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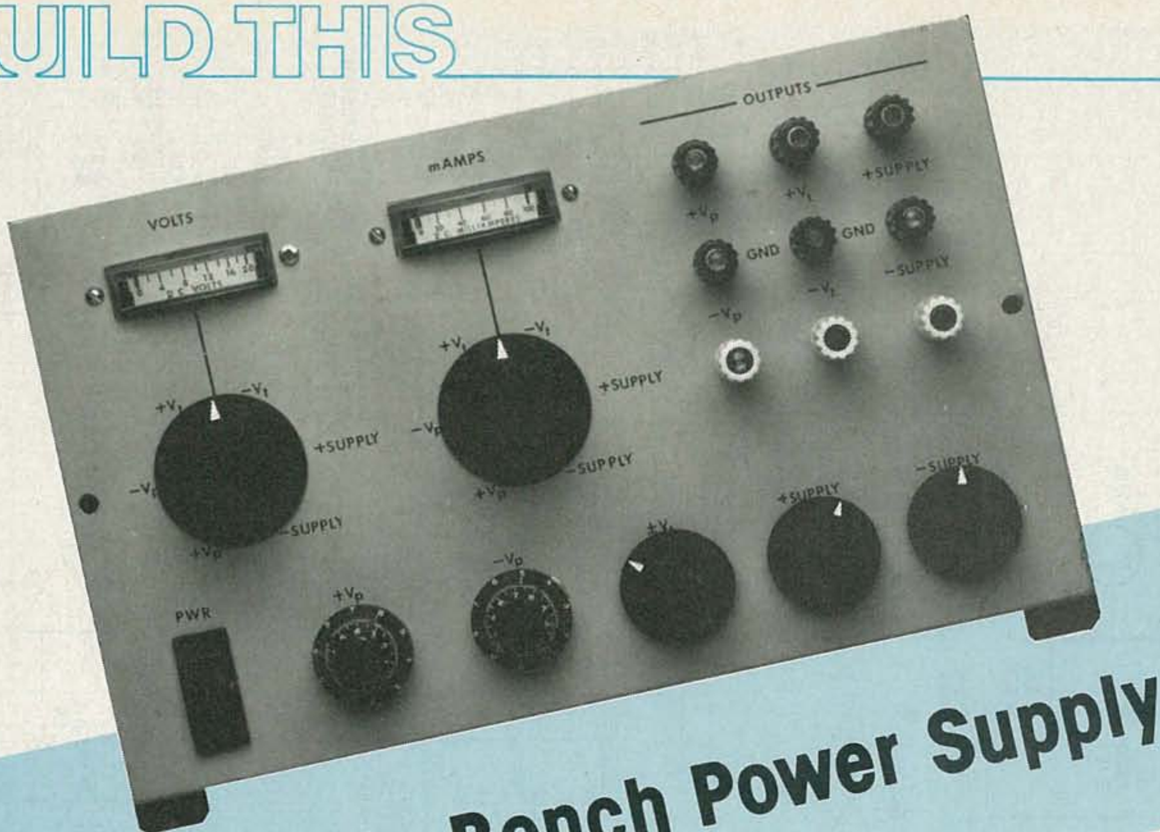



# Versatile Bench Power Supply

VAUGHN D. MARTIN

*No electronics workbench is complete without a variable power supply. If you're still missing that essential tool, here's a versatile six-output supply you'll want to build.*

A VARIABLE POWER SUPPLY IS AN ESSENTIAL part of any electronics workbench. If your workbench is lacking one, then this supply is for you! It's inexpensive, easy-to-build, and it's more than just a power supply: It includes two variable, precision voltage-reference outputs too!

The power supply provides three pairs of complementary voltage sources. Each output has built-in current limiting, and all share a common ground. While the supply is designed for low- to medium-current applications, we'll show you how to increase the current capability of the non-precision sources to 2 amps.

The first pair of voltage sources, $+V_S$ and $-V_S$, are independently adjustable. Each has a 15-volt range of adjustment and can supply a current of 100 ma.

The second pair, $+V_T$ and $-V_T$, is dual-tracking: The outputs, which are adjusted using a single control, are equal in magnitude and opposite in polarity. The adjustment range of the dual-tracking outputs is the same as for the independent supplies. The tracking sources can also supply 100 ma of current.

