or the slave supply results in the firing of both crowbars.

3-37 The trip point of each crowbar may be independently adjusted by following the procedure in Paragraphs 3-13 and 3-14. Note however, that if an overvoltage transient causes one supply to crowbar (output voltage falls to one volt or less), the other supply will automatically crowbar, even though it did not experience an overvoltage transient. For example, if the slave crowbar is set for 10 volts and the master crowbar is set for 15 volts, the output of both supplies will fall to one volt or less if the slave output exceeds 10 volts.

3-38 Reset of the two crowbars is accomplished by following either of the two alternate procedures detailed in Paragraph 3-16. Turning the power switch off and on or turning the master voltage control down to zero and up again will reset both crowbars.

## 3-39 OPTIONAL OPERATING MODES (TRACKING OR INDEPENDENT)

3-40 The following optional operating modes describe methods of programming the constant voltage output(s) of the instrument in either the tracking or the independent mode of operation. When operating in the independent mode, the programming procedures can be applied to either or both of the independent supplies; when operating in the tracking mode, the procedures are to be applied to the master (left) supply only, since programming the master automatically programs the slave.

3-41 REMOTE PROGRAMMING, CONSTANT VOLTAGE

3-42 The constant voltage output of the power supply can be programmed (controlled) from a remote location if required. Either a resistance or voltage source can be used as the programming device. The wires connecting the programming terminals of the supply to the remote programming device should be twisted or shielded to reduce noise pickup. Note that although the programming sources are connected to the rear control terminals, the output must be taken from the front panel terminals when the supply is operated in the tracking mode. When the supplies are operated independently, the output may be taken from the rear terminals as shown in Figures 3-3 through 3-5. The VOLTAGE controls are automatically disabled in the following procedures.

3-43 Resistance Programming (Figure 3-3). In this mode, the output voltage will vary at a rate determined by the programming coefficient of 200 ohms/volt. The programming coefficient is determined by the programming current. This current is factory adjusted to within 10% of 5mA. If greater programming accuracy is required, it may be achieved by adjusting R16 as discussed in Paragraph 5-84.

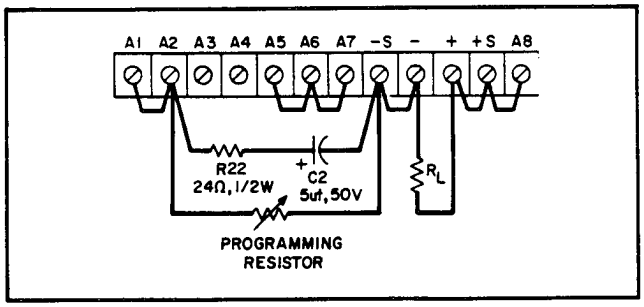



Figure 3-3. Remote Resistance Programming, Constant Voltage

3-44 When remote programmed in the tracking mode, the output voltage of each supply should be between zero and -60mV when zero ohms is connected across the master supply remote programming terminals. If the unit is operated in the independent mode, the master output voltage will be the same as above (between zero and -60mV) when zero ohms is connected across the master supply remote programming terminals, while the slave output voltage will be 0 ± 10mV when zero ohms is connected across its remote programming terminals. The output voltage of each supply may be adjusted to exactly zero under any of the above conditions by adjusting potentiometer R24 on each supply as described in Paragraph 5-82.

3-45 To maintain the stability and temperature coefficient of the power supply, use programming resistors that have stable, low noise, and low temperature coefficient (less than 20ppm per degree Centigrade) characteristics. Resistor-capacitor combination R22-C2 should be connected across the programming terminals as shown in Figure 3-3; these components reduce ripple in the supply



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

3-46 Voltage Programming, Unity Gain (Figure 3-4). Employ the strapping pattern shown in Figure 3-4 for voltage programming with unity gain. In this mode, the output voltage will vary in a 1-to-1 ratio with the programming voltage (reference voltage) and the load on the programming voltage source will not exceed 20μA. Impedance matching resistor ($R_X$) is required to maintain the temperature coefficient and stability specifications of the supply; resistor-capacitor combination R22-C2 is required to reduce ripple in the supply output.

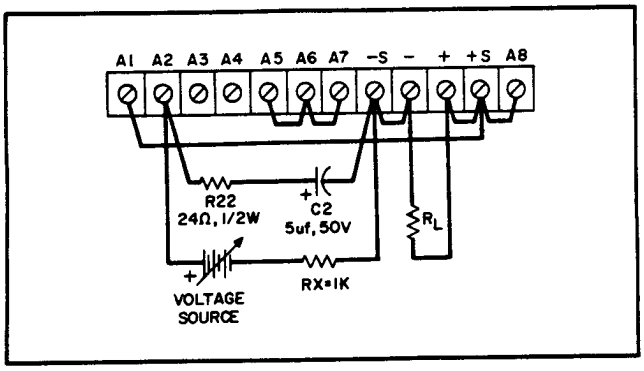



Figure 3-4. Remote Voltage Programming, Constant Voltage (Unity Gain)

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

3-48 External resistors $R_P$ and $R_R$ should have stable, low noise, and low temperature coefficient (less than 20ppm per degree Centigrade) characteristics in order to maintain the supply's temperature and stability specifications. The values of reference resistor $R_R$ and programming voltage source $V_S$ should be such that the value of $V_S/R_R$ is equal to or greater than 5mA. The value of resistor $R_R$ should not exceed 10KΩ; the power rating of resistor $R_R$ should be at least 10 times the actual power dissipated in the resistor. Resistor-capacitor combination R22-C2 should be connected across the programming terminals as shown in Figure 3-5; these components reduce ripple in the supply output. Note that it is possible to use the front panel voltage control already in the supply (R27A-R27B) as the voltage gain control ($R_P$) by simply removing the external Rp and strapping terminals A2 and A3 together.

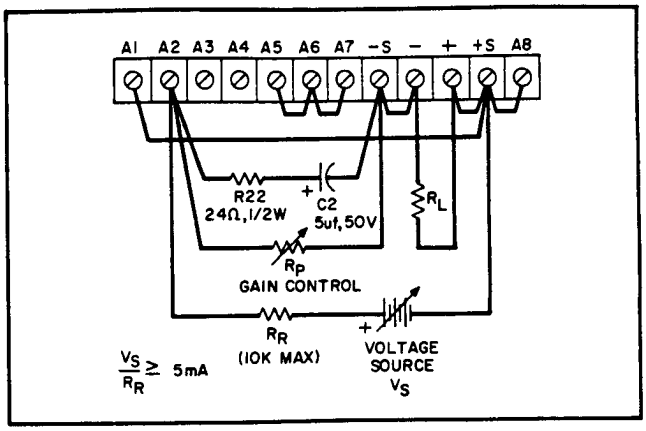



Figure 3-5. Remote Voltage Programming, Constant Voltage (Variable Gain)

3-49 The output voltage of the supply may be adjusted to exactly zero when the external programming voltage is zero by adjusting potentiometer R24 as discussed in Paragraph 5-82.

## 3-50 OPTIONAL OPERATING MODES (INDEPENDENT ONLY)

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

3-52 REMOTE PROGRAMMING, CONSTANT CURRENT

3-53 Either a resistance or a voltage source can be used to control the constant current output of the supply. The CURRENT controls on the front panel are automatically disabled in the following procedures.

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

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

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



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

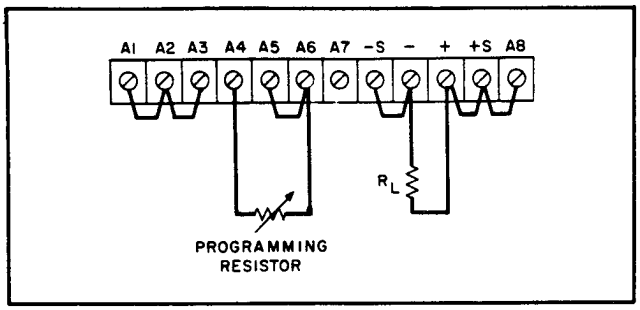



Figure 3-6. Remote Resistance Programming, Constant Current

3-55 Use stable, low noise, low temperature coefficient (less than 20ppm per degree Centigrade) programming resistors to maintain the power supply temperature coefficient and stability specifications. A switch may be used to set discrete values of output current. A make-before-break type of switch should be used since the output current will exceed the maximum rating of the power supply if the switch contacts open during the switching interval.

**CAUTION**

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

3-56 Voltage Programming, Unity Gain (Figure 3-7). In this mode, the output current will vary linearly with changes in the programming voltage. The programming voltage should not exceed 1.1 volt. Voltage in excess of 1.1 volt will result in excessive power dissipation in the instrument and possible damage.

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

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

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

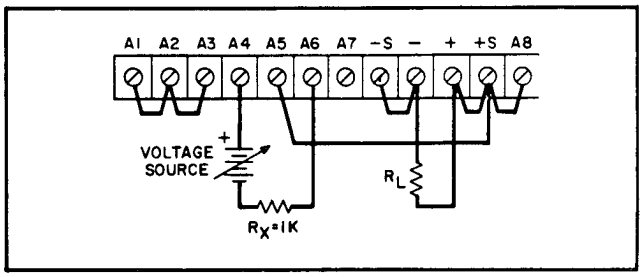



Figure 3-7. Remote Voltage Programming, Constant Current (Unity Gain)

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

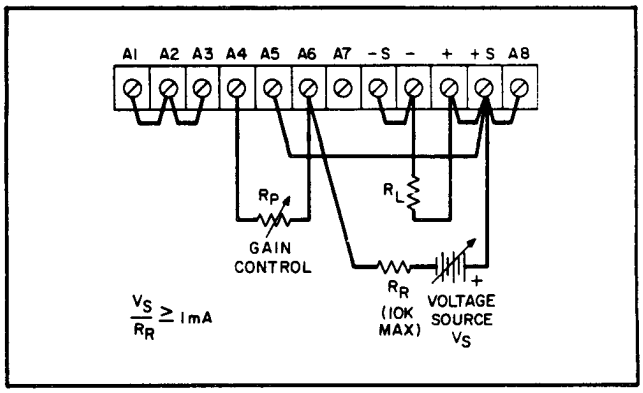



Figure 3-8. Remote Voltage Programming, Constant Current (Variable Gain)

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



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characteristics in order to maintain the stability and temperature specifications of the power supply. The values of reference resistor $R_R$ and programming voltage source $V_S$ should be such that the value of $V_S/R_R$ is equal to or greater than 1mA. The value of resistor $R_R$ should not exceed 10K$\Omega$; the power rating of resistor $R_R$ should be at least 10 times the actual power dissipated in the resistor. Note that it is possible to use the front panel current control (R4A-R4B) as the gain control ($R_P$) by simply removing the external $R_P$ and strapping terminals A6 and A7 together.

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

3-61 REMOTE SENSING (Figure 3-9)

3-62 Remote sensing is used to maintain good regulation at the load and reduce the degradation of regulation which would occur due to the voltage drop in the leads between the power supply and the load. Remote sensing is accomplished by utilizing the strapping pattern shown in Figure 3-9. Note that terminal A8 should be connected to the (+) terminal rather than +S. The power supply should be turned off before changing strapping patterns. The leads from the sensing (±S) terminals to the load will carry much less current than the load leads and it is not required that these leads be as heavy as the load leads. However, they must be twisted or shielded to minimize noise pickup.

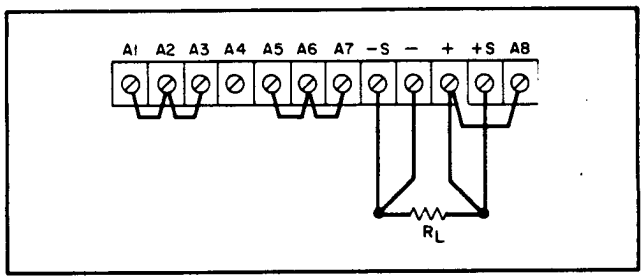



Figure 3-9. Remote Sensing

3-63 For reasonable load lead lengths, remote sensing greatly improves the performance of the supply. However, if the load is located a considerable distance from the supply, added precautions must be observed to obtain satisfactory operation. Notice that the voltage drop in the load leads subtracts directly from the available output voltage and also reduces the amplitude of the feedback error signals that are developed within the unit. Because of these factors it is recommended that the drop in each load lead not exceed 0.5 volt. If a larger drop must be tolerated, please consult an HP Sales Engineer.

**NOTE**

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

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

a. Disconnect output capacitor C1 by unstrapping terminal A8.

b. Connect a capacitor having similar characteristics (approximately the same capacitance, the same voltage rating or greater, and having good high frequency characteristics) across the load using short leads.

3-65 Although the strapping patterns shown in Figure 3-3 through 3-8 employ local sensing, note that it is possible to operate a power supply simultaneously in the remote sensing and constant voltage/constant current remote programming modes.

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

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

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



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

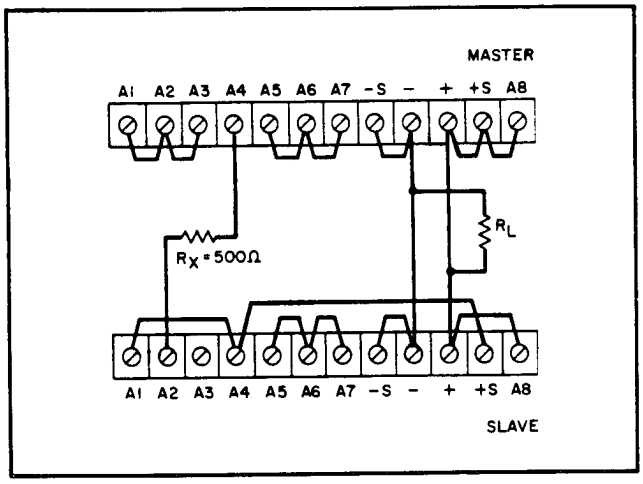



Figure 3-10. Auto-Parallel Operation, Two Units

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

3-70 AUTO-SERIES OPERATION (Figure 3-11)

3-71 Two or more power supplies can be operated in Auto-Series to obtain a higher voltage than that available from a single supply. When this connection is used, the output voltage of each slave supply varies in accordance with that of the master supply; thus the total output voltage of the combination is determined by the setting of the front panel VOLTAGE controls on the master. The master supply must be the most positive supply of the series. The output CURRENT controls of all series units are operative and the current limit is equal to the lowest control setting. If any of the output CURRENT controls are set too low, automatic crossover to constant current operation will occur and the output voltage will drop. Remote sensing and programming can be used, though the strapping arrangements shown in Figure 3-11 show local sensing and programming.

3-72 In order to maintain the temperature coefficient and stability specifications of the power supply, the external resistors ($R_X$) shown in Figure 3-11 should be stable, low noise, low temperature coefficient (less than 20ppm per degree Centigrade) resistors. The value of $R_X$ is the maximum voltage rating of the master supply divided by the voltage programming current of the slave supply ($1/K_P$ where $K_P$ is the voltage programming coefficient). The power rating of $R_X$ should be at least 10 times the actual power dissipated in the resistor. The voltage contribution of the slave is determined by its voltage control setting.

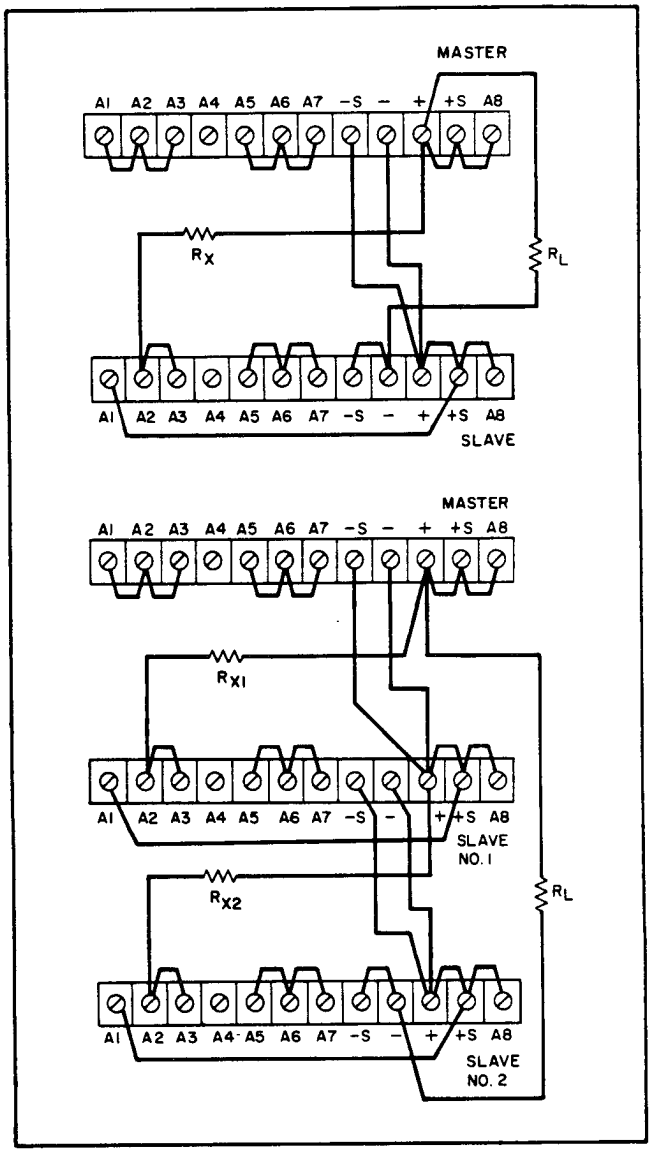



Figure 3-11. Auto-Series Operation, Two and Three Units

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



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

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

3-75 The Auto-Tracking configuration is used when several different voltages referred to a common bus must vary in proportion to the setting of a particular instrument (the control or master). A fraction of the master's output voltage is fed to the comparison amplifier of the slave supply, thus controlling the slave's output. The master must have the largest output voltage of any power supply in the group. It must be the most positive supply in the example shown in Figure 3-12.

