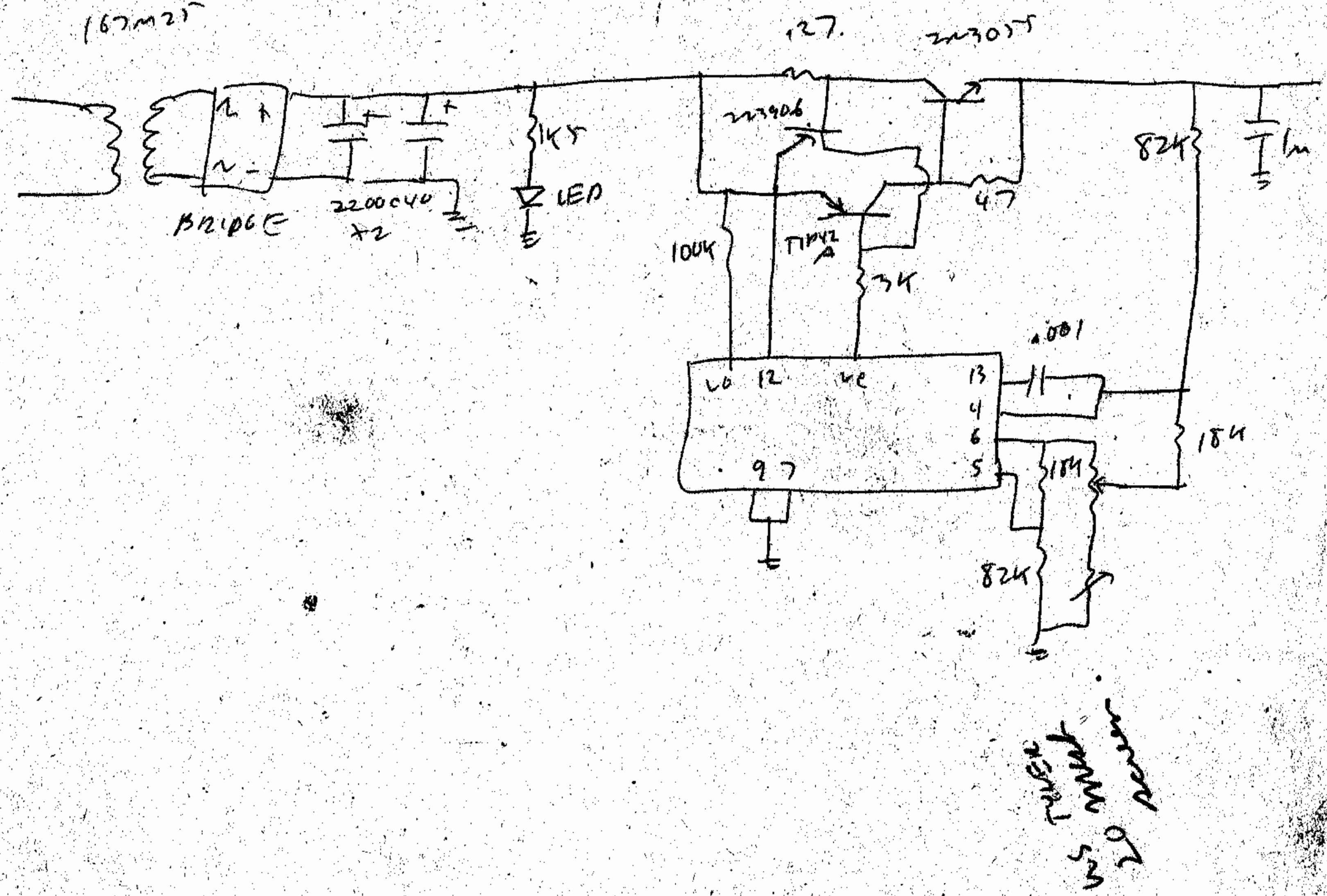
P.21 — 30V SUPPLY.