The third pair of outputs, $+V_P$ and $-V_P$, is a set of precision voltage sources, one positive and one negative with respect to ground. The output of each is set by a 10-turn potentiometer and turns-counting dial. Those supplies have a somewhat wider voltage range (25 volts each), but have very low current output (4 mA). They are intended, once calibrated, to be used as secondary calibration standards, not to supply operating current to working circuitry.

One of the special features of this power supply is that each pair of outputs is completely independent of the others, so you need only build the output pairs that you need. For example, if you don't need the precision source, simply omit all components associated with it. (Even if you omit one section, we recommend using the printed-circuit artwork provided; it will make it easy to add the section later.)

### Circuit operation

As you can see from Fig. 1, the power supply is made up of four main sections: The rectifier circuit is shown at the upper left of the diagram, the precision sources at the upper right, the dual-tracking supply at the lower left, and the independent supplies at the lower right.

### The rectifier circuit

The rectifier circuit supplies half-wave rectified DC to each section of the power supply. Note that the polarity of the diodes and capacitors for the positive supplies is opposite that of those for the negative supplies. The non-precision supplies are powered by the ±20-volt rectifier outputs, while the precision sources get their raw power from the ±40-volt rectifier outputs.

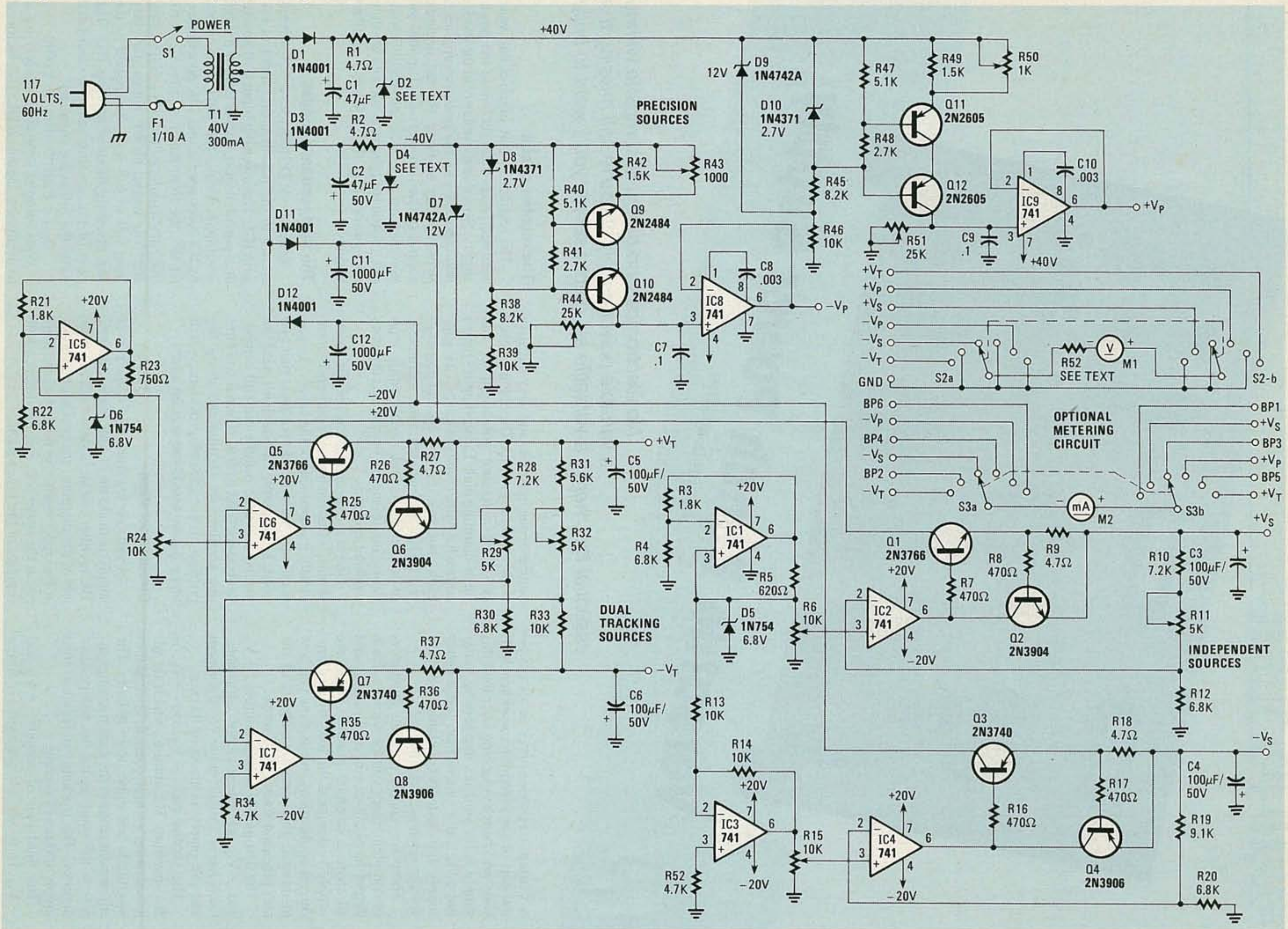
### The independent supplies

Zener diode D5 provides a 6.8-volt reference to the non-inverting input of op-amp IC1. The inverting input will also be at a potential of 6.8 volts due to normal op-amp feedback. The voltage developed by IC1 is dropped across 10K potentiometer R6, the front-panel +SUPPLY control that's used to adjust the $+V_S$ output voltage. The output of R6, which may vary from 0.0 to 6.8 volts, is applied to the non-inverting input of op-amp IC2. The gain of the op-amp may be calculated using the following equation:

