Instruction Manual for Model 1652

Dual-Output

POWER SUPPLY

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TABLE OF CONTENTS

INTRODUCTION

The **B & K-Precision** Model 1652 Dual-Output Power Supply provides two variable 0-to-25 volt outputs at 0-to-1.5 amps each. This unit is a general purpose bench supply, particularly well suited for powering both analog and MOS digital circuits.

Both supplies can be operated independently or in a tracking mode. In the tracking mode, the B supply can be preset to any percentage of the A supply voltage from 0 to 100%. Then, the B output will track variations of the A output. For example, if the tracking percentage is preset to 50%, and the A supply is set to 20 volts, the B supply will operate at 10 volts. If the A supply is then changed to 15 volts, the B supply will change to 7.5 volts.

The design of the 1652 employs a switching pre-regulator, which significantly reduces the internal dissipation compared with conventional power supplies. This extends operation at full rated output to 40° C (104° F) ambient.

The 1652 also offers excellent regulation and tracking accuracy, low ripple voltage, current limiting overload protection, and convenience features such as built-in metering for each supply and vernier controls.

Both outputs are completely isolated, even in the tracking mode. An opto-isolator design provides electrical isolation in the tracking mode. Complete isolation permits full flexibility of output connections. Both supplies may be operated independently at separate references or strapped together for a common reference. Either supply can be connected with + and - polarity. Either or both supplies may be floated to an external voltage or connected to chassis or earth ground. Both supplies can be connected in series as a 0-to-50 volt, 0-to-1.5 amp power source. Both supplies may be connected in parallel with suitable balancing resistors, and operated as a 0-to-25 volt, 0-to-3 amp power source.

The features and versatility of the unit make it an ideal power supply for engineering lab applications, production testing, service shops, school laboratories, and home use by electronic hobbyists. It can serve as a single or dual-voltage power source for breadboard and prototype circuits. It can provide single or simultaneously varying voltages for circuit evaluation. It can provide tracking + and - voltages for evaluating differential amplifiers. It may be used to power circuit boards or cards while removed from their mother system.

FEATURES

DUAL 0-to-25 VDC VARIABLE OUTPUTS
Two complete power supplies in one package. Each supply continuously variable over 0-to-25 volt range with convenient coarse and vernier controls.

DUAL 0-TO-1.5 AMP OUTPUTS
Each supply has 0-to-1.5 ampere current rating. Full rated output to 40° C (104° F).

INDEPENDENT MODE
Power supplies operate completely independently.

TRACKING MODE
B output tracks A output at any preset percentage from 0 to 100%. For example: with tracking ratio set at 50%, B output is 5 volts when A output is set to 10 volts. B output increases to 7.5 volts when A output is increased to 15 volts.

ISOLATED OUTPUTS
Each supply completely isolated, even in tracking mode with opto-isolator design. Isolated outputs offer full versatility of connections; may be independently floated or grounded, or strapped together for common reference.

LABORATORY QUALITY
Excellent regulation and tracking accuracy, low ripple voltage.

OVERLOAD PROTECTION
Current limiting at approximately 1.8 amps (each supply) if output is short-circuited or overloaded.

REVERSE POLARITY PROTECTION
Prevents damage to either supply from external voltage of reverse polarity.

BUILT-IN METERING
Separate meter for each supply may be switched to monitor output voltage or current.

OTHER FEATURES
Pilot light. Heavy-duty, 5-way, color-coded binding posts for the output of each supply and earth ground. Chassis, case and green binding post at earth ground via power cord.

SPECIFICATIONS

INPUT POWER REQUIREMENTS	100, 120, 220, or 240 VAC ±10%, 50/60 Hz; 130 Watts max. at full rated load. External line voltage selection from rear panel.
OUTPUTS	
A Supply	0-to-25 volts dc at 0-to-1.5 amps. Continuously variable with coarse and vernier controls.
B Supply	0-to-25 volts dc at 0-to-1.5 amps in independent mode; 0 to 100% of A supply voltage at 0-to-1.5 amps in tracking mode. Continuously variable with coarse and vernier controls.
TRACKING	B supply voltage tracks A supply voltage at selected ratio which is continuously variable from 0 to 100%.
TRACKING ERROR	Within ±1% ±250 mV when both supplies are operated in the 2-to-23 volt range. Tracking is obtained outside these limits with increased error.
RIPPLE VOLTAGE	Less than 2.5 mV rms.
LOAD REGULATION	Within ±0.1% or ±20 mV, whichever is greater, from no load to full rated load.
LINE REGULATION	Output variation ±0.1% for line voltage variation of ±10%.
TRANSIENT LOAD RESPONSE (50% CHANGE)	Within 10 mV in 40 milliseconds, maximum excursion 50 mV.
CURRENT LIMITING	Current limiting at approximately 1.8 amps (each supply) if output is short circuited or overloaded.
REVERSE POLARITY PROTECTION	Diode protected.
ISOLATION	Each supply may be floated independently, including tracking mode. Maximum voltage difference between supplies is 250 volts (dc + ac peak).
METERING	Independent built-in meters for A supply and B supply. Switchable to output voltage or current. 0-to-27 volt and 0-to-2.0 amp ranges.

SPECIFICATIONS

METER ACCURACY	±5% of full scale.
ENVIRONMENTAL	
Cooling	Convection.
Operating Temperature	0^{o} to $+40^{o}$ C (32^{o} to 104^{o} F) at full rated load. Maximum current is derated 50 mA per degree C above $+40^{o}$ C to a maximum operating temperature of 50^{o} C.
GENERAL	
Series Operation	Outputs may be connected in series for 0-to-50 volt, 0-to-1.5 amp dc output.
Parallel Operation	Outputs may be connected in parallel (current equalizing resistors required) for 0-to-25 volt, 0-to-3 amp output.
Dimensions (HWD)	8-5/8 x 6-3/8 x 9-1/2" (219 x 162 x 241 mm), including knob projection.
Weight	12-3/4 lb. (5.75 kg).

ACCESSORIES

ACCESSORIES SUPPLIED WITH UNIT

Detachable power cord.

Fuse for alternate line voltage.

Instruction manual.

Composite (schematic diagram & parts list).

OPTIONAL ACCESSORIES

RM-16 Rack Mount Kit

Adapts 1652 Power Supply for panel mounting in standard 19" relay rack. Accepts one Model 1652, two 1652's, or one 1652 and one 1654 Power Supply. Supplied with all mounting hardware and installation instructions.

CONTROLS AND INDICATORS

FRONT PANEL CONTROLS
(refer to Fig. 1)

1. **POWER ON-OFF Switch.**

2. **Pilot Light.** Red neon bulb lights whenever unit is on.

3. **A VOLTS Control.** Adjusts output voltage of A supply from 0-to-25 volts when mode switch (9) is in INDEPENDENT position. Adjusts output voltage of both A and B supplies when mode switch is in B TRACKS A position. Clockwise rotation increases voltage. Outer knob is coarse adjustment; inner knob is vernier adjustment.

4. **Meter A Switch.** Connects meter A (5) to measure output VOLTS or AMPS.

5. **Meter A.** Reads output voltage or current of A supply.

6. **Meter B.** Reads output voltage or current of B supply.

7. **Meter B Switch.** Connects meter B (6) to measure output VOLTS or AMPS.

8. **B VOLTS Control.** Adjusts output voltage of B supply from 0-to-25 volts when mode switch (9) is in INDEPENDENT position; clockwise rotation increases voltage. Adjusts output voltage of B supply from 0 to 100% of A supply voltage when mode switch is in B TRACKS A position; clockwise rotation increases percentage. Outer knob is coarse adjustment inner knob is vernier adjustment.

9. **Mode Switch.** Selects INDEPENDENT or B TRACKS A mode of operation.

10. **B Supply Output Terminals.** Red terminal is "+", black terminal is "-"; output is floating in both INDEPENDENT and B TRACKS A modes.

11. ⏚ **Terminal (Green).** Earth ground.

12. **A Supply Output Terminals.** Red terminal is "+", black terminal is "-"; output is floating in both INDEPENDENT and B TRACKS A modes.

REAR PANEL CONTROLS
(refer to Fig. 2)

13. **LINE VOLTAGE SELECT Switches.** Two switches operating in conjunction with each other to select line voltages of nominal 100, 120, 220, or 240 VAC.

14. **Fuse.**

15. **Line Cord Receptacle.**

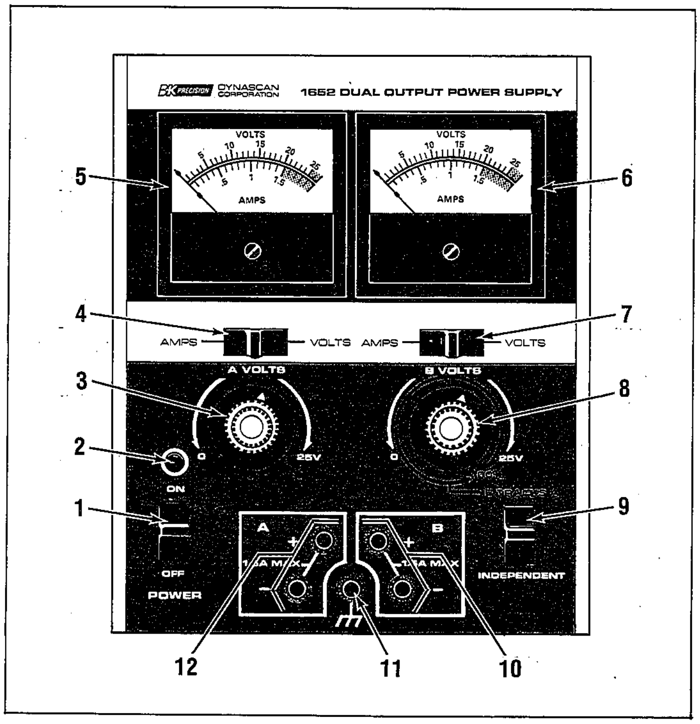


Fig. 1. Front Panel Controls.

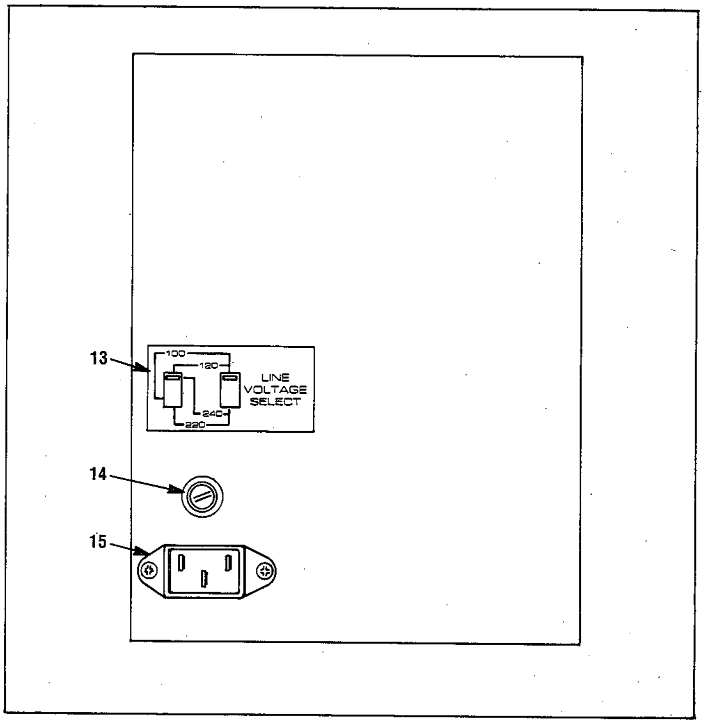


Fig. 2. Rear Panel Controls.

OPERATING INSTRUCTIONS

SAFETY PRECAUTIONS

Use only a polarized 3-wire ac outlet. This assures that the power supply chassis, case, and ground terminal are connected to a good earth ground and reduces danger from electrical shock. This protection is usually lost if the power supply input is obtained from an isolation transformer.

There are several operating conditions which may pose an electrical shock hazard. These conditions are identified and corresponding precautions listed in the TEST INSTRUMENT SAFETY recommendations, which are found starting on the inside front cover of this manual. Know and observe these precautions.

LINE VOLTAGE SELECTION
(Refer to Fig. 3)

CAUTION

Damage to the unit may result from using incorrect line voltage. Before connecting unit to line voltage, check that LINE VOLTAGE SELECT switches on rear panel are properly set as described below, and that fuse is correct value.

The unit is capable of operating from nominal 100 volt, 120 volt, 220 volt, or 240 volt, 50/60 Hz ac power. Use 1-1/2 amp slow-blow 3AG fuse for 100 V or 120 V operation, or 3/4 amp slow-blow 3AG fuse for 220 V or 240 V operation.

Set the LINE VOLTAGE SELECT switches on the rear panel to the positions that correspond to the line voltage to be used. Insert a flat blade screwdriver into the slot of each switch and move the slots to align with the graphics indicating the desired voltage as shown in Fig. 3.