Regulated power supply is adjustable from 0 to 38 V

by Frank P. Miles
Rochester, N.Y.

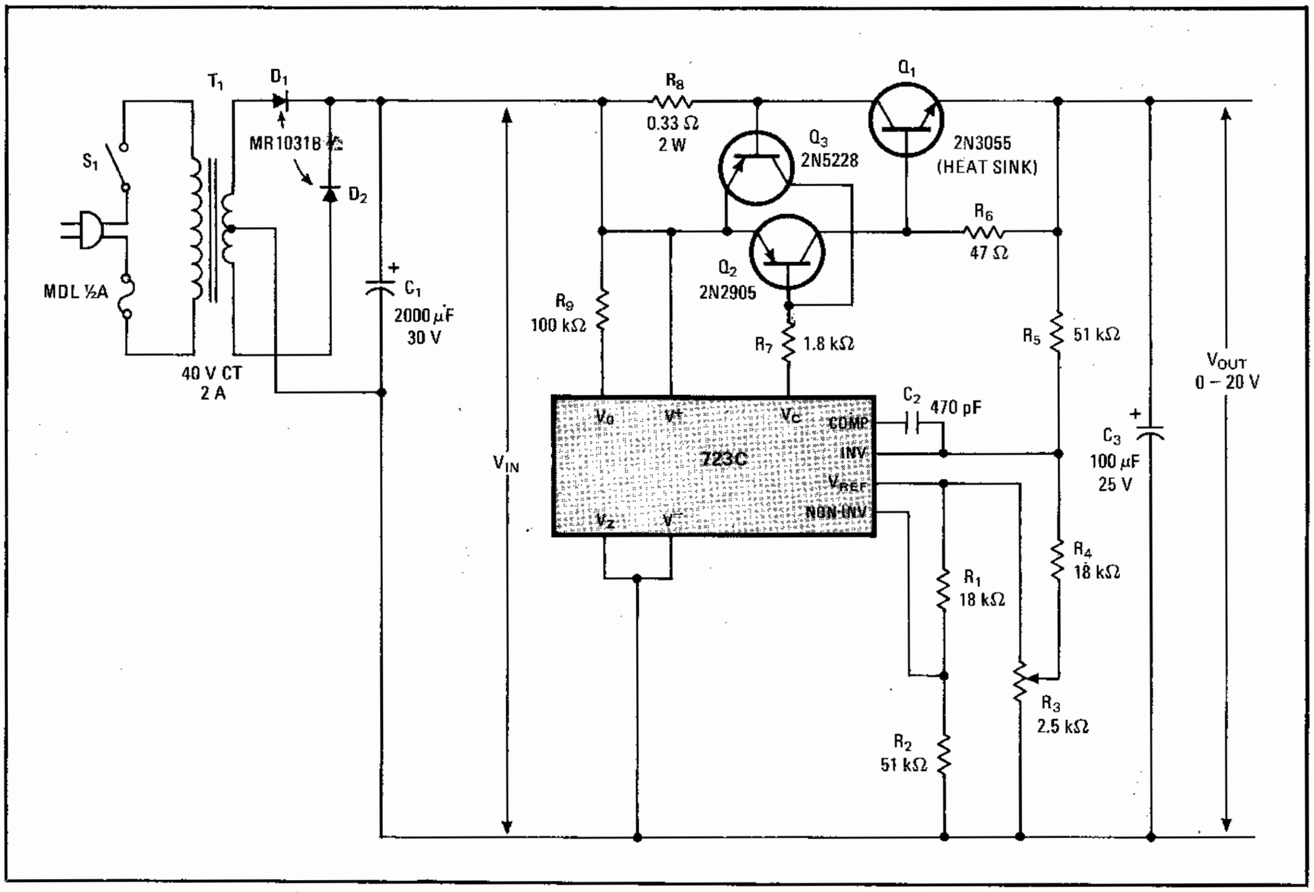
Through careful biasing of the error-sensing and the output driver for a 723C voltage regulator, a power supply that is variable from 0 to 38 volts can be designed. The stability of the circuit over both time and temperature is excellent, depending only on the internal reference of the chip and being essentially independent of output level. And finally, the circuit requires few components; most notably, it requires no zener diodes external to the 723C.