$$E_{OUT} = E_{IN}(R10 + R11 + R12)/R12$$

With trimmer potentiometer R11 set at its midpoint, about 2.5K, the factor in

FIG. 1—THE SCHEMATIC shows that the power supply is made up of three independent pairs of voltage sources, a rectifier circuit, and a metering circuit.



parentheses comes out to about 2.42. $E_{IN}$ is the reference voltage dropped across potentiometer R6. So the output voltage may vary, according to the position of R6, from $0 \times 2.42 = 0$ volts to $6.8 \times 2.42 = 16.5$ volts.

The op-amps provide current limiting, and series-pass transistor Q1 provides current amplification. Transistor Q2 senses the output voltage, and, as part of IC2's feedback loop, helps compensate for variations in load current.

The negative independent supply is composed of IC3, IC4 and associated circuitry. Its reference voltage is taken from D5, the same 6.8-volt Zener used in the positive-output circuit. Here, however, the reference is applied to the inverting input of IC3. Due to the ratio of R13 to R14, that op-amp has a gain of −1. Therefore IC3 has a −6.8-volt output that is applied to front-panel −SUPPLY control potentiometer R15. From that point on, the negative circuit operates just as the positive circuit does. The output voltage is determined by multiplying the input voltage by the factor (R19 + R20)/R20. Note that PNP series-pass transistors are used here, while NPN transistors are used in the positive supply.

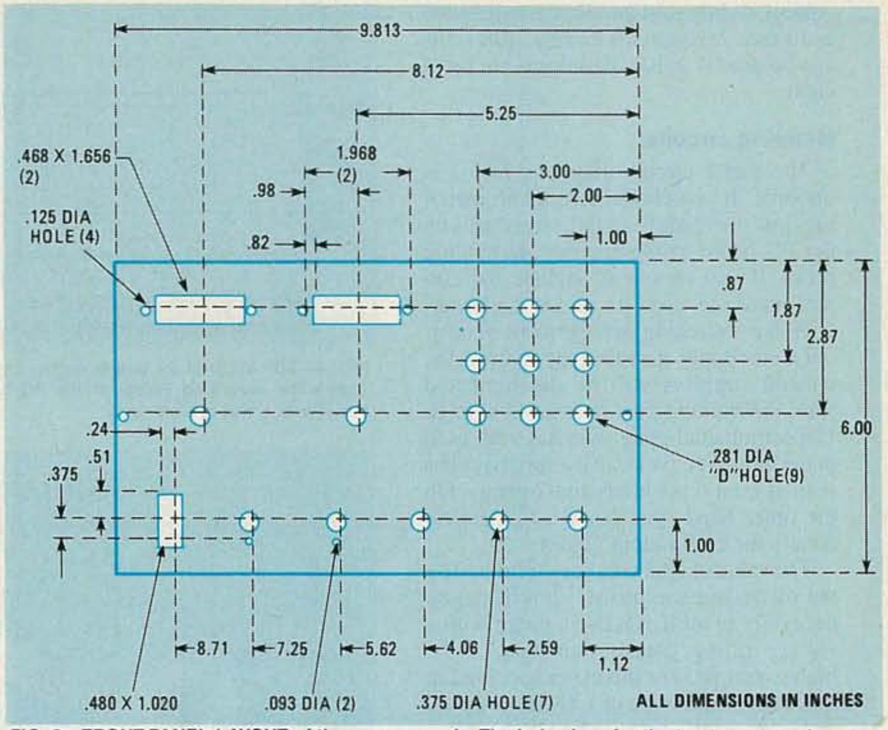



**FIG. 2—FRONT-PANEL LAYOUT of the power supply. The hole-sizes for the ten-turn potentiometers and turn-counting dials you use may differ from those given here.**