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

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

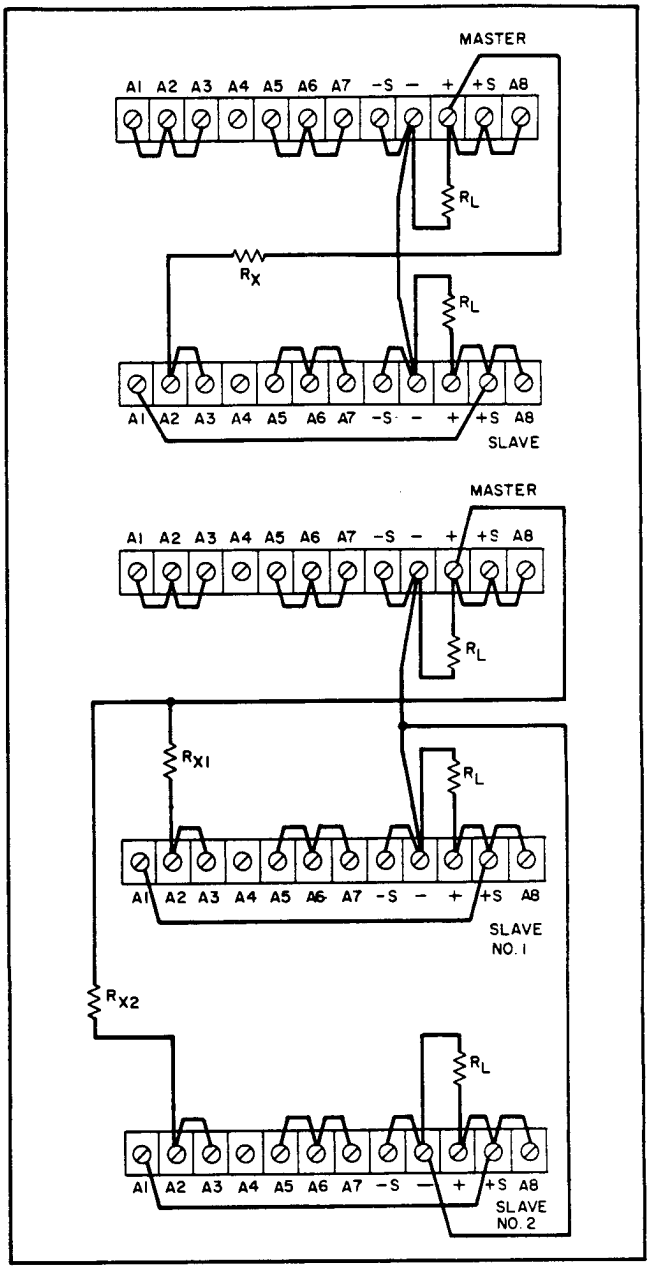



Figure 3-12. Auto-Tracking Operation, Two and Three Units

## 3-78 SPECIAL OPERATING CONSIDERATIONS

3-79 PULSE LOADING

3-80 The power supply will automatically cross over from constant voltage to constant current operation, or the reverse, in response to an increase (over the preset limit) in the output current or voltage, respectively. Although the preset limit may be set higher than the average output current or voltage, high peak currents or voltages (as occur in pulse loading) may exceed the preset limit and cause crossover to occur. If this crossover limiting is not desired, set the preset limit for the peak requirement and not the average.

3-81 OUTPUT CAPACITANCE

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



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surges, this capacitor can be removed by unstrapping terminal A8. Any capacitance added externally will improve the pulse current capability, but will decrease the safety provided by the constant current circuit. A high-current pulse may damage load components before the average output current is large enough to cause the constant current circuit to operate.

3-83 The effects of the output capacitor during constant current operation are as follows:

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

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

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

3-84 REVERSE VOLTAGE LOADING

3-85 A diode (CR2) is connected across the output terminals. Under normal operating conditions, the diode is reverse biased (anode connected to the negative terminal). If a reverse voltage is applied to the output terminals (positive voltage applied to the negative terminal), the diode will conduct, shunting current across the output terminals and limiting the voltage applied across the output terminals to the forward voltage drop of the diode. This diode protects the series transistors and the output electrolytic capacitors.

3-86 REVERSE CURRENT LOADING

3-87 Active loads connected to the power supply may actually deliver a reverse current to the power supply during a portion of its operating cycle. An external source cannot be allowed to pump current into the supply without loss of regulation and possible damage to the output capacitor. To avoid these effects, it is necessary to preload the supply with a dummy load resistor so that the power supply delivers current through the entire operation cycle of the load device.



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# SECTION IV
# PRINCIPLES OF OPERATION

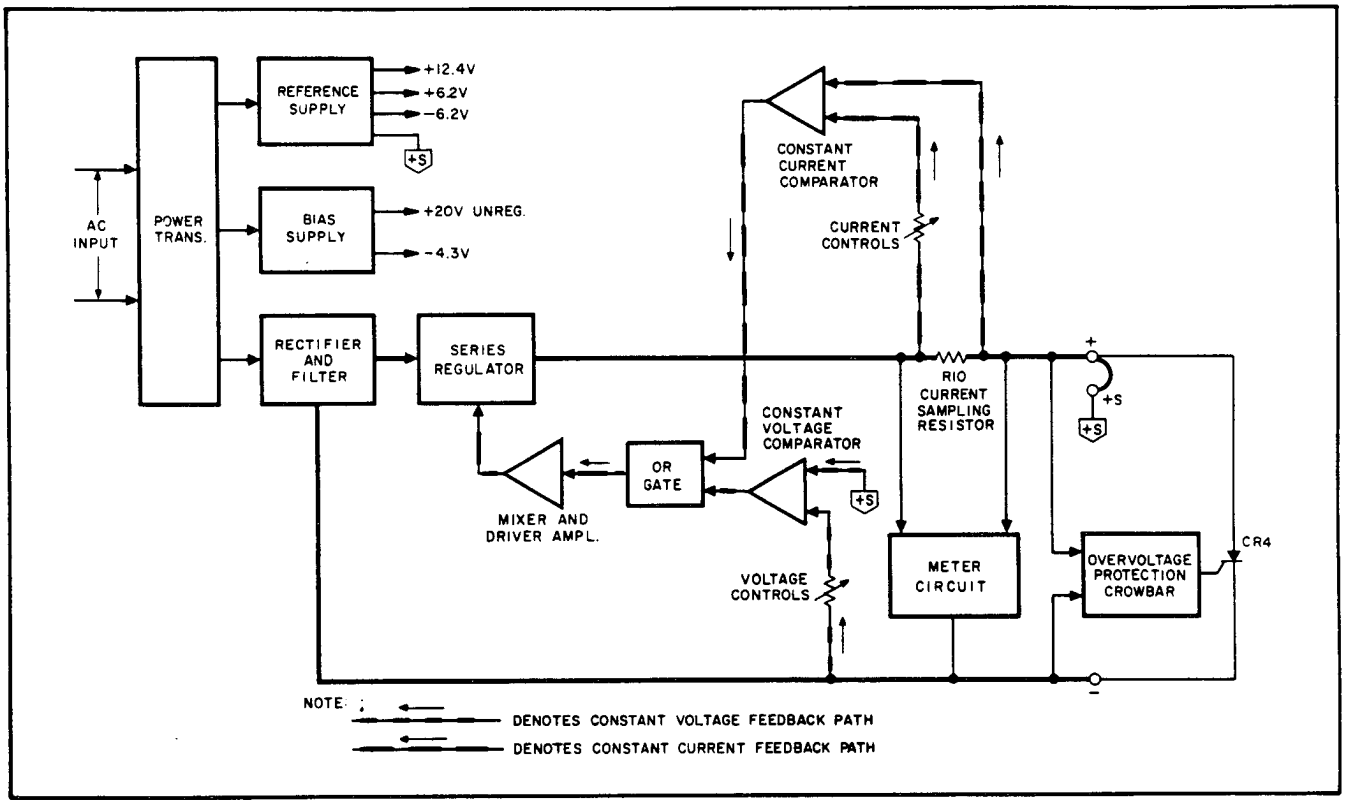



Figure 4-1. Overall Block Diagram

## 4-1 OVERALL BLOCK DIAGRAM DISCUSSION

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

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

4-4 The series regulator is part of a feedback loop consisting of the mixer and driver amplifiers and the constant voltage/constant current comparators. During constant voltage operation the constant voltage comparator continuously compares the output voltage of the supply with the drop across the VOLTAGE controls. If these voltages are not equal, the comparator produces an amplified error signal which is further amplified by the mixer and driver amplifiers and then fed back to the series regulator in the correct phase and amplitude to counteract the difference. In this manner, the constant voltage comparator helps to maintain a constant output voltage and also generates the error signals necessary to set the output voltage at the level established by the VOLTAGE controls.

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



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unequal, an error signal is generated which (after amplification) alters the conduction of the series regulator by the amount necessary to reduce the error voltage at the comparator input to zero. Hence, the IR drop across the current sampling resistor, and therefore the output current, is maintained at a constant value.

4-6 Since the constant voltage comparator tends to achieve zero output impedance and alters the output current whenever the load resistance changes, while the constant current comparator causes the output impedance to be infinite and changes the output voltage in response to any load resistance change, it is obvious that the two comparison amplifiers cannot operate simultaneously. For any given value of load resistance, the power supply must act either as a constant voltage source or as a constant current source — it cannot be both.

4-7 Figure 4-2 shows the output characteristic of a constant voltage/constant current power supply. With no load attached ($R_L = \infty$), $I_{OUT} = 0$, and $E_{OUT} = E_S$, the front panel voltage control setting. When a load resistance is applied to the output terminals of the power supply, the output current increases, while the output voltage remains constant; point D thus represents a typical constant voltage operating point. Further decreases in load resistance are accompanied by further increases in $I_{OUT}$ with no change in the output voltage until the output current reaches $I_S$, a value equal to the front panel current control setting. At this point the supply automatically changes its mode of operation and becomes a constant current source; still further decreases in the value of load resistance are accompanied by a drop in the supply output voltage with no accompanying change in the output current value. With a short circuit across the output load terminals, $I_{OUT} = I_S$ and $E_{OUT} = 0$.

4-8 The "crossover" value of load resistance can be defined as $R_C = E_S/I_S$. Adjustment of the front panel voltage and current controls permits this "crossover" resistance $R_C$ to be set to any desired value from 0 to ∞. If $R_L$ is greater than $R_C$, the supply is in constant voltage operation, while if $R_L$ is less than $R_C$, the supply is in constant current operation.

4-9 The reference supply provides stable reference voltages used by the constant voltage comparator, the constant current comparator, and the mixer amplifier. Less critical operating voltages are provided by the bias supply.

4-10 The meter circuit provides a continuous indication of the output voltage or current of the supply; the output voltage is sensed directly

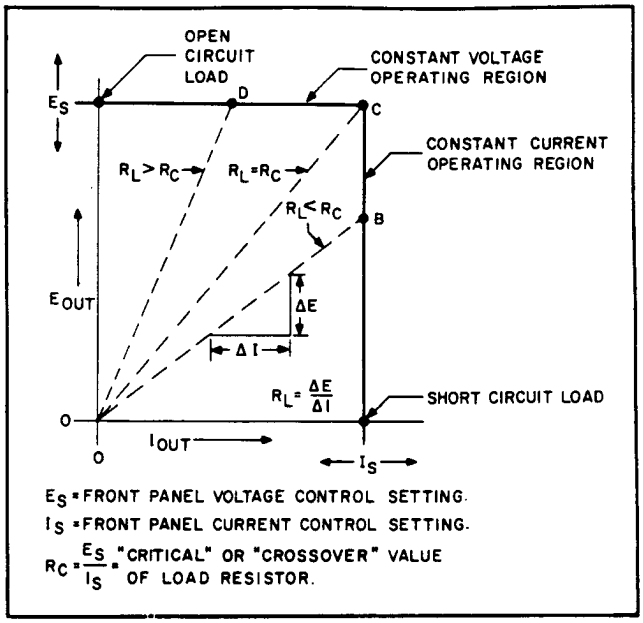



Figure 4-2. Operating Locus of a CV/CC Power Supply

across the sensing terminals, while the output current is sensed by monitoring the IR drop across the current sampling resistor.

4-11 The overvoltage protection crowbar monitors the output of the supply, and if it exceeds a preset (adjustable) threshold, fires an SCR which applies a virtual short circuit across the supply, thus reducing the output voltage to approximately zero.

## 4-12 DETAILED CIRCUIT ANALYSIS

4-13 VOLTAGE FEEDBACK LOOP

4-14 The voltage feedback loop functions to maintain the output voltage of the supply constant. For the purposes of this discussion, assume that the output voltage instantaneously rises (goes positive) due to a change in the external load circuit. The change may be in the form of a slow rise in the output voltage or a positive-going ac signal; the slow voltage change is coupled to a summing point A2 through VOLTAGE control R27, while the ac signal is coupled to A2 through capacitor C2.

4-15 The rise in output voltage causes the voltage at terminal A2 and thus pin 1 of the constant voltage comparator to decrease (go negative). The constant voltage comparator then decreases its conduction, and its output voltage rises. This positive-going error voltage is coupled through OR-gate diode CR8, amplified and inverted by mixer amplifier Q5, amplified further by pre-driver Q6, and then fed to the series regulator via emitter follower Q7. This negative-going input causes the



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

4-16 CURRENT FEEDBACK LOOP

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

4-18 SERIES REGULATOR

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

4-20 The regulator utilizes a "power sharing" circuit that results in considerably less internal power dissipation than would be present in a standard single-stage regulator. This saving in dissipation is achieved by dividing the output of the supply into two regions (0-11V and 11-25V), and using separate raw-dc supplies for each region. Maximum dissipation in any single-stage regulator circuit occurs when the supply is short-circuited at full output current; under this condition, the entire raw-dc voltage must be dropped across the series regulator while it is conducting the full output current. It can be seen then that if the raw-dc voltage is made as low as possible when the supply is operating at a low output voltage, the power dissipated in the series regulator will be minimized.

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

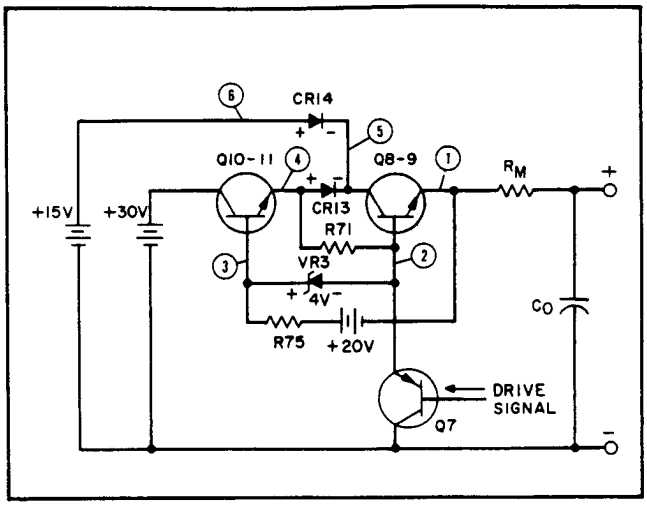



Figure 4-3. Series Regulator, Simplified Schematic

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

4-22 At a low output voltage (point (1) = 5V), transistors Q8 and Q9 are conducting; this requires point (2) to be at 6V. Zener diode VR3 (biased through R75) thus places the base of Q10 and Q11 (point (3) ) at 10V. Resistor R71 keeps Q10 and Q11 conducting at least a certain minimum current at all times; thus point (4) is at 9V. Diode CR13 must be either on or off; if it were on, point (5) would be at 8V. Since the anode of CR14 (point (6) ) is always at 15V, this condition is not possible, and CR13 must be off. Thus CR14 is on, point (5) is at 14V, and the 15V raw-dc source is supplying the load. The power dissipation in Q8 and Q9 is thus approximately 18 watts (9V drop between points (1) and (5) times 2A load current).

4-23 At a high output voltage (point (1) = 25V), transistors Q8 and Q9 are again conducting and point (2) is at 26V. Point (3) is thus at 30V due to zener diode VR3; point (4) is at 29V because (as before) Q10 and Q11 are always conducting at least a certain minimum current. Again diode CR13 must either be on or off; since point (6) is at 15V, CR13 must be on and CR14 must be off (point (5) = 28V). Thus the 30V raw-dc source is supplying the load. The switching point between the two ranges occurs when the voltage at point (4) equals that at point (6) (15V); this occurs when the output is 11V.

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



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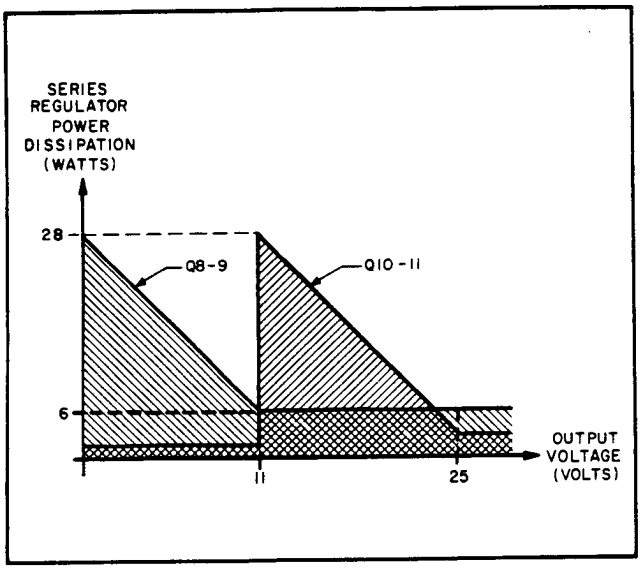



Figure 4-4. Series Regulator Power Dissipation

series regulator from a power dissipation point of view. When the output voltage is between zero and 11 volts, transistors Q8 and Q9 are controlling the output. In this region, the power dissipation of Q10 and Q11 is very low (approximately 1W), since the only current going through them is that flowing through R71. When the output voltage is between 11 and 25 volts, most of the regulator dissipation occurs in transistors Q10 and Q11. Note, however, that in this region these transistors serve as variable dissipative elements rather than control elements. The actual regulating action is, as in the lower output voltage range, performed by Q8 and Q9, operating at an approximate power dissipation of 6W. (In this region, VR3 maintains point (5) at a constant 3V higher than point (1), resulting in 3V x 2A = 6W power dissipation in Q8 and Q9.)

4-25 The obvious advantage in this type of regulator circuit is the saving in power dissipation. Consider the case discussed in Paragraph 4-22, where the supply output is 5 volts at 2 amps, and the regulator is dissipating 18 watts. If the supply used a conventional single-stage regulator, the raw-dc source would have to be approximately 30V (20% higher than the maximum rated output voltage of 25V). The power dissipated by the regulator would therefore be the voltage drop across it (25 volts) times the current conducted (2A), or 50 watts! The use of the power sharing regulator thus represents a power dissipation saving (in this particular case) of more than 170%.

4-26 Several series regulator components not shown in Figure 4-3 for the sake of clarity can be seen in Figure 7-7 (the foldout schematic diagram). Resistors R68-R69 and R73-R74 allow high output currents to be shared equally by the series regulating transistors; capacitor C5 prevents oscillation when switching between raw-dc sources. Resistor R72 minimizes output overshoot at turn-on and turn-off by serving as an alternate path for the series regulator drive current that normally flows through zener diode VR3. Fuse F2 provides protection for the power transformer and rectifier diodes in the event of failure (short circuit) of the series regulator transistors. In this situation, the crowbar will trip due to the higher-than-normal output voltage; up to 4A will then flow from the power transformer secondary winding supplying the defective supply. If no output current is being drawn from the other supply, the primary fuse will not blow since when viewed from the primary, 4A from one secondary and 0A from the other is the same as 2A from each secondary. Fuse F2 is thus provided to prevent damaging the power transformer by drawing twice the rated current from one secondary winding.

## 4-27 CONSTANT VOLTAGE COMPARATOR

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

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

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



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

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

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

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

4-34 CONSTANT CURRENT COMPARATOR

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

4-36 The constant current comparator circuit continuously compares the voltage drop across the CURRENT controls with the voltage drop across the current sampling resistor, R10-R11. If a difference exists, the differential amplifier produces an error signal which is proportional to this difference. The remaining components in the feedback loop (amplifiers and the series regulator) function to maintain the drop across the current sampling resistors, and hence the output current, at a constant value.