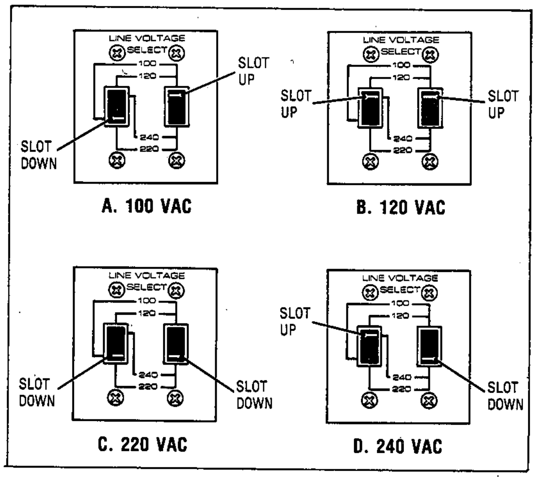


Fig. 3. Line Voltage Selection.

INDEPENDENT USE OF "A" SUPPLY
(Refer to Fig. 4 and 5)

The A supply provides a variable 0-to-25 volt dc output at up to 1.5 amps. This procedure covers the use of the A supply when it is the only power source of the dual-output unit in use.

Procedure

1. Set the A VOLTS control to zero (fully counterclockwise).
2. Connect the positive and negative polarity of the circuit being powered to the (+) and (-) terminals of the A supply, respectively, as shown in Fig. 4.
3. Make earth ground connection, if required, as shown in Fig. 5.
4. Place the meter A switch in the VOLTS position and read the voltage from the 0-to-27 V scale of meter A.
5. Adjust the A VOLTS control to obtain the desired voltage.
6. If the desired voltage cannot be attained, current limiting is probably occurring from an overload. Place meter switch A in the AMPS position and read output current from the 0-to-2.0 A scale of meter A. Greater than 1.5 amps reading indicates an overload and current limiting.

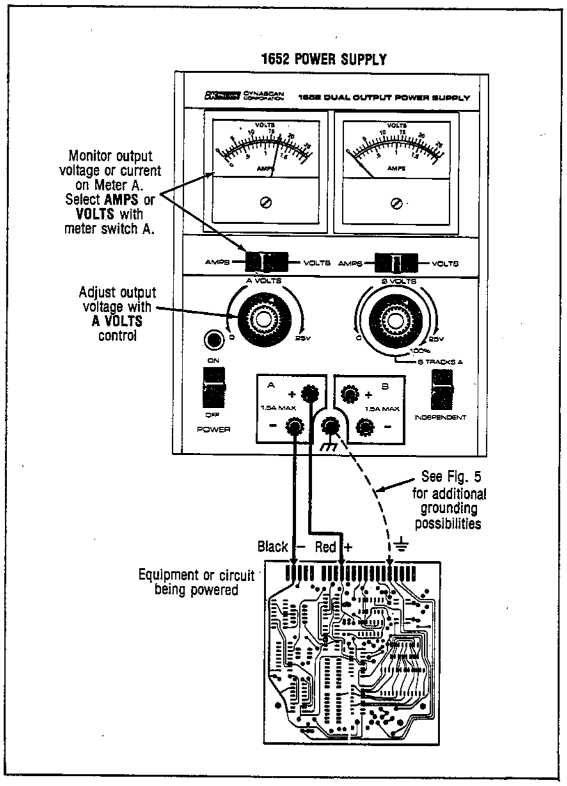


Fig. 4. Typical Use of A Supply.

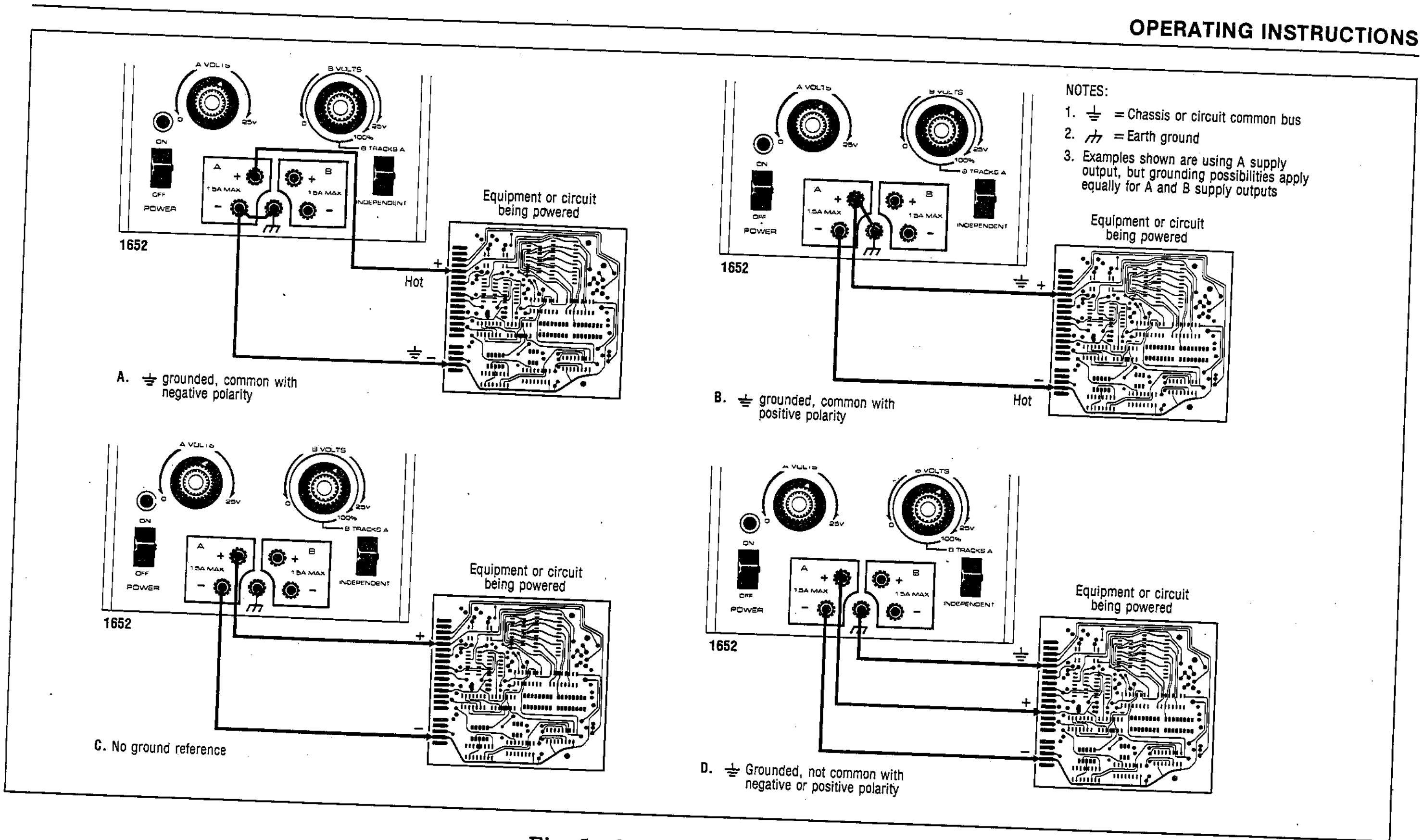


Fig. 5. Grounding Possibilities.

7. After initial set-up and connections, place meter switch A in the AMPS position and continuously monitor the load current on meter A.

8. Voltage may be varied as desired by readjusting the A VOLTS control. Revert the meter to voltage monitoring to make such readjustments.

Considerations

1. Observe proper polarity. If the circuit being powered is not equipped with reverse polarity protection, damage to the circuit can result from reverse polarity connections. Use color-coded leads, one red and one black for example, to readily identify polarity of connections.

2. Do not exceed the voltage rating of the circuit being powered. Many transistors and integrated circuits will not withstand voltage of 25 volts.

3. Fig. 5 illustrates the grounding possibilities. If the negative polarity of the equipment or circuit being powered is also the chassis or common bus, it may be grounded to earth by strapping the (-) terminal to the earth ground terminal (⏚) as shown in Fig. 5A. Similarly, the positive polarity can be grounded by strapping the (+) terminal to the earth ground terminal as shown in Fig. 5B. If an earth ground reference is not required, the configuration in Fig. 5C may be used. If the chassis or common bus is separate from both the positive and negative polarity power inputs, use the connection in Fig. 5D. The scheme in Fig. 5D should also be used where +, -, and chassis connections are possible and it is not known whether or not the chassis is common with either the positive or negative polarity. No damage can result if this configuration is used.

4. Make sure that the leads used to make the power connections offer low voltage drop between the power supply and the circuits being powered. Use power leads of at least 18 gauge diameter, and make sure that connectors and points of contact offer low resistance. At 1.5 amps, even 0.1 ohm resistance in each power lead will drop a 5.0-volt output to 4.7 volts at the equipment being powered.

5. For precision voltage readings, measure the output *across the load* with a high accuracy voltmeter. For precision current readings, measure the output *in series with the load* on a high accuracy ammeter.

6. Overload current limiting protects the A supply from overdissipation if the load is excessive. Overload conditions can be detected by observing the voltage and current readings of the meter. If the output is short-circuited, the voltage will approximate 0 volts regardless of the setting of the A VOLTS control. Also, current will be limited at approximately 1.8 amps. For overload conditions less severe than a short-circuited output, voltage readings will be normal near 0 volts. As the A VOLTS control setting is increased, voltage will reach a point where no further increase is possible. The greater the degree of overload, the lower the voltage at which this point occurs. This is the point where current reaches its limiting value and can be observed while monitoring the current meter.

7. After initial set-up and connections, the meter is normally set to continuously monitor load current. The effect upon load current by variables in the circuitry being powered may be instantly evaluated, or a change may denote an abnormal condition.

8. When supply B is not in use, it is possible to simultaneously monitor the output current and voltage of supply A on the two built-in meters as follows:

   a. First, set both meter switches to the VOLTS position. Adjust the A VOLTS control for the desired output value as read on meter A.

   b. Next, select the B TRACKS A mode and set the B VOLTS control so meter B reads exactly the same as meter A. This step enables the tracking mode, and sets tracking at 100%; the output voltage of the B supply now equals that of the A supply and will follow any subsequent variations in the A supply output.

   c. Leave meter switch B set to VOLTS. It will monitor the output voltage on meter B. (Meter accuracy is slightly less than if monitored on meter A because of the additional tracking accuracy factor of ±1%, ±250 mV. For most applications, this is insignificant.)

   d. Set meter switch A to AMPS and monitor output current on meter A.

INDEPENDENT USE OF "B" SUPPLY

(Refer to Fig. 6)

The B supply also provides a variable 0-to-25 volt dc output at up to 1.5 amps and may be used instead of the A supply if desired. Procedures are very similar to those for using the A supply.

Procedure

1. Select INDEPENDENT mode.

2. Set the B VOLTS control to zero (fully counterclockwise).

3. Connect the positive and negative polarity of the circuit being powered to the (+) and (-) terminals of the B supply, respectively, as shown in Fig. 6.

4. Make ground connection, if required, the same as for the A supply. The only exception, of course, is that strapping, if required, is between the ⏚ terminal and the + or - terminal of the B supply, rather than the + or - terminal of the A supply.

5. Place meter switch B in the VOLTS position and read the output from the 0-to-27 V scale of meter B.

6. Adjust the B VOLTS control to obtain the desired voltage.

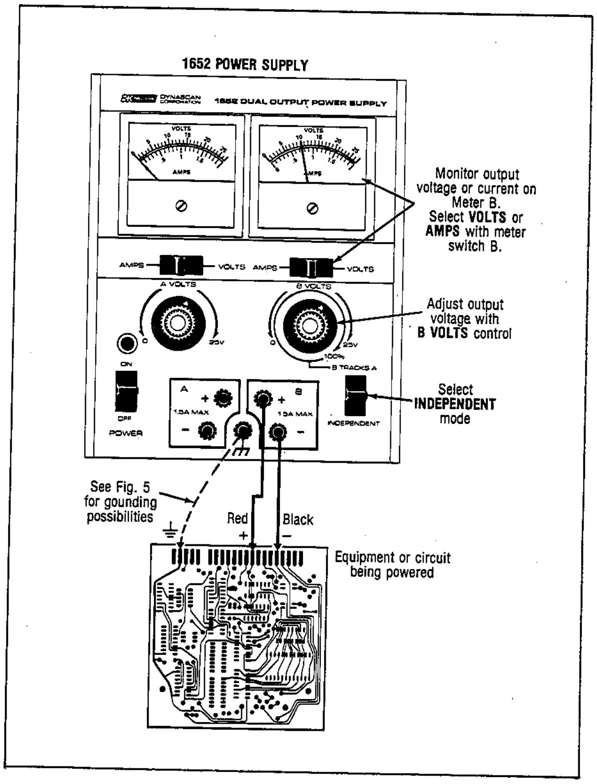


Fig. 6. Typical Use of B Supply.

7. If the desired voltage cannot be attained, current limiting is probably occurring from an overload. Place meter switch B in the AMPS position and read the output current from the 0-to-2.0 A scale of meter B. Greater than 1.5 amps indicates an overload.

8. After initial set-up and connections, place meter switch B in the AMPS position and continue to monitor the load current on meter B.

9. Voltage may be varied as desired by readjusting the B VOLTS control. Revert the meter to voltage monitoring to make such readjustments.

