



**PRECISION POWER SUPPLIES
MODELS**

6104A, 6114A, 6105A, 6115A

OPERATING AND SERVICE MANUAL
FOR SERIALS 1209A-00051 AND ABOVE *

*For Serials Above 1209A-00051 a change page may be included.

Hewlett-Packard

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SECTION I GENERAL INFORMATION

1-1 DESCRIPTION

1-2 This instruction manual contains operating and service instructions for four Hewlett-Packard precision power supplies. The four models (designated 6104A, 6105A, 6114A, and 6115A) are ideal for applications requiring an accurate, highly stable, and easily settable source of dc voltage or current. All models are completely solid-state and feature constant voltage/constant current operation, automatic dual-range operation, overvoltage crowbar protection, front-panel voltage and current metering, and provisions for remote voltage and current programming. In addition, all models are capable of auto-series, auto-parallel, and auto-tracking operation. Front-panel mounted controls allow current limit and overvoltage trip points to be conveniently set, while OVERVOLTAGE and CURRENT MODE light emitting diodes indicate when the corresponding condition is in effect.

1-3 Additional features and characteristics applicable to specific models are described in the following paragraphs. Section III of this manual covers the use of all controls and indicators and gives procedures for implementing the various operating modes.

1-4 MODELS 6104A and 6105A

1-5 These models employ individual voltage and current meters, and a 10-turn potentiometer for setting output voltage levels. With the exception of some component values and meter scale markings, the two models are physically identical. For improved settability, an optional three-digit decimal voltage control (option 013) is available.

1-6 Model 6104A Output Ratings. The Model 6104A can be operated in either of two ranges: 0 to 20V at 0 to 2A; or 20 to 40V at 0 to 1A. Automatic voltage range crossover occurs if the load current exceeds approximately 1A and the output voltage has been set above 20V.

1-7 The front panel CURRENT control allows the maximum output current to be set to any desired value from 0 amps up to the maximum current rating for the range. Using this control, the power supply can be operated as a constant current source with 0.01% current regulation. The front panel CURRENT MODE indicator lights when either the maximum (gross) current limit is reached, or when the current limit established by the front panel control is

reached. When the indicator is lighted, the output voltage is uncalibrated. However, the front panel voltmeter continues to indicate the output voltage with an accuracy of 2%.

1-8 Model 6105A Output Ratings. The Model 6105A can be operated in either of two ranges: 0 to 50V at 0 to 0.8A; or 50 to 100V at 0 to 0.4A. Automatic voltage range crossover occurs if the load current exceeds approximately 0.4A and the output voltage has been set above 50V.

1-9 The Model 6105A can also be used as a current source, as described in paragraph 1-7.

1-10 MODELS 6114A and 6115A

1-11 These models make use of a front-panel mounted four-digit pushbutton control to increase and decrease output voltage in unit steps. A thumbwheel control is used to set the fifth (or least significant) digit for output voltage accuracy in the fractional millivolt range. A single meter, combining both voltage and current functions, is also located on the front panel. A METER slide switch selects the function to be indicated on the meter. With the exception of some component values and meter scale markings, the 6114A and 6115A are physically identical.

1-12 Model 6114A Output Ratings. The Model 6114A can be operated in either of two ranges: 0 to 20V at 0 to 2A; or 20 to 40V at 0 to 1A. Automatic voltage range crossover occurs if the load current exceeds approximately 1A and the output voltage has been set above 20V.

1-13 The Model 6114A can also be used as a current source, as described in paragraph 1-7.

1-14 Model 6115A Output Ratings. The Model 6115A can be operated in either of two ranges: 0 to 50V at 0 to 0.8A; or 50 to 100V at 0 to 0.4A. Automatic voltage range crossover occurs if the load current exceeds approximately 0.4A and the output voltage has been set above 50V.

1-15 The Model 6115A can also be used as a current source, as described in paragraph 1-7.

1-16 SPECIFICATIONS

1-17 Detailed specifications for all four models are given in Table 1-1.

Table 1-1. Specifications, Models 6104A, 6105A, 6114A, 6115A

<p style="text-align: center;">NOTE</p> <p>Specifications apply to all models, unless otherwise indicated.</p> <hr/> <p style="text-align: center;">GENERAL</p> <hr/> <p>INPUT POWER: 104-127 Vac, 48-440Hz, 150VA maximum (Standard) 208-254 Vac, 48-440Hz, 150VA maximum (Switch Selected)</p> <p>DC OUTPUT: Single output, dual range with automatic cross-over between ranges. <u>Models 6104A & 6114A:</u> 0-20V, 2A/20-40V, 1A <u>Models 6105A & 6115A:</u> 0-50V, 0.8A/50-100V, 0.4A</p> <p>METERS: <u>Models 6104A and 6105A:</u> Individual voltage and current meters, with $\pm 2\%$ full scale accuracy. <u>Models 6114A and 6115A:</u> Single, dual-function (voltage and current) meter, with $\pm 2\%$ full scale accuracy.</p> <p>TEMPERATURE RATINGS: Operating: 0 to 55°C. Storage: -40 to +75°C.</p> <p>COOLING: Convection cooling is employed. The supplies have no moving parts.</p> <p>DIMENSIONS: See outline diagram, Figure 2-1.</p> <p>WEIGHT: 17 lbs. (7,7kg.) net. 21 lbs. (9,5kg.) shipping.</p> <hr/> <p style="text-align: center;">CONSTANT VOLTAGE OUTPUT</p> <hr/> <p>LOAD REGULATION: For load current change equal to current rating of supply (measured at rear terminals). <u>Models 6104A & 6114A:</u> 0.0005% + 100μV <u>Models 6105A & 6115A:</u> 0.0005% + 50μV</p> <p>LINE REGULATION: For a $\pm 10\%$ change in line voltage from nominal value (115 Vac or 230 Vac). <u>Models 6104A & 6114A:</u> 0.0005% + 40μV <u>Models 6105A & 6115A:</u> 0.0005% + 100μV</p> <p>RIPPLE AND NOISE: 40μVrms/100μV p-p (up to 20MHz) at any line voltage and under any load condition within rating.</p>	<p>TEMPERATURE COEFFICIENT: Output voltage change per degree Centigrade change in ambient following 30-minute warm up. <u>Model 6104A:</u> 0.005% + 25μV <u>Model 6105A:</u> 0.005% + 50μV <u>Model 6114A:</u> 0.001% + 15μV <u>Model 6115A:</u> 0.001% + 15μV</p> <p>DRIFT: Total voltage drift over 8-hour interval under constant line, load, and ambient following a 30-minute warm up. Conditions must be held constant during warm up. <u>Models 6104A & 6105A:</u> 0.005% + 50μV ** <u>Models 6114A & 6115A:</u> 0.0015% + 15μV *</p> <p>TRANSIENT RECOVERY TIME: Less than 50μsec is required for output voltage recovery to within 10mV of the nominal output voltage following a change in output current equal to the current rating of the supply.</p> <p>OUTPUT IMPEDANCE (typical): Equivalent to a .05mΩ resistor in series with a 3μH inductor.</p> <p>RESOLUTION: Minimum output voltage change obtainable using front panel voltage controls. <u>Model 6104A:</u> 8mV <u>Model 6114A:</u> 200μV <u>Model 6105A:</u> 16mV <u>Model 6115A:</u> 200μV</p> <p>OUTPUT VOLTAGE ACCURACY: 0.025% + 1mV, at 23°C \pm 3°C, at any line vol. and load cur. within rating, after 5-min. warm up.</p> <p>REMOTE RESISTANCE PROGRAMMING: 2000Ω/V \pm 0.01% Programming Coefficient.</p> <p>REMOTE VOLTAGE PROGRAMMING: Programming Coefficient: 1V/V Programming Accuracy: Accuracy of remote source, \pm 0.2mV</p> <p>REMOTE PROGRAMMING SPEED: The maximum time required to non-repetitively program from 0V to within 99.9% of the maximum rated output voltage (up programming), or from the maximum rated output voltage to within 0.1% of that voltage above 0V (down programming).</p> <table style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th style="text-align: center;"><u>6104A/6114A</u></th> <th style="text-align: center;"><u>6105A/6115A</u></th> </tr> </thead> <tbody> <tr> <td>up prog.</td> <td>60msec (no load) 30msec (full load)</td> <td>150msec (no load) 75msec (full load)</td> </tr> <tr> <td>down prog.</td> <td>600msec (no load) 30msec (full load)</td> <td>1.5sec (no load) 75msec (full load)</td> </tr> </tbody> </table>		<u>6104A/6114A</u>	<u>6105A/6115A</u>	up prog.	60msec (no load) 30msec (full load)	150msec (no load) 75msec (full load)	down prog.	600msec (no load) 30msec (full load)	1.5sec (no load) 75msec (full load)
	<u>6104A/6114A</u>	<u>6105A/6115A</u>								
up prog.	60msec (no load) 30msec (full load)	150msec (no load) 75msec (full load)								
down prog.	600msec (no load) 30msec (full load)	1.5sec (no load) 75msec (full load)								

Table 1-1. Specifications, Models 6104A, 6105A, 6114A, 6115A (continued)

<p>OVERVOLTAGE CROWBAR PROTECTION: Trip Voltage Range (approximate): 0.5V to 10% above rated output voltage of supply. Margin: Minimum 2% + 0.5V above output voltage to prevent false activation.</p> <p>DC OUTPUT ISOLATION: Supply may be floated at up to 300V above ground.</p> <hr/> <p style="text-align: center;">CONSTANT CURRENT OUTPUT</p> <hr/> <p>LOAD REGULATION: 0.01% + 500μA for load voltage change equal to the voltage rating of the supply.</p> <p>LINE REGULATION: For a \pm10% change in line voltage from nominal value (115 Vac or 230 Vac). <u>Models 6104A & 6114A:</u> 0.005% + 40μA <u>Models 6105A & 6115A:</u> 0.005% + 20μA</p> <p>RIPPLE AND NOISE: 200μA rms/lmA p-p at any line voltage and under any load condition within rating.</p>	<p>TEMPERATURE COEFFICIENT: Output change per degree Centigrade change in ambient following 30-minute warm up. <u>Models 6104A & 6114A:</u> 0.02% + 50μA <u>Models 6105A & 6115A:</u> 0.02% + 25μA</p> <p>DRIFT: Total current drift in output over 8-hour interval under constant line, load, and ambient following 30-minute warm up. Conditions must be held constant during warm up. <u>Models 6104A & 6114A:</u> 0.25% + 7mA ‡ <u>Models 6105A & 6115A:</u> 0.25% + 4mA ‡</p> <p>RESOLUTION: Minimum output current change obtainable using front panel current control. <u>Models 6104A & 6114A:</u> 15mA <u>Models 6105A & 6115A:</u> 8mA</p> <p>REMOTE RESISTANCE PROGRAMMING: <u>Models 6104A & 6114A:</u> 500Ω/A \pm 0.5% <u>Models 6105A & 6115A:</u> 1000Ω/A \pm 0.25%</p> <p>REMOTE VOLTAGE PROGRAMMING: <u>Models 6104A & 6114A:</u> 0.5V/A \pm 1% <u>Models 6105A & 6115A:</u> 1V/A \pm 1%</p>
<p>* Specified with final decade potentiometer set to zero. If potentiometer is set to value other than zero thermally induced resistance shifts may cause drift of 0.0015% + 200μV.</p> <p>** Potentiometer wiper jump effect may add 5mV (6104A) or 10mV (6105A). When remote programmed, drift is 0.001% + 15μV plus stability of remote programming device.</p> <p>‡ When remote programmed, drift is 0.25% + 500μA plus stability of remote programming device.</p>	

1-18 OPTIONS

1-19 Options are customer-requested factory modifications of a standard instrument. All of the options described below apply to Models 6104A and 6105A. All except option 013 apply to Models 6114A and 6115A.

<u>Option No.</u>	<u>Description</u>
008	<u>Ten-turn Output Current Control:</u> Replaces standard single-turn current control to allow greater resolution in setting the output current of supply.
013	<u>Three Digit Graduated Decadial Voltage Control:</u> Replaces standard 10-turn voltage control of Models 6104A and 6105A for improved output voltage settability.