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

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

4-39 VOLTAGE CLAMP CIRCUIT

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

4-41 Voltage divider Z2A, Z2B, and VR5 reverse biases CR4 and Q3 during constant voltage operation. When the power supply goes into constant current operation, CR4 becomes forward biased by the voltage at pin 12 of Z1. This results in conduction of Q3 and the clamping of the summing point at a potential only slightly more negative than the normal constant voltage potential. Clamping this voltage at approximately the same potential that exists in constant voltage operation results in



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

4-42 MIXER AND DRIVER AMPLIFIERS

4-43 The mixer and driver amplifiers amplify the error signal from the constant voltage or constant current input circuit to a level sufficient to drive the series resulting transistors. Transistor Q5 receives the error voltage input from either the constant voltage or constant current comparator via the OR-gate diode (CR8 or CR9) that is conducting at the time. Diode CR8 is forward biased and CR9 is reverse biased during constant voltage operation. The reverse is true during constant current operation.

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

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

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

4-47 OVERVOLTAGE PROTECTION CROWBAR

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

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

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

4-51 REFERENCE REGULATOR

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



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

4-53 The regulating circuit consists of series regulating transistor Q15, driver Q14, and differential amplifier Q12 and Q13. The voltage across zener diodes VR1 and VR2 (+12.4V) and the voltage at the junction of divider Z2L-R52 and Z2J are compared, and any difference is amplified by the differential amplifier. The error voltage thus appearing at the collector of Q13 is amplified by driver stage Q14 and applied to series regulator Q15 in the correct phase and amplitude to maintain the +12.4 volt output at a constant level.

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

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

4-56 METER CIRCUIT

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

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

4-59 When measuring current, the meter with its

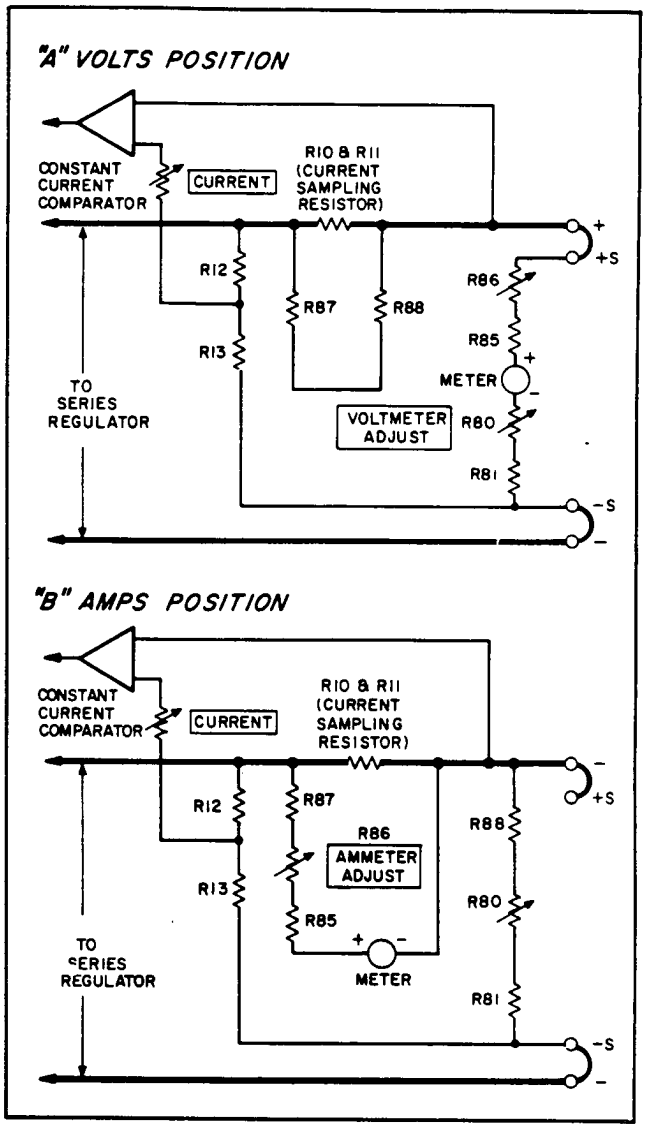



Figure 4-5. Meter Circuit, Simplified Schematic

series resistors (R87, R86, and R85) is connected across the current sampling resistor as shown in Figure 4-5B. Potentiometer R86 allows calibration of the ammeter circuit. Resistors R88, R80, and R81, connected from the positive output terminal to the negative sensing terminal, act as a "replacement" for the voltage measuring circuit.

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



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subtracted voltage causes the constant current comparator to increase the output current just enough to balance the current supplied to the meter circuit.

4-61 ADDITIONAL PROTECTION FEATURES

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

4-63 Resistors R18 and R19 limit the output of the supply if the connections between both output terminals and the sensing terminals (±S) are inadvertently removed. Diode CR11, previously mentioned in the driver amplifier description, protects the driver stage from damage due to same-polarity voltages that might be applied to the supply in such applications as battery charging and discharging. Fuse F2, previously mentioned in the series regulator description, protects the power transformer and rectifier diodes against damage due to series regulator failure.

## 4-64 TRACKING OPERATION

4-65 BASIC CIRCUIT DESCRIPTION

4-66 Figure 4-6 illustrates the basic tracking connections for any pair of power supplies. The principle involved is straightforward: the slave supply is connected in series with the master supply, and a voltage divider (resistors R1 and R2) is placed across the series combination. One input of the slave supply comparison amplifier is connected to the junction of the two resistors, while the other input is connected to the positive output terminal of the slave supply. Since the normal feedback action of the slave supply maintains zero error voltage between the two inputs to the comparison amplifier, the slave supply will contribute a fraction of the total output voltage determined by the voltage divider R1 and R2.

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

4-68 Note that the tracking combination can be

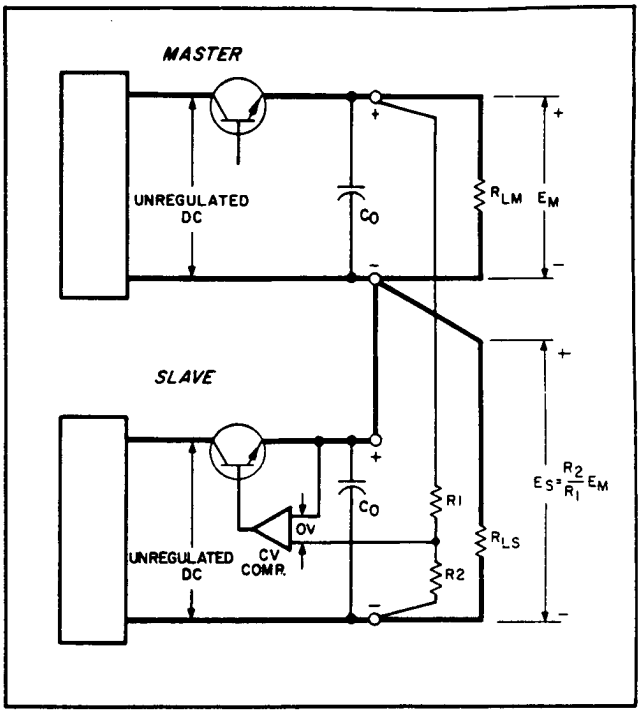



Figure 4-6. Tracking Operation, Basic Circuit Configuration

used to produce either a single output voltage greater than either the master or the slave, or coordinated positive and negative output voltages. In the former case, a single load is connected across the series combination; in the latter case, the center tap serves as the common point, with the slave producing the negative output voltage and the master producing the positive output voltage.

4-69 DETAILED CIRCUIT DESCRIPTION

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

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



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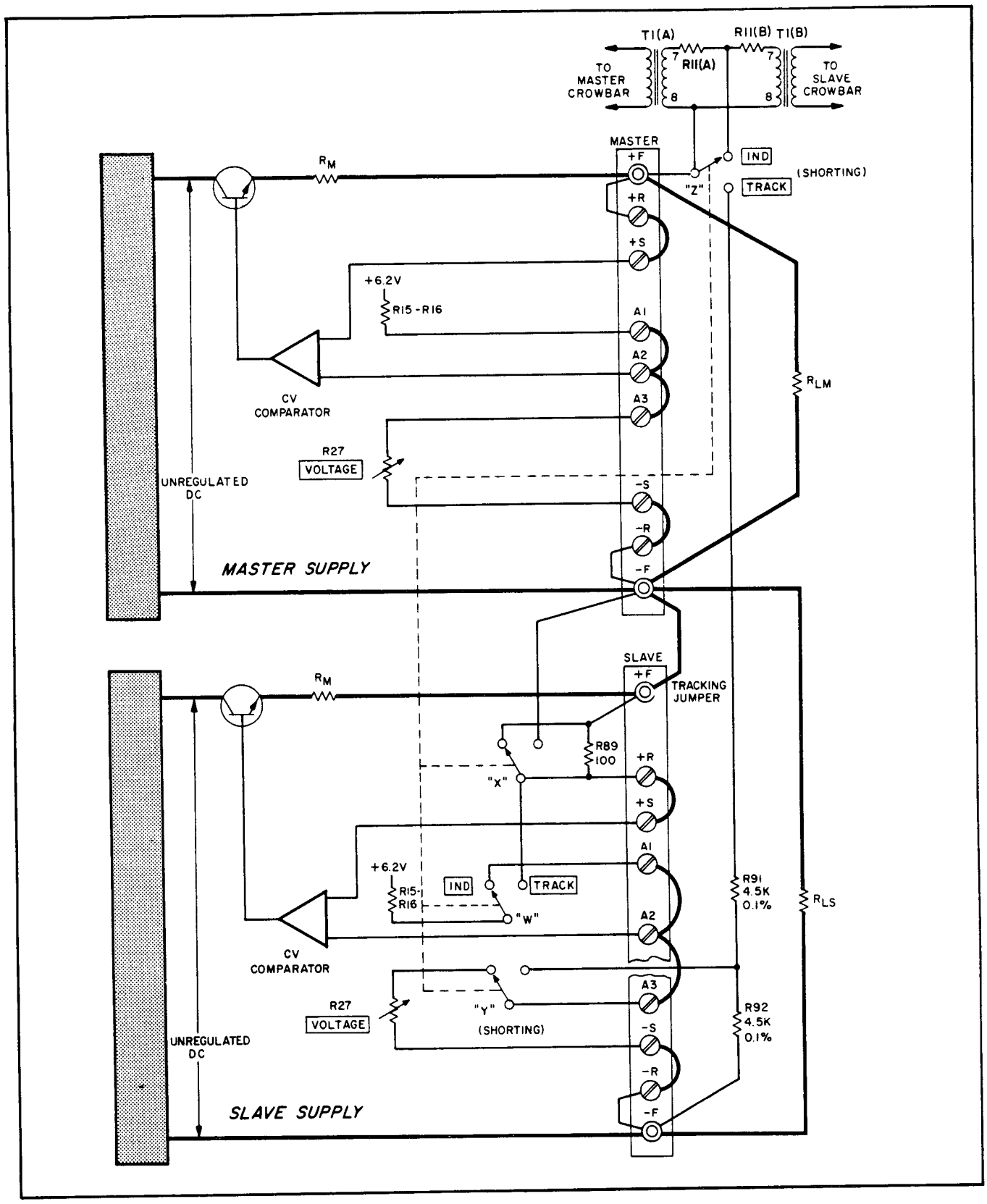



Figure 4-7. Tracking Switch Connections, Simplified Schematic



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

4-72 In the INDEPENDENT position, pole "X" of the tracking switch connects together the front and rear positive output terminals of the slave supply. In the tracking position, this pole connects one of the inputs of the voltage comparison amplifier (+S) to the common point of the tracking combination (the negative output terminal of the master supply). This action allows the slave comparison amplifier to sense directly across the slave supply load resistor, rather than through the tracking jumper (the finite voltage drop across the resistance of the front output terminal and the tracking jumper wire would degrade the slave supply regulation specification). Protection resistor R89 protects the two-supply combination against operation without the tracking jumper in place; this resistor is normally shorted out by the jumper. Pole "Z" of S2 serves a dual function — in the TRACKING position it connects the R91-R92 voltage divider across the total voltage span, and it allows the crowbars to slave one another. In the INDEPENDENT position it allows the crowbars to function independently. The pole is "shorting" in order to prevent momentarily opening the programming circuit formed by the voltage divider resistors.

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



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# SECTION V
# MAINTENANCE

## 5 -1 INTRODUCTION

5-2 Upon receipt of the power supply, the performance check (Paragraph 5-5) should be made. This check is suitable for incoming inspection. If a fault is detected in the power supply while making the performance check or during normal operation, proceed to the troubleshooting procedures (Paragraph 5-56). After repair and replacement (Paragraph 5-71), perform any necessary adjustments and calibrations (Paragraph 5-73). Before returning the power supply to normal operation, repeat the performance check to ensure that the fault has been properly corrected and that no other faults exist. Before performing any maintenance checks, turn on the power supply and allow a half-hour warm-up.

## 5-3 TEST EQUIPMENT REQUIRED

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

Table 5-1. Test Equipment Required

| TYPE | REQUIRED CHARACTERISTICS | USE | RECOMMENDED MODEL |
|---|---|---|---|
| Differential Voltmeter | Sensitivity: 500μV full scale (min.). Input impedance: 10MΩ (min.). | Measure dc voltages; calibration procedures. | HP 3420B (See Note on Page 5-2.) |
| Oscilloscope | Sensitivity and bandwidth: 50μV/cm and 300kHz for all measurements except noise spike; 1mV and 20MHz for noise spike measurement. | Measure ripple; display transient recovery waveforms; measure noise spikes. | HP 140A with 1403A vertical plug-in and 1423A time base; HP 180A with 1803A vertical plug-in and 1820A time base for spike measurement. |
| DC Voltmeter | Sensitivity: 1mV full scale (min.). Accuracy: 1%. | Measure dc voltages. | HP 412A. |
| AC Voltmeter | Sensitivity: 50μV full scale (min.). Frequency range: 5Hz to 250kHz (min.). Accuracy: 3%. | Measure output impedance, ripple, and ac voltages. | HP 3410A. |
| Oscillator | Frequency range: 5Hz to 20kHz (min.). Output: 5V rms into 600Ω. Accuracy: 3%. | Measure output impedance. | HP 209A. |
| Amplifier | Power output: 50 watts. Frequency response: ±3dB 5Hz to 20kHz (min.). | Measure output impedance. | HP 6824A. |



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Table 5-1. Test Equipment Required (Continued)

| TYPE | REQUIRED CHARACTERISTICS | USE | RECOMMENDED MODEL |
|---|---|---|---|
| Variable Voltage Transformer | Range: 103 to 127Vac. Recommended minimum output current: 5.5A. | Vary ac input for line regulation measurement. | --- |
| Repetitive Load Switch | Switching rate: 60 to 400Hz. Rise time: 2μsec. | Measure transient recovery time. | See Figure 5-5. |
| Resistive Loads | Values: See Figures 5-2 and 5-11. | Power supply load resistors. | --- |
| Current Sampling Resistors | Values: See Figures 5-7 and 5-11. | Measure output impedance; measure output current; calibrate ammeter. | R10 and R11 (6227B); R10 (6228B); see Replaceable Parts List. |
| Terminating Resistors | Value: 50 ohms, $\frac{1}{2}$ watt, ±5%, non-inductive, 4 required. | Noise spike measurement. | --- |
| Blocking Capacitors | Values: 0.01μF, 100Vdc, 2 required; 1000μF, 60Vdc, 1 required. | Noise spike measurement; output impedance measurement. | --- |

**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 betweenthe supply being measured and the reference voltage will have the required resolution for the measurement being made. The voltage difference will be a function of the null detector that is used. Examples of satisfactory null detectors are: HP 419A null detector, a dc coupled oscilloscope utilizing differential input, or a 10 mV meter movement with a 100 division scale. For the latter, a 0.5mV change in voltage will result in a meter deflection of five divisions.

**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.

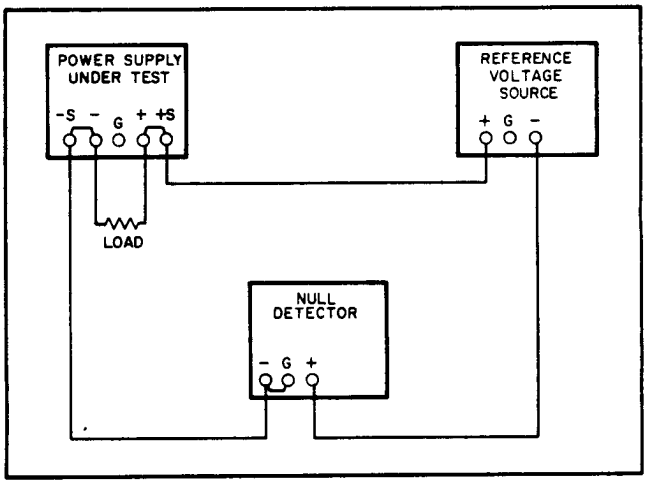



Figure 5-1. Differential Voltmeter Substitute Test Setup

## 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 115V ac, 60Hz, single phase input power source.



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

## 5-7 CONSTANT VOLTAGE TESTS

5-8 All measuring devices must be connected to the rear sensing terminals of the supply and not to the front output terminals (with the exception of the tracking specification, as noted in Paragraph 5-42), if maximum accuracy is to be obtained in the the following measurements. In addition, the measuring devices must be connected as close to the sensing terminals as possible. This is particularly important when measuring the transient response, regulation, or ripple of the power supply. Note that under no circumstances should the measuring instruments be connected across the load. A measurement made across the load includes the impedance of the leads to the load and such lead lengths can easily have an impedance several orders of magnitude greater than the supply impedance, thus invalidating the measurement.

5-9 To avoid mutual coupling effects, each monitoring device must be connected to the sensing terminals by a separate pair of leads. Twisted pairs or shielded two-wire cables should be used to avoid pickup on the measuring leads. The load resistor should be connected across the output terminals as close to the supply as possible. When measuring the constant voltage performance specifications, the current controls should be set well above (at least 10%) the maximum output current which the supply will draw, since the onset of constant current action will cause a drop in output voltage, increased ripple, and other performance changes not properly ascribed to the constant voltage operation of the supply.

5-10 Voltage Output and Voltmeter Accuracy. To check the output voltage, proceed as follows:

a. Connect load resistor ($R_L$) indicated in Figure 5-2 across output terminals of supply.

b. Connect differential voltmeter across +S and -S terminals of supply, observing correct polarity.

c. Turn CURRENT controls fully clockwise.

d. Turn on supply and adjust VOLTAGE controls until front panel meter indicates exactly maximum rated output voltage.

e. Differential voltmeter should indicate the following:

| | |
|---|---|
| 6227B | 25 ± 0.6Vdc |
| 6228B | 50 ± 1.2Vdc |

5-11 Load Regulation.

Definition: The change $\Delta E_{OUT}$ in the static value of dc output voltage resulting from a change in load resistance from open circuit to a value which yields maximum rated output current (or vice versa).

5-12 To check the constant voltage load regulation, proceed as follows:

a. Connect test setup shown in Figure 5-2.

b. Turn CURRENT controls fully clockwise.