Considerations

All considerations are identical to those of the A supply except for consideration No. 8. Output voltage and current of the B supply cannot be simultaneously monitored on the two built-in meters.

DUAL OUTPUT (INDEPENDENT MODE)
(Refer to Fig. 7)

Both supplies may be used simultaneously if desired. The supplies may be used to power two separate pieces of equipment or to power a circuit that requires two different voltage sources. In the INDEPENDENT mode, the A and B supply voltages are independently variable.

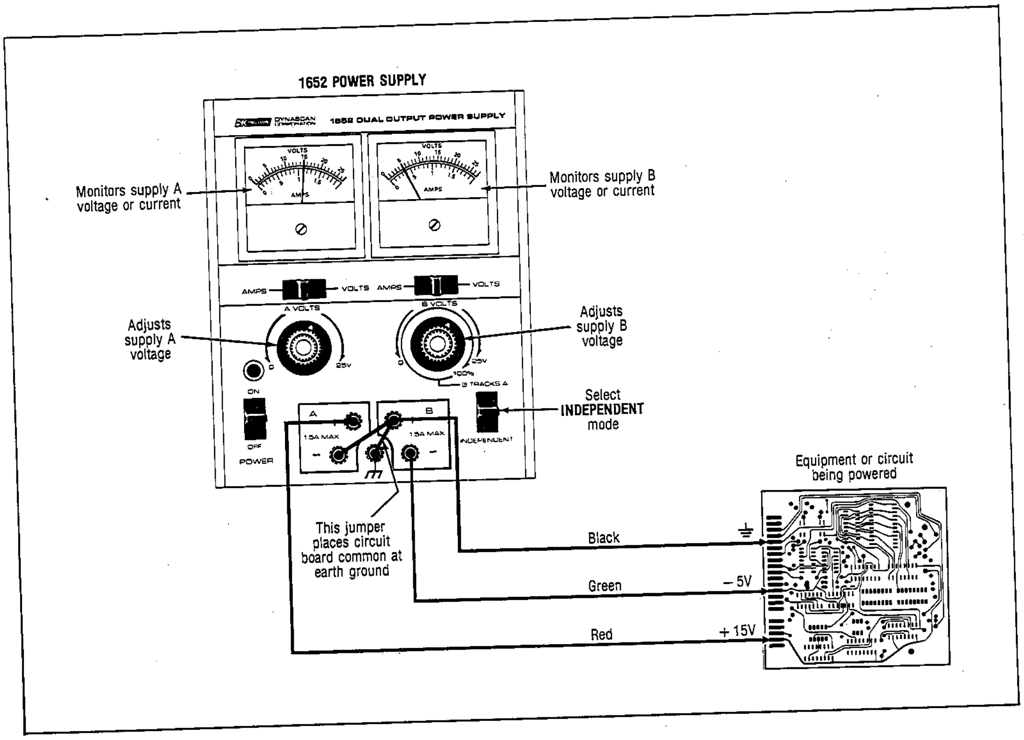


Fig. 7. Typical Simultaneous Use of Both Supplies.

Operation is virtually the same as combining the operation for each individual supply as previously described. However, when providing two voltages to a single circuit such as shown in Fig. 7, a few additional factors should be considered.

1. Each supply's output is floating and independent of the other supply. The chassis or common bus of the circuit being powered must be connected to each of the supplies. Only one common lead from the circuit being powered to the power supply is required if strapping or jumpering is used between the common terminals of the two supplies (see Fig. 7 for an example).

2. Since more connections are required, and the possibility of making an incorrect connection increases, it is even more important to turn off the power supply while making connections. Additional power lead colors provide the handiest method of preventing incorrect connections.

TRACKING OPERATION

In the tracking mode, the output voltages of both the A and B supplies can be simultaneously varied with one control. The B supply voltage is preset to any desired percentage of the A supply voltage from 0 to 100%. Thereafter, adjustment of the A VOLTS control will vary both the A and B output voltages, while retaining the preset ratio between A and B. If the tracking ratio is set for 100%, the A and B voltages will remain equal for any desired voltage setting (for highest tracking accuracy, stay within the 2-to-23 volts range). If the tracking ratio is set for 70%, the B voltage will track at 70% of whatever voltage is selected for the A supply. The A and B outputs may be connected in the same polarity (both positive or both negative), or back-to-back (one positive and one negative), or may be completely isolated, each with its own separate reference.

Procedure
(Refer to Fig. 8)

Steps 1 thru 6 should be performed before the power supply is connected to the circuit to be powered.

1. Select the B TRACKS A mode.

2. Monitor the A supply voltage on meter A.

3. Adjust the A supply voltage to the desired value with the A VOLTS control. If the tracking voltages are to be of unequal magnitude, *the A supply must be set to the higher of the two values.*

4. Monitor the B supply voltage on meter B.

5. Adjust the B supply voltage to the desired percentage of the A supply voltage with the B VOLTS control. Do not change this control setting after this step, except for a possible touch-up in Step 9. For 100% ratio, adjust for the same value on both meters (also see consideration No. 3).

6. Turn off power supply while making connections, but leave controls as previously set.

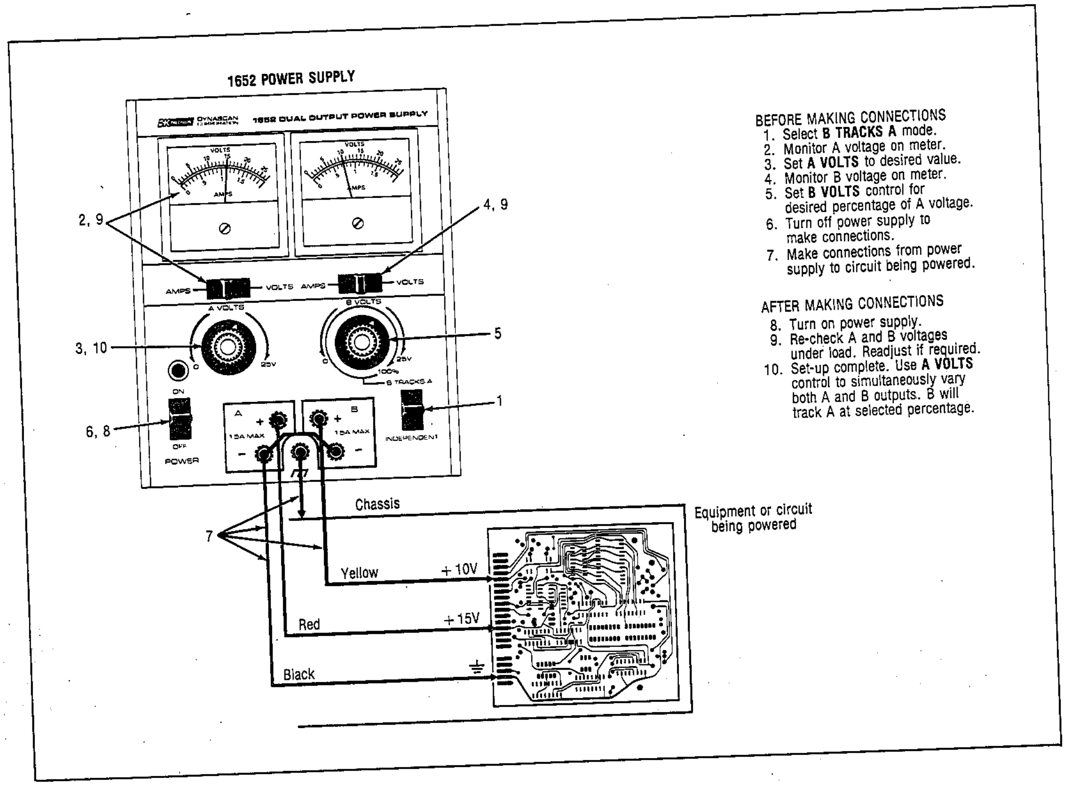


Fig. 8. Set-Up Procedure for Tracking Mode.

7. Make connections between the supplies and the circuit being powered. Connections are the same as previously described for independent operation. Figs. 8 and 9 show some typical examples.

8. Turn on the power supply.

9. Recheck voltage and current of the A and B supplies under load. Make sure that current limiting is not occurring from an overload on either supply. If any touch-up of the voltage settings is desired, first adjust the A supply voltage, then the B supply voltage. Do not readjust the B VOLTS control after this step unless you intentionally want to change the ratio between the A and B voltages.

10. The unit is now ready for tracking operation. Monitor the A supply voltage on meter A and adjust the A VOLTS control throughout the desired voltage range. The B supply will track at the preset ratio and can be monitored on meter B.

Considerations

1. For best tracking accuracy, both supplies should be operating in the 2-to-23 volt range. Tracking will operate over the entire 0-to-25 volt range, but at slightly less accuracy below 2 volts and above 23 volts. Set-up should be performed at the higher end of the desired voltage range, rather than near zero volts.

2. Tracking operation implies that the voltages are to be varied over a certain range and the results evaluated. Therefore, the ratio between the A and B supply voltages may be more critical than the specific value of voltage during set-up. If so, the A supply may be set to a convenient reference such as 10 volts. The desired ratio is then easily converted into the desired voltage for the B supply.

3. An alternate method of setting tracking to 100% is to preset the B VOLTS controls for 25.2 volts output in the INDEPENDENT mode. Without changing the B VOLTS setting, switch to the B TRACKS A mode. This corresponds to the 100% setting.

4. In the tracking mode, the B supply voltage is adjustable from at least 0 to 100% of the A supply voltage. Turn the B VOLTS control clockwise to increase the voltage; fully clockwise equals slightly more than 100%.

5. For higher tracking ratios (above 50%), more accuracy in set-up may be achieved by using an external voltmeter and measuring the difference between the A and B voltages. At 100% tracking ratio, the difference should be zero. This technique can be used regardless of whether the outputs are to be used with equal or opposite polarities if the following procedure is used.

   a. Before connecting to the circuit to be powered, strap the negative polarities of the A and B supplies together.

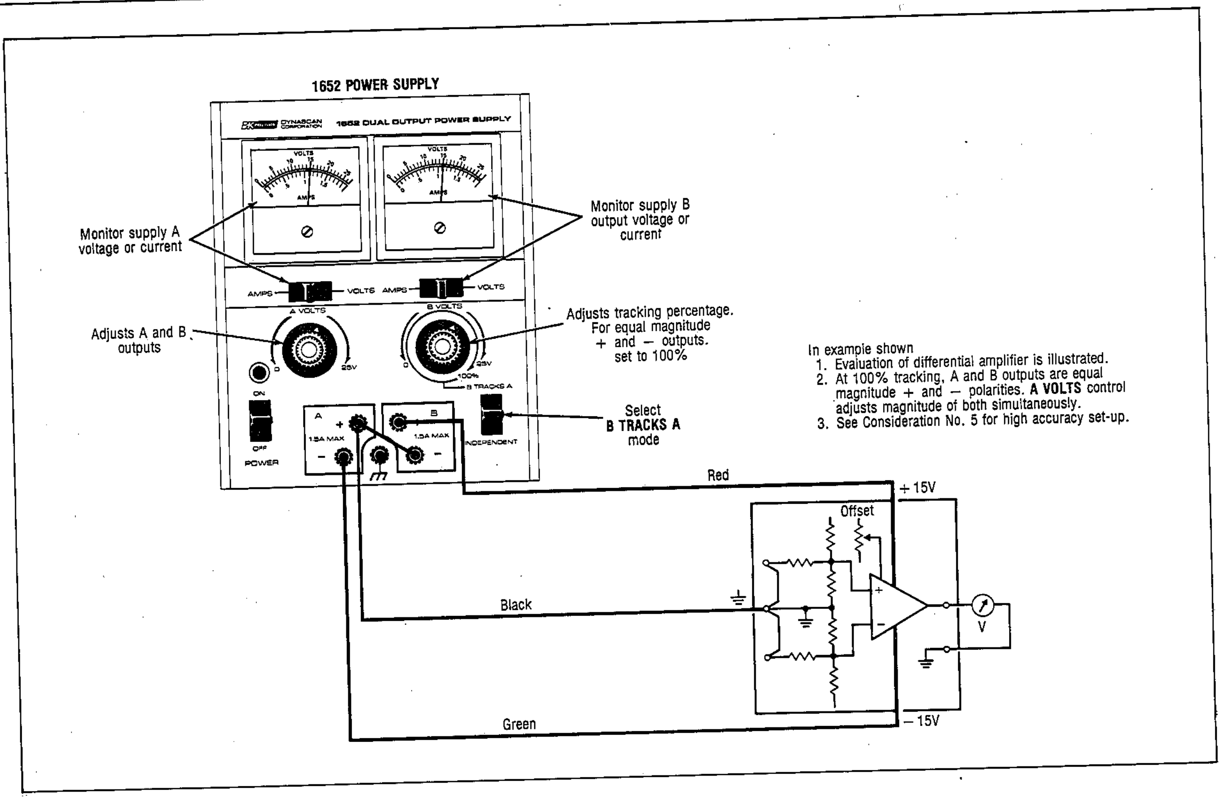


Fig. 9. Typical Use of Tracking Mode for Generating Back-To-Back Voltages.

b. Next, connect a voltmeter between the positive terminal of the A supply and the positive terminal of the B supply to measure the difference between the two voltages.

c. Adjust the A VOLTS control for the desired voltage on meter A, and adjust the B VOLTS control for the desired difference between A and B on the external voltmeter. For a tracking ratio of 100%, adjust for exact zero.

d. Remove the strap and voltmeter and connect the power supply to the equipment being powered in the desired polarity. If this technique is used, do not attempt touch-up at Step 9 of the standard procedure.