<u>Option No.</u>	<u>Description</u>
014	<u>Three Digit Graduated Decadial Current Control:</u> Includes 10-turn control, replacing standard single-turn current control for greater resolution in setting the output current of supply.
040	<u>Interfacing for Multiprogrammer Operation:</u> Prepares standard HP power supplies for resistance programming by the 6940A Multiprogrammer or 6941A Multiprogrammer Extender. Operation with either of these instruments requires that the power supply be subjected to (1) Special Calibration, and (2) Protection Checkout. The former procedure insures that the power supply can be accurately set to zero and

the maximum rated output voltage or current when programmed by the Multiprogrammer; the latter procedure insures that the power supply will not be damaged by the rapid, repetitive programming possible with the Multiprogrammer.

1-20 ACCESSORIES

1-21 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).

<u>HP Part No.</u>	<u>Description</u>
5060-8762	Dual Rack Adapter: Kit for rack mounting one or two supplies in standard 19-inch rack.
5060-8760	Blank Panel: Filler panel to block unused half of rack when mounting only one supply.
1052A	Combining Case for mounting one or two units in standard 19" rack.
5060-0789	Cooling kit for above combining case, 115Vac, 50-60Hz.
5060-0796	Cooling kit for above combining case, 230Vac, 50-60Hz.

1-22 INSTRUMENT IDENTIFICATION

1-23 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 (12 = 1972, 13 = 1973, 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.

1-24 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.

1-25 ORDERING ADDITIONAL MANUALS

1-26 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.

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 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 Models 6104A, 6105A, 6114A, and 6115A.

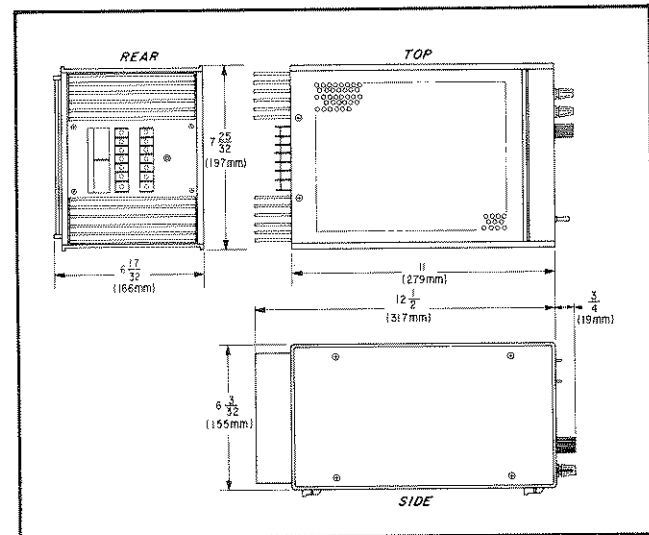


Figure 2-1. Outline Diagram

2-15 RACK MOUNTING

2-16 The Model 6104A, 6105A, 6114A, and 6115A power supplies may be rack mounted using either the dual rack adapter kit or the combining case (with appropriate cooling kit) described in paragraph 1-20. The necessary installation instructions are provided with the accessories.

2-17 INPUT POWER REQUIREMENTS

2-18 Models 6104A, 6105A, 6114A, and 6115A may be operated continuously from either a nominal 120 volt or 240 volt, 48-440Hz power source. A two-position selector switch (⬆) located within the a-c power module on the rear panel selects the power source. Before connecting the instrument to

the power source, check that the selector switch setting matches the nominal line voltage of the source. If required, move the switch to the other position. Note that the power cable must be removed, the plastic door on the power module must be moved aside, the fuse extractor must be pulled outward and the fuse must be removed in order to gain access to the selector switch.

2-19 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. Make sure that the correct fuse is installed if the position of the slide switch is changed (2A for 115 volt operation, and 1A for 230 volt operation).

2-20 POWER CABLE

2-21 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.

2-22 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.

SECTION III OPERATING INSTRUCTIONS

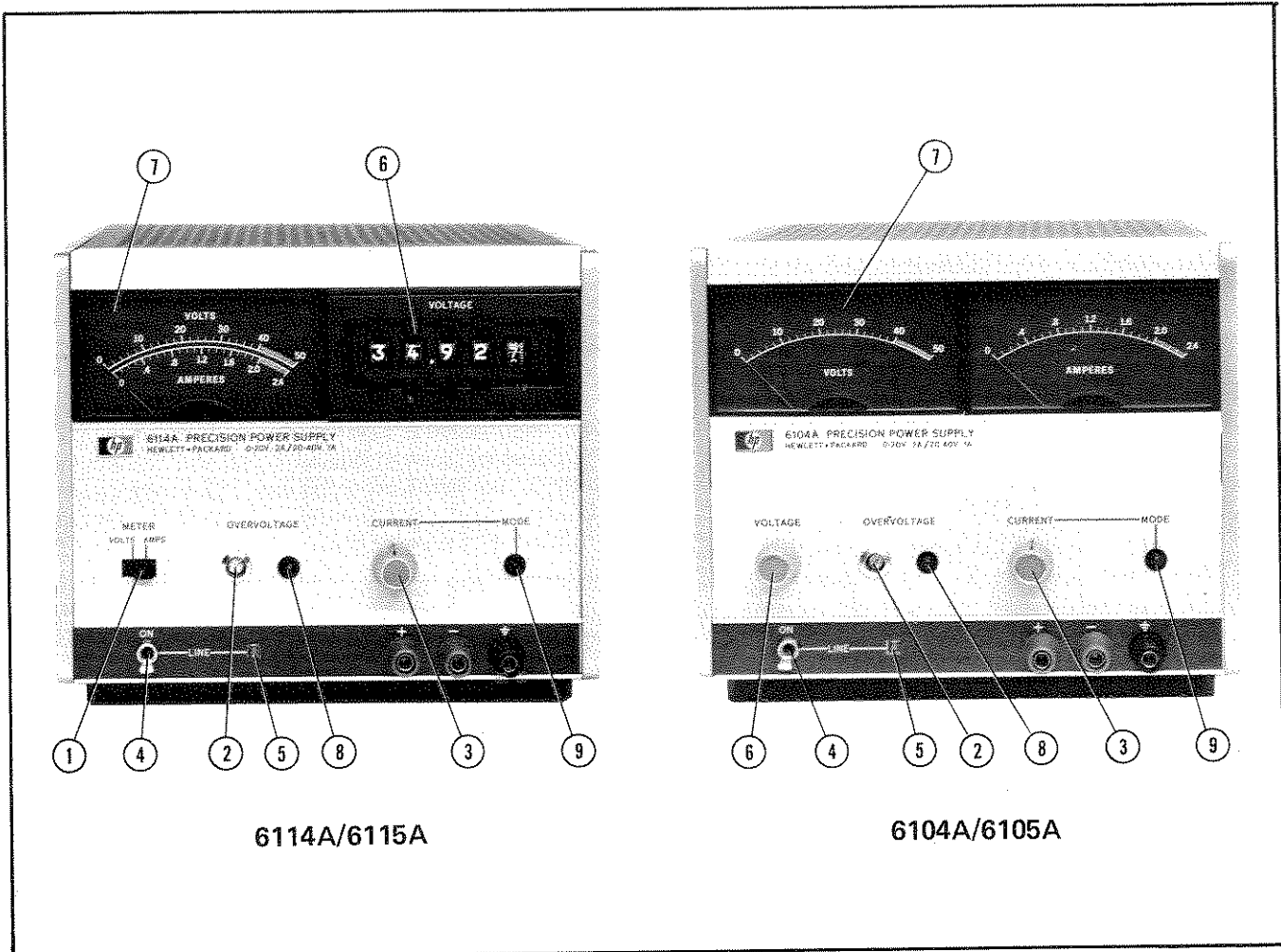


Figure 3-1. Operating Controls and Indicators

3-1 TURN-ON CHECKOUT PROCEDURES

3-2 The following checkout procedure describes the use of the front panel controls and indicators (Figure 3-1) for either the dual meter, ten-turn VOLTAGE control supplies (the 6104A or 6105A) or the single meter, pushbutton VOLTAGE control supplies (the 6114A or 6115A). The checkout procedures ensure that the power supply is operational.

- a. For the 6114A/6115A, set meter switch ① to VOLTS (there is no meter switch on the 6104A or 6105A).
- b. Rotate OVERVOLTAGE (crowbar) control ② (screwdriver adjust) fully clockwise; and rotate CURRENT control ③ to middle of range.

c. Set LINE switch ④ to ON and observe that indicator ⑤ lights.

d. Adjust VOLTAGE control ⑥ through the entire output voltage range as indicated on meter.

⑦ Adjust output for desired operating voltage.

NOTE

To increase the 6114A/6115A output voltage, depress the pushbutton switch above the associated digit. To decrease the voltage, depress the pushbutton switch below the associated digit. Fine output voltage adjustment is provided by the millivolt digit thumbwheel potentiometer.

e. To ensure that the overvoltage crowbar circuit is operational, rotate the OVERVOLTAGE control counterclockwise until the supply crowbars. Output voltage will fall to approximately one volt and the OVERVOLTAGE and CURRENT MODE indicators (⑧ and ⑨ , respectively) will light.

f. To deactivate the crowbar, return the OVERVOLTAGE control to maximum clockwise position and turn off supply. Turn supply back on and output voltage should again be value obtained in step (d).

g. To checkout the constant current circuit, first turn off supply. Short circuit front panel output terminals (+ to -). On the 6114A or 6115A supplies set meter switch to AMPS. Turn on the supply; CURRENT MODE indicator ⑨ comes on.

h. Adjust CURRENT control through the entire output current range as indicated on meter. Adjust output for desired operating current.

i. Remove short and connect load to output terminals. Note that for maximum load protection by the crowbar, the load should be connected to the rear terminals.

NOTE

The power supply features automatic dual-range operation. If operating voltage and current are both set above the mid-points of supply's voltage and current ratings, the supply will gross current limit if current attempts to exceed one-half the maximum current rating of the supply. If output current increases further, the supply enters the constant current mode in which output voltage is reduced in order to supply the desired current. The VOLTAGE control setting, therefore, is overridden. See paragraph 3-65 for more details.

3-3 OPERATING MODES

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

3-5 NORMAL OPERATING MODE

3-6 The power supply is normally shipped with its rear terminal strapping connections arranged for constant Voltage/Constant Current, local sensing, local programming, single unit mode of operation. This strapping pattern is illustrated in Figure 3-2.

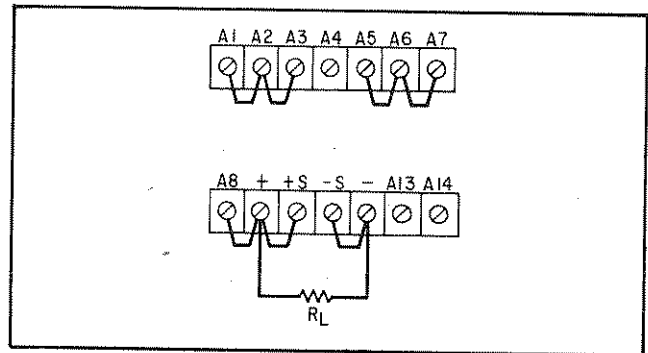


Figure 3-2. Normal Strapping Pattern

3-7 The operator selects either a constant voltage or a constant current output using the front panel controls (for local programming, no strapping changes are necessary). Each supply is rated for two voltage and current ranges as follows:

Model	Low Range		High Range	
	Voltage	Current	Voltage	Current
6104A/6114A	0-20V	0-2A	20-40V	0-1A
6105A/6115A	0-50V	0-.8A	50-100V	0-.4A

When the VOLTAGE and CURRENT settings are within the specified ranges, the constant voltage and constant current modes of operation are selected as described below. If, however, VOLTAGE and CURRENT settings are required that are outside of the specified ranges for normal operation (for instance, the 6104A is set for 30V and 1.5A), the power supply provides automatic dual-range switching if output current attempts to exceed the low range current rating. As current is limited (to approximately 65% of the maximum, low range, rating at nominal line voltage), the VOLTAGE setting is overridden and output voltage is reduced to the low range (approximately 65% of the maximum, high range, voltage rating at nominal line voltage). The supply next enters the constant current mode during which output voltage is reduced in order to supply the desired current. Refer to paragraph 3-65 for more information on how the supply operates to gross current limit and automatically switch ranges.