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

d. Read and record voltage indicated on differential voltmeter.

e. Disconnect load resistor.

f. Reading on differential voltmeter should not vary from reading recorded in Step (d) by more than the following:

| | |
|---|---|
| 6227B | 3.5mV |
| 6228B | 6.0mV |

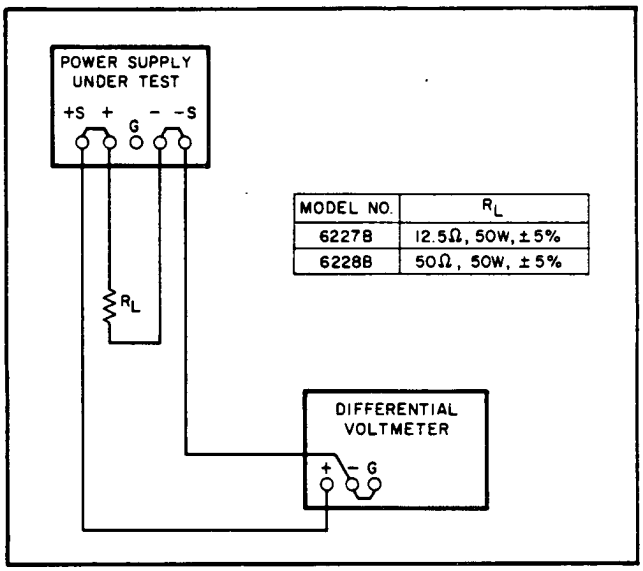



Figure 5-2. Constant Voltage Load Regulation Test Setup

5-13 Line Regulation.

Definition: The change $\Delta E_{OUT}$ in the static value of dc output voltage resulting from a change in ac input voltage over the specified range from low line (usually 103.5 volts) to high line (usually 126.5 volts), or from high line to low line.

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

a. Connect test setup shown in Figure 5-2.

b. Connect variable auto transformer



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between input power source and power supply power input.

c. Adjust variable auto transformer for 103.5 volts ac input.

d. Turn CURRENT controls fully clockwise.

e. Turn on supply and adjust VOLTAGE controls until front panel meter indicates exactly maximum rated output voltage.

f. Read and record voltage indicated on differential voltmeter.

g. Adjust variable auto transformer for 126.5 volts ac input.

h. Reading on differential voltmeter should not vary from reading recorded in Step (f) by more than 1mV.

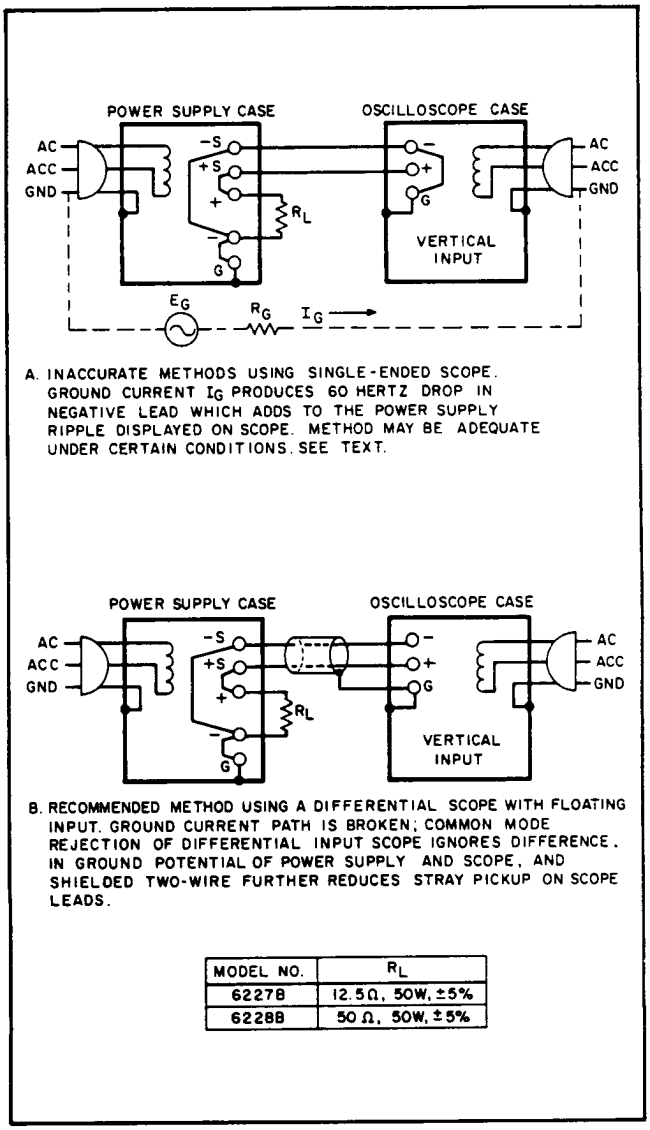
5-15 Ripple and Noise.

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

Ripple and noise measurement can be made at any input ac line voltage combined with any dc output voltage and load current within the supply's rating.

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

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




| MODEL NO. | $R_L$ |
|---|---|
| 62278 | 12.5Ω, 50W, ±5% |
| 62288 | 50Ω, 50W, ±5% |

Figure 5-3. Ripple Test Setup

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



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5-19 Although the method shown in Figure 5-3A is not recommended for ripple measurements, it may prove satisfactory in some instances provided certain precautionary measures are taken. One method of minimizing the effects of ground current flow ($I_E$) is to ensure that both the supply and the test instrument are plugged into the same ac power buss.

5-20 To minimize pick up, a twisted pair or (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 a twisted pair, care must be taken that one of the two wires is connected both to the grounded terminal of the power supply and the grounded input terminal of the oscilloscope. When using shielded two-wire cable, it is essential for the shield to be connected to ground at one end only to prevent any ground current flowing through this shield from inducing a signal in the shielded leads.

5-21 To verify that the oscilloscope is not displaying ripple that is 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 If the foregoing measures are used, the single-ended scope of Figure 5-3A may be adequate to eliminate non-real components of ripple so that a satisfactory measurement can be obtained. However, in stubborn cases or in measurement situations where it is essential that both the 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 5-3B. If desired, 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 oscilloscope in this manner, however, it is imperative that the common mode rejection capability of the oscilloscope be verified by shorting together its two input leads at the power supply sensing terminals and observing the trace on the CRT. If this trace is a straight line, then the oscilloscope 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 ripple output, proceed as follows:

a. Connect oscilloscope or RMS voltmeter as shown in Figures 5-3A or 5-3B.

b. Turn CURRENT controls fully clockwise.

c. Adjust VOLTAGE controls until front panel meter indicates maximum rated output voltage.

d. The observed ripple should be less than 250μV rms and 4mV p-p.

5-24 Noise Spike Measurement. When a high frequency spike measurement is being made, an instrument of sufficient bandwidth must be used; an oscilloscope with a bandwidth of 20MHz or more is adequate. Measuring noise with an instrument that has insufficient bandwidth may conceal high frequency spikes detrimental to the load.

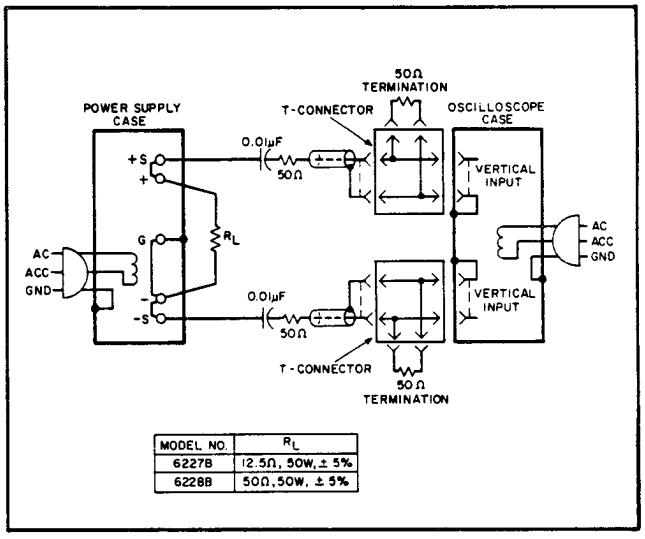
5-25 The test setup illustrated in Figure 5-3A is generally not acceptable for measuring spikes; a differential oscilloscope is necessary. Furthermore, the measurement concept of Figure 5-3B must be modified if accurate spike measurement is to be achieved:

1. As shown in Figure 5-4, two coax cables must be substituted for the shielded two-wire cable.

2. Impedance matching resistors must be included to eliminate standing waves and cable ringing, and capacitors must be inserted to block the dc current path.

3. The length of the test leads outside the coax is critical and must be kept as short as possible; the blocking capacitor and the impedance matching resistor should be connected directly from the inner conductor of the cable to the power supply sensing terminals.

4. Notice that the shields of the power supply end of the two coax cables are not connected




| MODEL NO. | $R_L$ |
|---|---|
| 6227B | 12.5Ω, 50W, ± 5% |
| 6228B | 50Ω, 50W, ± 5% |

Figure 5-4. Noise Spike Measurement Test Setup



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to the power supply ground, since such a connection would give rise to a ground current path through the coax shield, resulting in an erroneous measurement.

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

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

5-27 Transient Recovery Time.
Definition: The time "X" for the output voltage recovery to within "Y" millivolts of the nominal output voltage following a "Z" amp step change in load current, where: "Y" is specified as 10mV, the nominal output voltage is defined as the dc level halfway between the static output voltage before and after the imposed load change, and "Z" is the specified load current change of 5 amps or the full load current rating of the supply, whichever is less.

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

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

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

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

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

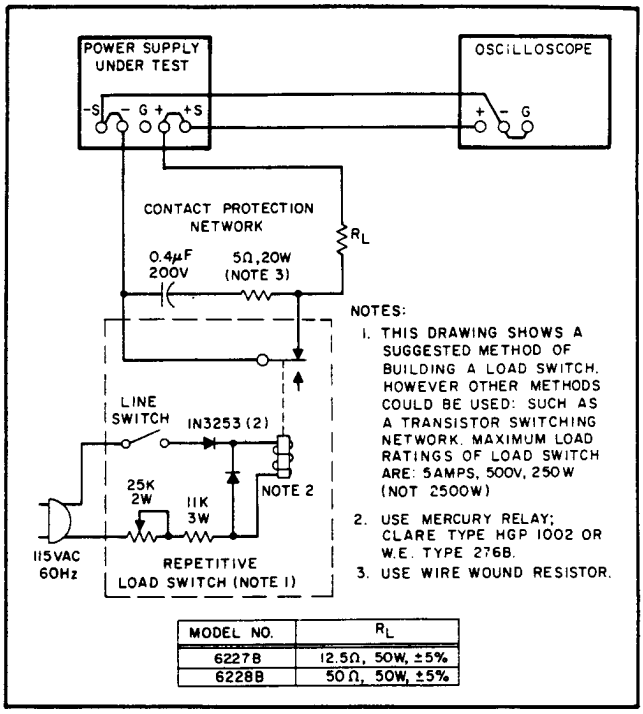



Figure 5-5. Transient Recovery Time Test Setup

c. Turn on supply and adjust VOLTAGE controls until front panel ammeter indicates maximum rated output current.
d. Close line switch on repetitive load switch setup.
e. Set oscilloscope for internal sync and lock on either positive or negative load transient spike.
f. Set vertical input of oscilloscope for ac coupling so that small dc level changes in power supply output voltage will not cause display to shift.
g. Adjust the vertical centering on the scope so that the tail ends of the no load and full load waveforms are symmetrically displayed about the horizontal center line of the oscilloscope. This center line now represents the nominal output voltage defined in the specification.
h. Adjust the horizontal positioning control so that the trace starts at a point coincident with a major graticule division. This point is then representative of time zero.
i. Increase the sweep rate so that a single transient spike can be examined in detail.
j. Adjust the sync controls separately for the positive and negative going transients so that not only the recovery waveshape but also as much as possible of the rise time of the transient is displayed.
k. Starting from the major graticule division representative of time zero, count to the right 50μsec and vertically 10mV. Recovery should be within these tolerances as illustrated in Figure 5-6.



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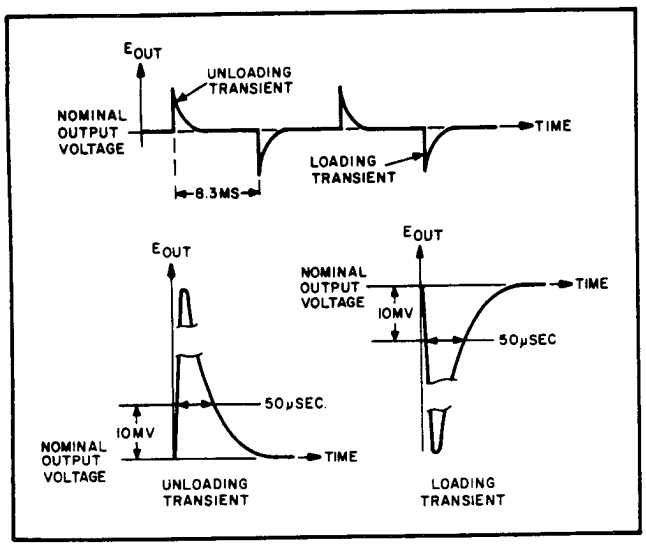



Figure 5-6. Transient Recovery Time Waveforms

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

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

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

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

a. Connect load resistance and differential voltmeter as illustrated in Figure 5-2.

b. Turn CURRENT controls fully clockwise.

c. Adjust front panel VOLTAGE controls until front panel voltmeter indicates maximum rated output voltage.

d. Place power supply in temperature-controlled oven (differential voltmeter remains outside oven). Set temperature to 30°C and allow 30 minutes warm-up.

e. Record differential voltmeter reading.

f. Raise temperature to 40°C and allow 30 minutes warm-up.

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

| | |
|---|---|
| 6227B | 5.2mV |
| 6228B | 10.2mV |

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

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

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

a. Connect load resistance and differential voltmeter as illustrated in Figure 5-2.

b. Turn CURRENT controls fully clockwise.

c. Adjust front panel VOLTAGE controls until differential voltmeter indicates maximum rated output voltage.

d. Allow 30 minutes warm-up, then record differential voltmeter reading.

e. After 8 hours, differential voltmeter should change from reading recorded in Step (d) by less than the following:

| | |
|---|---|
| 6227B | 52mV |
| 6228B | 102mV |

5-39 Output Impedance.
Definition: At any given frequency of load change, $E_{OUT}/I_{OUT}$. Strictly speaking the definition applies only for a sinusoidal load disturbance, unless, of course, the measurement is made at zero frequency (dc). The



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output impedance of an ideal constant voltage power supply would be zero at all frequencies, while the output impedance of an ideal constant current power supply would be infinite at all frequencies.

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

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

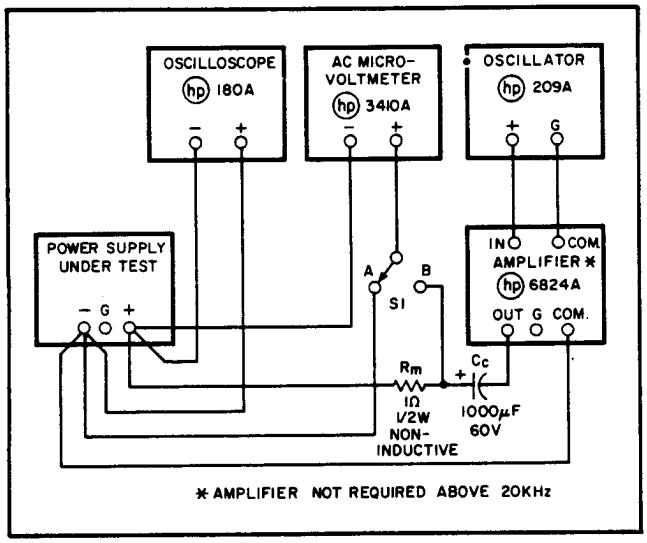



Figure 5-7. Output Impedance Test Setup

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

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

b. Turn CURRENT controls fully clockwise.

c. Turn on supply and adjust VOLTAGE controls for maximum rated output voltage.

d. Move switch S1 connected to ac microvoltmeter to position A (measure ac voltage impressed across power supply output terminals).

e. Set oscillator frequency for 5Hz.

f. Adjust amplitude controls of oscillator and amplifier for largest possible undistorted waveform on oscilloscope. Record reading on microvoltmeter.

g. Move switch S1 to position B (measure ac voltage drop across 1 ohm resistor, and therefore ac current delivered to power supply under test).

h. Without changing amplitude controls on oscillator or amplifier, read and record voltage indicated on ac microvoltmeter.

i. Output impedance (at 5Hz) is found by dividing the voltage reading from Step (f) by the voltage reading from Step (h); the value should not exceed 0.002 (ohms) for the 6227B and 0.006 (ohms) for the 6228B.

j. Repeat Steps (d) through (i) for any other frequencies of interest up to 250kHz. (Note: Amplifier is not required at frequencies above 20kHz.) For any given frequency, the output impedance should be less than that indicated by the value of the curve in Figure 5-8. For example, at 1kHz the output impedance should be less than approximately 11 milliohms for the 6227B and 40 milliohms for the 6228B.

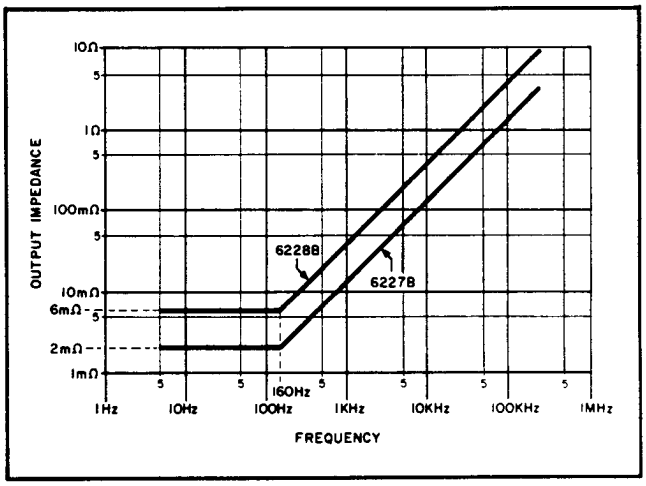



Figure 5-8. Output Impedance versus Frequency

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



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common to both supplies; the positive terminal of the slave (right) supply should not be used.