6. **CAUTION:** *Be sure to turn off the power supply or reduce the B VOLTS control setting to minimum before switching from the B TRACKS A mode to the INDEPENDENT mode. Without this precaution, overvoltage damage to the circuit being powered may occur if the circuit will not withstand 25 volts. Remember that at 100% or other high ratio tracking percentages, the B VOLTS control is at or near the fully clockwise limit. If switched to the INDEPENDENT mode in this condition, the B output immediately goes to its maximum or near maximum value of roughly 25 volts.*

Applications (Refer to Fig. 9)

Tracking voltages are useful in evaluating the effects of voltage variation on circuits that are powered from two commonly derived voltages such as shown in Fig. 8. Tracking allows both voltages to be simultaneously varied the same percentage, which accurately simulates a fluctuation of the circuit's normal power source.

Back-to-back voltages at 100% tracking are useful in evaluating differential amplifiers, such as shown in Fig. 9. Such evaluation requires that the voltage values track very closely; the precision set-up of Consideration No. 5 is recommended. The same set-up would be used to evaluate the effects of voltage variation on circuits that are normally powered from equal + and - sources (+15 volts and -15 volts for example).

CONNECTING OUTPUTS IN SERIES
(Refer to Fig. 10)

The outputs of the A and B supply may be connected in series to provide variable 0-to-50 volt output at up to 1.5 amps. See Fig. 10 for the connection scheme. A 0-to-50 volt output can be obtained in either the independent or tracking mode.

The tracking mode is the handiest for most general purpose applications. Place the mode switch in the B TRACKS A position and set the B VOLTS control for 100% ratio. Now adjust the output voltage to the desired value with the A VOLTS control. Add the meter A and meter B voltage readings to determine the total output voltage, or multiply the voltage reading on either meter by two, or an external voltmeter may be connected across the load. Load current may be monitored from either meter A or meter B;

the readings should be identical since they are connected in series.

If the INDEPENDENT mode is used, the A VOLTS and B VOLTS knobs each exercise control over a 0-to-25 volt range, giving finer adjustment of the desired output voltage.

CONNECTING OUTPUTS IN PARALLEL
(Refer to Fig. 11)

The A and B supplies may be connected in parallel to double the maximum load current. Such a configuration will provide a variable 0-to-25 volt output at up to 3 amps. Current equalizing resistors must be used as shown in Fig. 11. However, the protective current limiting feature will prevent damage if current is temporarily unbalanced during set-up.

The power supply may be operated in either the independent or tracking mode while operating with parallel outputs. The tracking mode at 100% tracking ratio is usually preferred because it is easier to maintain an approximate current balance when the voltage is changed. In either mode, use the A VOLTS control to adjust to the desired voltage and the B VOLTS control to obtain current balance. The output current of the A and B supplies should be equal. If the current equalizing resistors are not well matched, it is preferable that the A and B voltages be slightly unbalanced to achieve current balance. If a precision voltage is desired, it should be measured across the load on an external voltmeter. Total load current is the sum of A + B.

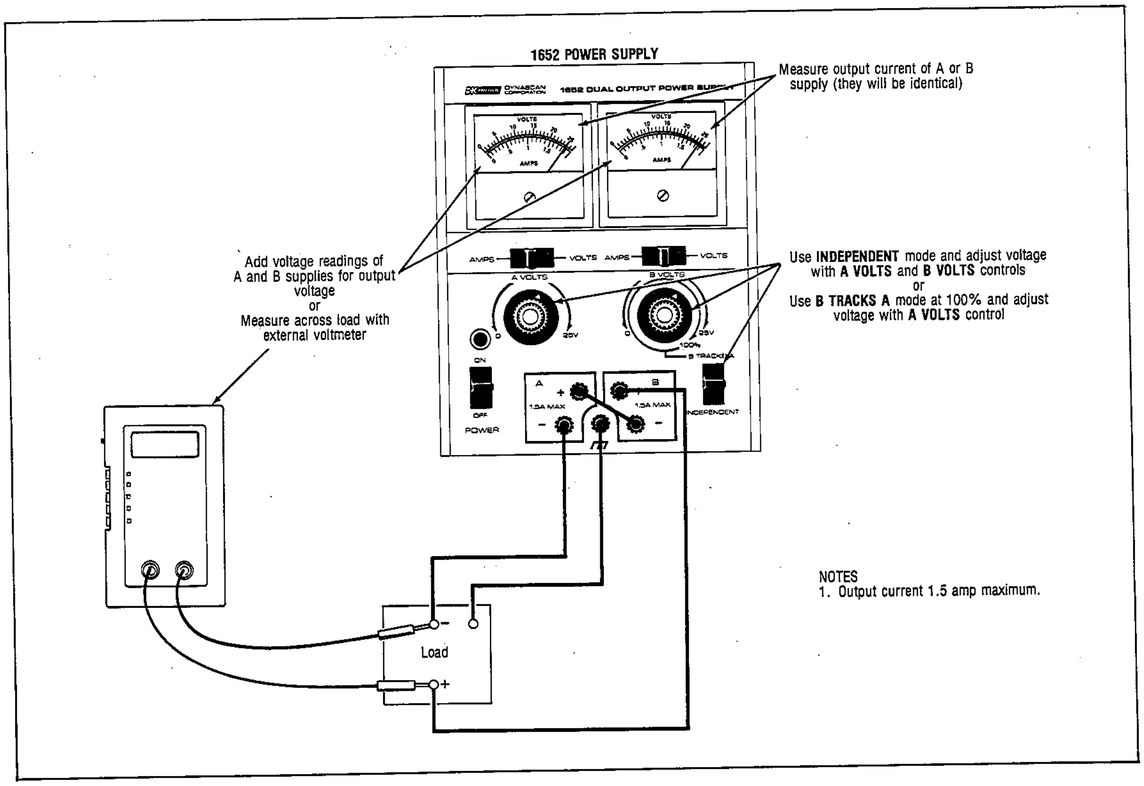


Fig. 10. Connecting A and B Supplies in Series for 0-to-50 volt output.

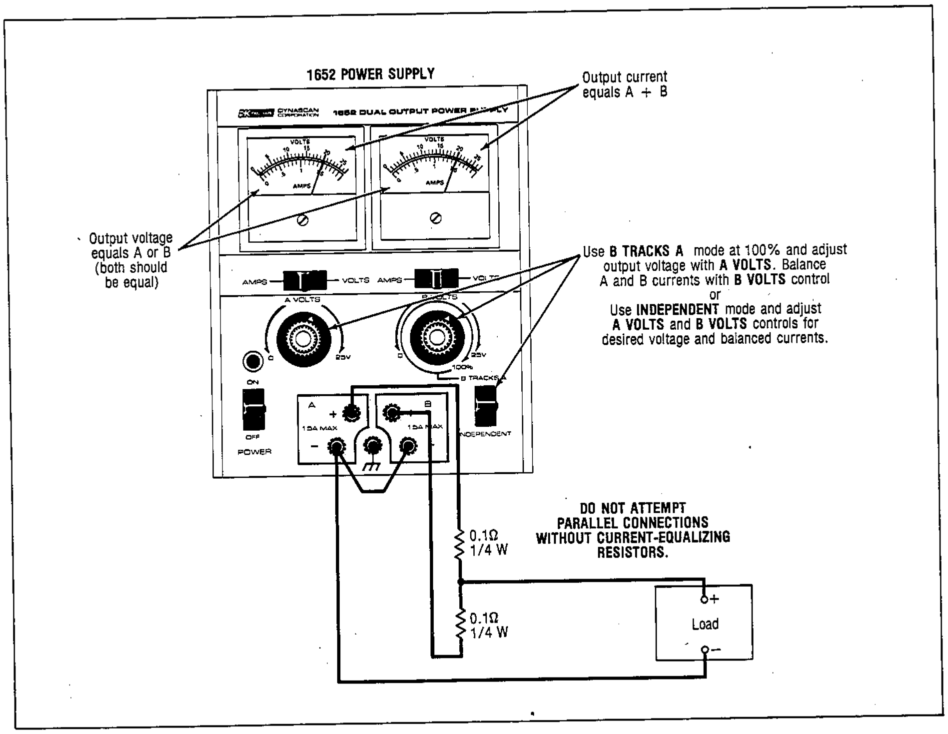


Fig. 11. Connecting A and B Supplies in Parallel for 0-to-25 Volt, 0-to-3.0 Amp Output.

CIRCUIT ANALYSIS

This circuit description can be followed completely on the accompanying figures, which separate the main circuit into smaller portions. If desired, the separately supplied schematic diagram may be consulted for an overall view.

GENERAL

As shown in Fig. 12, the 1652 consists of five major sections, the channel A preregulator, channel A linear regulator, channel B preregulator, channel B linear regulator, and the tracking circuit. Each switching preregulator limits the input of the linear regulator circuit to within 2 volts of the output voltage. The linear regulator is conventional except that dissipation in the series pass transistor is regulated by the switching preregulator. The two channels are linked together by means of the tracking circuit, which uses an opto-isolator to maintain electrical isolation between channels.

CHANNEL A SWITCHING PREREGULATOR

Overview

Refer to Fig. 13. The preregulator generates a series of triangular current pulses to charge storage capacitor C3 to maintain the voltage at point A4 at 1.8 volts above the output. Unlike most other switching supplies, pulse width modulation is not used to control the output. Rather, the repetition rate of the pulses changes to keep C3 charged sufficiently to maintain 1.8 to 2 volts across Q3. Charging pulses occur most frequently when the output voltage or current is high, and progressively less frequently as the output voltage or current is reduced. The circuit operates as follows.

Input Voltages

The transformer secondary voltage is fed to diodes D1 and D2, and capacitor C1, which furnish a full-wave rectified dc level of approximately 35 to 50 volts at the collector of Q1. This voltage is used to charge C3 as required, and is also fed to IC8. This 15-volt regulator is referenced to 16 volts by divider R84 and R85 to provide a 31 volt output to power IC1, IC2, and IC3. Full-wave rectified -15 volts is provided by D7, D8, R16, and C6 to be used in the linear regulator.

Initiation of Charging Pulse

V_{ce} of pass transistor Q3 is scaled down to furnish the emitter-to-base voltage of Q5 via resistors R24 and R25. The ratio is set so that 1.8 volts across Q3 equals the turn-on threshold of Q5. If the voltage is not at that threshold (if, say, C3 is "catching up" after the A VOLTS control has been quickly turned up), Q5 turns off, cutting off the flow of current through R20 and lowering the voltage at IC1b pin 4 toward zero. This is compared with a reference supplied by IC1c, and the amplified difference appears at IC1b pin 13. As

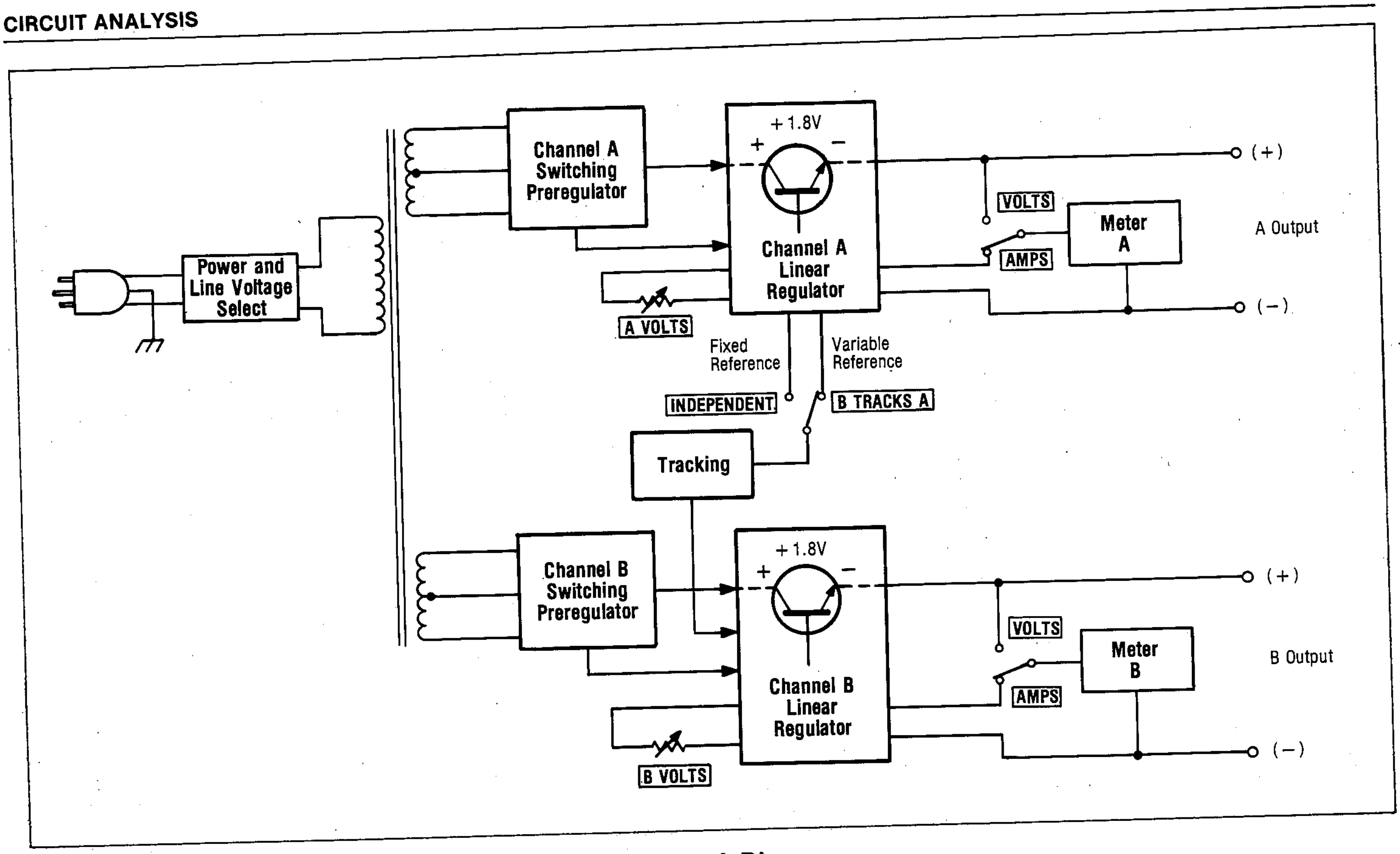


Fig. 12. Block Diagram.