3-8 CONSTANT VOLTAGE

3-9 To select a constant voltage output, within the normal range ratings of the supply, proceed as follows:

a. Remove load from output terminals; turn-on supply and adjust VOLTAGE control for desired

output voltage.

b. Short output terminals and adjust CURRENT control for maximum output current allowable (current limit) as determined by load conditions and voltage range selected in step (a). If a load change attempts to cause the output current to exceed this setting, the power supply will automatically crossover to constant current mode and output current will be constant at the level set by the CURRENT control. The CURRENT MODE indicator will come on and output voltage will drop proportionately to maintain constant current. In setting the CURRENT control, allowance must be made for high peak current which can cause unwanted cross-over (refer to paragraph 3-56). As discussed above, however, if voltage is set too high with respect to current, the supply will gross current limit and override the VOLTAGE setting, see paragraph 3-65.

3-10 CONSTANT CURRENT

3-11 To select a constant current output, within the normal range ratings of the supply, proceed as follows:

- a. Short output terminals and adjust CURRENT control for desired output current.
- b. Open output terminals and adjust VOLTAGE controls for maximum output voltage allowable (voltage limit) as determined by load conditions and current selected in step (a). If a load change causes the voltage setting to be exceeded, the power supply will automatically crossover to constant voltage output at the voltage setting and output current will drop proportionately. As discussed above, however, if voltage is set too high with respect to current, the supply will gross current limit and override the VOLTAGE setting, see paragraph 3-65. In setting the voltage limit, allowance must be made for high peak voltages which can cause unwanted crossover (refer to paragraph 3-56).

3-12 OVERVOLTAGE CROWBAR OPERATION

3-13 Trip Point Adjustment. The crowbar trip voltage can be adjusted using the OVERVOLTAGE screwdriver control on the front panel. The trip voltage range of the crowbar is approximately 0.5 to 45Vdc for the 6104A and 6114A supplies and 0.5 to 110Vdc for the 6105A and 6115A supplies. To set the crowbar trip voltage, perform the following procedures:

NOTE

Do not connect a load to the power supply when setting the crowbar trip voltage.

- a. Turn OVERVOLTAGE control fully clockwise and turn-on supply.
- b. Set output voltage to desired trip voltage. If the desired trip voltage is above 40 volts for the

6114A or 100 volts for the 6115A, perform the next step. If the desired trip setting is within the maximum voltage rating of the 6114A or 6115A supplies or in order to set the trip voltage for the 6104A and 6105A supplies, go on to step (d).

c. If the output of the 6114A or 6115A cannot be set to the desired crowbar trip voltage:

1. Turn off the supply.
2. Disconnect the voltage programming pushbutton switch assembly (two wires connect the switch assembly to Main Power Supply Board A1).
3. Temporarily connect an external resistor (5%, 1/2W) in place of the voltage programming resistor according to the following formula:

$$E_{OUT} = .5mA \times R$$

Where: E_{OUT} is the desired output voltage;

.5mA is the voltage programming current; &

R is the external resistor.

For example, connect a 90K Ω , 5%, 1/2W resistor if the 6114A is to be set to 45V or a 220K Ω , 5%, 1/2W resistor if the 6115A is to be set to 110V.

4. Turn on the supply, the output will be the desired output voltage.

NOTE

The output voltage can be set above the recommended ranges but the crowbar trip voltage may not be adjustable above the recommended ranges.

d. Slowly turn the OVERVOLTAGE control counterclockwise until the crowbar trips: output falls towards 0 volt and OVERVOLTAGE indicator comes on.

e. The crowbar remains activated and the output shorted until the supply is turned off. To reset the crowbar, turn the supply off. If necessary, before turning the supply back on, remove the external resistor installed in step (c) and replace the voltage programming pushbutton switch assembly connections to the A1 board. Next, set output voltage to zero. Turn supply back on and set it to desired output voltage (see next paragraph for an important operating consideration).

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, a transient in the output or load can falsely trip the crowbar. It is recommended that the crowbar trip voltage be set higher than the operating output voltage by 2% + 0.5V. For example, the crowbar should be set to trip at a minimum of 31.1Vdc if the output voltage is set to 30Vdc. This operating margin, of course, is not possible if the crowbar is set to trip at or near its lower limit.

3-15 Resetting Crowbar. If the crowbar trips during normal operation (supply output goes to near

zero and OVERVOLTAGE indicator comes on), turn off the supply and then disconnect any load from the power supply. Turn the supply back on and determine if the crowbar again trips. If it does, there is a problem in the power supply. Refer to Section V for troubleshooting procedures that can be used to isolate the cause of the overvoltage condition. If the supply does not crowbar when the load is removed, check the load circuit or the trip point setting.

3-16 Crowbar Terminals. Terminals A13 and A14 at the rear of the supply allow the crowbar trigger to be either monitored by an external circuit or to be used to trip crowbar circuits in other precision power supplies (by interconnecting the A13 and A14 terminals). If precision power supply crowbars are to be interconnected, be sure that all A13 terminals (the positive terminal) are connected and all A14 terminals are connected (see figures 3-9 through 3-11). The crowbar trigger pulse specifications are given below and assume that no supplies are interconnected:

Input Trigger Pulse:

Voltage: 3V minimum, 10V maximum

Width: (between 90% point at leading edge and 90% point at falling edge): 10 μ sec minimum.

Output Pulse:

Voltage: 5 \pm 1V

Rise and Fall Time (between 10% and 90% points): 200nsec.

Width: 15 \pm 3 μ sec.

Load Impedance: 10 Ω (min.)

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 3-36)

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, re-

gardless 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 NORMAL RATED OUTPUT

3-22 The shaded area on the front panel meter face(s) indicates the amount of output voltage or current that may be available in excess of the normal rated outputs (each supply is rated for two voltage/current ranges). Although the supply can be operated in this shaded region without being damaged, it cannot be guaranteed to meet all of its performance specifications. Generally, when operating the supply in this manner, the output is unstable when a load is connected. However, if the line voltage is maintained above its nominal value, the supply will probably operate within the specifications above the rated output. In addition, the supply may be operated slightly above (approximately 130% at nominal line voltage) the voltage/current range specifications (i.e. at about 1.3A up to 40V for the 6104A/6114A or at about 0.52A up to 100V for the 6105A/6115A; or at 2A up to 26V for the 6104A/6114A or .8A up to 65V for the 6105A/6115A). In these operating regions, however, the supply is in gross current limit and certain power supply specifications (such as ripple, etc.) are degraded.

3-23 REMOTE PROGRAMMING, CONSTANT VOLTAGE

3-24 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. The front panel VOLTAGE control is automatically disabled in the following procedures.

3-25 Resistance Programming (Figure 3-3). In this mode, the output voltage will vary at a rate determined by the programming coefficient — 2000 ohms.

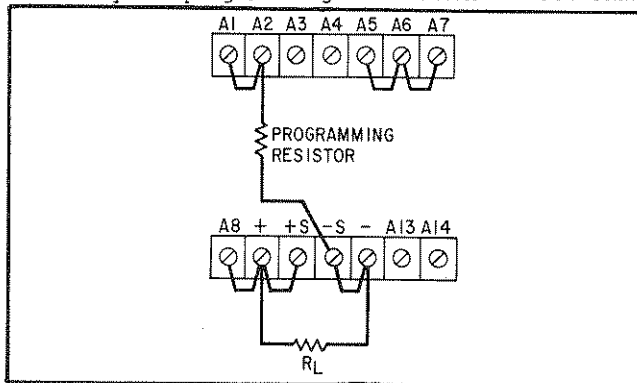


Figure 3-3. Remote Resistance Programming (Constant Voltage)

per Volt (i.e. the output voltage will increase 1 Volt for each 2000 ohms added in series with the programming terminals). The programming accuracy is .01% of the programmed value.

3-26 The output voltage of the power supply should be zero Volts ± 1 millivolt when zero ohms is connected across the programming terminals. The output voltage may be adjusted closer to zero by adjusting potentiometer A2R13 as described in paragraph 5-91.

3-27 To maintain the stability and temperature coefficient of the power supply, use programming resistors that have stable, low noise, and low temperature (at least less than 5ppm per degree centigrade, but preferably 2ppm resistors) characteristics. A switch can be used in conjunction with various resistance values in order to obtain discrete output voltages. The switch should have make-before-break contacts to avoid momentarily opening the programming terminals during the switching interval.

3-28 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 $1\mu\text{A}$. Impedance matching resistor (R_X) is required to maintain the temperature coefficient and stability specifications of the supply.

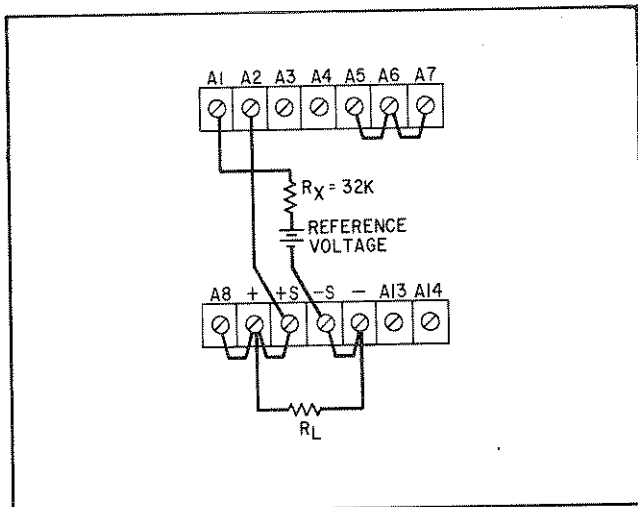


Figure 3-4. Remote Voltage Programming, Constant Voltage

3-29 REMOTE PROGRAMMING, CONSTANT CURRENT

3-30 Either a resistance or a voltage source can be used to control the constant current output of the supply. The CURRENT control on the front panel is automatically disabled in the following procedures.

3-31 Resistance Programming (Figure 3-5). In this mode, the output current varies at a rate determined by the programming coefficient as follows:

Model	Programming Coefficient
6104A/6114A	500 ohms/ampere
6105A/6115A	1,000 ohms/ampere

The programming accuracy is 0.25% of the programmed value. The output current of the supply when zero ohms is placed across the programming terminals may be set to zero by adjusting A2R12 as discussed in paragraph 5-95.

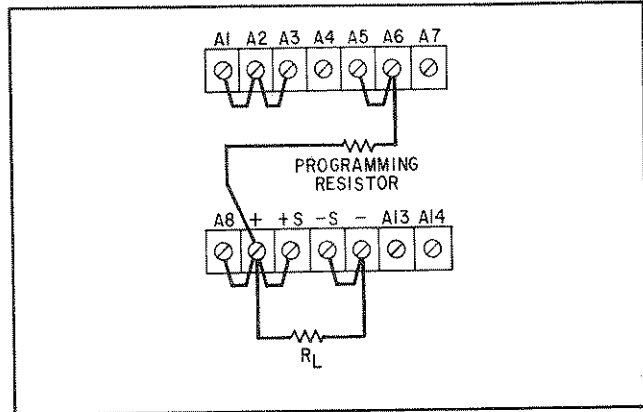


Figure 3-5. Remote Resistance Programming, Constant Current

3-32 Use stable, low noise, low temperature coefficient (at least less than 5ppm per degree Centigrade, but preferably 2ppm) 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 (A6 and +) 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 $1.0\text{K}\Omega$ 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.

3-33 Voltage Programming (Figure 3-6). In this mode, the output current will vary linearly with changes in the programming voltage. The programming voltage must not exceed 1.0 volt. Voltage in excess of 1.0 volt will result in excessive power dissipation in the instrument and possible damage.