5-43 To check the tracking error, proceed as follows:

a. Connect test setup shown in Figure 5-9.

b. Set front panel mode switch to TRACKING, and connect jumper between minus output terminal of left supply and positive output terminal of right supply as shown on front panel and in Figure 5-9.

c. Turn CURRENT controls fully clockwise and set switch S1 to position A (measure master supply output voltage).

d. Turn on supply and adjust master VOLTAGE controls until differential voltmeter reads exactly maximum rated output voltage.

e. Move switch S1 to position B (measure slave output voltage). Differential voltmeter reading should be within following tolerances:

| | |
|---|---|
| 6227B | 25V ± 52mV |
| 6228B | 50V ± 102mV |

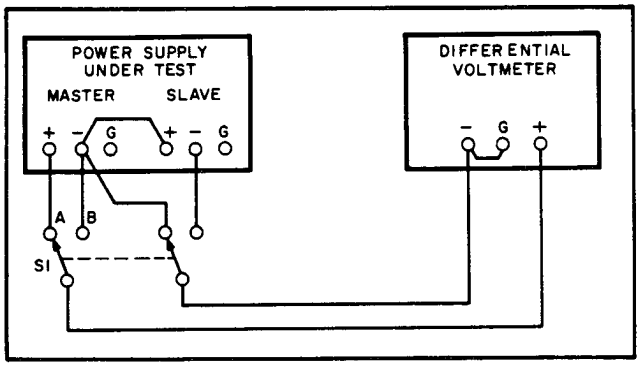



Figure 5-9. Tracking Error Test Setup

5-44 CONSTANT CURRENT TESTS

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

5-46 For all output current measurements the current sampling resistor must be treated as a four terminal device. In the manner of a meter shunt, the load current is fed to the extremes of the wire leading to the resistor while the sampling terminals are located as close as possible to the resistance portion itself (see Figure 5-10). Generally, any current sampling resistor should be of the low noise, low temperature coefficient (less than 20ppm/°C) type and should be used at no more than 10% of its rated power so that its temperature rise will be minimized. If difficulty is experienced in obtaining a resistor suitable for current sampling, a duplicate of the sampling resistor used in this unit (R10 and R11 in the 6227B; R10 in the 6228B) may be obtained from the factory.

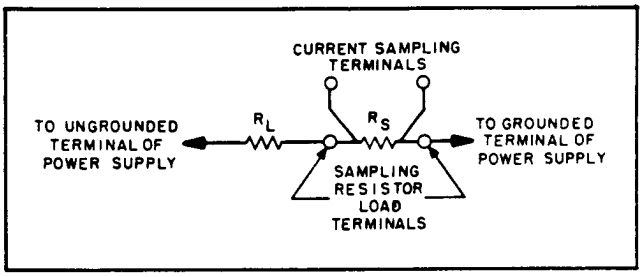



Figure 5-10. Current Sampling Resistor Connections

5-47 Rated Output and Meter Accuracy.

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

b. Turn VOLTAGE controls fully clockwise.

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

d. Differential voltmeter should read 1.0 ± 0.024Vdc.

5-48 Load Regulation.

Definition: The change $\Delta I_{OUT}$ 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.

5-49 To check the constant current load regulation, proceed as follows:

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

b. Turn VOLTAGE controls fully clockwise.

c. Adjust CURRENT controls until front panel meter reads exactly maximum rated output voltage.

d. Read and record voltage indicated on differential voltmeter.

e. Short circuit load resistor ($R_L$).

f. Reading on differential voltmeter should not vary from reading recorded in Step (d) by more than the following:

| | |
|---|---|
| 6227B | 225μV |
| 6228B | 350μV |

5-50 Line Regulation.

Definition: The change $\Delta I_{OUT}$ in the static value of dc output current resulting from a change in ac input voltage over the specified range from low



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

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

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

b. Connect variable auto transformer between input power source and power supply power input.

c. Adjust auto transformer for 103.5Vac input.

d. Turn VOLTAGE controls fully clockwise.

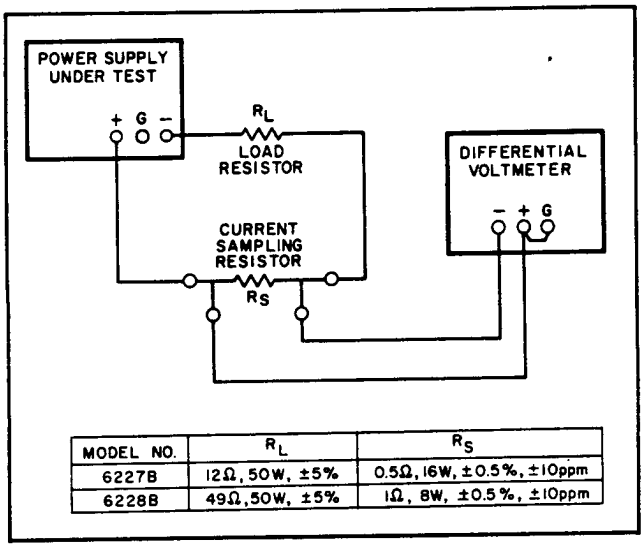
e. Adjust CURRENT controls until front panel ammeter reads exactly maximum rated output current.

f. Read and record voltage indicated on differential voltmeter.

g. Adjust variable auto transformer for 126.5Vac input.

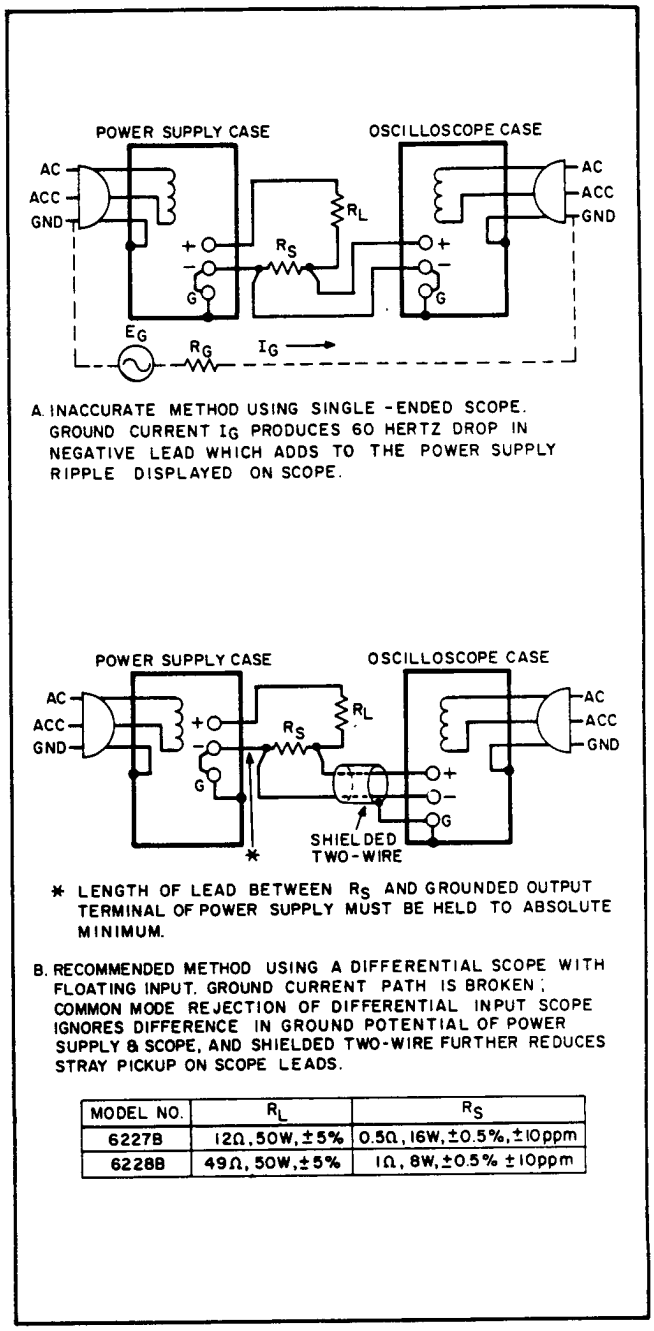
h. Reading on differential voltmeter should not vary from reading recorded in Step (f) by more than the following:

6227B 50μV
6228B 100μV




| MODEL NO. | $R_L$ | $R_S$ |
|---|---|---|
| 6227B | 12Ω, 50W, ±5% | 0.5Ω, 16W, ±0.5%, ±10ppm |
| 6228B | 49Ω, 50W, ±5% | 1Ω, 8W, ±0.5%, ±10ppm |

Figure 5-11. Constant Current Load Regulation Test Setup




| MODEL NO. | $R_L$ | $R_S$ |
|---|---|---|
| 6227B | 12Ω, 50W, ±5% | 0.5Ω, 16W, ±0.5%, ±10ppm |
| 6228B | 49Ω, 50W, ±5% | 1Ω, 8W, ±0.5% ±10ppm |

Figure 5-12. Constant Current Ripple Test Setup

5-52 Ripple and Noise.

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

5-53 Most of the instructions pertaining to the ground loop and pickup problems associated with constant voltage ripple and noise measurements also apply to the measurement of constant current ripple and noise. Figures 5-12 and 5-13 illustrate the most important precautions to be observed when measuring the ripple and noise of a constant current supply. The presence of a 120Hz waveform on the oscilloscope is normally indicative of a correct measurement method. A waveshape having 60Hz as its fundamental component is typically associated with an incorrect measurement setup.

5-54 Ripple Measurement. To check the ripple



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output, proceed as follows:

a. Connect oscilloscope or RMS voltmeter as shown in Figures 5-12A or 5-12B.

b. Turn VOLTAGE controls fully clockwise.

c. Adjust CURRENT controls until front panel ammeter reads exactly maximum rated output current.

d. The observed ripple should be less than:

6227B 125μV
6228B 250μV

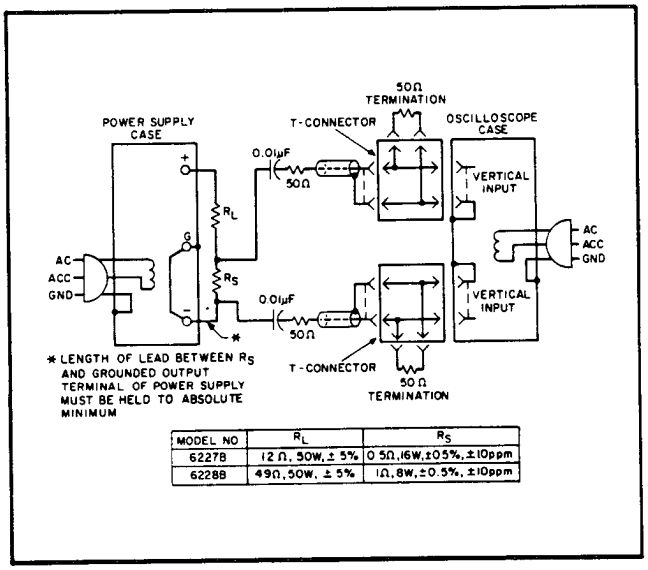
5-55 Noise Spike Measurement. To check the noise spike output, proceed as follows:

a. Connect test setup shown in Figure 5-13.

b. Turn VOLTAGE controls fully clockwise.

c. Adjust CURRENT controls until front panel ammeter indicates exactly rated output current.

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




| MODEL NO | $R_L$ | $R_S$ |
|---|---|---|
| 6227B | 12Ω, 50W, ± 5% | 0.5Ω, 16W, ±0.5%, ±10ppm |
| 6228B | 49Ω, 50W, ± 5% | 1Ω, 8W, ±0.5%, ±10ppm |

Figure 5-13. Constant Current Noise Spike Test Setup

## 5-56 TROUBLESHOOTING

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

5-58 A good understanding of the principles of operation is a helpful aid in troubleshooting, and it is recommended that the reader review Section IV of the manual before attempting to troubleshoot the instrument. Once the principles of operation are understood, refer to the overall troubleshooting procedure in Paragraph 5-61 to locate the symptom and its probable cause.

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

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

5-61 OVERALL TROUBLESHOOTING PROCEDURE

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

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

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

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

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

**NOTE**

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

e. Disconnect load, set mode switch to



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

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

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

**CAUTION**

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

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

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

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

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

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



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Table 5-3. Initial Troubleshooting (Common Troubles)

<table>
<tr><th>SYMPTOM</th><th>PROBABLE CAUSE AND REMEDIAL ACTION</th></tr>
<tr><td>No output voltage under loaded conditions; normal output voltage and slow up-programming under no-load conditions</td><td>a. Fuse F2 blown. Replace fuse, isolate crowbar by disconnecting anode of CR4, and turn on supply. If output voltage is high, refer to "High Output Voltage" symptom below. If output voltage is low, refer to "Low or No Output Voltage" symptom below. If output voltage is normal, check constant current comparator by performing the following test:
<table>
<tr><th>ACTION</th><th>RESPONSE</th><th>PROBABLE CAUSE</th></tr>
<tr><td>Turn off supply, and disconnect cathode of CR8. Connect $\frac{1}{4}$-current load resistor across output terminals (100Ω, 25W for 6227B and 200Ω, 25W for 6228B). Set meter switch to AMPS and turn on supply. Ammeter will indicate approximately 0.5A on 6227B and 0.25A on 6228B. (If meter switch is set to VOLTS, meter will go off-scale.) Check turn-off of constant current comparator by shunting R5 with 10kΩ resistor.</td><td>a. Output current remains constant.<br>b. Output current decreases.</td><td>a. Z1 defective.<br>b. R4A or R4B open; strap missing between terminals A6 and A7.</td></tr>
</table></td></tr>
<tr><td>High output voltage after replacing fuse F2 and isolating crowbar</td><td>a. Series regulator feedback loop in high voltage condition. Refer to Table 5-4.</td></tr>
<tr><td>Low or no output voltage after replacing fuse F2 and isolating crowbar</td><td>a. Check voltage across main filter capacitors C6 and C7. If no voltage is present, check CR15 through CR18 and fuse F1. If correct voltage is present, series regulator feedback loop is in low voltage condition. Refer to Table 5-5.</td></tr>
<tr><td>Crowbar trips every time supply is turned on regardless of setting of CROWBAR ADJUST control</td><td>a. Regulator loop in high voltage condition. Isolate crowbar by disconnecting anode of CR4, and refer to Table 5-4.<br>b. Defective crowbar. Check SCR CR4 for anode-to-cathode short, and check CROWBAR ADJUST control R10 for short.<br><br>NOTE<br>Uncertainty over whether the crowbar has tripped and shorted the output of the supply, or the supply output has fallen to zero due to a regulating loop failure can be resolved by switching the meter switch to AMPS. If the crowbar is tripped, the ammeter will indicate the current flowing through the SCR (the level is determined by the setting of the CURRENT control); if the crowbar is not tripped, the ammeter will read zero.</td></tr>
<tr><td>Crowbar will not trip regardless of setting of CROWBAR ADJUST control; output voltage falls slowly when unloaded supply is turned off</td><td>a. Defective crowbar. Refer to Table 5-6.</td></tr>
</table>



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

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

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

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



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

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

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

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



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

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

Table 5-7. Less Common Troubles

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



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Table 5-7. Less Common Troubles (Continued)

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

## 5-67 DISASSEMBLY PROCEDURES

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

5-69 Master and Slave Circuit Board (A2 and A3) Removal. To remove the master and slave printed circuit boards, proceed as follows:

a. Remove top, bottom, and side covers (total 12 Phillips screws).

b. Remove 4 Phillips screws holding rear aluminum frame to main side frames.

c. Exerting gentle rearward pressure on heatsink and rear aluminum frame, unplug entire assembly (consisting of heatsink and both circuit boards) from connectors on A1 mother board.

d. With master/slave board assembly completely removed, A1 mother board and chassis-mounted components may now be easily accessed.

5-70 Crowbar Circuit Board (A4) Removal. To remove the A4 crowbar circuit board, proceed as follows:

a. Remove top, bottom, and side covers (total 12 Phillips screws).

b. Turn unit upside down and remove 2 Phillips screws holding bracing rod to main side frames at bottom front of unit.

c. Remove 6 Phillips screws holding internal aluminum tray chassis to main side frames.

d. Remove 2 Phillips screws holding top front trim (aluminum extrusion) to main side frames.

e. Using $\frac{1}{4}$" Allen wrench and working from front panel, remove two bushings holding CROWBAR ADJUST potentiometers to front panel.

f. While spreading main side frames slightly apart, pull lower (control) portion of front panel away from unit.



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

## 5-71 REPAIR AND REPLACEMENT

5-72 Section VI of this manual contains a list of replaceable parts. If the part to be replaced does not have a standard manufacturers' part number, it is a "special" part and must be obtained directly from Hewlett-Packard. After replacing a semiconductor device, refer to Table 5-8 for checks and adjustments that may be necessary. All components listed in Table 5-8 without A-designators or asterisks (*) are on the master and slave printed circuit boards (A2 and A3); components with asterisks are chassis-mounted.

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

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



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

| REFERENCE | FUNCTION OR CIRCUIT | CHECK | ADJUST |
|---|---|---|---|
| CR11, CR12 | Driver amplifier protection. | Output voltage. | --- |
| CR13, CR14 | Series regulator switching diodes. | Output voltage over full range. | --- |
| A1CR15, A1CR16, A1CR17, A1CR18 | Main rectifier diodes. | Output voltage. | --- |
| A1CR19, A1CR20 | Bias supply rectifier diodes. | +20V and -4.3V bias voltages. | --- |
| A1CR21, A1CR22 | Reference regulator rectifier diodes. | +12.4V, +6.2V, and -6.2V reference voltages. | --- |
| A4VR1, A4VR2 | Crowbar. | Crowbar action, trip voltage range. | R10 |
| VR1, VR2 | Reference regulator. | +6.2V and -6.2V reference voltages. | R2 and R16. |
| VR3 | Series regulator. | Output voltage over full range. | --- |
| VR4 | Bias supply. | -4.3V reference voltage. | --- |
| VR5 | Voltage clamp. | CC load regulation. | --- |

Table 5-9. Adjustment and Calibration Summary

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



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## 5-73 ADJUSTMENT AND CALIBRATION

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

5-75 METER ZERO

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

a. Turn on instrument and allow it to come up to normal operating temperature (about 30 minutes).

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.

5-77 METER CALIBRATION

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

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

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

b. Turn VOLTAGE controls fully clockwise and set meter switch to AMPS.

c. Turn on supply and adjust CURRENT controls until differential voltmeter reads 1.0 volts.

d. Adjust potentiometer R86 until front panel meter indicates exactly maximum rated output current.

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

a. Connect test setup shown in Figure 5-2.

b. Turn CURRENT controls fully clockwise and set meter switch to VOLTS.

c. Turn on supply and adjust VOLTAGE controls until differential voltmeter reads exactly maximum rated output voltage.

d. Adjust potentiometer R80 until front panel meter also reads exactly maximum rated output voltage.

5-81 CONSTANT VOLTAGE PROGRAMMING CURRENT

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

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

a. Connect test setup shown in Figure 5-9, and set switch S1 to position "A".

b. Set front panel mode switch to TRACKING, and connect jumper between minus output terminal of left supply and positive output terminal of right supply as shown on front panel and in Figure 5-9.

c. If instrument is to be locally programmed, turn master VOLTAGE controls fully counterclockwise. If instrument is to be remote programmed, connect remote programming setup (Figures 3-3, 3-4, or 3-5) to master supply, and adjust remote resistance or voltage to zero (minimum).

Rotate both sets of CURRENT controls fully clockwise and turn on supply.

e. Adjust potentiometer R24 in master supply until differential voltmeter reads exactly zero.

f. Move switch S1 to position "B".

g. Adjust potentiometer R24 in slave supply until differential voltmeter reads exactly zero.