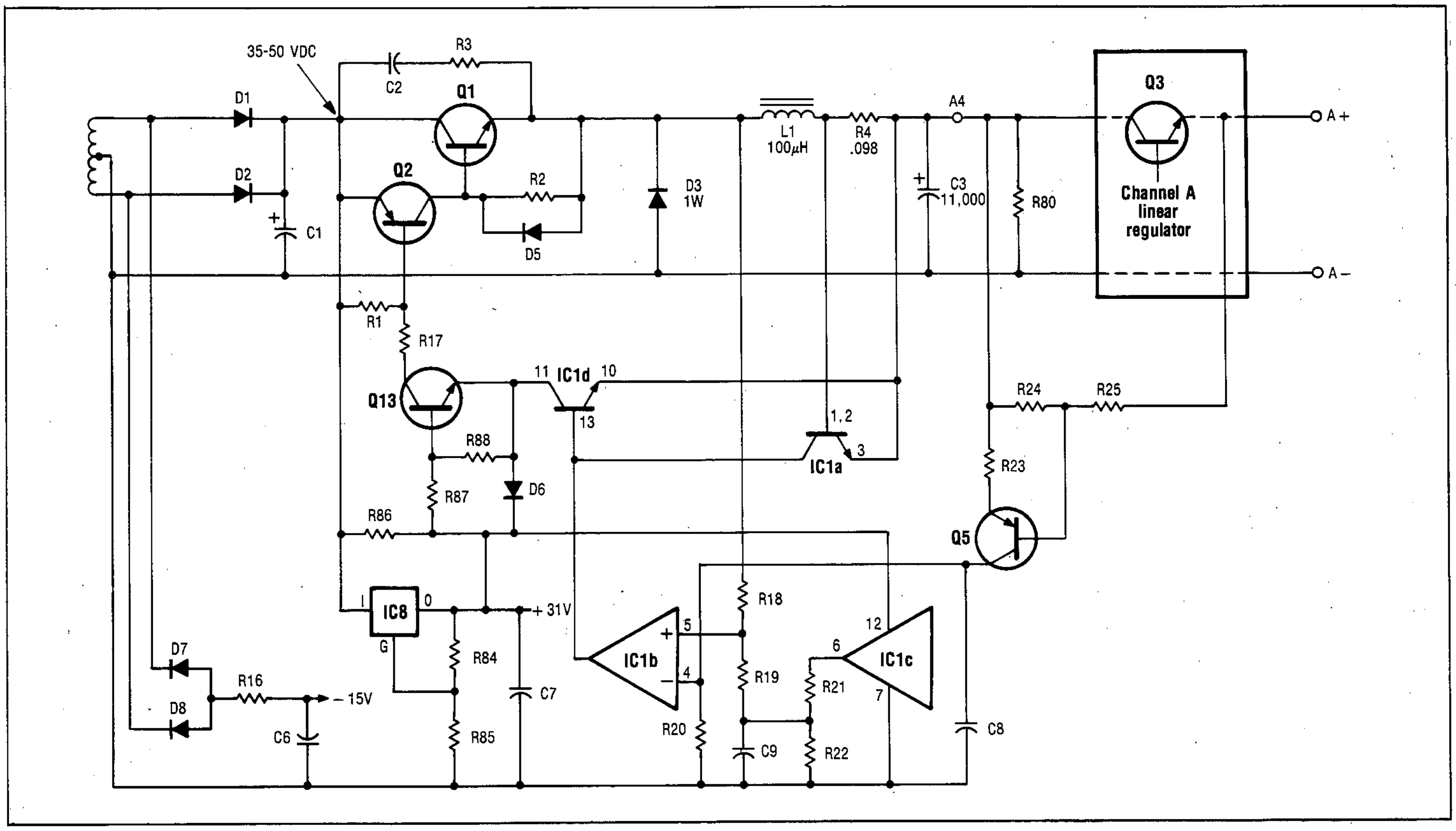


Fig. 13. Channel A Switching Preregulator.

the R20 voltage goes to zero, the result at pin 13 tries to approach the 31 volt supply. The base of transistor IC1d is now positive with respect to point A4, where the emitter is connected. This turns on IC1d, and the resultant conduction through R88 turns on Q13. Accordingly, R1 conducts, switching Q2 on, and finally, the current through R2 turns on Q1. Current is thus fed to charge up C3. This situation is the interval from t_0 to t_1 in Fig. 14a, which gives the switching waveform at the emitter of Q1.

Charge Pulse Waveform

Once Q1 "closes", the following process shapes the current into a pulse. When Q1 first turns on, the charging current starts at zero and ramps upward. The inherent counter-emf of choke L1 defines the time interval required for the current to reach its maximum value of six amps. When this point is reached, the voltage across R4 becomes sufficient to turn on transistor IC1a. The V_{be} of IC1d then goes very low, regardless of IC1b. Conduction through R88 ceases, switching off Q13, Q2, and Q1. The collapsing magnetic field of L1 maintains the flow of charging current into C3, though now the current flows through free-wheeling diode D3 rather than through Q1. A certain amount of hysteresis prevents IC1a from turning off immediately, so Q1 stays off, and the current ramps back down toward zero. This condition is shown as the interval t_1 to t_2 in Fig. 14a.

Triangular pulses are thus formed whose repetition rate changes as determined by the voltage requirements. (Fig. 14b. shows these pulses, and their time relationship to the switching waveform of Fig. 14a.) The basic triangle shape of the pulses varies according to output level. This is because the rate of change of the current is dependent on the voltage across L1, which is, in turn, dependent on the output voltage and the current state of Q1 (on or off).

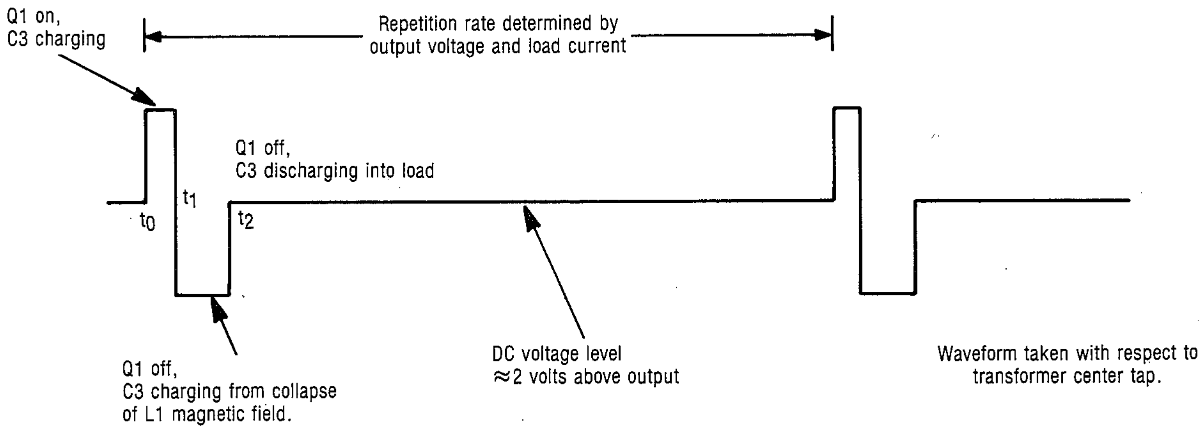
Non-Charging Period

If the voltage across Q3 is greater than 1.8 volts, Q5 turns on, and the R20 voltage rises, bringing the IC1 pin 13 voltage toward zero. The V_{be} of IC1d thus drops, turning it off, and switching off Q13, Q2, and Q1, effectively cutting off the charging current. No new pulses are generated until the Q3 voltage goes somewhat below the threshold, due to hysteresis of Q5. This non-charging period is represented by the interval after t_2 in Fig. 14a.

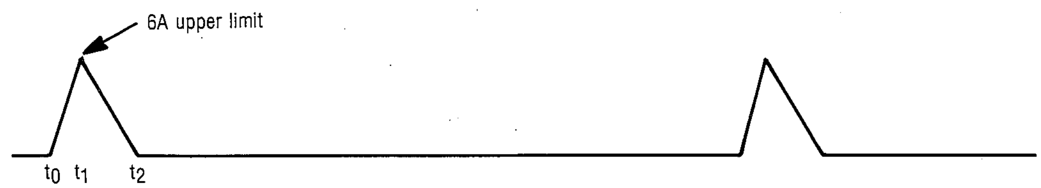
CHANNEL A LINEAR REGULATOR

Output Regulation

Refer to Fig. 15. IC2c provides a constant reference to comparator IC2b. This is compared with the combination of the voltage of the A VOLTS control, R35, and feedback from the output through R30. The result is used to control the pass transistor. For example, if the output tries to go a bit lower than specified, the IC2b output rises, resulting in more conduction through IC2d. Greater current through R90 turns Q14 on harder, resulting in more conduction through R6. This increases conduction through Q4 and R7, resulting in an increase in the charging current through Q3 into C4 and C5. The output thus rises to the proper level.



a. Waveform of voltage at emitter of Q1.



b. Waveform of voltage across (current through) R4.

Fig. 14. Switching Preregulator Waveforms.

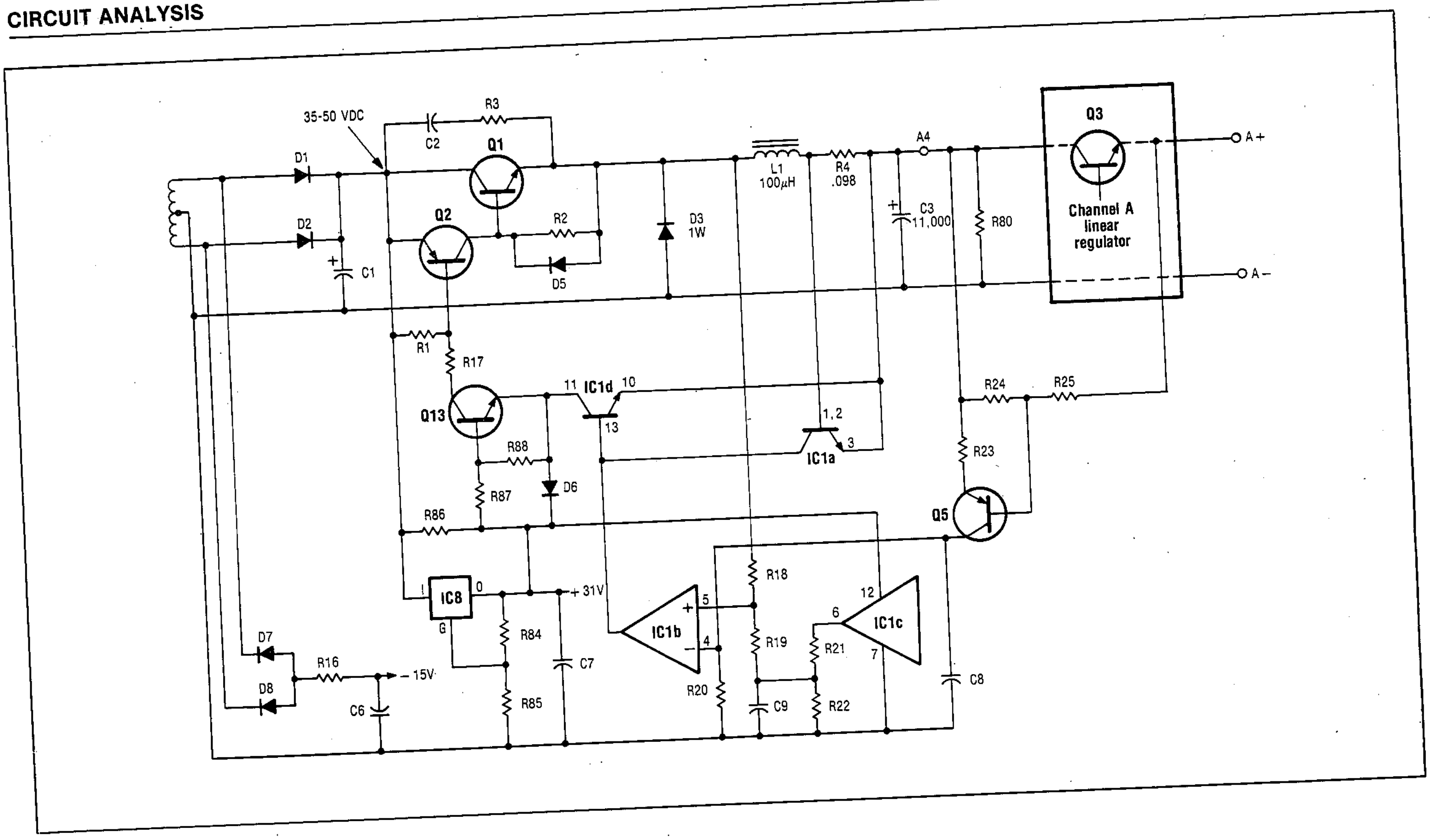


Fig. 15. Channel A Linear Regulator.