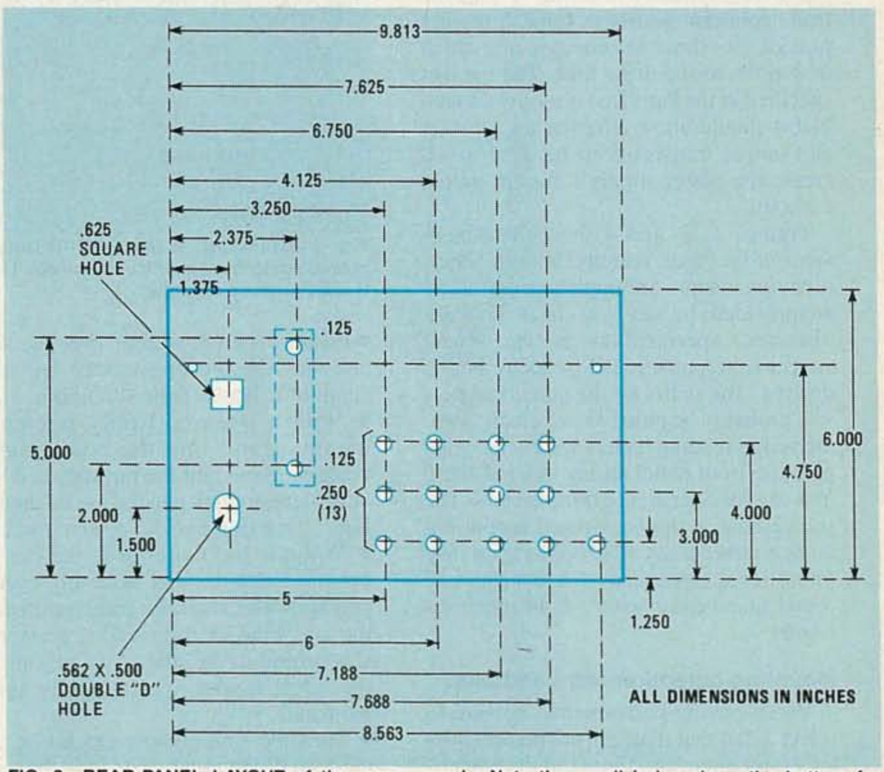



**FIG. 3—REAR-PANEL LAYOUT of the power-supply. Note the small holes along the bottom for adjusting the trimmer potentiometers.**

## Dual-tracking supply

The dual-tracking supplies operate in a manner similar to that of the independent supplies. A 6.8-volt reference is derived from Zener diode D6 and applied to the non-inverting input of IC5, which functions just as IC1 does. Its output is dropped across front-panel $\pm V_T$ potentiometer R24. The output of R24 is then applied to non-inverting amplifier IC6, which functions just as IC2 does. IC7 is slaved to the output of the positive portion of the circuit, and thereby provides the tracking action that produces an output equal in magnitude but opposite in polarity.

## Precision output supplies

Zener diode D9 establishes a 12-volt bias on the bases of a pair of complementary transistors, Q11 and Q12. That bias produces a constant 1-ma current through the collector circuits of the two transistors. The magnitude of that current may be adjusted by R50. The voltage developed across R51 by that current is fed to the non-inverting input of IC9, which is used as a voltage follower (an amplifier with a voltage gain of +1). Here IC9 also provides current amplification. The op-amps used in this circuit can provide a maximum current of about 4 ma.

The non-inverting input of IC9 has an input impedance of at least 10 megohms, so very little of the 1-ma current generated by transistors Q1 and Q2 leaks through that point. Of course, 1 ma through 25K potentiometer R51 will provide a 25-volt drop. As more and more of the resistance of the potentiometer is shunted to ground, the voltage presented to the op-amp decreases proportionately and so, therefore, does the output voltage. For example, when R51 measures 10K (from the non-inverting input of the op-amp to ground), output voltage would be 0.001 ma × 10,000 ohms = 10 volts.