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

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

| | |
|---|---|
| 6227B | 5KΩ |
| 6228B | 10KΩ |



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

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

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

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

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

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

5-85 CONSTANT CURRENT PROGRAMMING CURRENT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5-89 CROWBAR DISABLEMENT

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



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# 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 | E | = miscellaneous electronic part |
| B | = blower (fan) | F | = fuse |
| C | = capacitor | J | = jack, jumper |
| CB | = circuit breaker | K | = relay |
| CR | = diode | L | = inductor |
| DS | = device, signaling (lamp) | M | = meter |
| P | = plug | V | = vacuum tube, neon bulb, photocell, etc. |
| Q | = transistor | VR | = zener diode |
| R | = resistor | X | = socket |
| S | = switch | Z | = integrated circuit or network |
| T | = transformer | | |
| TB | = terminal block | | |
| TS | = thermal switch | | |

Table 6-1. Reference Designators (Continued)

Table 6-2. Description Abbreviations

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



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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. | Berkeley Heights, 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



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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.



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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. Semi-conductor Prod. Div. | Woburn, Mass. |
| 93410 | Essex Wire Corp. Stemco Controls Div. | Mansfield, Ohio |
| 94144 | Raytheon Co. Components Div. Ind. Components Oper. | Quincy, Mass. |
| 94154 | Wagner Electric Corp. Tung-Sol Div. | Livingston, N.J. |
| 94222 | Southco Inc. | Lester, Pa. |
| 95263 | Leecraft Mfg. Co. Inc. | L.I.C., N.Y. |
| 95354 | 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. |



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Table 6-4. Replaceable Parts

| REF. DESIG. | DESCRIPTION | TQ | MFR. PART NO. | MFR. CODE | HP PART NO. | RS |
|---|---|---|---|---|---|---|
| | A1 MOTHER BOARD - ELECTRICAL | | | | | |
| A1 | Printed Circuit Board, Mother | 1 | | 28480 | 06227-60020 | |
| C9A, 9B | fxd, elect 325µF 35Vdc | 2 | | 28480 | 0180-0332 | 1 |
| C10A, 10B | fxd, elect 80µF 65Vdc | 2 | 72D1005 | 56289 | 0180-2258 | 1 |
| C11A-14A, 11B-14B | fxd, ceramic .05µF 500V | 8 | 33C17A | 56289 | 0150-0052 | 2 |
| CR15A-18A, 15B-18B | Rect. Si. 3A 200prv | 8 | MR1032B | 04713 | 1901-0416 | 6 |
| CR19A, 19B, 20A, 20B, 21A, 21B, 22A, 22B | Rect. Si. 200mA 180V | 8 | 1N5059 | 03508 | 1901-0327 | 6 |
| J1, J2 | Connector, PC Board edge | 2 | 252-22-30-340 | 71785 | 1251-1887 | 2 |
| R75A, 75B | fxd, ww 135Ω ±5% 5W | 2 | Type 5XM | 63743 | 0812-0098 | 1 |
| R76A, 76B | fxd, ww 1kΩ ±5% 5W | 2 | Type 5XM | 63743 | 0812-0099 | 1 |
| R91, 92 | fxd, ww 4.5kΩ ±.1% ±10ppm 2½W | 2 | Type T2C | 01686 | 0811-1993 | 1 |
| T1 | Transformer, Power | 1 | | 28480 | 06227-80091 | |
| | A2 MASTER BOARD - ELECTRICAL | | | | | |
| A2 | Printed Circuit Board, Master | 1 | | 28480 | 06227-60021 | |
| C1 | fxd, elect 1500µF 40Vdc | 1 | | 28480 | 0180-1894 | 1 |
| C2 | fxd, elect 5µF 50Vdc | 1 | 30D505G050BB2 | 56289 | 0180-0301 | 1 |
| C3 | fxd, mylar .01µF 200V | 1 | 192P10392 | 56289 | 0160-0161 | 1 |
| C4 | fxd, mylar .0022µF 200V | 1 | 192P22292 | 56289 | 0160-0154 | 1 |
| C5 | fxd, mylar .22µF 80V | 1 | 192P2249R8 | 56289 | 0160-2453 | 1 |
| C6, 7 | fxd, elect 3000µF 40V | 2 | | 28480 | 0180-1899 | 1 |
| C11 | fxd, elect 4.7µF 35Vdc | 1 | 150D475X9035B2 | 56289 | 0180-0100 | 1 |
| C13 | fxd, elect 22µF 35Vdc | 1 | 150D226X0035R2 | 56289 | 0180-0160 | 1 |
| C15 | fxd, mylar .47µF 25V | 1 | 5C11B75 | 56289 | 0160-0174 | 1 |
| CR1 | Diode, Si. 250mW 200V | 5 | | 28480 | 1901-0033 | 5 |
| CR2 | Rect. Si. 3A 200prv | 3 | MR1032B | 04713 | 1901-0416 | 3 |
| CR3 | Diode, Si. 250mA 75V | 1 | | 28480 | 1901-0050 | 1 |
| CR4 | Diode, Si. 400mW 15V | 3 | | 28480 | 1901-0461 | 3 |
| CR5-7 | Diode, Si. 250mW 200V | | | 28480 | 1901-0033 | |
| CR8, 9 | Diode, Si. 400mW 15V | | | 28480 | 1901-0461 | |
| CR10 | Diode, Si. 250mW 200V | | | 28480 | 1901-0033 | |
| CR11 | Diode, Si. 400mW 10V | 1 | | 28480 | 1901-0460 | 1 |
| CR12 | Rect. Si. 1A 200prv | 1 | 1N5059 | 03508 | 1901-0327 | 1 |
| CR13, 14 | Rect. Si. 3A 200prv | | MR1032B | 04713 | 1901-0416 | |
| F2 | Fuse Cartridge, 3A 250V 3AG Normal Blow Pigtail | 1 | 318003 | 75915 | 2110-0290 | 5 |
| Q1, 2, 7-11 | NOT ASSIGNED | - | - | - | - | - |
| Q3 | SS PNP Si. | 3 | | 28480 | 1853-0099 | 3 |
| Q4 | SS PNP Si. | 5 | | 28480 | 1854-0071 | 5 |
| Q5 | SS PNP Si. | | | 28480 | 1853-0099 | |
| Q6, 12-14 | SS NPN Si. | | | 28480 | 1854-0071 | |
| Q15 | SS PNP Si. | | | 28480 | 1853-0099 | |
| R1 | fxd, ww 7.5kΩ ±5% 3W | 1 | Type 242E | 56289 | 0811-1815 | 1 |
| R2 | fxd, comp (Selected) ±5% ½W | 2 | Type EB (obd) | 01121 | | |
| R3 | fxd, met. film 1kΩ ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0757-0280 | 1 |



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| REF. DESIG. | DESCRIPTION | TQ | MFR. PART NO. | MFR. CODE | HP PART NO. | RS |
|---|---|---|---|---|---|---|
| R5 | fxd, comp 220kΩ ±5% ½W | 1 | EB-2245 | 01121 | 0686-2245 | 1 |
| R6 | fxd, met. film 1.5kΩ ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0757-0427 | 1 |
| R7 | fxd, comp 750kΩ ±5% ½W | 1 | EB-7545 | 01121 | 0686-7545 | 1 |
| R8 | fxd, comp 300Ω ±5% ½W | 2 | EB-3015 | 01121 | 0686-3015 | 1 |
| R9, 14, 17, 23, 27-29, 39, 43, 47, 49, 53-67, 78, 79, 82, 83 | NOT ASSIGNED | - | - | - | - | - |
| R10, 11 | fxd, ww 1Ω ±0.5% 8W | 2 | Type T-7A | 01686 | 0811-2133 | 1 |
| R12 | fxd, comp 3.3Ω ±5% ½W | 2 | EB-0335 | 01121 | 0686-0335 | 1 |
| R13 | fxd, met. film 200kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0472 | 1 |
| R15 | fxd, ww 1.3kΩ ±5% 3W | 1 | Type 242E | 56289 | 0811-1803 | 1 |
| R16 | fxd, comp (Selected) ±5% ½W | | Type EB (obd) | 01121 | | |
| R18, 19 | fxd, comp 100Ω ±5% ½W | 3 | EB-1015 | 01121 | 0686-1015 | 1 |
| R20 | fxd, ww 1kΩ ±5% 3W | 1 | Type 242E | 56289 | 0813-0001 | 1 |
| R21 | fxd, comp 200Ω ±5% ½W | 2 | EB-2015 | 01121 | 0686-2015 | 1 |
| R22 | fxd, comp 24Ω ±5% ½W | 1 | EB-2405 | 01121 | 0686-2405 | 1 |
| R24 | var. comp 25kΩ ±30% (Zero Volt Adjust) | 1 | | 28480 | 2100-1534 | 1 |
| R25 | fxd, met. film 1.5kΩ ±1% 1/8W | | Type CEA T-0 | 07716 | 0757-0427 | |
| R26 | fxd, met. film 249kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0270 | 1 |
| R30 | fxd, met. film 61.9kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0460 | 1 |
| R31 | fxd, met. film 2kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0283 | 1 |
| R32 | fxd, met. film 3.4kΩ ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0698-4440 | 1 |
| R33 | fxd, comp 100Ω ±5% ½W | | EB-1015 | 01121 | 0686-1015 | |
| R34 | fxd, comp 10kΩ ±5% ½W | 2 | EB-1035 | 01121 | 0686-1035 | 1 |
| R35 | fxd, met. film 6.2kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0698-5087 | 1 |
| R36 | fxd, comp 2kΩ ±5% ½W | 1 | EB-2025 | 01121 | 0686-2025 | 1 |
| R37 | fxd, comp 200Ω ±5% ½W | | EB-2015 | 01121 | 0686-2015 | 1 |
| R38 | fxd, comp 150Ω ±5% ½W | 1 | EB-1515 | 01121 | 0686-1515 | 1 |
| R40 | fxd, met. film 470Ω ±1% ¼W | 1 | Type CEB T-0 | 07716 | 0698-3506 | 1 |
| R41, 42 | fxd, met. film 7.5kΩ ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0757-0440 | 1 |
| R44 | fxd, met. film 600Ω ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-1100 | 1 |
| R45 | fxd, comp 10kΩ ±5% ½W | | EB-1035 | 01121 | 0686-1035 | |
| R46 | fxd, comp 470Ω ±5% ½W | 1 | EB-4715 | 01121 | 0686-4715 | 1 |
| R48 | fxd, met. film 2kΩ ±1% ¼W | 1 | Type CEB T-0 | 07716 | 0757-0739 | 1 |
| R50 | fxd, met. film 5.49kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0698-3382 | 1 |
| R51 | fxd, comp 820Ω ±5% ½W | 1 | EB-8215 | 01121 | 0686-8215 | 1 |
| R52 | fxd, met. film 3.4kΩ ±1% 1/8W | | Type CEA T-0 | 07716 | 0698-4440 | |
| R68, 69 | fxd, ww 0.5Ω ±5% 3W 20ppm | 4 | | 28480 | 0811-1830 | 1 |
| R70 | fxd, comp 10Ω ±5% ½W | 1 | EB-1005 | 01121 | 0686-1005 | 1 |
| R71 | fxd, comp 51Ω ±5% ½W | 1 | EB-5105 | 01121 | 0686-5105 | 1 |
| R72 | fxd, comp 300Ω ±5% ½W | | EB-3015 | 01121 | 0686-3015 | |
| R73, 74 | fxd, ww 0.5Ω ±5% 3W 20ppm | | | 28480 | 0811-1830 | |
| R77 | fxd, ww 1kΩ ±5% 5W | 1 | Type 5XM | 63743 | 0812-0099 | 1 |
| R80 | var. ww 5kΩ ±20% (Voltmeter Adjust) | 1 | Type 110-F4 | 11236 | 2100-1824 | 1 |
| R81 | fxd, met. film 27.4kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0452 | 1 |
| R85 | fxd, met. film 42.2Ω ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0316 | 1 |
| R86 | var. ww 250Ω ±20% (Ammeter Adjust) | 1 | Type 110-F4 | 11236 | 2100-0439 | 1 |
| R87 | fxd, met. film 1kΩ ±1% 1/8W | | Type CEA T-0 | 07716 | 0757-0280 | 1 |
| R88 | fxd, met. film 196Ω ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0698-3440 | 1 |
| VR1, 2 | Diode, zener 6.2V 250mW | 2 | | 28480 | 1902-1221 | 2 |
| VR3, 4 | Diode, zener 4.32V 1W | 2 | | 28480 | 1902-0797 | 2 |



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| REF. DESIG. | DESCRIPTION | TQ | MFR. PART NO. | MFR. CODE | HP PART NO. | RS |
|---|---|---|---|---|---|---|
| VR5 | Diode, zener 4.22V 400mW | 1 | | 28480 | 1902-3070 | 1 |
| Z1 | Dual Independent Diff. Amp | 1 | CA3026 | 02735 | 1820-0240 | 1 |
| Z2 | Resistor Network | 1 | | 28480 | 1810-0042 | 1 |
| | A3 SLAVE BOARD - ELECTRICAL | | | | | |
| A3 | Printed Circuit Board, Slave | 1 | | 28480 | 06227-60022 | |
| C1 | fxd, elect 1500μF 40Vdc | 1 | | 28480 | 0180-1894 | 1 |
| C2 | fxd, elect 5μF 50Vdc | 1 | 30D505G050BB2 | 56289 | 0180-0301 | 1 |
| C3 | fxd, mylar .01μF 200V | 1 | 192P10392 | 56289 | 0160-0161 | 1 |
| C4 | fxd, mylar .0022μF 200V | 1 | 192P22292 | 56289 | 0160-0154 | 1 |
| C5 | fxd, mylar .22μF 80V | 1 | 192P2249R8 | 56289 | 0160-2453 | 1 |
| C6,7 | fxd, elect 3000μF 40V | 2 | | 28480 | 0180-1899 | 1 |
| C11 | fxd, elect 4.7μF 35Vdc | 1 | 150D475X9035B2 | 56289 | 0180-0100 | 1 |
| C13 | fxd, elect 22μF 35Vdc | 1 | 150D226X0035R2 | 56289 | 0180-0160 | 1 |
| C15 | fxd, mylar .47μF 25V | 1 | 5C11B75 | 56289 | 0160-0174 | 1 |
| CR1 | Diode, Si. 250mW 200V | 5 | | 28480 | 1901-0033 | 5 |
| CR2 | Rect. Si. 3A 200prv | 3 | MR1032B | 04713 | 1901-0416 | 3 |
| CR3 | Diode, Si. 250mA 75V | 1 | | 28480 | 1901-0050 | 1 |
| CR4 | Diode, Si. 400mW 15V | 3 | | 28480 | 1901-0461 | 3 |
| CR5-7 | Diode, Si. 250mW 200V | | | 28480 | 1901-0033 | |
| CR8,9 | Diode, Si. 400mW 15V | | | 28480 | 1901-0461 | |
| CR10 | Diode, Si. 250mW 200V | | | 28480 | 1901-0033 | |
| CR11 | Diode, Si. 400mW 10V | 1 | | 28480 | 1901-0460 | 1 |
| CR12 | Rect. Si. 1A 200prv | 1 | 1N5059 | 03508 | 1901-0327 | 1 |
| CR13,14 | Rect. Si. 3A 200prv | | MR1032B | 04713 | 1901-0416 | |
| F2 | Fuse Cartridge, 3A 250V Normal Blow Pigtail 3AG | 1 | 318003 | 75915 | 2110-0290 | 5 |
| Q1,2, 7-11 | NOT ASSIGNED | - | - | - | - | - |
| Q3 | SS PNP Si. | 3 | | 28480 | 1853-0099 | 3 |
| Q4 | SS NPN Si. | 5 | | 28480 | 1854-0071 | 5 |
| Q5 | SS PNP Si. | | | 28480 | 1853-0099 | |
| Q6,12-14 | SS NPN Si. | | | 28480 | 1854-0071 | |
| Q15 | SS PNP Si. | | | 28480 | 1853-0099 | |
| R1 | fxd, ww 7.5kΩ ±5% 3W | 1 | Type 242E | 56289 | 0811-1815 | 1 |
| R2 | fxd, comp (Selected) ±5% ½W | 2 | Type EB (obd) | 01121 | | |
| R3 | fxd, met. film 1kΩ ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0757-0280 | 1 |
| R5 | fxd, comp 220kΩ ±5% ½W | 1 | EB-2245 | 01121 | 0686-2245 | 1 |
| R6 | fxd, met. film 1.5kΩ ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0757-0427 | 1 |
| R7 | fxd, comp 750kΩ ±5% ½W | 1 | EB-7545 | 01121 | 0686-7545 | 1 |
| R8 | fxd, comp 300Ω ±5% ½W | 2 | EB-3015 | 01121 | 0686-3015 | 1 |
| R9,14,17, 23,27-29, 39,43,47, 49,53-67, 78,79,82, 83 | NOT ASSIGNED | - | - | - | - | - |
| R10,11 | fxd, ww 1Ω ±0.5% 8W | 2 | Type T-7A | 01686 | 0811-2133 | 1 |
| R12 | fxd, comp 3.3Ω ±5% ½W | 2 | EB-0335 | 01121 | 0686-0335 | 1 |
| R13 | fxd, met. film 200kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0472 | 1 |
| R15 | fxd, ww 1.3kΩ ±5% 3W | 1 | Type 242E | 56289 | 0811-1803 | 1 |
| R16 | fxd, comp (Selected) ±5% ½W | | Type EB (obd) | 01121 | | |
| R18,19 | fxd, comp 100Ω ±5% ½W | 3 | EB-1015 | 01121 | 0686-1015 | 1 |
| R20 | fxd, ww 1kΩ ±5% 3W | 1 | Type 242E | 56289 | 0813-0001 | 1 |