If the output tries to go higher than specified, the reverse occurs. The IC2b output goes lower, decreasing the conduction of IC2d, Q14, Q4, and Q3. Charging current to C4 and C5 is thus reduced.

Q3 is strapped to -15 volts via R10 to enable it to maintain an adequate collector-to-emiter current at outputs near zero volts.

Current Limiting

Output current is monitored by resistor R9. At approximately 1.8 amps, the voltage across it reaches the threshold for turn-on of IC2a. When this occurs, the output of IC2b is unable to increase any further regardless of inputs, and IC2d and the three transistors dependent on it are prevented from any further increase in conduction. The output voltage remains at the level determined by current limiting.

CHANNEL B SWITCHING PREREGULATOR

This section is made up of exactly the same types of components as its channel A counterpart, and functions in the same manner. By using the separate schematic diagram, the operation of this preregulator can be analyzed following the above channel A description.

CHANNEL B LINEAR REGULATOR

Refer to Fig. 16. The operation of this section is also basically the same as that of channel A. It should be noted, however, that the output is fed back through divider R66 and R68 to be compared in IC5b with the B VOLTS voltage from R70. The R70 reference voltage is derived from the A supply via the tracking circuit. In INDEPENDENT mode, is a constant, obtained from pin 6 of IC2c (Fig. 17). In B TRACKS A mode, it varies according to the channel A output, as described below.

TRACKING CIRCUIT

Opto-Isolator

Refer to Fig. 17. The heart of the tracking circuit is opto-isolator IC6. The input section of this device consists of two IREDs (infrared emitting diodes) which convert electrical current into light energy. The output section uses two light-sensitive photo diodes driving output transistors. When light energy is directed to the photo-diode junctions, the output transistors conduct. Conduction in the output is proportional to the amount of input conduction, but electrically isolated. The proportionality in a given device is quite linear, and R71 is provided as a means of compensating for variations in the transfer ratio from device to device.

Tracking Circuit Operation

When the tracking switch is set to B TRACKS A, the channel A output is scaled down and fed to pin 5 of IC3. IC3 attempts to equalize the pin 5 and 6 voltages by sending the appropriate current through the feedback path, which includes pins 1 and 2 of the opto-isolator. This current causes

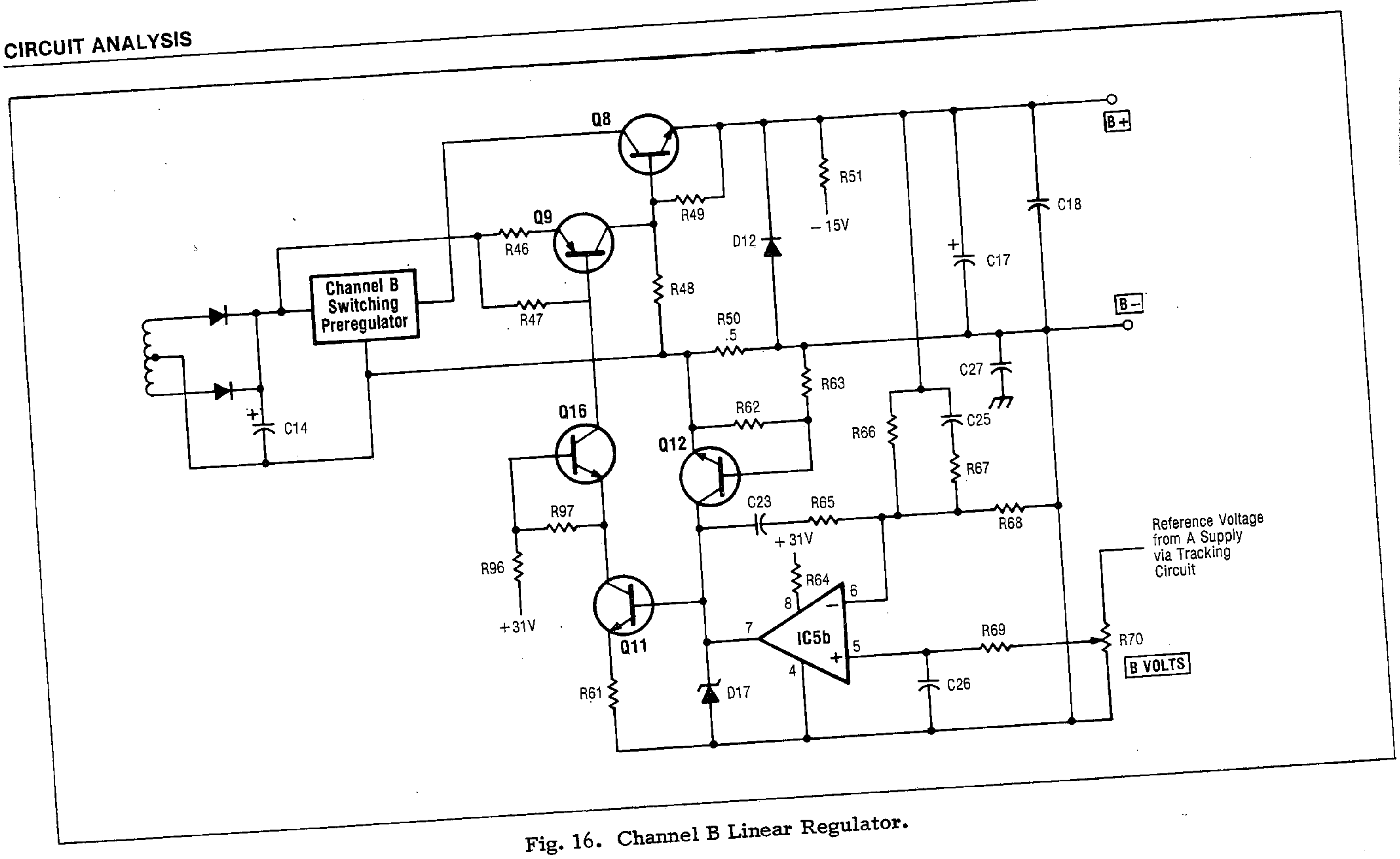


Fig. 16. Channel B Linear Regulator.

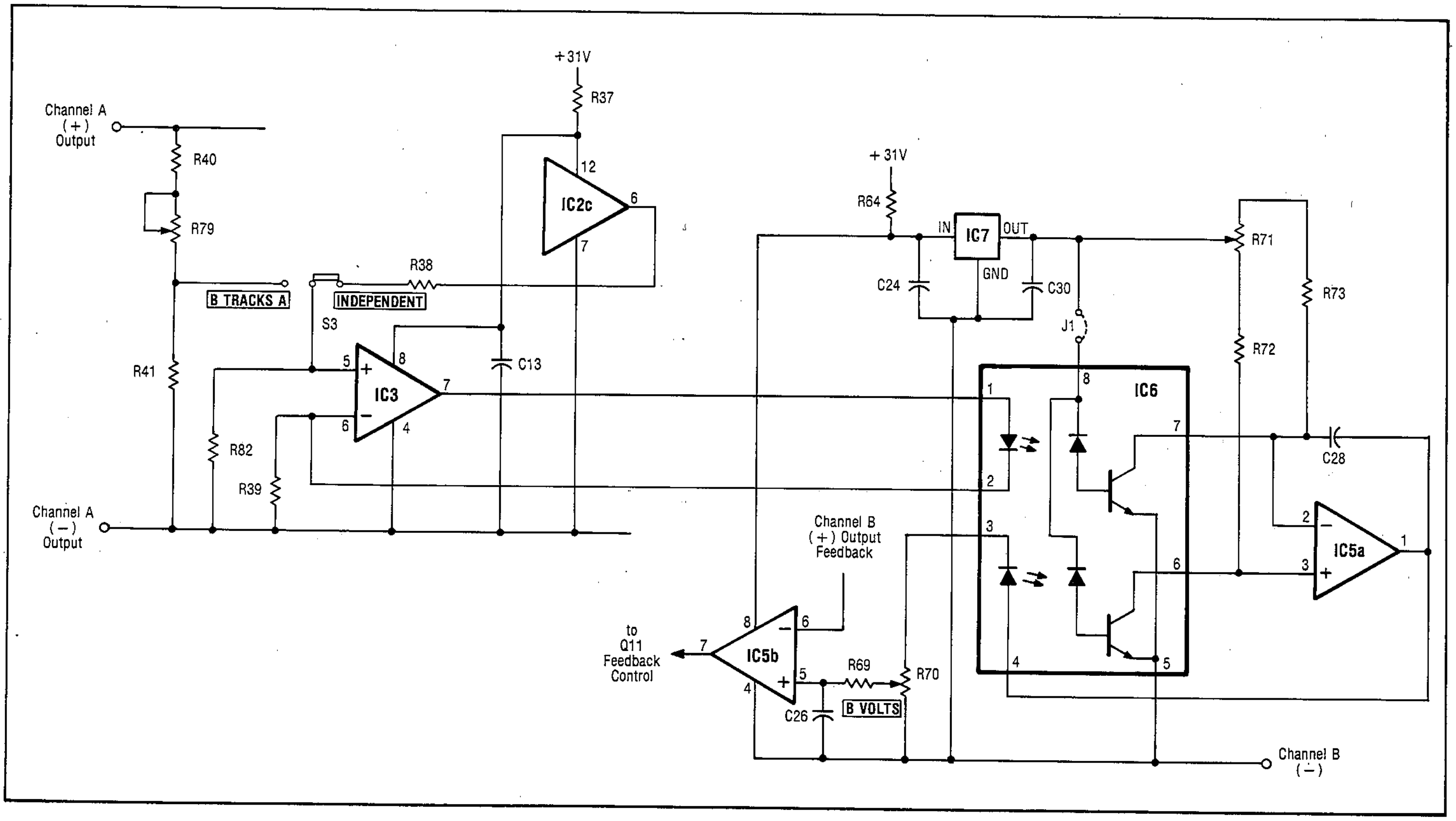


Fig. 17. Tracking Circuit.

the IRED at pins 1 and 2 to light, causing conduction in the corresponding output transistor. A voltage drop is thus produced across R73 and part of R71, showing up at IC5a pin 2. The output of IC5a sources current to the IRED at IC6 pins 3 and 4. This produces a voltage drop across R72 and part of R71, which is just enough to equalize the voltages at IC5a pins 2 and 3. The same current flows through the B VOLTS control R70; since the channel B regulator reference is dependent on this pot, the reference will increase or decrease according to the channel A output.

CHANNEL A AND B METERING

Each of the front panel meters is connected in the same fashion as in Fig. 18, which shows the channel A connections. In the VOLTS position, the meter is connected across a scaled portion of the output voltage via divider R13, R14, and R15 and calibrated for proper voltage reading. In the AMPS position, it is connected to read the voltage across the current sensing resistor R9, and scaled to read in amps by means of R12.

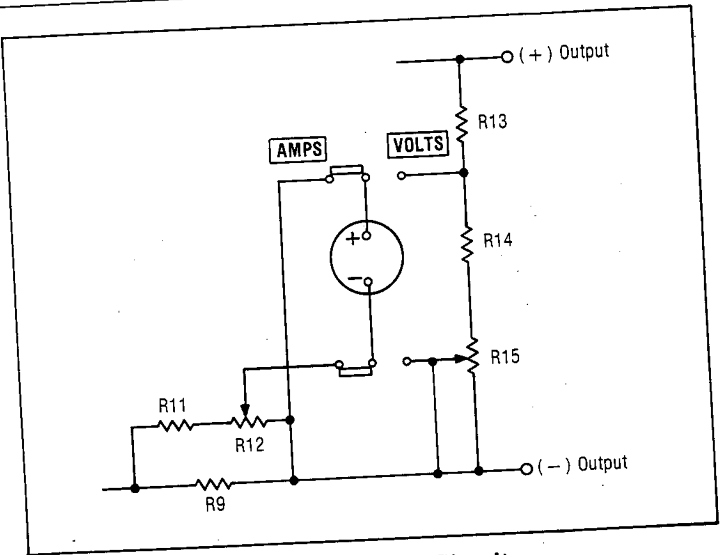


Fig. 18. Metering Circuit.