The negative precision source is quite similar to the positive source, except that NPN transistors are used for the 1-ma current source, and the polarity of the Zener diodes is reversed. Op-amp IC8 functions as a voltage follower, as IC9 does in the positive output circuit. The output voltage is adjusted by R44, the front-panel $-V_P$

control. While R44 and R51 are specified as 10-turn 25K potentiometers, 10K units can be used if ±10-volt outputs are sufficient.

### Metering circuits

The meter circuit shown in Fig. 1 is optional. If you choose to omit all metering, just run leads from the output pads on the PC board to the appropriate binding posts. If you choose to include the current-metering circuit, understand that, with the switching arrangement shown, only one supply at a time may be used; the unused supplies will be disconnected from the binding post outputs. Although 12-position dual-gang switches were used in the prototype, you can use any switches with at least 6 positions and 2 gangs. On the other hand, you could add separate meters for each output circuit.

The value of R52 will be determined by the meter you use for M1. It will not be necessary at all if you use a meter with a voltage rating greater than that of the highest output. For the meter specified in the Parts List, a value of 1.8K is adequate, and gives a full-scale reading of 40 volts.

### Construction

Most components are easily obtainable from common sources; some hints are provided for those few components which may prove difficult to find. The cabinet specified in the Parts List is roomy enough that it should allow a heftier transformer and output transistors to be used to increase the power supply's current-output capacity.

Figures 2, 3, and 4 show the dimensions of the front, rear and bottom panels of the enclosure. Although hole diameters are provided, be sure you check the manufacturer's specifications for the dimensions of the parts you'll be using before drilling. The shafts for the potentiometers will probably be either ⅛ or ¼ inch. Two-inch edge-reading meters were selected to give the front panel an uncluttered look. You can, of course, use other meters. The square hole in the back panel accommodates a rather fancy fuse holder; you may find it more convenient to use a standard round fuse holder with a 0.440-inch diameter.

### Mounting potentiometers and dials

When buying components, be sure to select a dial that matches the potentiometer's shaft diameter. To mount the potentiometers and dials, refer to Fig. 5 and follow the procedure described below, adapted from instructions prepared by Beckman Instruments for the *Helipot Duodial* series of potentiometers and turns-counting dials which were used on the prototype.

- Turn the potentiometer shaft against its counterclockwise stop and insert the shaft into the shaft hole.

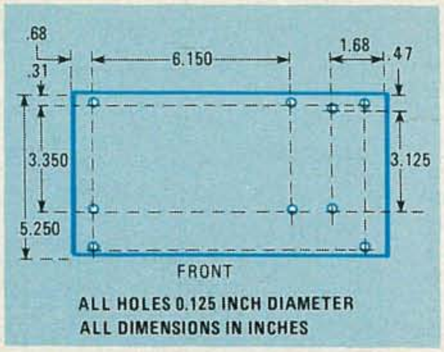



**FIG. 4—TOP VIEW of the power supply chassis shows the mounting holes for the PC board, transformer, and cabinet feet.**

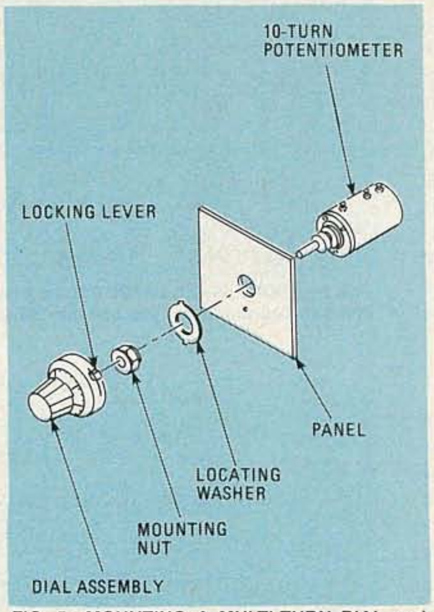



**FIG. 5—MOUNTING A MULTI-TURN DIAL and potentiometer can be difficult if you don't follow the instructions carefully.**

- Slip a locating washer over the shaft, and seat the locating-washer lug in the small hole beneath the shaft hole.
- With a wrench, firmly tighten the mounting nut into the potentiometer bushing. Note that the nut supplied is reversible. For thick panels, use as shown in Fig. 5. For thin panels, reverse the nut.
- With the locking lever in the OFF (up) position, slip the dial assembly over the potentiometer shaft. Be sure that the lug at the top of the locating washer seats in the slot behind of the dial. Also be sure that the whole assembly rests lightly against the panel.
- Turn the dial counter-clockwise until the zero of the outer scale is in the center of the window. Now turn the dial slowly until the scale reads between 10 and 20 at the index line. Tighten the set screw until a very slight drag on the shaft is felt. Turn the knob very slowly until both zeros line up with the index line. Tighten the set screw firmly.