3-34 The output current varies at a rate determined by the programming coefficient as follows:

Model	Programming Coefficient
6104A/6114A	0.5 volts/ampere
6105A/6115A	1.0 volts/ampere

The current required from the voltage source will be less than $1\mu\text{A}$. Impedance matching resistor R_X is required to maintain the temperature coefficient and stability specifications of the supply.

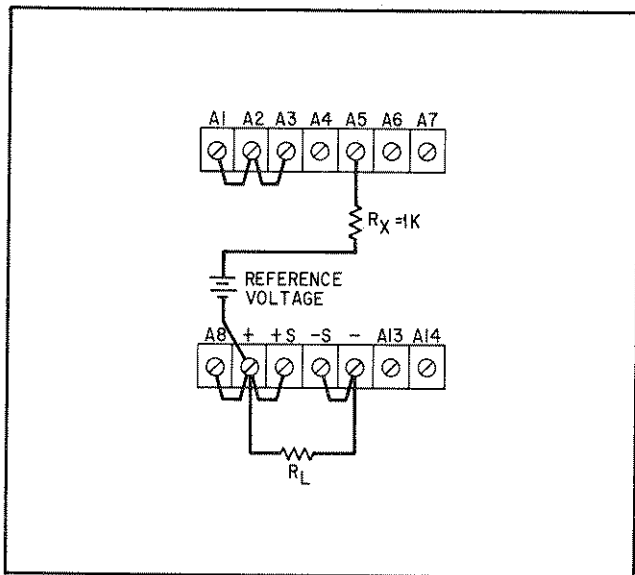


Figure 3-6. Remote Voltage Programming, Constant Current

3-35 The output current of the supply may be adjusted to exactly zero when the external programming voltage is zero by adjusting resistor A2R12 as discussed in paragraph 5-95.

3-36 REMOTE SENSING (Figure 3-7)

3-37 Remote sensing is used to maintain good regulation at the load and reduce the degradation of regulation which would occur due to the voltage drop in the leads between the power supply and the load. Remote sensing is accomplished by utilizing the strapping pattern shown in Figure 3-7. The power supply should be turned off before changing strapping patterns. The leads from the sensing ($\pm S$) terminals to the load will carry much less current than the load leads and it is not required that these leads be as heavy as the load leads. However, they must be twisted or shielded to minimize noise pickup.

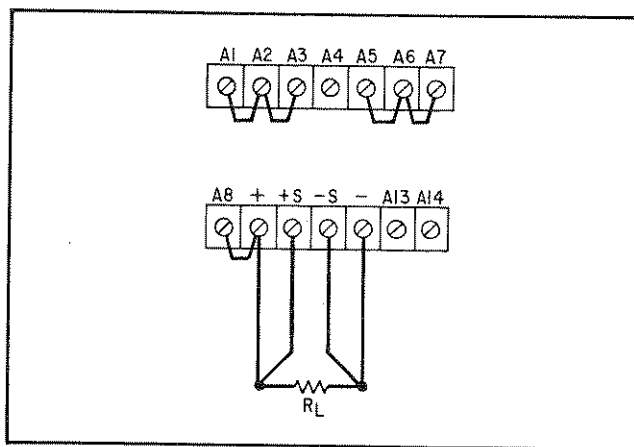


Figure 3-7. Remote Sensing

3-38 For reasonable load lead lengths, remote sensing greatly improves the performance of the supply. However, if the load is located a considerable distance from the supply, added precautions must be observed to obtain satisfactory operation. Notice that the voltage drop in the load leads subtracts directly from the available output voltage and also reduces the amplitude of the feedback error signals that are developed within the unit. Because of these factors it is recommended that the drop in each load lead not exceed 1.0 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 constant current setting in the remote sensing mode.

3-39 Observance of the precautions in paragraph 3-37 will result in a low dc output impedance at the load. However, another factor that must be considered is the inductance of long load leads. This causes a high ac impedance and could affect the stability of the feedback loop seriously enough to cause oscillation. In this case, it is recommended that the following precautions be taken:

- Disconnect output capacitor C12 by unstrapping terminal A8.
- Connect a capacitor having similar characteristics (approximately the same capacitance, the same voltage rating or greater, and having good high frequency characteristics) across the load using short leads.

3-40 Although the strapping patterns shown in Figure 3-3 through 3-6 employ local sensing, note that it is possible to operate a power supply simultaneously in the remote sensing and constant voltage/constant current remote programming modes.

3-41 SERIES OPERATION

3-42 Normal Series Connections (Figure 3-8). Two or more power supplies can be operated in series to obtain a higher voltage than that available from a single supply. When this connection is used, the output voltage is the sum of the voltages of the individual supplies. Each of the individual supplies must be adjusted in order to obtain the total output voltage. The power supply contains a protective diode connected internally across the output which protects the supply if one power supply is turned off while its series partner(s) is on.

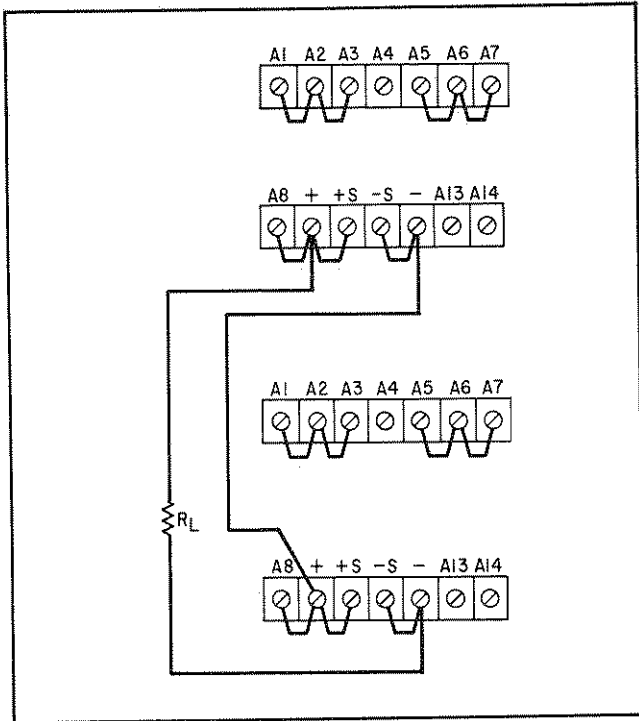


Figure 3-8. Normal Series

3-43 AUTO-SERIES OPERATION (Figure 3-9)

3-44 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 3-9 show local sensing and programming. Notice that the overvoltage

crowbar terminals (A13 and A14) are connected in parallel which means that if any supply crowbars, all supplies will be tripped.

3-45 In order to maintain the temperature coefficient and stability specifications of the power supply, the external resistors (R_X) shown in Figure 3-9 should be stable, low noise, low temperature coefficient (less than 5ppm 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.

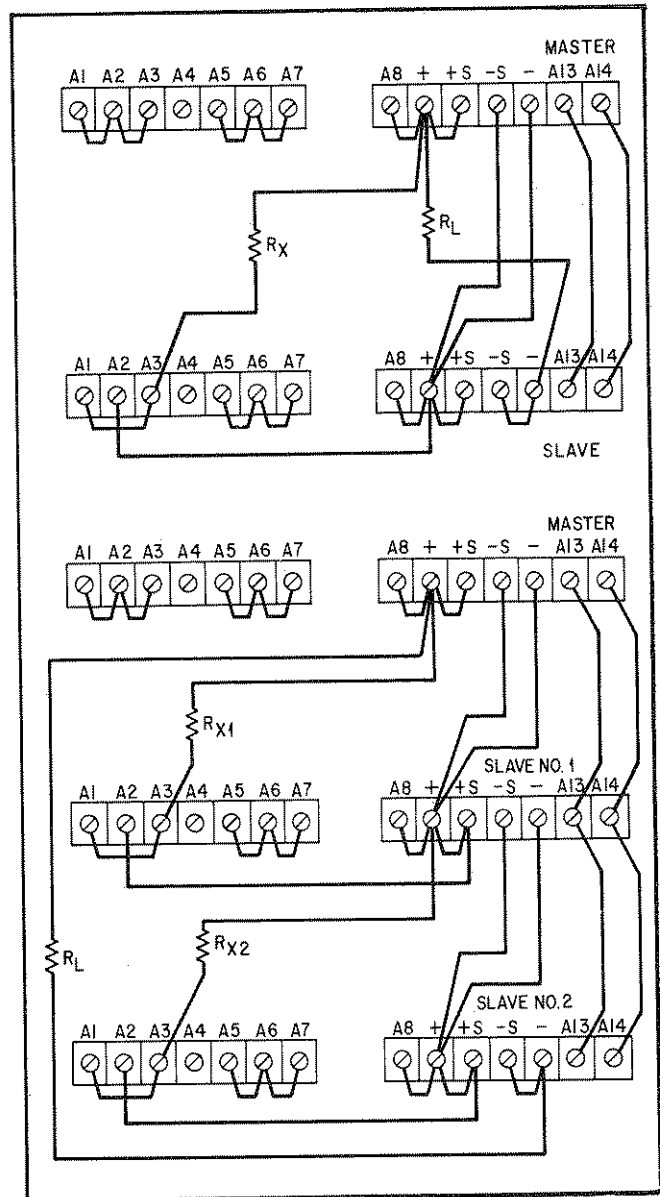


Figure 3-9. Auto-Series Operation, Two and Three Units

3-46 When the center tap of an Auto-Series combination is grounded, coordinated positive and negative voltages result. This technique is commonly referred to as "rubber-banding" and an external reference source may be employed if desired. Any change in the internal or external reference source (e. g. drift, ripple) will cause an equal percentage change in the outputs of both the master and slave supplies. This feature can be of considerable use in analogue computer and other applications, where the load requires a positive and a negative power supply and is less susceptible to an output voltage change occurring simultaneously in both supplies than to a change in either supply alone.

3-47 PARALLEL OPERATION

3-48 Normal Parallel Connections (Figure 3-10). Two or more power supplies can be connected in parallel to obtain a total output current greater than that available from one power supply. The total output current is the sum of the output currents of the individual power supplies. The output CURRENT controls of each power supply can be separately set. The output voltage controls of one power supply should be set to the desired output voltage; the other power supply should be set for a slightly larger output voltage. The supply set to the lower output voltage will act as a constant voltage source; the supply set to the higher output will act as a constant current source, dropping its output voltage until it equals that of the other supply. The constant voltage source will deliver only that fraction of its total rated output current which is necessary to fulfill the total current demand.

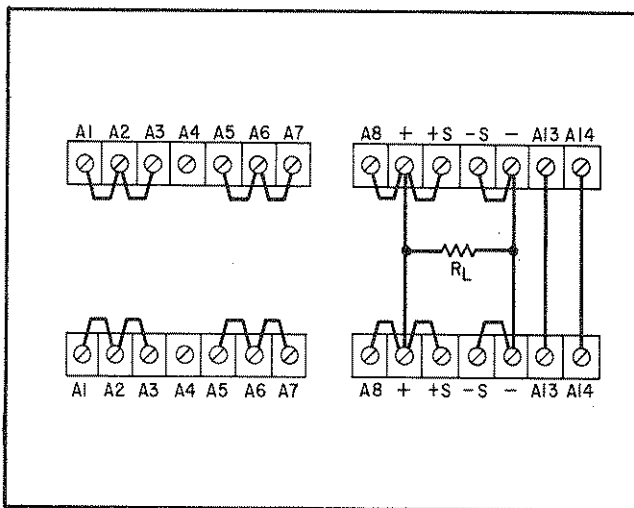


Figure 3-10. Normal Parallel

3-49 AUTO-PARALLEL OPERATION (Figure 3-11)

3-50 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.