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| REF. DESIG. | DESCRIPTION | TQ | MFR. PART NO. | MFR. CODE | HP PART NO. | RS |
|---|---|---|---|---|---|---|
| R21 | fxd, comp 200Ω ±5% ½W | 2 | EB-2015 | 01121 | 0686-2015 | 1 |
| R22 | fxd, comp 24Ω ±5% ½W | 1 | EB-2405 | 01121 | 0686-2405 | 1 |
| R24 | var. comp 25kΩ ±30% (Zero Volt Adj.) | 1 | | 28480 | 2100-1534 | 1 |
| R25 | fxd, met. film 1.5kΩ ±1% 1/8W | | Type CEA T-0 | 07716 | 0757-0427 | |
| R26 | fxd, met. film 249kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0270 | 1 |
| R30 | fxd, met. film 61.9kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0460 | 1 |
| R31 | fxd, met. film 2kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0283 | 1 |
| R32 | fxd, met. film 3.4k. ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0698-4440 | 1 |
| R33 | fxd, comp 100Ω ±5% ½W | | EB-1015 | 01121 | 0686-1015 | |
| R34 | fxd, comp 10kΩ ±5% ½W | 2 | EB-1035 | 01121 | 0686-1035 | 1 |
| R35 | fxd, met. film 6.2kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0698-5087 | 1 |
| R36 | fxd, comp 2kΩ ±5% ½W | 1 | EB-2025 | 01121 | 0686-2025 | 1 |
| R37 | fxd, comp 200Ω ±5% ½W | | EB-2015 | 01121 | 0686-2015 | |
| R38 | fxd, comp 150Ω ±5% ½W | 1 | EB-1515 | 01121 | 0686-1515 | 1 |
| R40 | fxd, met. film 270Ω ±1% ¼W | 1 | Type CEB T-0 | 07716 | 0698-3506 | 1 |
| R41, 42 | fxd, met. film 7.5kΩ ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0757-0440 | 1 |
| R44 | fxd, met. film 600Ω ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-1100 | 1 |
| R45 | fxd, comp 10kΩ ±5% ½W | | EB-1035 | 01121 | 0686-1035 | |
| R46 | fxd, comp 470Ω ±5% ½W | 1 | EB-4715 | 01121 | 0686-4715 | 1 |
| R48 | fxd, met. film 2kΩ ±1% ¼W | 1 | Type CEB T-0 | 07716 | 0757-0739 | 1 |
| R50 | fxd, met. film 5.49kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0698-3382 | 1 |
| R51 | fxd, comp 820Ω ±5% ½W | 1 | EB-8215 | 01121 | 0686-8215 | 1 |
| R52 | fxd, met. film 3.4kΩ ±1% 1/8W | | Type CEA T-0 | 07716 | 0698-4440 | |
| R68, 69 | fxd, ww 0.5Ω ±5% 3W ±20ppm | 4 | | 28480 | 0811-1830 | 1 |
| R70 | fxd, comp 10Ω ±5% ½W | 1 | EB-1005 | 01121 | 0686-1005 | 1 |
| R71 | fxd, comp 51Ω ±5% ½W | 1 | EB-5105 | 01121 | 0686-5105 | 1 |
| R72 | fxd, comp 300Ω ±5% ½W | | EB-3015 | 01121 | 0686-3015 | |
| R73, 74 | fxd, ww 0.5Ω ±5% 3W ±20ppm | | | 28480 | 0811-1830 | |
| R77 | fxd, ww 1kΩ ±5% 5W | 1 | Type 5XM | 63743 | 0812-0099 | 1 |
| R80 | var. ww 5kΩ ±20% (Voltmeter Adj.) | 1 | Type 110-F4 | 11236 | 2100-1824 | 1 |
| R81 | fxd, met. film 27.4kΩ ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0452 | 1 |
| R85 | fxd, met. film 42.2Ω ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0757-0316 | 1 |
| R86 | var. ww 250Ω ±20% (Ammeter Adjust) | 1 | Type 110-F4 | 11236 | 2100-0439 | 1 |
| R87 | fxd, met. film 1kΩ ±1% 1/8W | | Type CEA T-0 | 07716 | 0757-0280 | |
| R88 | fxd, met. film 196Ω ±1% 1/8W | 1 | Type CEA T-0 | 07716 | 0698-3440 | 1 |
| VR1, 2 | Diode, zener 6.2V 250mW | 2 | | 28480 | 1902-1221 | 2 |
| VR3, 4 | Diode, zener 4.32V | 2 | | 28480 | 1902-0797 | 2 |
| VR5 | Diode, zener 4.22V 400mW | 1 | | 28480 | 1902-3070 | 1 |
| Z1 | Dual Independent Diff. Amp. | 1 | CA3026 | 02735 | 1820-0240 | 1 |
| Z2 | Resistor Network | 1 | | 28480 | 1810-0042 | 1 |
| | A4 CROWBAR BOARD - ELECTRICAL | | | | | |
| A4 | Printed Circuit Board, Crowbar | 1 | | 28480 | 06227-60023 | |
| C1A, 1B | fxd, mylar 0.22μF 80Vdc | 2 | 192P2249R8 | 56289 | 0160-2453 | 1 |
| CR1A-3A, 1B-3B | Diode, Si. 200mA 200prv | 6 | | 28480 | 1901-0033 | 6 |
| Q1A, 1B | SS NPN Si. | 2 | | 28480 | 1854-0027 | 2 |
| Q2A, 2B | SS NPN Si. | 2 | 2N3417 | 03508 | 1854-0087 | 2 |
| R1A, 1B | fxd, comp 750Ω ±5% ½W | 2 | EB-7515 | 01121 | 0686-7515 | 1 |
| R2A, 2B | fxd, comp 200kΩ ±5% ½W | 2 | EB-2045 | 01121 | 0686-2045 | 1 |
| R3A, 3B | fxd, comp 10kΩ ±5% ½W | 2 | EB-1035 | 01121 | 0686-1035 | 1 |
| R4A, 4B | fxd, comp 3.9kΩ ±5% ½W | 2 | EB-3925 | 01121 | 0686-3925 | 1 |
| R5A, 5B | fxd, ww 820Ω ±5% 3W | 2 | Type 242E | 56289 | 0813-0010 | 1 |



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| REF. DESIG. | DESCRIPTION | TQ | MFR. PART NO. | MFR. CODE | HP PART NO. | RS |
|---|---|---|---|---|---|---|
| R6A, 6B | fxd, comp 4.7Ω ±5% ½W | 2 | EB-47G5 | 01121 | 0698-0001 | 1 |
| R7A, 7B | fxd, comp 10Ω ±5% ½W | 4 | EB-1005 | 01121 | 0686-1005 | 1 |
| R8A, 8B | fxd, met. oxide 300Ω ±5% 2W | 2 | Type C42S | 16299 | 0698-3630 | 1 |
| R9A, 9B | fxd, met. film 909Ω ±1% 1/8W | 2 | Type CEA T-0 | 07716 | 0757-0422 | 1 |
| R10A, 10B | var. comp 5kΩ ±20% ½W (Crowbar Adjust) | 2 | | 28480 | 2100-0011 | 1 |
| R11A, 11B | fxd, comp 10Ω ±5% ½W | | EB-1005 | 01121 | 0686-1005 | |
| T1A, 1B | Transformer, Pulse | 2 | | 28480 | 9100-2160 | 1 |
| VR1A, 1B | Diode, zener 5.62V 400mW | 2 | | 28480 | 1902-3104 | 2 |
| VR2A, 2B | Diode, zener 12.4V 400mW | 2 | | 28480 | 1902-3185 | 2 |
| | FRONT PANEL - ELECTRICAL | | | | | |
| | Front Panel Assembly (Loaded, excluding M1) | 1 | | 28480 | 06227-60001 | |
| DS1 | Indicator Lamp, Neon (Line On) | 1 | A1C | 08806 | 2140-0047 | 1 |
| E1A, 1B | 5 Way Binding Post, Maroon | 2 | DF21MRN | 58474 | 1510-0040 | 1 |
| E2A, 2B | 5 Way Binding Post, Green | 2 | DF21GNC | 58474 | 1510-0066 | 1 |
| E3A, 3B | 5 Way Binding Post, Black | 2 | DF21BLK | 58474 | 1510-0039 | 1 |
| M1A, 1B | Meter, 0-30V and 0-2.4A | 2 | | 28480 | 1120-1241 | 1 |
| R4A(A), 4B(A); R4A(B), 4B(B) | var. ww 1.1kΩ-10 Dual Concentric, (Current, Fine and Coarse) | 2 | | 28480 | 2100-2942 | 1 |
| R27A(A), 27B(A); R27A(B), 27B(B) | var. ww 5kΩ-50 Dual Concentric, (Voltage, Fine and Coarse) | 2 | | 28480 | 2100-2526 | 1 |
| R89 | fxd, comp 100Ω ±5% ½W | 1 | EB-1015 | 01121 | 0686-1015 | 1 |
| R90 | fxd, comp 47kΩ ±5% ½W | 1 | EB-4735 | 01121 | 0686-4735 | 1 |
| S1 | Switch, Toggle, SPST 15A (Line On) | 1 | | 28480 | 3101-1296 | 1 |
| S2 | Switch, Slide, 4PDT 3A (Mode: Tracking/Independent) | 1 | | 28480 | 3101-1293 | 1 |
| S3A, 3B | Switch, Slide, 3PDT 3A (Meter: Volts/Amperes) | 2 | | 28480 | 3101-1288 | 1 |
| | REAR PANEL - ELECTRICAL | | | | | |
| E4 | 5 Way Binding Post (GND) | 1 | | 28480 | 1510-0044 | 1 |
| F1 (115V) | Fuse Cartridge, 4A 250V 3AG | 1 | 312.004 | 75915 | 2110-0055 | 5 |
| F1 (230V) | Fuse Cartridge, 2A 250V 3AG | 1 | 312.002 | 75915 | 2110-0002 | 5 |
| P1 | Power Cord, AC Line | 1 | KH-4096 | 70903 | 8120-0050 | 1 |
| Q8A-11A, 8B-11B | Power NPN Si. | 8 | | 28480 | 1854-0225 | 6 |
| S5 | Switch, Slide, DPDT (115/230V Line Selector) | 1 | | 28480 | 3101-1234 | 1 |
| | CHASSIS - ELECTRICAL | | | | | |
| CR4A, 4B | SCR, 12.5A 600prv | 2 | 2N3669 | 02735 | 1884-0019 | 2 |
| Q7A, 7B | Power PNP Si. | 2 | | 28480 | 1853-0052 | 2 |



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| REF. DESIG. | DESCRIPTION | TQ | MFR. PART NO. | MFR. CODE | HP PART NO. | RS |
|---|---|---|---|---|---|---|
| | A1, A2, A3, A4 BOARDS - MECHANICAL | | | | | |
| | Hex Nut Bushing | 2 | | 28480 | 2950-0334 | |
| | Bushing | 2 | | 28480 | 1410-0052 | |
| | Barrier Block | 2 | | 28480 | 0360-1573 | |
| | Jumper | 14 | | 82480 | 0360-1143 | |
| | FRONT PANEL - MECHANICAL | | | | | |
| | Meter Trim, Top | 1 | | 28480 | 5020-5770 | |
| | Bezel, Meter, $3\frac{1}{2}$" | 2 | | 28480 | 4040-0483 | 1 |
| | Meter Combining Pin | 1 | | 28480 | 1480-0181 | 1 |
| | Front Panel, Basic | 1 | | 28480 | 5020-5773 | |
| | Front Panel, Control Section Insert | 1 | | 28480 | 5000-6265 | |
| | Front Panel, Output Section Insert | 1 | | 28480 | 5000-6266 | |
| | Corporate Logo | 1 | | 28480 | 7120-1254 | |
| | Knob | 4 | | 28480 | 0370-0179 | 1 |
| | Knob | 4 | | 28480 | 0370-0101 | 1 |
| | Knurled Nut (R4A, R4B, R27A, R27B) | 4 | 76320NP | 73734 | 0590-0856 | 1 |
| | Lampholder, Clear, DS1 | 1 | | 28480 | 5040-0234 | 1 |
| | Lampholder, Base, DS1 | 1 | | 28480 | 5040-0305 | 1 |
| | Stand, Tilt, Foot Assembly | 1 | | 28480 | 1490-0032 | |
| | Hinge, Foot Assembly | 2 | | 28480 | 5040-0700 | |
| | Foot Assembly | 1 | | 28480 | 5060-0728 | |
| | REAR PANEL - MECHANICAL | | | | | |
| | Heat Sink, Rear Panel, Q8-11 (A & B) | 1 | | 28480 | 5020-5774 | |
| | Rear Panel - Lower | 1 | | 28480 | 5000-6264 | |
| | Rear Panel - Upper | 1 | | 28480 | 5000-6263 | |
| | Cover, Rear Barrier Strips | 2 | | 28480 | 5000-6275 | |
| | Shoulder Washer (CR4A, 4B Q7A, 7B) | 8 | | 28480 | 2190-0491 | 6 |
| | Bushing, Insulator (Q7A, 7B) | 2 | | 28480 | 0340-0171 | 2 |
| | Insulator, Mica (Q7A, 7B) | 2 | | 28480 | 0340-0180 | 2 |
| | Insulator, Mica (CR4A, 4B Q8-11A, Q8-11B) | 10 | | 28480 | 0340-0174 | 6 |
| | Serial Plate | 1 | | 28480 | 7120-1111 | |
| | Bushing, Insulator, Emitter-Base, Q8-11 (A & B), CR4A, CR4B | 20 | | 28480 | 0340-0166 | 8 |
| | Bushing, Insulator, Collector Screws, Q8-11 (A & B) | 16 | | 28480 | 0340-0168 | 8 |
| | Fuseholder, F1 | 1 | 342014 | 75915 | 1400-0084 | 1 |
| | Hex Nut, Fuseholder | 1 | | 28480 | 2950-0038 | 1 |
| | Lockwasher, Fuseholder | 1 | | 28480 | 2190-0037 | 1 |
| | Flat Neoprene Washer, Fuseholder | 1 | | 28480 | 1400-0090 | 1 |
| | Spacer | 4 | | 28480 | 0380-0912 | 1 |
| | Strain Relief Bushing | 1 | | 28480 | 0400-0013 | |
| | CHASSIS ASSEMBLY - MECHANICAL | | | | | |
| | Chassis, Center | 1 | | 28480 | 5000-6262 | |
| | Cover, Side | 2 | | 28480 | 5000-6145 | |
| | Cover, Top | 1 | | 28480 | 5060-0724 | |
| | Cover, Bottom | 1 | | 28480 | 5000-6261 | |
| | Fastener, Top and Bottom Covers | 4 | | 28480 | 0590-0052 | |
| | Side Frame Assembly | 2 | | 28480 | 5060-0703 | |
| | Cable Clamp | 4 | | 28480 | 1400-0116 | 1 |
| | Guide, Printed Circuit Boards | 4 | | 28480 | 0403-0150 | |
| | Bracing Rod, Insulated | 1 | | 28480 | 0380-0951 | |



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| REF. DESIG. | DESCRIPTION | TQ | MFR. PART NO. | MFR. CODE | HP PART NO. | RS |
|---|---|---|---|---|---|---|
| | MISCELLANEOUS | | | | | |
| | Manual | 1 | | 28480 | 06227-90001 | |
| | Carton, Packing | 1 | | 28480 | 9211-1183 | |
| | Floater Pad, Packing | 2 | | 28480 | 9220-1404 | |
| | Fuse Envelope, F1 (230V) | 1 | | 28480 | 9320-0234 | |
| | OPTION 007: 10-Turn Voltage Control | | | | | |
| R27(A), 27(B) | var. ww 5kΩ ±5% 2W, 10-Turn | 2 | | 28480 | 2100-1865 | 1 |
| | Knob, Black | 2 | | 28480 | 0370-0846 | 1 |
| | OPTION 008: 10-Turn Current Control | | | | | |
| R4(A), 4(B) | var. ww 1kΩ ±5% 2W, 10-Turn | 2 | | 28480 | 2100-1864 | 1 |
| | Knob, Black | 2 | | 28480 | 0370-0846 | |
| | OPTION 009: 10-Turn Current & Voltage Controls | | | | | |
| R4(A), 4(B) | var. ww 1kΩ ±5% 2W, 10-Turn | 2 | | 28480 | 2100-1864 | 1 |
| R27(A), 27(B) | var. ww 5kΩ ±5% 2W, 10-Turn | 2 | | 28480 | 2100-1865 | 1 |
| | Knob, Black | 4 | | 28480 | 0370-0846 | 1 |
| | OPTION 013: 3 Digit Decadial Voltage Control | | | | | |
| R27(A), 27(B) | var. ww 5kΩ ±5% 2W, 10-Turn | 2 | | 28480 | 2100-1865 | 1 |
| | 3-Digit Decadial | 2 | RD-411 | 07716 | 1140-0020 | 2 |
| | OPTION 014: 3 Digit Decadial Current Control | | | | | |
| R4(A), 4(B) | var. ww 1kΩ ±5% 2W, 10-Turn | 2 | | 28480 | 2100-1864 | 1 |
| | 3-Digit Decadial | 2 | RD-411 | 07716 | 1140-0020 | 2 |



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# SECTION VII
# SCHEMATIC DIAGRAM AND COMPONENT LOCATION DIAGRAMS

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

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

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



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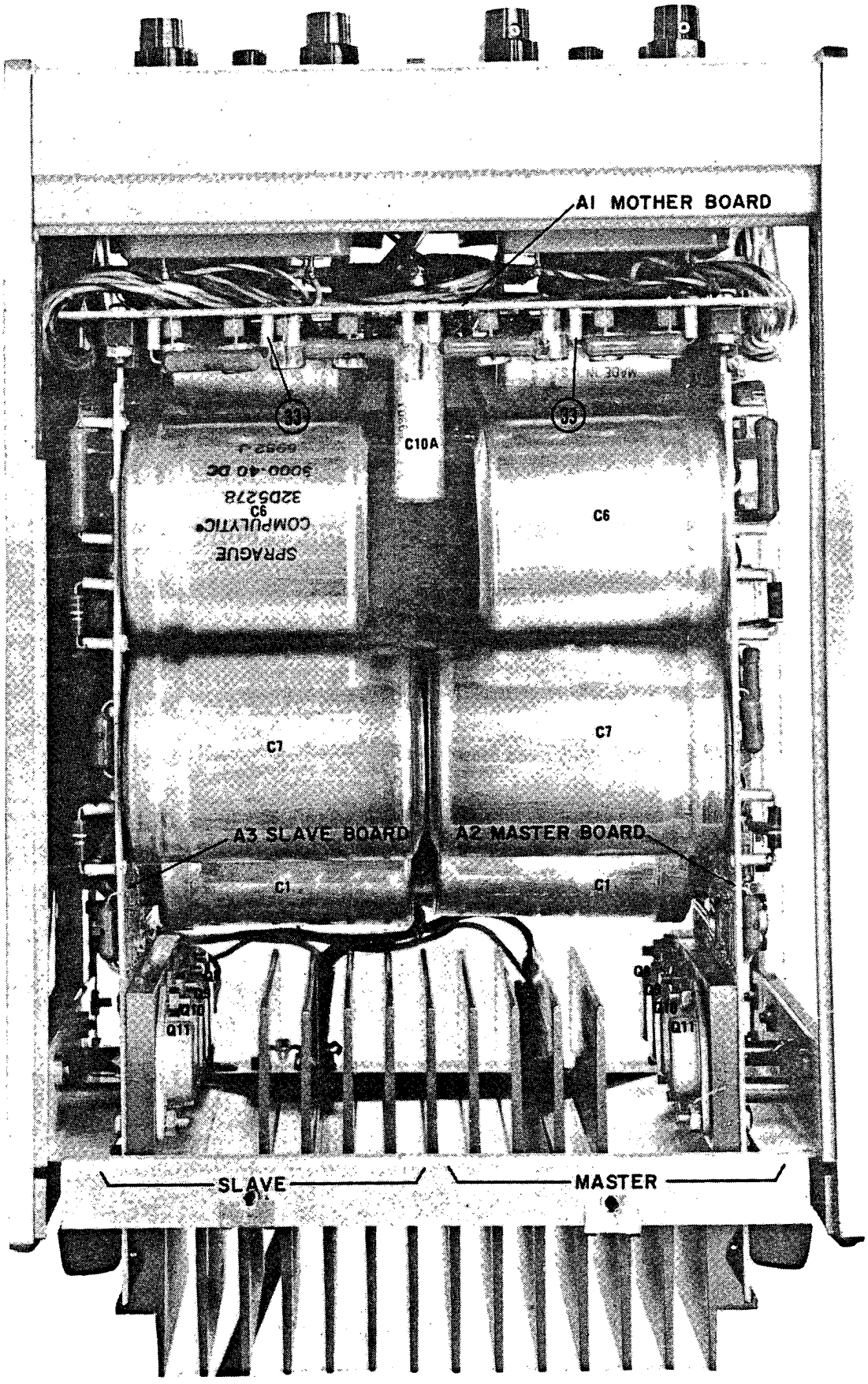