### The PC board

The recommended way to build the power supply is to use a printed-circuit board. Full-size foil patterns for a suitable board are shown in the "PC Service" section. (See page 83.) If you choose not to make your own board, you can purchase an etched and drilled board from the source mentioned in the Parts List. Whichever board you use, check it carefully for shorts and broken traces *before* you mount any components. Be particularly careful when you check areas that will be hidden under components

### PARTS LIST

**All resistors are ¼-watt, 5%, unless otherwise noted.**

R1, R2, R9, R18, R27, R37—4.7 ohms
R3, R21—1800 ohms
R4, R12, R20, R22, R30—6800 ohms
R5—620 ohms
R6, R15, R24—10,000 ohm panel-mount potentiometer
R8, R16, R17, R25, R26, R35, R36—470 ohms
R10, R28—7200 ohms
R11, R29, R32—5000 ohms, 15-turn, PC-mount trimmer potentiometer
R13, R14, R33, R39, R46—10,000 ohms
R19—9100 ohms
R23—750 ohms
R31—5600 ohms
R34—4700 ohms
R38, R45—8200 ohms
R40, R47—5100 ohms
R41, R48—2700 ohms
R42, R49—1500 ohms
R43, R50—1000 ohm, 10-turn PC-mount trimmer potentiometer
R44, R51—25,000 ohm, 10-turn panel-mount potentiometer
R52—See Text

**Capacitors**

C1, C2—47 µF, 50 volts, electrolytic
C3, C4, C5, C6—100 µF, 50 volts, electrolytic
C7, C9—0.1 µF
C8, C10—0.003 µF
C11, C12— 1000 µF, 50 volts, electrolytic

**Semiconductors**

IC1-IC9—LM101, or LM741 op-amp
D1, D3, D11, D12—1N4001
D2, D4—See Text
D5, D6—1N754 6.8-volt Zener
D7, D9—1N4742A 12.0-volt Zener
D8, D10—1N4371 2.7-volt Zener
Q1, Q5—2N3766
Q2, Q6—2N3904
Q3, Q7—2N3740
Q4, Q8—2N3906
Q9, Q10—2N2484
Q11, Q12—2N2605

**Other Components**

F1—Fuse ⅒ amp, 250 volts
S1—SPST, 115 volts AC, 1 amp
S2, S3—6-position, 2-pole rotary switch
BP1-BP9—Binding posts

**Miscellaneous**: Turns-counting dials (2); Cabinet: Bud No. SE3030; heatsinks for Q1, Q3, Q5, and Q7; line cord, hookup wire, etc.

**Note: An etched and drilled PC board is available from Specialty Electronic Services, Inc., P.O. Box 3320, San Antonio, TX 78211, for $48.50 postpaid.**