3-51 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

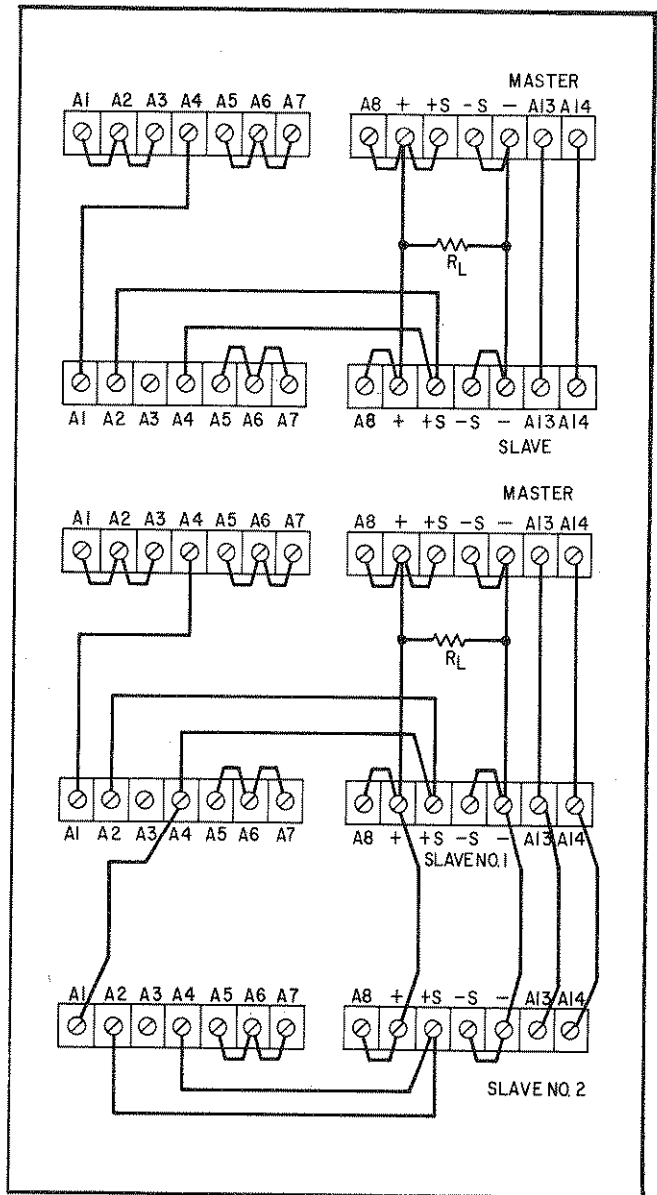


Figure 3-11. Auto-Parallel Operation, Two Units and Three Units

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 3-11 show 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 5ppm per degree Centigrade) resistors. The power rating of R_X should be at least 10 times the actual power dissipated in the resistor.

3-52 AUTO-TRACKING OPERATION (Figure 3-12)

3-53 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.

3-54 The output voltage of the slave (E_S) is a percentage of the master's output voltage (E_M), and is determined by the voltage divider consisting of R_X and the voltage control of the slave supply, R_P , where $E_S = E_M [R_P / (R_X + R_P)]$. Remote sensing and programming can be used (each supply senses at its own load), though the strapping patterns given in Figure 3-12 show only local sensing and programming. In order to maintain the temperature coefficient and stability specifications of the power supply, the external resistors (R_X) should be stable, low noise, low temperature coefficient (less than 5ppm/ $^{\circ}$ 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.

3-55 SPECIAL OPERATING CONSIDERATIONS

3-56 PULSE LOADING

3-57 When operated within either of the two range ratings, 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.

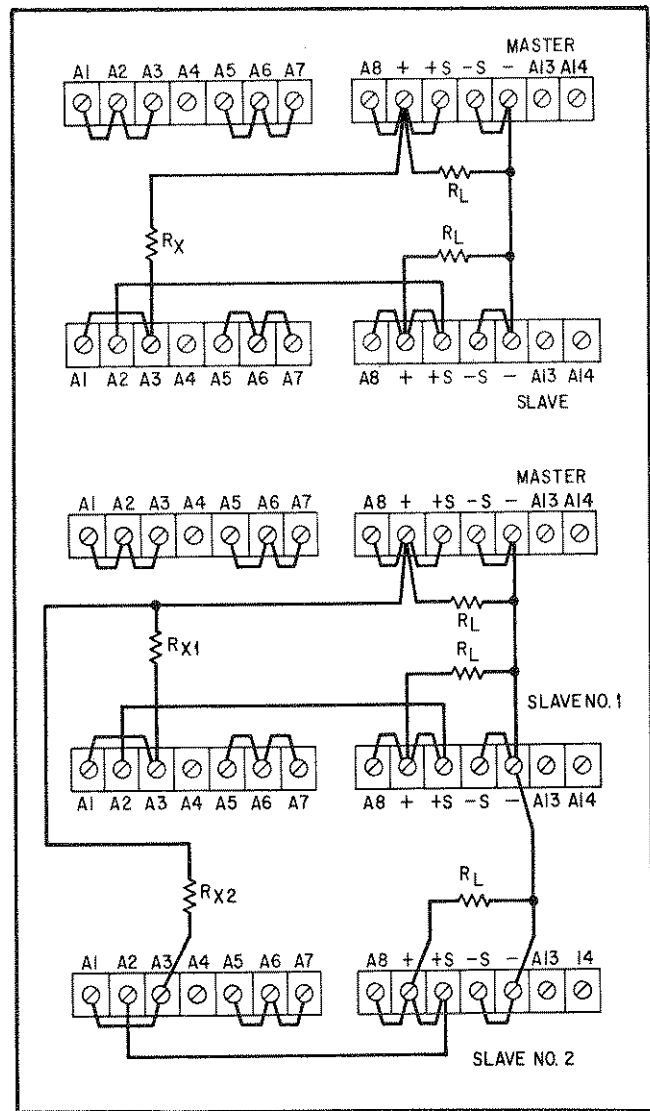


Figure 3-12. Auto-Tracking Operation, Two and Three Units

3-58 OUTPUT CAPACITANCE

3-59 An internal capacitor (C12) 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 surges, this capacitor can be removed by unstrapping terminal A7. 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 regulator current is large enough to cause the constant current circuit to operate.

3-60 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.

3-61 REVERSE VOLTAGE LOADING

3-62 A diode (CR15) 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.

3-63 REVERSE CURRENT LOADING

3-64 Active loads connected to the power supply may actually deliver a reverse current to the power supply during a portion of its operating cycle. An external source cannot be allowed to pump current into the supply without loss of regulation and possible damage to the output capacitor. To avoid these effects, it is necessary to preload the supply with a dummy load resistor so that the power supply delivers current through the entire operation cycle of the load device.

3-65 GROSS CURRENT LIMIT/AUTOMATIC DUAL-RANGE SWITCHING

3-66 The power supply can be operated at a CURRENT setting above the high range VOLTAGE rating as given below:

Model	Low Range		High Range	
	Voltage	Current	Voltage	Current
6104A/6114A	0-20V	0-2.0A	20-40V	0-1.0A
6105A/6115A	0-50V	0-0.8A	50-100V	0-0.4A

For instance, the 6104A can be operated with the CURRENT control set to 1.5A and the VOLTAGE control set to 30V. However, as shown in Figure 3-13, if the load resistance draws output current above the high range rating (i. e. greater than 1A for the 6104A/6114A or 0.4A for the 6105A/6115A), the power supply enters the gross current limit

region (the CURRENT MODE indicator comes on). In the gross current limit region, output current is maintained up to approximately 130% (at nominal line voltage) of the high range rating (1.3A for the 6104A/6114A or 0.52A for the 6105A/6115A) of the supply while output voltage is maintained at the VOLTAGE setting up to the maximum high range rating. If load resistance continues to change and causes output current to exceed the gross current limit region, however, the supply is automatically switched to the low range and output voltage is reduced to approximately 130% (again, at nominal line voltage) of the low range rating (26V for the 6104A/6114A or 65V for the 6105A/6115A). Of course, at this point the VOLTAGE setting of the supply is overridden. Further load reductions cause the supply to enter the constant current mode and output voltage is further reduced as necessary to supply the necessary output current depending upon load requirements and the CURRENT setting. Notice that when operated in the gross current limit region, the supply's output is uncalibrated and may not meet certain specifications (ripple, etc). Note, further, that if the supply is operated at low or high line, the gross current limit region will vary (decrease at low line and increase at high line).

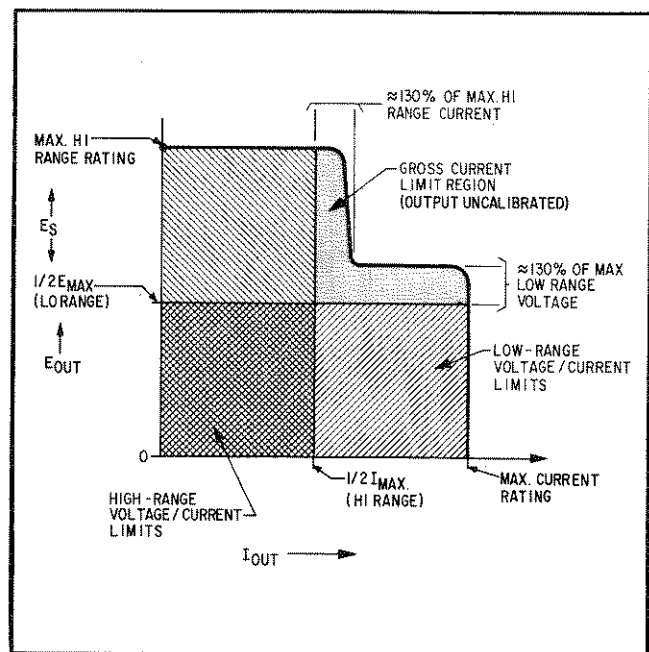


Figure 3-13. Gross Current Limit/Dual-Range Switching

SECTION IV PRINCIPLES OF OPERATION

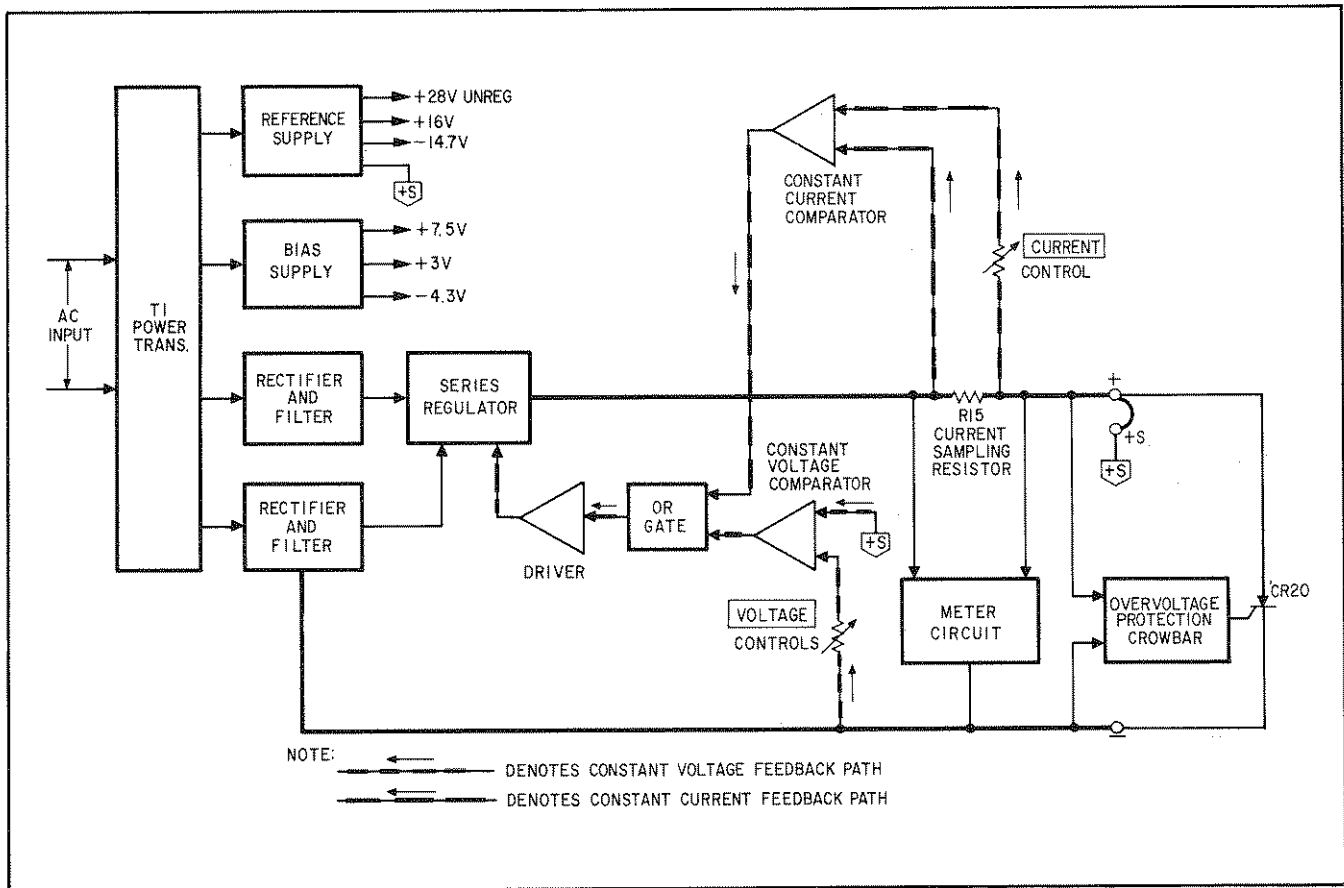


Figure 4-1. Overall Block Diagram

4-1 OVERALL BLOCK DIAGRAM DISCUSSION

4-2 The major circuits of the power supply are shown on the overall block diagram, Figure 4-1. 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. The series regulator includes a current limit circuit that automatically places the supply in the low voltage range depending upon the output voltage and current settings that have been selected and the output current of the supply. For instance, if the supply is set for high voltage output and high current output and the load attempts to draw current above the high voltage range current specification (that is, above 1A for the 6104A/6114A supplies or above