MAINTENANCE AND CALIBRATION

WARNING

1. *The following instructions are for use by qualified personnel only. To avoid electric shock, do not perform servicing other than contained in the operating instructions unless you are qualified to do so.*

2. *When the unit is plugged into an ac outlet, even if POWER switch is OFF, ac line voltage is present on the POWER switch area of the circuit board. Observe caution any time the case is removed from the instrument.*

LINE VOLTAGE CONVERSION

The Model 1652 Power Supply may be operated from nominal line voltage of 100, 120, 220, or 240 VAC, 50/60 Hz. The unit may be converted from one of these line voltages to any other by simply operating the two LINE VOLTAGE SELECT switches on the rear panel. Procedures are given at the beginning of the OPERATING INSTRUCTIONS section of this manual (refer to Fig. 3). Whenever the line voltage is changed, also be sure the correct fuse value is installed.

FUSE REPLACEMENT

The fuse is in series with the primary of the power transformer. If the fuse blows, there will be no output from either of the two supplies and the pilot light will not operate. Automatic current limiting protects the power supply from overloading; thus, the fuse should not normally open unless a problem has developed in the unit.

Try to determine and correct the cause of the blown fuse, then replace only with a fuse of the correct value; 1-1/2 amp slow-blow for 100 or 120 volt operation, 3/4 amp slow-blow for 220 or 240 volt operation. The fuseholder is externally accessible from the rear panel of the unit.

DISASSEMBLY

Removal of Top Cover

The top cover must be removed from the power supply for performing all maintenance and calibration adjustment procedures and for troubleshooting and servicing. Virtually all testing and troubleshooting can be performed without further disassembly. To remove the top cover, remove the screws from the top and sides of the case and lift off the cover.

Circuit Board Removal

Board removal is not normally required except for parts replacement of board mounted components. For access to the component side of the circuit board, first detach capacitors C3 and C16 from the chassis for more clearance, the remove the four mounting screws (two at top and two at bottom of board) and pull the board away from the front panel. The slide switches are board mounted, but no knob removal is required. All other front panel controls and meters are hard wired to the board with a service loop.

Chassis Mounted Parts

Some of the larger components of the power supply are mounted on the chassis. Fig. 19 and 20 identify those parts.

CALIBRATION ADJUSTMENTS

This unit was carefully checked and calibrated at the factory prior to shipment. Readjustment is recommended only if repairs have been made in a circuit that affects calibration, or if you have reason to believe the unit may be out of calibration. If the accuracy of the test equipment used for calibration is less than specified, the accuracy of the 1652 will be proportionaltely degraded. Perform calibration adjustments at room temperature and normal line voltage after a 30-minute warmup. Locations of calibration adjustments are shown in Fig. 20.

Test Equipment Required

1. Multimeter, dc voltage accuracy of 0.5% or better; dc current accuracy of 1% or better at 1.5 amps; **B & K-PRECISION** Model 2845 or equivalent.

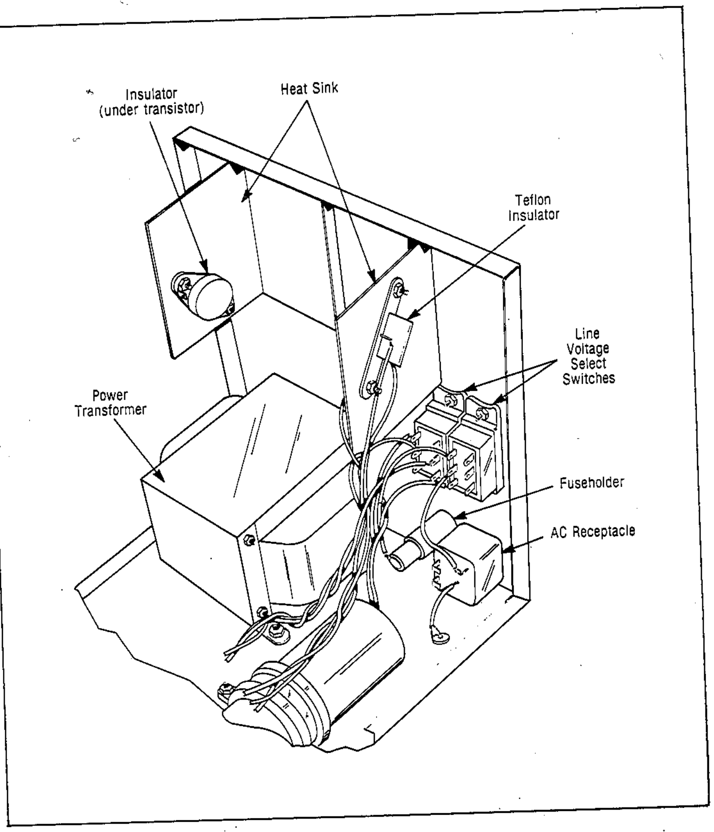


Fig. 19. Chassis Mounted Parts.

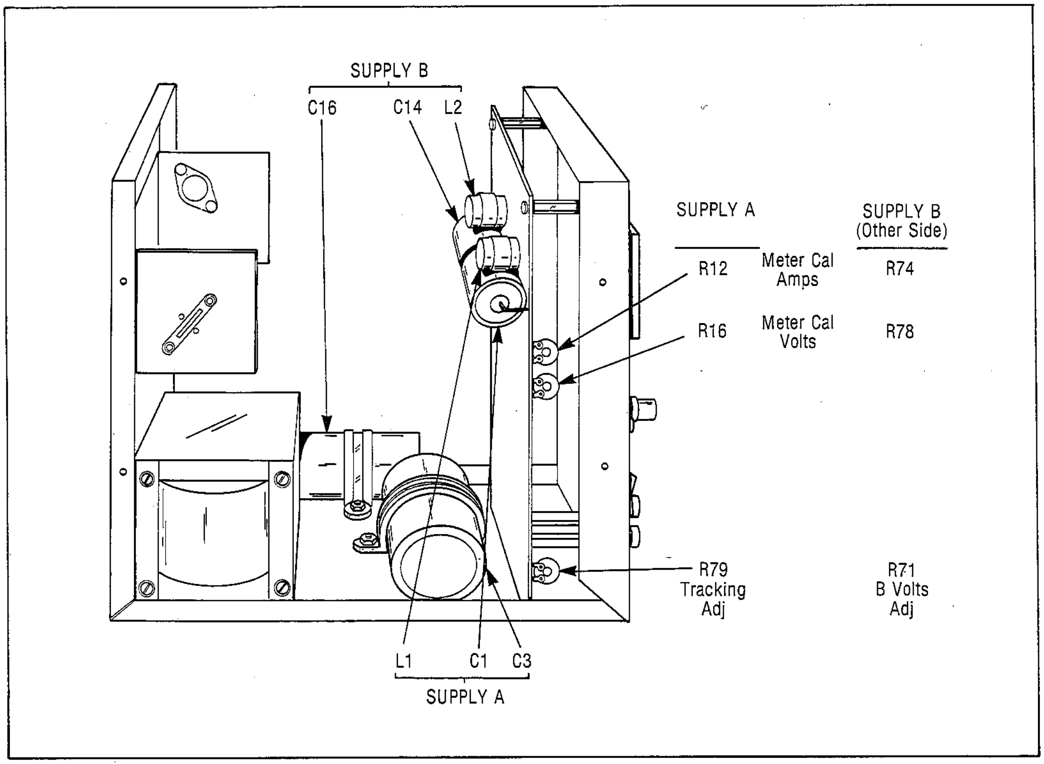


Fig. 20. Additional Chassis Mounted Parts and Locations of Calibration Adjustments.

2. Power supply load. Must load each supply to 1.5 amps. A variable load such as an electronic load or power resistor decade box may be used, but a 10-ohm fixed load of at least 40 watts rating is also suitable.

B Volts Adjustment

1. Connect an external multimeter, set up to measure voltage, across the output terminals of the B supply.
2. Select the INDEPENDENT mode and set the B VOLTS control to maximum (fully clockwise).
3. Adjust R71 (B volts adj) for a reading of 26.5 to 27.0 volts on the multimeter.

Tracking Adjustment

1. Perform the B volts adjustment.
2. Connect an external multimeter to measure the output voltage of the B supply.
3. While still in INDEPENDENT mode, set the B VOLTS control for precisely 25.2 volts on the multimeter. Do not change the B VOLTS knob setting after this step.
4. Next, connect the multimeter to measure the output of the A supply.
5. Adjust the A VOLTS control for precisely 25.2 volts on the multimeter. Do not change A VOLTS knob after this step.
6. Connect the multimeter to measure the voltage difference between the A and B supplies. Jumper together the negative polarities of the A and B supplies. Connect the + meter lead to the A supply + terminal and the - meter lead to the B supply + terminal.
7. Set the mode switch to the B TRACKS A mode and adjust R79 (tracking adj) for 0 volts ±10 mV on the multimeter.

Meter A VOLTS Calibration

1. With the power supply turned off, adjust the mechanical zero of meter A to exact zero.
2. Connect an external multimeter of ±0.5% or better dc voltage accuracy to the A supply output terminals.
3. Turn on the power supply and set the A VOLTS control for 25.0 volts on the multimeter.
4. Set meter switch A to VOLTS.
5. Adjust R15 (meter A volts adj) for 25.0 volts reading on meter A.

Meter B VOLTS Calibration

1. With the power supply turned off, adjust the mechanical zero of meter B to exact zero.
2. Connect an external voltmeter of ±0.5% or better dc voltage accuracy to the B supply output terminals.

3. Turn on the power supply and select the INDEPENDENT mode.

4. Set the B VOLTS control for 25.0 volts on the multimeter.

5. Set meter switch B to VOLTS.

6. Adjust R78 (meter B volts adj) for 25.0 volts reading on meter B.

Meter A AMPS Calibration

1. Connect a fixed 10-ohm load of at least 40 watts, or a constant-current type electronic load across the output of the A supply.

2. Connect a calibrated multimeter of ±1% or better dc current accuracy in series with the load to measure dc current.

3. If a fixed 10-ohm load is used, set the A VOLTS control for 1.50 amps on the multimeter (which should occur at approximately 15 volts on meter A).

4. If a constant-current type electronic load is used, set it for 1.5 amps load. Any setting of the A VOLTS control may be used; the multimeter should read roughly 1.5 amps. Note the exact reading for reference in step 6.

5. Set meter switch A to AMPS.

6. Adjust R12 (meter A amps adj) for precisely the same reading on meter A that was obtained on the external multimeter in step 3 or 4.

Meter B AMPS Calibration

1. Connect a fixed 10-ohm load of at least 40 watts, or a constant-current type electronic load across the output of the B supply.

2. Connect a calibrated multimeter of ±1% or better dc current accuracy in series with the load to measure dc current.

3. Select INDEPENDENT mode.

4. If a fixed 10-ohm load is used, set the B VOLTS control for 1.50 amps on the multimeter (which should occur at approximately 15 volts on meter B).

5. If a constant-current type electronic load is used, set it for 1.5 amps load. Any setting of the B VOLTS control may be used; the multimeter should read roughly 1.5 amps. Note the exact reading for reference in step 7.

6. Set meter switch B to AMPS.

7. Adjust R74 (meter B amps adj) for precisely the same reading on meter B that was obtained on the external multimeter in step 4 or 5.

PERFORMANCE TESTS

Functional Checks

The following checks test all functions of the power supply for proper operation. The sequence of the checks also provides a logical symptom and fault isolation technique for troubleshooting. After troubleshooting and repair, these tests should be performed to assure that all faults have been corrected.

1. Before the power supply is turned on, meter A and meter B should rest at exact zero. If mechanical zero adjustment is required, meter adjustments should also be recalibrated.

2. Set the POWER switch to ON. The pilot light should illuminate.

3. Set meter switch A to VOLTS and rotate the A VOLTS control to minimum (fully counterclockwise). The output should go to 0 volts, or slightly negative, as read on meter A.

4. Rotate the A VOLTS control to maximum. The output should go to at least 25 volts, as read on meter A.

5. Short circuit the output of the A supply and note that the voltage drops to near zero.

6. Set meter switch A to AMPS; current limiting should be observed on meter A at 1.7 to 1.9 amps.

7. Remove the short circuit from the A supply output terminals and set the mode switch to the INDEPENDENT mode.

8. Set meter switch B to VOLTS and rotate the B VOLTS control to minimum (fully counterclockwise). The output should go to 0 volts as read on meter B.

9. Rotate the B VOLTS control to maximum. The output should go to at least 25 volts as read on meter B.

10. Short circuit the output of the B supply. Note that the output voltage drops to near zero.

11. Set meter switch B to AMPS; current limiting should be observed on meter B at 1.7 to 1.9 amps.

12. Remove the short from the output terminals of the B supply, set the mode switch to the B TRACKS A mode, and return both meter switches to VOLTS.