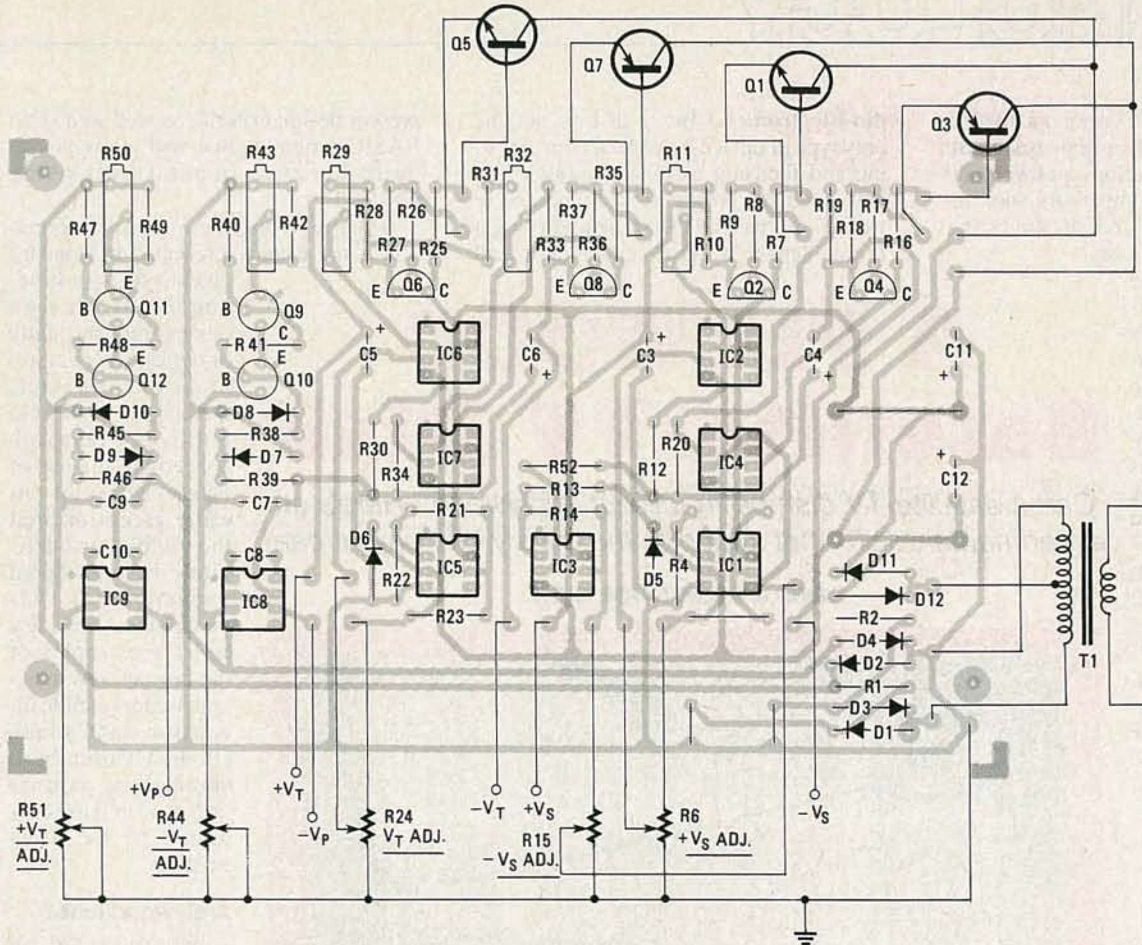



**FIG. 6—PARTS PLACEMENT DIAGRAM shows how on-board and off-board components are wired.**

once they're mounted on the PC board.

After checking your board and correcting any problems, you can mount the components using the parts-placement diagram in Fig. 6 as a guide. Be sure to observe the polarity of all semiconductors and electrolytic capacitors. Use sockets for the op-amps, but don't insert the op-amps at this time. Orient the small transistors (Q2, Q4, Q6, Q8-Q12) and diodes on the PC board carefully.

Transistors Q1, Q3, Q5, and Q7 require heat sinks, and should be mounted to the chassis. Be sure to use mica insulators so that their collectors won't short to the chassis; and coat the insulators on both sides with silicone grease to ensure efficient heat transfer. Attach the complete assemblies to the rear panel.