0.4A for the 6105A/6115A supplies), the series regulator limits the output current and then decreases the output voltage to the low range. When in the low range, the output current is then allowed to reach the CURRENT setting up to the maximum rating of the supply. Notice, further, that dual rectifier-filter circuits are employed to provide a low value of raw dc voltage to the series regulator in order to minimize internal power consumption during low voltage (high current) operation. Each rectifier-filter furnishes most of the raw dc voltage to the regulator during one of the two output voltage/current ranges of the supply.

4-3 The series regulator is part of a feedback loop consisting of the driver and the constant voltage/constant current comparators. When operated within the specified ranges, during constant voltage

operation the constant voltage comparator continuously compares the output voltage of the supply with the drop across the VOLTAGE control. If these voltages are not equal, the comparator produces an amplified error signal which is further amplified by the driver 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 signal necessary to set the output voltage at the level established by the VOLTAGE controls.

4-4 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 control. If the two inputs to the comparator are momentarily 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.

4-5 The constant voltage comparator, then, tends to achieve zero output impedance by altering the output current whenever the load resistance changes. Conversely, the constant current comparator attempts to achieve infinite output impedance by changing the output voltage in response to any load resistance changes. Thus, it is obvious that the two comparison amplifiers cannot operate simultaneously. When the supply is operated within the two normal ranges of output voltage/current, it must act either as a constant voltage source or as a constant current source - it cannot be both. Further, as previously mentioned, if the supply is set to operate outside of the specified high voltage range current rating (i.e. both VOLTAGE and CURRENT are set to high values), the supply will enter the current mode and limit output current if the load resistance attempts to draw more than one-half of the maximum current rating of the supply. As it limits output current, the supply also lowers output voltage (overriding the VOLTAGE setting) until the low voltage range is reached. At this point, the supply enters the constant current mode in which the output current is maintained (up to the maximum rating of the supply) at the CURRENT setting by altering the output voltage.

4-6 Figure 4-2 shows the output characteristics of a constant voltage/constant current power supply. When operated within either of the two normal output voltage/current ranges (0-40V up to 1A or 0-20V up to 2A for the 6104A/6114A supplies or 0-100V up to .4A or 0-50V up to .8A for the 6105A/6115A supplies). 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 $E_{OUT} = 0$.

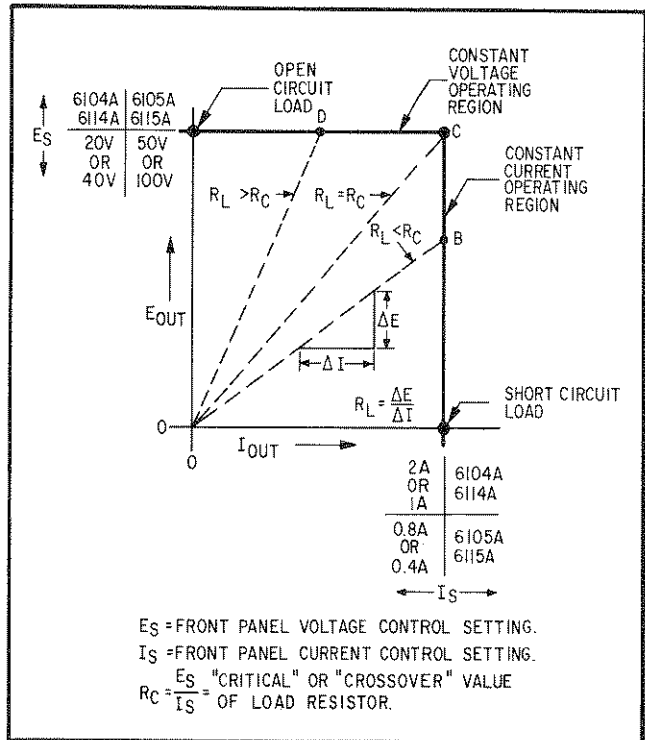


Figure 4-2. Operating Locus of a CV/CC Supply Operated Within Range Ratings

4-7 Thus, at VOLTAGE and CURRENT settings within the two normal ranges, 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.

4-8 Figure 4-3 shows the output characteristics of the supply when it is operated at an output current setting above the high voltage range rating

(assume the CURRENT control, I_S , and VOLTAGE control, E_S , are set at the maximum rating of the supply). As can be seen, up to the maximum high voltage range current rating, the supply operates as a constant voltage source furnishing the high range output voltage as specified by the setting of the VOLTAGE control. As load resistance decreases and output current reaches the maximum high voltage range current rating (point A), the supply goes into the gross current limit region in which the output current is maintained up to approximately 130% (at nominal line voltage) of the high voltage range current rating. If the load resistance continues to decrease and attempts to draw more current, the output current will increase slightly while the output voltage decreases rapidly (since the gross current limit circuit supplies a near constant current output, a decrease in load resistance results in a decrease in output voltage). When the output voltage reaches a point approximately 130% (again, at nominal line) of the low voltage range rating (point B), the gross current limit circuit turns off and the output current increases up to the programmed value. At this point, the supply enters the constant current mode in which, as described above, the output voltage is varied to maintain the output current at the setting of the CURRENT control. Notice, then, that under these circumstances the VOLTAGE control of the supply is overridden by the gross current limit circuit and the supply is automatically switched to the low voltage range. Since the gross current limit circuit is not as precise as the constant voltage and current comparators, the maximum voltage and current outputs of the supply dur-

ing gross current limit is slightly above the maximum ratings of the supply thus allowing for a margin of safety in that the supply will provide up to approximately 130% of high voltage range current rating and, conversely, it will supply 130% of low voltage range voltage while supplying maximum current (if operated in this region, however, power supply specifications such as output ripple are adversely affected).

4-9 The reference supply provides stable reference voltages used by the constant voltage comparator, the constant current comparator, and the driver. In addition, unregulated +28V is supplied to front panel indicator circuits. Less critical operating voltages are provided by the bias supply.

4-10 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.

4-11 The meter circuit provides a continuous indication of the output voltage and/or current of the supply (two meters are provided in the 6104A and 6105A models). Output voltage is sensed directly across the sensing terminals, while output current is sensed by monitoring the IR drop across the current sampling resistor.

4-12 DETAILED CIRCUIT ANALYSIS

4-13 GENERAL

4-14 Except for differences due to the different voltage/current ratings of the power supplies and the different VOLTAGE controls and meter circuits employed, all of the supplies operate in a similar fashion. Since the supplies are similar, two schematics have been provided, one for the dual-meter, ten-turn VOLTAGE control supplies (the 6104A and 6105A) and one for the single meter, pushbutton VOLTAGE control supplies (the 6114A and 6115A). Generally, then, the following discussions apply to the 6104A, 6114A, 6105A, or 6115A supplies. For clarity, however, certain circuits (i.e., the series regulator) are discussed for specific supplies (the 6104A/6114A). Except for the different voltage and current values, these discussions apply equally to the other supplies. Further, where specific differences in circuit operation exist between power supply models, they are discussed for each supply.

4-15 VOLTAGE FEEDBACK LOOP

4-16 The voltage feedback loop functions to maintain the output voltage of the supply constant. For purposes of this discussion, assume that the output voltage instantaneously rises (goes positive) due to a change in the external load circuit. The

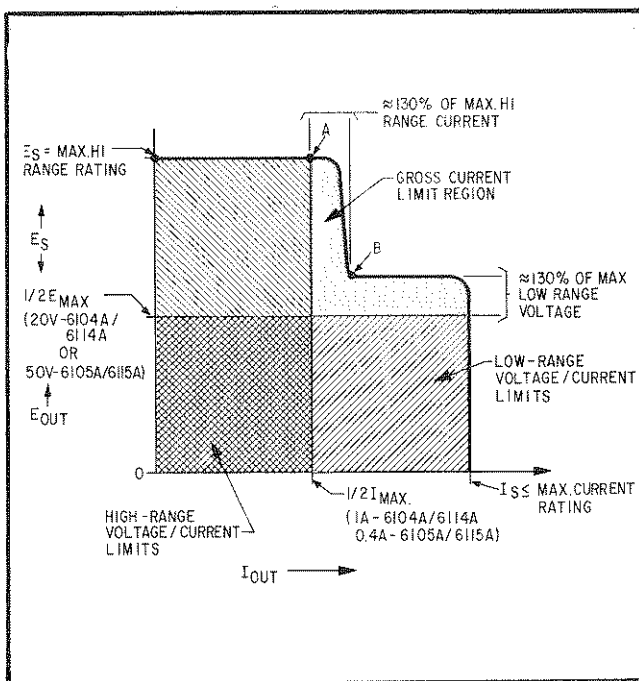


Figure 4-3. Operating Locus of Supply When Operated Out of Voltage/Current Range Limits

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 summing point A1 through the VOLTAGE control (either the ten-turn potentiometer for Models 6104A and 6105A or the pushbutton assembly for Models 6114A and 6115A). The ac signal is coupled to A1 through capacitor C1.

4-17 The rise in output voltage causes the voltage at terminal A1 and thus pin 3 of the constant voltage comparator to decrease (the +S potential rises, goes positive, so that -S is more negative with respect to +S; therefore, the input to the voltage comparator goes negative). This input (pin 3) of the constant voltage comparator is the non-inverting input so that the comparator's output voltage also decreases. This negative-going error voltage is coupled through OR-gate diode A2CR2, amplified by pre-driver A1Q1, and then fed to the series regulator via driver Q4 (located on the rear heat sink). The negative-going input to the series regulator causes the series transistors to decrease their conduction so that they drop more of the raw dc input voltage, thus reducing the output voltage to the original pre-disturbance level.

4-18 CURRENT FEEDBACK LOOP

4-19 When operated within either of the two specified range ratings, if the external load resistance decreases below the "crossover" point discussed in paragraph 4-7, 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 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 change is coupled through front panel CURRENT control R2 to summing point A5 and thus to pin 3 of the constant current comparator as a decreasing (less positive) input. The output of the comparator, then, decreases. This negative-going error voltage is coupled through OR-gate diode A2CR3 to pre-driver A1Q1. At this point the voltage and current feedback loops are joined. As discussed in paragraph 4-17, the negative-going error voltage is amplified in pre-driver A1Q1, and fed through driver Q4 (mounted on the heat sink) to the series regulator. The series regulator thus decreases its conduction and returns the output current to the original pre-disturbance level by decreasing output voltage.

4-20 CONSTANT VOLTAGE COMPARATOR

4-21 The constant voltage comparator consists of the VOLTAGE programming resistors (R4 for models 6104A/6105A and A3R1-A3R17 for models 6114A/

6115A) and a differential amplifier stage (A2U2 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.