The schematic shows how simple it is to custom-design the supply. R_3 is a 2.5-kilohm potentiometer, chosen to keep the reference current below 5 milliamperes. $R_1 = R_4$ and $R_2 = R_5$ for best bias stability and output-range swing. The leakage-limiting resistor R_6 has a value of 47 ohms; it increases the safe operating area of Q_1.

The maximum output voltage is given by

$$V_{OUT(max)} = (R_2/R_1)V_{REF}$$

where the reference voltage V_{REF}, a characteristic of the 723C, is typically 7.15 V. Resistor R_1 is picked to be high enough to minimize loading of R_3, but small enough to avoid bias-current problems at the error-am-



Regulated power supply. Setting of R_3 gives output voltage as low as 0 V, or as high as V_{IN} minus small drop across Q_1. Value of V_{IN} must not exceed 40-V limit of the 723C. Components shown here are for 0–20-V, 2-A supply.

plifier inputs. Resistor R_2 is then calculated from

$$R_2 = (V_{OUT(max)}/V_{REF})R_4$$

The other resistors are calculated from straightforward circuit considerations. Resistor R_7 limits the output drive of the 723C to about 10 mA because the internal zener diode is used. Its value, in kilohms, is

$$R_7 \approx 0.1\, V_{IN} - 0.62$$

where V_{IN} is the unregulated voltage out of the rectifier. (The value of V_{IN} must not exceed the 40-v limit of the 723C.) R_8, calculated in ohms, provides the proper current-limit point:

$$R_8 \approx 0.65/I_{LIMIT}$$

where I_{LIMIT} is the maximum output current (in amperes). The pass transistor characteristics and heat sink are also determined by the value of I_{LIMIT}. Resistor R_9, calculated in kilohms, maintains zener regulation for low output currents:

$$R_9 \approx 5V_{IN} - 31$$

The output voltage from this supply can be as low as 0 V, or as high as V_{IN} minus a small drop across the pass transistor. The component values shown in the circuit diagram are chosen for a 0–20-V, 2-A supply. □

Dc-dc power supply regulates down to 0 volt

by P.R.K. Chetty and A. Barnaba
ISSP, Bangalore, India, and CNES, Toulouse, France