Figure 7-1. Main Chassis Component Location Diagram, Top View



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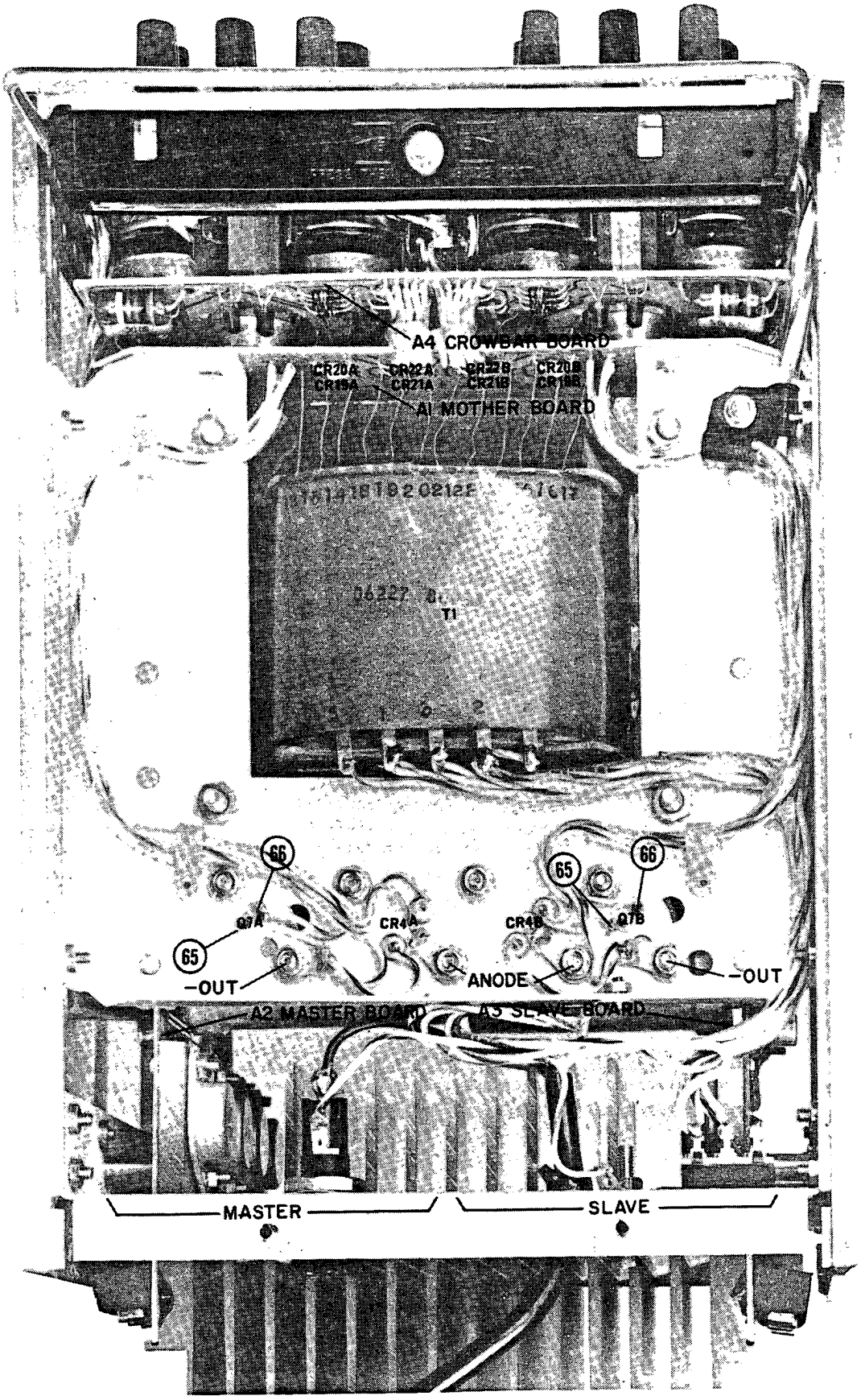



Figure 7-2. Main Chassis Component Location Diagram, Bottom View



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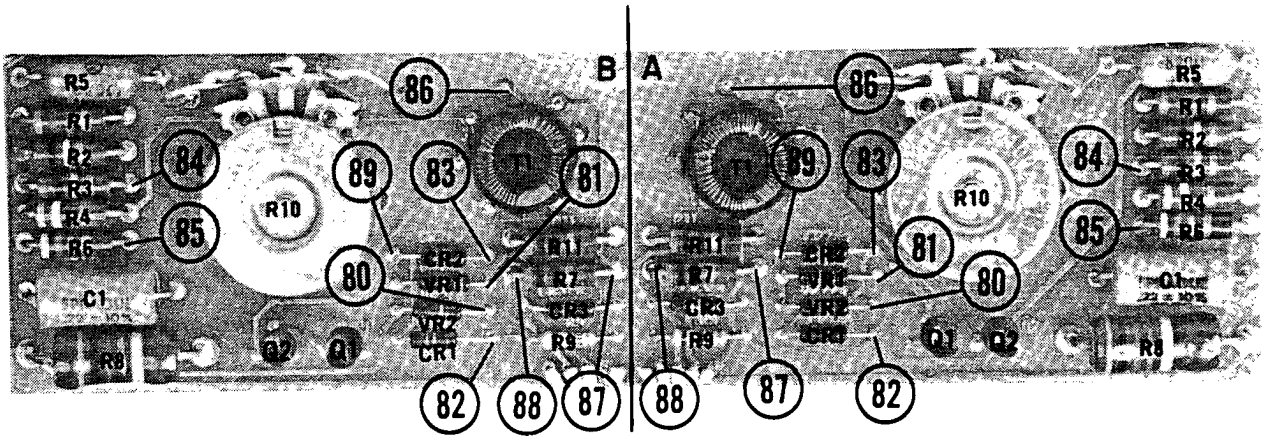



Figure 7-3. A4 Crowbar Printed Circuit Board Component Location Diagram

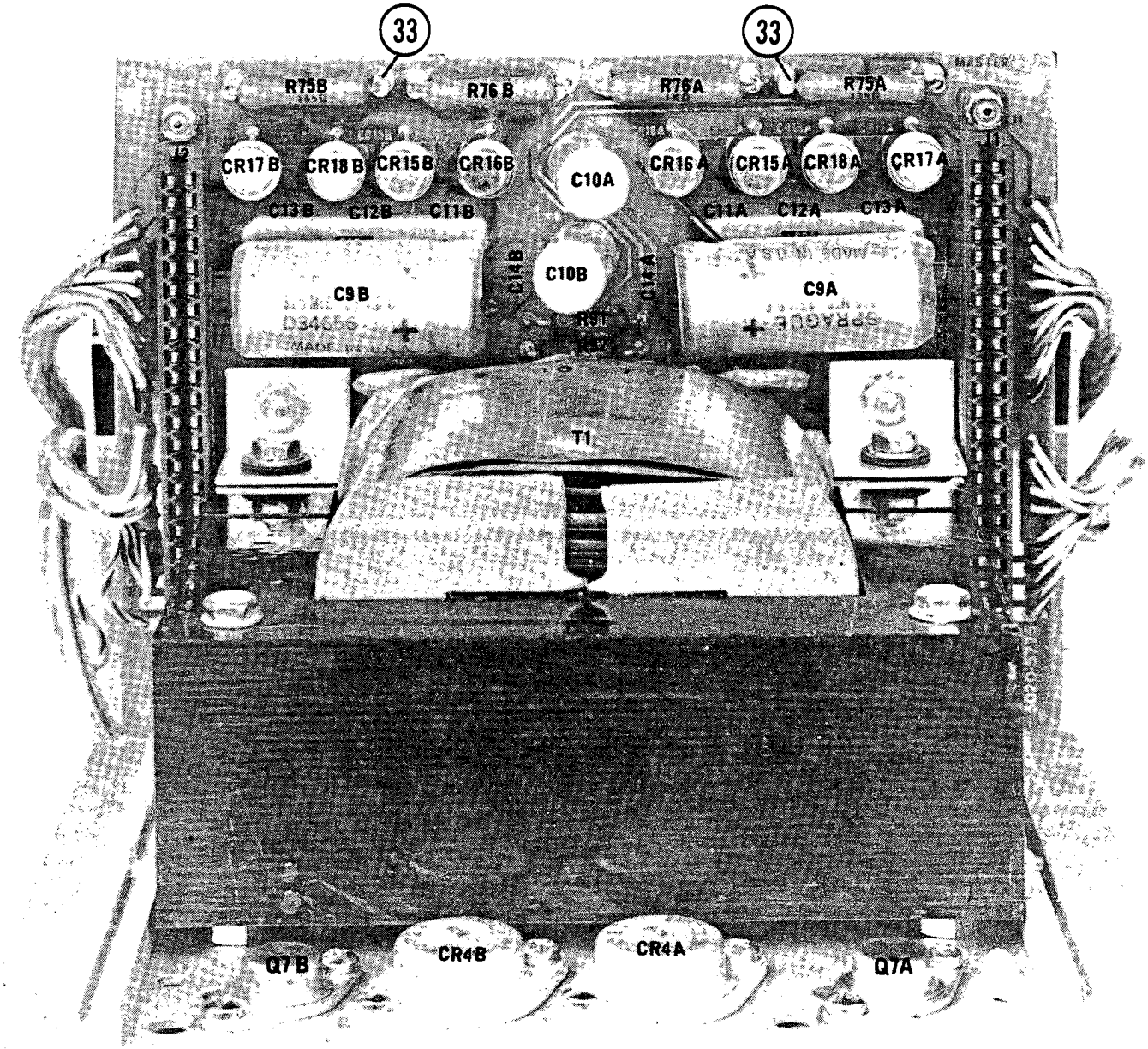
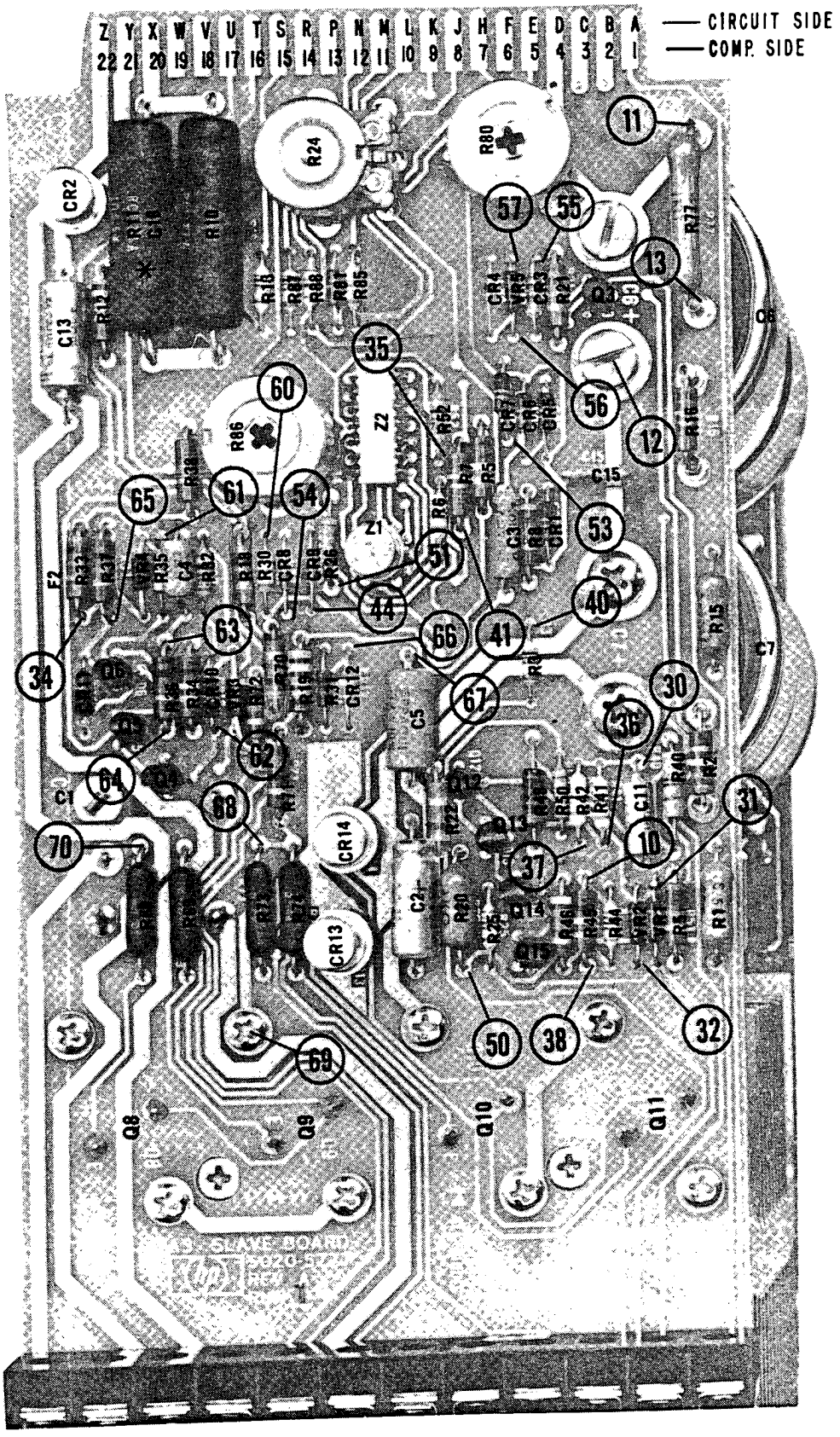



Figure 7-4. A1 Mother Printed Circuit Board Component Location Diagram



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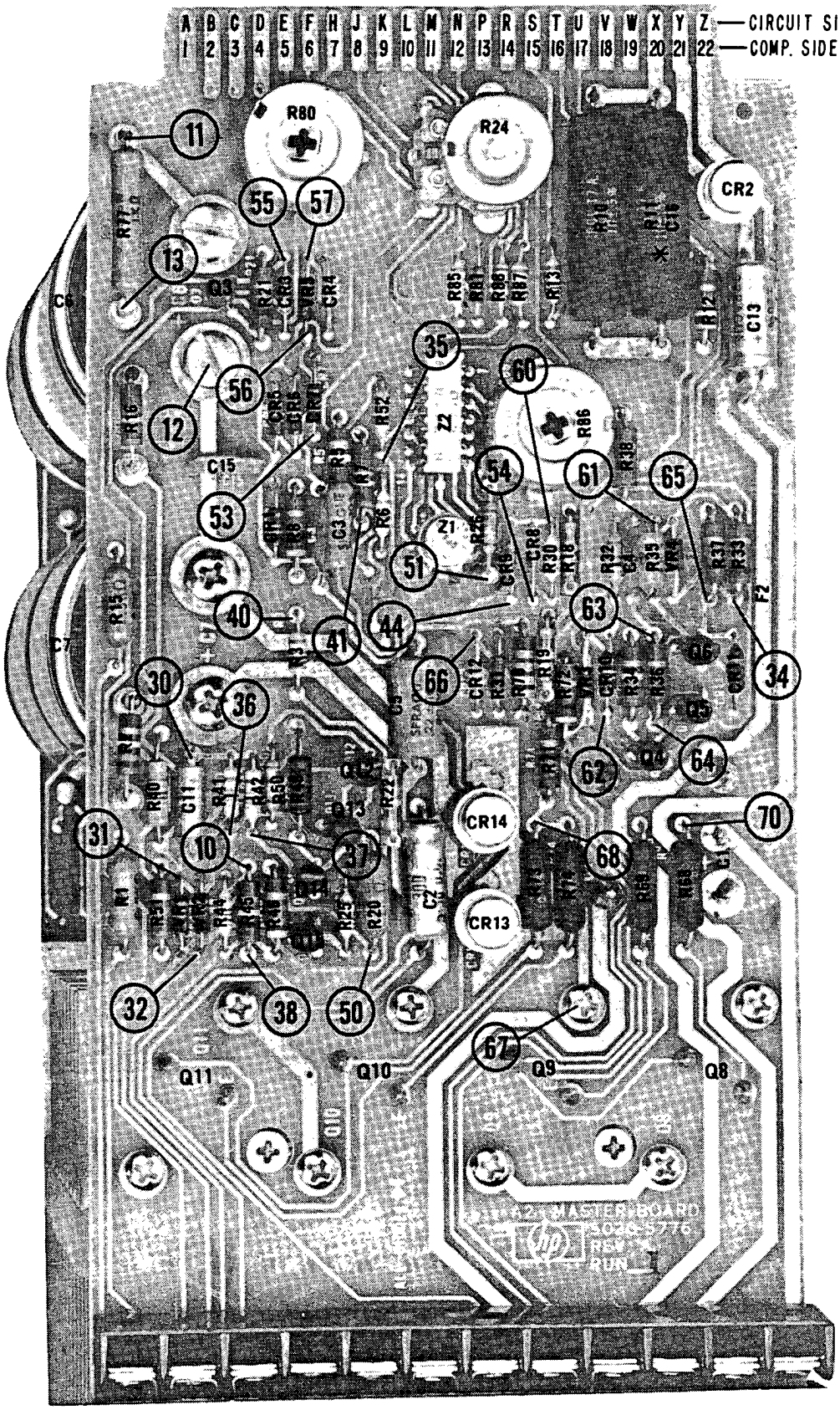



*-NOT USED ON 6228B

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



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* - NOT USED ON 6228B

Figure 7-6. A2 Master Printed Circuit Board Component Location Diagram



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# APPENDIX A
# MANUAL BACKDATING CHANGES

Manual backdating changes describe changes necessary to adapt this manual to earlier instruments. To adapt the manual to serial numbers prior to 1019A00141, inspect the following table for your serial number and then make the appropriate changes. For serial numbers 1019A00141 and up, a change page may be included.

| SERIAL | | MAKE CHANGES |
|---|---|---|
| Prefix | Number | |
| 1019A | 00140 - 00121 | 1 |
| 0B | 00120 - 00101 | 1, 2 |

CHANGE 1: In the replaceable parts list and on the schematic diagram, make the following changes:

CR6: On both the A2 and A3 boards, disconnect anode from junction of CR3 and R20, and connect it instead to junction of CR5 and R20.

R22: Delete on both the A2 and A3 boards.

R70: On both the A2 and A3 boards, change to fxd, comp 3.3Ω, ±5%, ½W, HP Part No. 0686-0335, Mfr. 01121, Mfr. Part No. EB-0335.

R84: On both the A2 and A3 boards, add, thermistor, 64Ω, HP Part No. 0837-0023, connected in parallel with R85 in meter circuit.

CHANGE 2: In the replaceable parts list, make the following change:

Bracing Rod, Insulated: Delete.

Substitute the following for Paragraph 1-16 on Page 1-2:

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. The number designates the year, and the letter A through M designates the month, January through December, respectively, with "I" omitted. The third part is the power supply serial number; a different sequential number is assigned to each power supply.



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