4-22 The constant voltage comparator continuously compares the voltage drop across the VOLTAGE control 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 control. Hence, through feedback action, the difference between the two inputs to A2U2 is held at zero volts.

4-23 One input of the differential amplifier (pin 2) is connected to the output voltage sensing terminal of the supply (+S) through matching resistor R16. Potentiometer R13 provides 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 3) is connected to a summing point (TB1-A1) at the junction of the programming resistors and the current pullout resistor A2R24. Instantaneous changes in the output voltage at the summing point due to manipulation of the VOLTAGE control 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 6) as an error voltage which ultimately varies the conduction of the series regulator.

4-24 Resistor R15, 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 over driving the differential amplifier. Notice that when the power supply is in the constant current mode, the output of the voltage differential amplifier (A2U2) approximately +15.5V (with respect to $\boxed{+S}$) and turns on transistor A2Q3 thereby turning on the front panel CURRENT MODE indicator DS2 (a light-emitting diode). Triple junction diode CR7 provides sufficient voltage drop to keep Q3 cutoff when the supply is in constant voltage mode.

4-25 During constant voltage operation, the programming current flowing through the programming resistor(s) (VOLTAGE control) is held constant because of selectable resistor A2R3 and potentiometer A2R5 which allow the +16V reference to be calibrated. The reference voltage is dropped across high-tolerance (.05%) current pullout resistor A2R24

thereby assuring a constant current flow through the VOLTAGE programming resistors. See Section V for procedures to be used in calibrating this reference and thereby assuring linear voltage programming capability.

4-26 Main output capacitor A1C12 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 (C1), 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. C1 also prevents any spikes in the output from reaching the load.

4-27 CONSTANT CURRENT COMPARATOR

4-28 While basically similar in operation to the constant voltage comparator, the constant current comparator includes a current programming constant current source circuit not employed in the constant voltage comparator. This circuit provides a constant current for the CURRENT programming control and is not utilized in the constant voltage comparator because the voltage comparator must respond to variations in programming voltage (current) when remote voltage sensing is employed (the variations may be caused by the remote sensing leads). As in the constant voltage comparator, the constant current comparator employs an integrated circuit (A2U3) for the differential amplifier in order to minimize differential voltages due to mismatched transistors and thermal differentials.

4-29 The constant current comparator circuit continuously compares the voltage drop across the CURRENT control with the voltage drop across the current sampling resistor, A1R15. If a difference exists, the differential amplifier produces an error signal which is proportional to this difference. The remaining components in the feedback loop (driver and series regulator) function to maintain the drop across the current sampling resistor, and hence the output current, at a constant value.

4-30 One input (pin 2) of the differential amplifier is connected to the inboard side of current sampling resistor A1R15 through matching resistors A2R11 and A1R18. Potentiometer A2R12 provides a variable input bias that allows the output of the supply to be adjusted to zero current when the supply is set for zero output. The other input to the differential amplifier (pin 3) is connected to the summing point (terminal A5) at the junction of the current programming resistor (A1R2) and current programming constant current source (A2Q4 and A2Q5).

Changes in the output current due to load changes or changes in the voltage at the summing point due to manipulation of the CURRENT control 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 varies the conduction of the series regulator (assuming the supply is in constant current operation in which case the output of the constant voltage comparator is approximately +15.5V which reverse biases OR gate diode A2CR2).

4-31 The programming current constant current source (Q4 and Q5 and associated components) provides a constant current for the CURRENT programming control. Zener diode A2VR2 is a constant current source and places the emitter of Q4 at a fixed +9.8V. With the collector and base of Q4 strapped together, the transistor acts as a diode and drops .7V so that the base of Q5 is held at a positive voltage and the transistor is forward biased, supplying a fixed, constant current to the programming control. Potentiometer A2R19 allows the constant programming current to be precisely set at the full output current rating of the supply (see Section V, for calibration procedures).

4-32 DRIVER CIRCUIT

4-33 The driver amplifies the error signal from the constant voltage or constant current input circuit to a level sufficient to drive the series regulating transistors. Transistor A1Q1 receives the error voltage input from either the constant voltage or constant current comparator via the OR-gate diode (A2CR2 or A2CR3) that is conducting at the time. Diode CR2 is forward biased and CR3 is reverse biased during constant voltage operation. The reverse is true during constant current operation.

4-34 Predriver transistor A1Q1 receives the error signal and applies it to driver transistor Q4. Driver Q4 controls the conduction of the series regulator by controlling the amount of drive current diverted away from the regulator. As Q4 increases its conduction, more drive current (flowing from the +7.5V bias source through R33) is diverted from the bases of Q2 and Q3, causing a decrease in their conduction and a corresponding decrease in the output voltage.

4-35 Driver transistor Q4 performs an additional function, that of discharging the output capacitor during rapid down-programming. When the supply is rapidly down-programmed, diode CR13 conducts; a current path is thus established from the positive of output capacitor A1C12 through Q4 and back to the negative of the capacitor (thru R25). A1R14, in series with CR13 and CR14, limits the current that

can flow through this path. Triple junction diode CR14 protects Q4 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, CR14 also maintains the emitter of Q1 and the base of Q4 at a constant potential, thus limiting the power dissipated in Q4 under conditions where an external same-polarity voltage is applied to the output terminals of the supply (such as battery charging/discharging).

4-36 SERIES REGULATOR

4-37 The series regulator consists of transistors Q1 through Q3 (mounted, along with driver Q4, on the heat sink) which serve 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 during in-range operation. The regulator utilizes a "power sharing" circuit that results in considerably less internal power dissipation than would be the case if a standard, single-stage regulator were employed. This saving in dissipation is achieved by dividing the output of the supply into two regions (the low and high voltage ranges), and using separate raw-dc supplies for each region (range). 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.

4-38 The series regulator also includes a gross current limit circuit (zener diode A1VR2 and associated resistors R5, R6, and R7) that overrides the error signal produced by the comparators if excessive current is drawn when the output voltage is in the high range. The following paragraphs discuss the operation of the 6104A/6114A series regulator during two modes of operation: (1) when the voltage and current settings are within the normal limits for both two output ranges (and, therefore, the comparators have complete control of the series regulator) and (2) when the voltage setting is at the high range and the current setting is also set at a high value (in which case the gross current limit circuit activates if the high voltage range current rating, half of the low voltage range current rating, is exceeded). The 6105A/6115A series regulator circuit operates in the same way except that voltage levels are higher (and output current less).

4-39 The power supply utilizes dual full-wave rectifier-filters to obtain two raw-dc supply volt-

ages which are represented as two independent sources in Figure 4-4, a simplified schematic of the series regulator circuit. Switching between the sources is accomplished by diodes CR11 and CR12. In order to best understand the action of these diodes, the circuit will be analyzed for two separate, in-range conditions — high and low output voltage after which it will be discussed from the point of view of an out-of-range condition (i. e. the voltage and current controls are both set to high rating). To simplify the discussion, assume that the diode voltage drops and the transistor base-emitter junction voltages are all 1V when forward biased. Similarly, assume that the voltage across zener diodes VR3 and VR4 is 6.5V total.

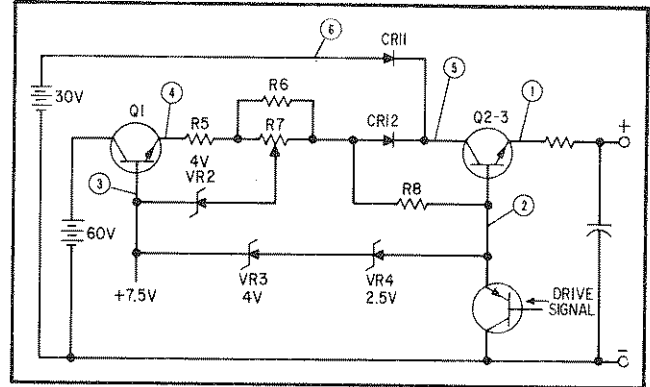


Figure 4-4. Series Regulator, Simplified Schematic (Models 6104A/6114A)

4-40 At a low output voltage (point ① = 5V), transistors Q2 and Q3 are conducting; this requires point ② to be at 6V. Zener diodes VR3 and VR4 thus place the base of Q1 (point ③) at 12.5V. Resistor R8 keeps Q1 conducting at least a certain minimum current at all times; thus point ④ is at 11.5V. Diode CR12 must be either on or off. If it were on, point ⑤ would be at 10.5V. Since the anode of CR11 (point ⑥) is always at 30V, this condition is not possible so that CR12 must be off. Thus, CR11 is on, point ⑤ is at 29V, and the 30V raw-dc source is supplying the load. The power dissipation in Q2 and Q3 is thus approximately 48 watts (24V drop between points ① and ⑤ times 2A load current). Notice that under these conditions, with a minimum current through Q1, the drop across R5 is small and the bias across zener diode VR2 is not sufficient for the zener to conduct current (the zener is not biased past its breakdown voltage) so that the gross current limit circuit has no effect on the operation of the series regulator.

4-41 At a high output voltage (point ① = 40V), transistors Q2 and Q3 are again conducting and point ② is at 41V. Point ③ thus is at 40.5V due to zener diodes VR3 and VR4. Point ④ is at 47.5V because (as before) Q1 is always conducting at least a certain minimum current. Again, diode CR12 must either be on or off. Since point ⑥ is

at 30V, CR12 must be on and CR11 must be off (point ⑤ = 46.5V). Thus, the 60V raw-dc source is supplying the load. Notice, again, that in the high voltage range, up to 1 amp. supplied by the 60V source so that the voltage drop across R5 is still not great enough to bias VR2 past its breakdown point. VR2, then, still has no effect on the operation of the series regulator. The switching point between the two ranges occurs when the voltage at point ④ equals that at point ⑥ (30V); this occurs when the output is approximately 21V (51V for the 6105A and 6115A).

4-42 Figure 4-5 illustrates the in-range operation of the series regulator from a power dissipation point of view. When the output voltage is in the low range (between zero and 21 volts for the 6104A and 6114A or 0-51 volts for the 6105A and 6115A), transistors Q2 and Q3 are controlling the output. In this region, the power dissipation of Q1 is very low (approximately 1W), since the only current going through it is that flowing through R8. When the output voltage is in the high range (between 21 and 40 volts or 51 and 100) most of the regulator dissipation occurs in transistor Q1 with transistors Q2 and Q3 clamped to a low voltage (and dissipating approximately 7.5W).

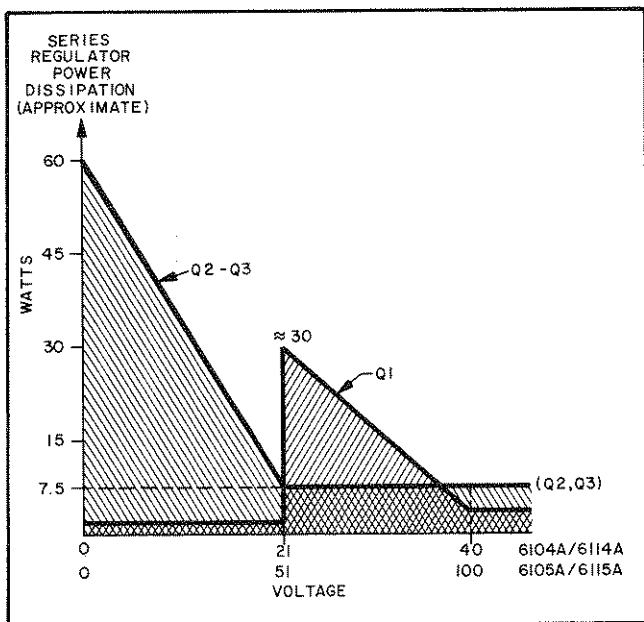


Figure 4-5. Series Regulator Power Dissipation

4-43 The obvious advantage in this type of regulator circuit is the saving in power dissipation. Consider the case discussed in paragraph 4-40, where the supply output is 5 volts at 2 amps, and the regulator is dissipating 48 watts. If the supply used a conventional single-stage regulator, the raw-dc source would have to be approximately 48V (20% higher than the maximum rated output voltage of 40V). The power dissipated by the regulator would therefore be the voltage drop across it (43

volts) times the current conducted (2A), or 86 watts. The use of the power sharing regulator thus represents a power dissipation saving (in this particular case) of more than 170%.