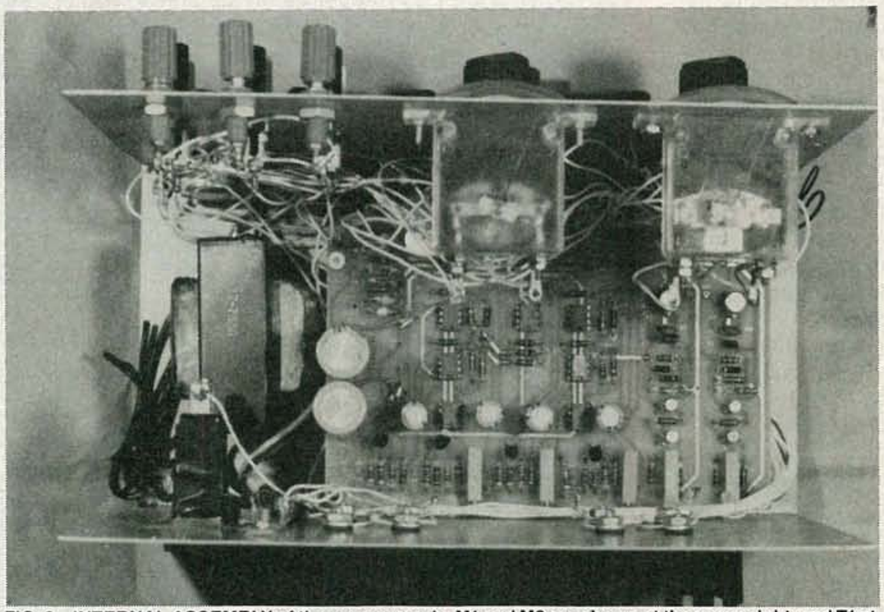


**FIG. 8—INTERNAL ASSEMBLY of the power supply. M1 and M2 are shown at the upper right, and T1 at the lower left.**

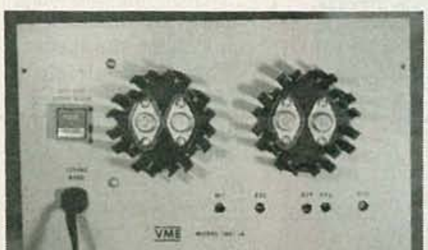



**FIG. 7—THE REAR PANEL OF THE POWER SUPPLY.**

## Final assembly

After all components have been mounted, but before the IC's have been installed in their sockets, check the board carefully for solder bridges and unsoldered pads. Fix any problems, and then connect the transformer to the PC board. Verify the presence of +40 and

*continued on page 114*

## BENCH POWER SUPPLY

*continued from page 57*

−40 volts across D2 and D4, and +20 volts across C11 and C12. While you're at it, verify the presence of +20 volts on pin 7, and −20 volts at pin 4 of each op-amp. If everything checks out, remove power and insert the IC's. Be sure to orient pin 1 correctly.

Run wires from the transistors mounted on the rear panel (see Fig. 7) to the PC board. Finally, using Fig. 6, complete the point-to-point wiring between the board and the front- and rear-panel components. At this point, your power supply should appear similar to the prototype shown in Fig. 8.

### Calibration

A DMM or VOM accurate to at least 4½ digits should be used to calibrate the precision sources. To obtain sufficient resolution, allow the supply to run for 10 minutes or more so that the temperature within the cabinet—and the output voltages of the precision sources—will stabilize. Adjust R44 and R51 so that their dials read 10.00 (i.e., their resistance should be exactly 10K ohms). Then adjust trimmer potentiometers R43 and R50 so that each output reads exactly 10.000 volts.

To get symmetrical outputs from the independent supplies, adjust R11 so that equal rotation of potentiometers R6 and R15 gives the same output voltage.

To adjust the dual-tracking source, turn potentiometer R24 to maximum resistance. Then adjust R29 for an output of exactly +15.000 volts, as measured at the $+V_T$ output. Then adjust R32 so that exactly −15.000 volts appears at the $-V_T$ output.

### Substituting components

Some of the components specified in the Parts List may be difficult—if not impossible—to find. For example, you may have that problem with the 40-volt Zener diodes (D2 and D4). However, two 20-volt Zener diodes may be connected in series to achieve the same result.

The 2.7-volt Zener diodes (D8 and D10) may also be difficult to find. If they are, 3.3-volt units may be substituted (1N5226B). If doing so produces more than 1 mA from the constant-current sources, trimmer potentiometers R43 and R50 can be adjusted to compensate. The 6.8-volt reference diodes (D5 and D6) are not critical and may be either 1N957B, 1N5235B, or 1N4736A devices. The two 12-volt Zener diodes may be 1N963, 1N5242B, or 1N4742A units.

All electrolytic capacitors are polarized aluminum types, and radial-lead devices were used in the prototype to conserve space on the PC board.

All five cermet trimmer potentiometers used in the project are the ¾-inch long rectangular type.

### Increasing power output

If you want to beef up the outputs of the non-precision supplies, you must increase the current capacity of the transformer, the output transistors, etc.

The transformer specified for this project has a rated output of 40-volts center-tapped at 300-ma. You may replace it with a unit having higher current capacity, but if you use a transformer with a higher voltage rating, be careful not to exceed the voltage rating of the op-amps and transistors.

The 2N3766 transistors (Q1 and Q5) may be replaced by 2N6057 devices; the latter have a maximum collector current of 12 amps. The 2N3740 transistors (Q3 and Q7) may be replaced by 2N6050 units, which also have a maximum of 12 amps. Both the 2N6050 and 2N6057 are housed in TO-3 cases and will require additional heat-sinking.

If you are using the metering circuit, the value of R52 might have to be increased, as well as the the rating of the current meter. **R-E**