13. Set the B VOLTS control for 100% tracking (both voltages equal at 20 volts). Vary the A VOLTS control. The meter B reading should equal the meter A reading for all values from 2 to 23 volts.

14. With the A and B outputs at 25 volts, momentarily short circuit the A supply output and note that both the A and B output voltages both drop to near zero.

15. Momentarily short circuit the B supply output and note that the B output voltage drops to near zero, but the A output voltage remains at 25 volts.

Specification Checks

If the unit successfully completes the functional checks, the following additional tests may be performed, if desired, to verify that the power supply meets specifications and to determine whether adjustments may be required.

1. Meter accuracy may be checked by using a calibrated external multimeter to measure voltage and current outputs of supply A and B. The multimeter readings are then compared with the readings obtained on meter A and B. Voltage readings should correspond within 1.25 volt from 0 to 25 volts. Current readings should correspond within .075 amp from 0 to 1.5 amps; rotating the A VOLTS and B VOLTS controls will provide a variable current to a fixed 10-ohm load.

2. Tracking accuracy may be checked by setting tracking to 100% and measuring the difference between the A and B outputs on an external voltmeter. Difference voltage should be ±1% of reading ±250 mV over the 2-to-23 volt range.

3. Load regulation may be checked by measuring output voltage at full load (1.5 amps) and no load. Variation should not exceed 20 mV at any output voltage from 0 to 20 volts. Variation should not exceed 0.1% of output above 20 volts (25 mV at output of 25 volts).

4. Line regulation may be checked by measuring output voltage while varying the input voltage ±10%. A variable isolation transformer is normally used to vary the input line voltage. Variation of the output voltage should not exceed ±0.1%.

5. Ripple voltage should be measured at full load on an ac coupled oscilloscope. Ripple voltage should not exceed 2.5 mV rms (20 mV peak to peak).

TROUBLESHOOTING

If the previously listed "Functional Checks" are performed in the sequence listed, this provides a logical approach to defining symptoms and isolating defective circuitry. The following information may help further isolate the problem.

No Pilot Light

This symptom indicates a fault in the primary power circuit. The following checks should isolate the problem.

1. Make sure the unit is plugged into a "live" outlet.

2. Check the fuse and replace if burned out.

   a. If fuse is okay, verify whether there is any output from the A or B supply. If output is available, the pilot light bulb is probably defective.

   b. If no output is noted in step a., the trouble is probably an open in the power transformer primary circuit. Check continuity of the power cord, fuseholder, POWER switch, LINE VOLTAGE SELECT switches, power transformer, and the wiring interconnecting these parts.

c. If replacement fuse burns out when unit is turned on, disconnect secondary leads of power transformer and replace fuse again.

(1) If fuse does not blow, trouble is in transformer secondary circuit. Reconnect secondaries, one at a time to isolate circuit with fault. A possible fault is a shorted rectifier diode D7, D8, D15, and D16. If one of these diodes is shorted, it shorts out a secondary winding and cause repeated blown fuses. Diodes D1, D2, D9, or D10 could also cause such a symptom, but are less suspect because of their rugged characteristics.

(2) If fuse still blows, trouble is short in primary wiring or within the power transformer.

A or B Outputs Do Not Adjust to Zero

This symptom usually denotes loss of -15 volts. There is a separate -15 volt circuit for each supply.

A or B Outputs Do Not Adjust to 25 Volts

Check the the LINE VOLTAGE SELECT switches are set to the correct line voltage. If switches are set to 220 or 240 volt positions and operated from 100 or 120 VAC power, maximum output will be about 12 or 15 volts.

If LINE VOLTAGE SELECT switches are ok, the problem probably lies in one of the reference voltage dividers. For channel A, check voltages and resistances in divider networks R31/R32, and R30/R34/R35/R36. For channel B, check divider networks R38/R82, R66/R68, and R71/R72/R73.

No Output From Either Supply

Most of the circuits for the A supply and B supply are independent; thus, this symptom indicates a failure in a circuit that is common to both supplies. Check IC2c (pin 6, 7, 12) and its circuit. This circuit establishes the reference voltage for both the A and B supplies. Also check for possible loss of regulated +31 V (A); i.e., regulator IC8. Another possibility, of course, is separate failures in both the A and B supply.

A Supply Normal, No Output From Supply B

This symptom could be caused by a fault in the switching preregulator or linear regulator of the B supply, or could be in the reference voltage/opto-isolator circuit. Temporarily jumper from +31 V (B) to the high end of the B VOLTS control (R70). If output is now obtainable from the B supply, a failure in the reference voltage/opto-isolator is indicated. Check IC3, IC5a (pins 1, 2, and 3), IC6 (opto-isolator), and IC7 (see Table 1 for IC6 and IC7).

If no output is obtainable with the temporary jumpering, the problem is in the switching preregulator or linear regulator section of the B supply. An isolation technique is given in the "Troubleshooting Switching Preregulator" paragraph.

B Supply Normal (INDEPENDENT Mode), No Output From A Supply

This symptom indicates a failure in the switching preregulator or the linear regulator of supply A. However, regulated +31 V (A) and IC2c are okay, since these circuits are also used in supply B. An isolation technique is given in the "Troubleshooting Switching Preregulator" paragraph.

Troubleshooting Switching Preregulator

The following technique applies equally to supply A or supply B. For simplicity, component designations are those for supply A.

The primary purpose of the preregulator is to limit the voltage across the pass transistor. Therefore, a fairly accurate indication of proper preregulator operation can be made by measuring the voltage from collector to emitter of Q3. If it is between 1.8 and 2 volts, it is almost a certainty that the preregulator is operating normally. Refer to the paragraph on "Troubleshooting Linear Regulator" for further fault isolation.

If the Q3 voltage is not within the proper range, then a fault probably exists in the preregulator. However, before proceeding, check Q3, Q4, and R5. If the preregulator is faulty, chances are good that one of these components has also subsequently burned out. (If the preregulator is stuck at the transformer input voltage, overdissipation in Q3 results. If preregulator is always off, Q4 and R5 become a series pass regulator circuit and overdissipation in those components results.)

The value of R5 can be measured in-circuit. Normal value should be about 47 Ω; a short or opening in this resistor will be readily apparent without removal. Q3 and Q4 can be checked using the information of Table 1, which gives in-circuit resistances of various transistor and IC junctions and other components in the supply. (pay particular attention to the footnotes concerning type of ohmmeter, etc.).

If Q3, Q4, or R5 were replaced, or if they all checked normal, recheck the voltage across Q3. If it is not within 1.8 to 2 volts, the preregulator is defective. The two most likely conditions are zero or negative voltage (preregulator always off) and roughly +40 volts (preregulator always on). Since the preregulator consists of a closed loop, a failure anywhere in the loop will cause all voltage readings to be abnormal.

Exceptions are the constant 7.1 volts at IC1 pin 6, and the constant +31 volts at the output of IC8. The first value would be affected only by faults in IC6, IC8, R21, or R22; the second would only be affected by problems in IC8, R84, R85, or the input rectifier circuit. Table 1 gives values of various resistances within IC8.

For the rest of the circuit, however, fault isolation consists of ohmmeter checks of transistor and IC junctions, and other components as follows.

Check Q1, Q2, Q13, Q5, D6, and D3 according to Table 1. Test R4 for a break (positive ohmmeter lead must go to point A4 for valid reading). Test transistors IC1d and IC1a (IC1a base-to-emitter measurement requires removal of R4 from circuit), and check resistance from pin 13 to pin 12.

After a faulty component has been located and replaced, normal operation may be checked using the schematic diagram which is annotated with typical voltage readings. Also, during normal operation, the preregulator exhibits pulse waveforms at various points. If an oscilloscope is available, we recommend that these waveforms be examined to confirm that proper operation has been restored. Fig. 21 shows the normal waveform obtained at the emitter of Q1, under moderate load and voltage conditions. Bear in mind that under no-load, the switching frequency is very low and waveforms may be very difficult to observe.

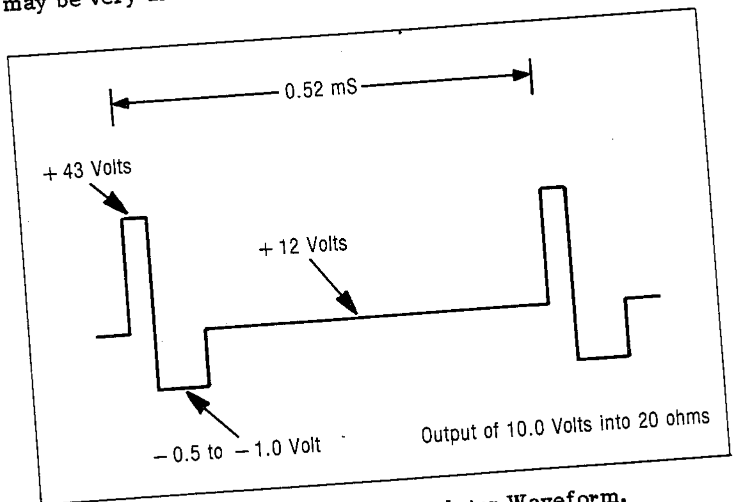


Fig. 21. Switching Preregulator Waveform, at Emitter of Q1 or Q6.

Troubleshooting Linear Regulator

If the voltage across Q3 (Q8 for channel B) is found to be normal, check for problems in the linear regulator as follows.

CHANNEL A

Check Q3 using Table 1. With the unit on, check the voltage at pin 6 of IC2; it should be a constant of 7.1 volts. The voltages at pins 4 and 5 should be equal and constant at approximately 3.5 volts. However, if the output is dead or very low, pin 4 may be lower than pin 5; in this case the expected output at pin 13 would be some positive voltage. Check IC2a, IC2d (transistors at pins 1,2, and 3 and pins 10, 11, and 13, respectively), Q14, Q4, and D4 according to Table 1. Also, check the Zener of IC2 from pins 8 to 10 (also in Table 1).

CHANNEL B

Check Q8 using Table 1. With the unit on, check the voltage from point B8 to point B10; it should be approximately 8.5 volts and should not vary considerably as the B VOLTS knob is turned (in INDEPENDENT mode). Check the voltage at IC5b pin 6. Under normal conditions it should equal that of pin 5, and the two should vary identically as B VOLTS is turned. If the output is dead or very low, pin 6 may be lower than pin 5; in this case the pin 7 output should be some positive voltage. Check Q11, Q12, Q16, Q9, and D12 using Table 1.

TRANSISTORS[3]

Discreet Transistors

Q1, Q6	BE 15 Ω	BC 0.51 kΩ
Q2, Q7	EB 100 Ω	CB 0.58 kΩ
Q3, Q8	BE 47 Ω	BC 0.48 kΩ
Q4, Q9	EB 0.52 kΩ	CB 0.56 kΩ
Q5, Q10	EB 0.71 kΩ	CB 0.71 kΩ
Q11	BE 0.72 kΩ	BC 0.71 kΩ
Q12	BE 0.54 kΩ	BC 0.66 kΩ
Q13, Q15	BE 0.63 kΩ	BC 0.63 kΩ
Q14, Q16	BE 0.65 kΩ	BC 0.65 kΩ

IC Transistors

IC1a, IC4a	BE[4] (pin 2 to pin 3)	0.78 kΩ
	BC (pin 2 to pin 13)	0.75 kΩ
IC1d, IC4d	BE (pin 13 to pin 10)	1.43 kΩ
	BC (pin 13 to pin 11)	1.1 - 1.3 kΩ
IC2a	BE (pin 2 to pin 3)	0.74 kΩ
	BC (pin 2 to pin 13)	0.78 kΩ
IC2d	BE (pin 13 to pin 10)	1.45 kΩ
	BC (pin 13 to pin 11)	1.1 - 1.3 kΩ

DIODES

D3, D11	Forward resistance	0.44 kΩ
D4, D12	Forward resistance	0.53 kΩ
D6	Forward resistance	0.54 kΩ

OTHER

IC7	Input to output	1.68 kΩ
	Output to input	0.65 kΩ
	Input to ground	1.38 kΩ
	Output to ground	1.85 kΩ
	Ground to input	0.57 kΩ
	Ground to output	1.17 kΩ
IC8, IC9	Input to output	1.23 kΩ
	Output to input	0.63 kΩ
	Input to ground	over 1.99 kΩ
	Output to ground	1.4 kΩ
	Ground to input	0.61 kΩ
	Ground to output	0.84 kΩ
IC1	Pin 13 to pin 12	0.84 kΩ
IC6	Pins 1 to 2, 4 to 3	1.44 kΩ

[1] All readings must be taken with constant-current type ohmmeter set to source 1 mA (**B & K-Precision** Models 283, 2800, 2810, 2830, or 2831 on 1 kΩ HIGH OHMS range). Ratiometric type ohmmeter will give inconclusive results.
[2] All readings ±10%.
[3] Junction labels indicate polarity of ohmmeter connection; e.g. BE indicates positive lead to base, return lead to emitter.
[4] For this reading to be valid, R4 must be disconnected from circuit.

Table. 1. Resistance Chart for Troubleshooting Switching Preregulator and Linear Regulator.