4-44 Referring back to paragraph 4-41, it was noted that since the output current is held (by the constant current comparator) to 1A when the output voltage is in the high range, zener diode VR2 had no effect on circuit operation since the voltage across it does not exceed its breakdown voltage. However, assuming that the CURRENT control is set to 2A and the VOLTAGE control is still set at 40V, if the load resistance decreases and attempts to draw more than approximately 1A through Q1 (and R5), the reverse voltage across VR2 exceeds the breakdown voltage of the zener diode. At breakdown, the diode becomes a constant current source and limits the current through the regulator to approximately 1.3A (at nominal line voltage). If load resistance decreases further, output voltage is reduced (since the zener is a constant current source) until the crossover point between the raw-dc sources is reached (point ⑤ is at approximately 21V). At this point, CR12 is cut off and CR11 is forward biased and the regulator reverts to the low voltage range of operation described in paragraph 4-40. The supply, then, will output the specified current and operate as a constant current source, responding to the error signal developed by the constant current comparator. The voltage setting, then, is overridden and output voltage will be adjusted between 0 and 20V to maintain the output current at the required value. Resistor R7 allows the gross current limit region to be calibrated (R7 is set at the factory at low line voltage to allow gross current limit at approximately 1.2A for the 6104A and 6114A supplies or at 0.48A for the 6105A and 6115A supplies).

4-45 REFERENCE SUPPLY

4-46 The reference supply includes a feedback regulator, similar to the main supply, that provides stable reference voltages (referenced to $\oplus S$) that are used throughout the unit. The regulated +16V reference voltage is derived from dc obtained from full wave rectifier A1CR1-CR2 and filter capacitor A1C1. In addition, zener diode A1VR3 provides -14.7V reference voltage that is also used throughout the unit. Also, zener diode VR4 (with R26) provides a regulated -6.2V for use in the overvoltage crowbar circuit. The -14.7V and -6.2V are derived from dc obtained from full wave rectifier A1CR3-CR4 and filter capacitor A1C2. The +16V and -14.7V/-6.2V reference rectifiers are returned to common point $\oplus S$. Notice, too, that the raw-dc input to the +16V regulator is 28V (nominal) which is used, unregulated, in the CURRENT MODE indicator and overvoltage crowbar circuits.

4-47 The +16V regulating circuit consists of series regulating transistor A2Q1, driver A2Q2, and comparison amplifier A2U1. As for the constant voltage and constant current comparators, the +16V regulator utilizes an integrated circuit for the comparison amplifier to minimize transistor mismatches and thermal differentials. The voltage across zener diode VR1 and resistor R9 and the voltage at the junction of the voltage divider comprised of resistors R8B, R5, R8A, and R3 (R3 is selected at the factory) are compared and any difference is amplified by the comparison amplifier. The error voltage thus appearing at the output (pin 6) of the comparison amplifier is amplified by driver stage A2Q2 and applied to series regulator Q1 in the correct phase and amplitude to maintain the +16V output at a constant level. Potentiometer R5 is provided to allow the +16V reference to be precisely calibrated (see Section V).

4-48 Resistor R1 and diode CR1 provide an initial turn on current path for the base-emitter circuit of series regulator Q1. This current flow initiates the series regulator action by turning on Q1. In addition, diode CR1 assures the correct operation of the comparison amplifier by establishing the positive bias of the amplifier at a level that is always above (by an amount equal to the drop across CR1) the output of the comparison amplifier. Capacitor A2C2, connected across the output of the reference supply, removes spikes and stabilizes the reference regulator loop.

4-49 BIAS SUPPLY

4-50 Additional +7.5V, +3V, and -4.3V bias voltages are derived from dc obtained from full wave rectifier A1CR5-CR6 and filter capacitor A1C3 along with dropping resistor A1R3. Capacitor A1C10 removes spikes from the bias supply output voltages. The +7.5V bias output is developed across zener diodes A2VR3 and VR4 in the series regulator. Zener diode VR4, in conjunction with the drop across series regulator transistors Q2 and Q3, develops the +3V bias voltage. The -4.3V bias voltage is supplied by zener diode A2VR5. Resistor R40, connected across VR5 limits the maximum current through the diode and also reduces overshoot when the supply is turned on or off.

4-51 OVERVOLTAGE PROTECTION CROWBAR

4-52 The overvoltage protection crowbar circuit protects the load from high voltage conditions such as might result from the failure of the series regulator transistors. This protection is accomplished by placing a short across the output of the supply thus driving output voltage and current towards 0. The overvoltage protection crowbar circuit utilizes an integrated circuit (A1U1) comparison amplifier

that provides high gain and high speed with low temperature coefficient and power consumption. Under normal operating conditions (no overvoltage), the output of the comparison amplifier is positive and capacitor C14 is charged positive. No trigger signal, therefore, is received by silicon controlled rectifier (SCR) CR20 and it is an open circuit having no effect on the normal output voltage.

4-53 Potentiometer R3 (OVERVOLTAGE) has -6.2V (with respect to +S) applied across it from the reference supply. The other input to the comparison amplifier is taken at the junction of voltage divider R29 and R30 which is across the output terminals of the supply and divides the output voltage to a maximum of approximately -6.2V when the supply is set to maximum rated output. When the voltage input to pin 3 of the comparison amplifier exceeds (is less negative) the voltage at pin 2, the output of the amplifier goes negative (approximately 0) and capacitor C14 discharges through the primary of transformer T1. A positive trigger pulse, then, is applied to the gate lead of CR20 and the SCR is turned on, placing a virtual short across the output of the supply. Potentiometer R3, adjusts the point at which the crowbar will trip by increasing (or decreasing) the negative reference input to the comparison amplifier and, thereby, requiring the output voltage to increase (or decrease) in a negative direction before it is more negative than the reference input (to cause the amplifier output to go towards 0).

4-54 When triggered, the SCR has two paths through which it conducts current as follows. Assuming the series regulator transistors (Q2 and Q3) are not open, diode CR16 is forward biased when the SCR fires and the output current flows from the + output terminal, the base-emitter junctions of Q2-Q3, the +7.5V supply, this diode, and through the SCR. Thus, current is diverted from the series regulator transistors and the output current (and of course, voltage) is turned down rapidly. The current surge through the SCR, therefore, is minimized. The other current path for the SCR is via diode CR17 and the output terminals. However, if the series regulator transistors are operable, most current flows through the CR16 path. In the case when the series regulator transistors collector-emitter junction shorts (which would open the CR16 current path described above), the SCR will conduct all the current through this path (the current surge will, however, be sustained for a longer time until the supply fuse opens). Diode CR17 assures that the CR16 path is not turned on during normal operation when output voltage is set below +7.5V.

4-55 Resistor R27 limits the current flowing into the gate of the SCR and diode CR18 prevents ringing in the pulse transformer when the positive

trigger pulse collapses. Resistor R34 limits the current flowing through the SCR and inductor L1 is included to decrease the response time of the SCR and minimize false triggering (triggering of the SCR due to noise spikes). Note, also, that when the crowbar fires, diode CR16 is forward biased (as mentioned previously) which forward biases front panel OVERVOLTAGE indicator DS3 which is a light-emitting diode.

4-56 A slaving arrangement of crowbar circuits in more than one unit is made possible by an extra secondary winding (terminals 7 and 8) on transformer T1. Terminals on the rear barrier strip (A13 and A14) allow easy connection to this winding. Connecting these windings in parallel when operating in a multiple-supply configuration will result in all the crowbars being activated if one of the crowbars is tripped. To reset the crowbars in this arrangement, all of the units must be turned off and then on. Correct polarity (A13 is positive) must be observed when connecting the windings in parallel. Figures 3-10 through 3-12 (Parallel, Auto-Parallel, and Auto-Series) demonstrate these connections. Also, the crowbars can be interconnected down to a load impedance of approximately 10Ω (each crowbar pulse winding has approximately 100Ω impedance) after which considerable degradation of the pulse may occur.

4-57 METER CIRCUIT

4-58 The meter circuit provides continuous indication of the output voltage and/or output current. Individual voltage and current meters are supplied in the 6104A and 6105A supplies while a single meter that can be used either as an ammeter or a voltmeter, depending on the position of the front panel METER switch S2, is provided in the 6114A and 6115A supplies. The following paragraphs describe each of the two meter circuits.

4-59 Dual-Meter Circuit (6104A and 6105A). To measure voltage, the voltmeter and its series resistors, A1R20 and A1R22, are connected between the positive and negative sensing terminals. Potentiometer A1R22 allows the voltmeter to be calibrated. For current measurements, the ammeter is connected across the current sampling resistor. Potentiometer A1R17 allows the ammeter to be calibrated. Notice that during constant current operation, the voltmeter and its resistors act as a shunt load across the output terminals of the supply, drawing a small amount of current away from the load (0-1mA, depending on the output voltage). Voltage divider A1R18 and A1R21 compensates for this decrease in load current by subtracting a small voltage (the drop across R18) from the voltage drop across the current sampling resistor. The sub-

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

4-60 Single Meter Circuit (6114A and 6115A). The voltage and current measuring circuits for the 6114A and 6115A are selected by front slide switch S2 and are similar to the associated dual meter circuit previously discussed. For voltage measurements, the meter and series resistors A1R17, A1R22, and A1R20 are connected across the positive and negative sensing terminals with A1R22 used to calibrate the meter. Notice, also, that when slide-switch S2 is in the VOLTS position, resistors A1R16 and A1R19 are connected across the current sampling resistor in order to "replace" the current measuring circuit that is connected across the current sampling resistor when the switch is in the AMPS position. Thus, the effect of the meter circuit on the constant current performance of the supply will be the same regardless of the position of the meter switch. Similarly, when measuring current (S2 in AMPS position), the meter and series resistors A1R16 and A1R17 are connected across the current sampling resistor with A1R17 used to calibrate the meter. Further, resistors A1R19 and A1R20, and A1R22 are connected across the positive output terminal and the negative sensing terminal to "replace" the voltage measuring circuit. As described for the dual-meter circuit, the small voltage drop across resistor R18 compensates for the shunt load of the meter circuit which might (because it drains up to 1mA) affect constant current operation. This voltage drop causes the constant current comparator to increase 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 it in the event of unusual circumstances. One of these components is diode A1CR15. Connected across the output terminals of the supply, the diode 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 Diodes CR23 and CR24 limit the output of the supply if the connections between both output terminals and the sensing terminals ($\pm S$) are inadvertently removed. Diode CR14, 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.

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 5-53). After repair and replacement (Paragraph 5-70), perform any necessary adjustments and calibrations (Paragraph 5-83). 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: 500 μ V full scale (min.). Input impedance: 100M Ω (min.).	Measure dc voltages; calibration procedures.	HP 3420B (See Note on Page 5-2.)
Oscilloscope	Sensitivity and bandwidth: 50 μ V/cm and 300kHz for all measurements except noise spike; 1mV and 20MHz for noise spike measurement.	Measure ripple; display transient recovery waveforms; measure noise spikes.	HP 140A with 1403A vertical plug-in and 1423A time base; HP 180A with 1803A vertical plug-in and 1820A time base for spike measurement.
DC Voltmeter	Sensitivity: 1mV full scale (min.). Accuracy: 1%.	Measure dc voltages.	HP 412A.
AC Voltmeter	Sensitivity: 50 μ V full scale (min.). Frequency range: 5Hz to 250kHz (min.). Accuracy: 3%.	Measure output impedance, ripple, and ac voltages.	HP 3410A.
Oscillator	Frequency range: 5Hz to 20kHz (min.). Output: 5V rms into 600 Ω . Accuracy: 3%.	Measure output impedance.	HP 209A.
Amplifier	Power output: 50 watts. Frequency response: \pm 3dB 5Hz to 20kHz (min.).	Measure output impedance.	HP 6824A.