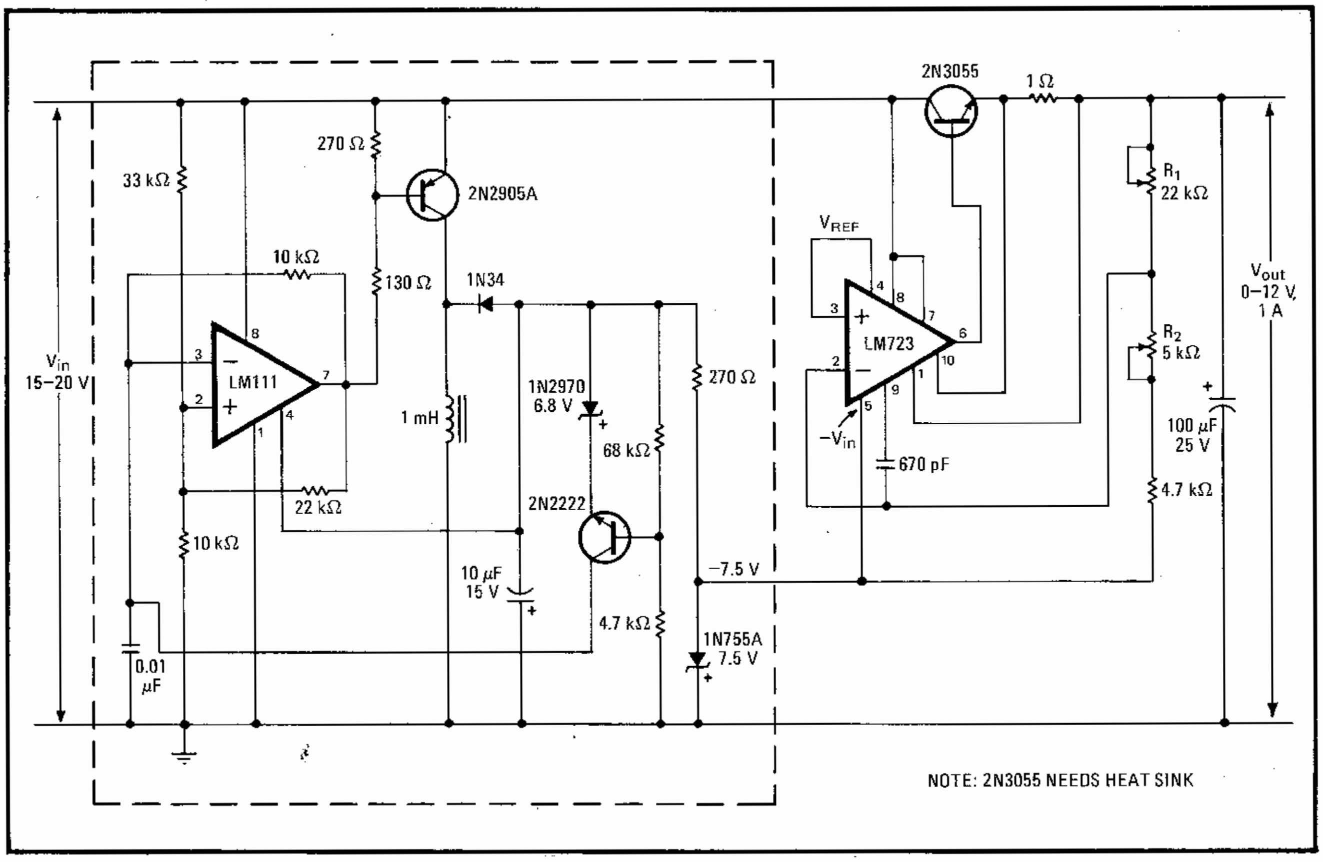
In most dc-input, regulated power supplies, regulation is poor when the desired output voltage is less than the source's internal reference voltage. In addition, circuit considerations usually limit the minimum reference voltage attainable and consequently the minimum regulated output voltage possible. This circuit, however, with a configuration that can bring the reference voltage to virtually zero, overcomes both problems.

The LM723 voltage regulator shown, which provides 12 volts at 1 ampere, must be biased with a negative supply voltage at its $-V_{in}$ port (pin 5) for proper operation. This voltage is provided by the switching inverter shown within the dotted lines.

The LM111 voltage comparator is configured as an astable multivibrator that oscillates at a frequency of about 10 kilohertz. With the aid of the 1-millihenry inductor, which generates the counterelectromotive force required to produce a negative potential from a switched-source voltage, the inverter delivers a well-regulated −7.5 v to the $-V_{in}$ port of the 723.

The magnitude of this voltage is essentially equal to that of the regulator's internal reference voltage, V_{REF}, appearing at pin 4, and properly biases its voltage-reference amplifier. This condition in turn precipitates a condition in the amplifier whereby V_{REF} clamps to ground potential. Thus the output voltage may be adjusted throughout its maximum possible range by potentiometers R_1 and R_2. Although the potential of V_{REF} as measured with respect to ground has been changed, the circuit will retain the regulating properties of the 723. Both the line and the load regulation of the supply are 0.4%. □

Designer's casebook is a regular feature in *Electronics*. We invite readers to submit original and unpublished circuit ideas and solutions to design problems. Explain briefly but thoroughly the circuit's operating principle and purpose. We'll pay $50 for each item published.



Full-range regulation. Dc-input supply is regulated all the way down to 0 V. LM111 and associated circuitry provide negative bias required for LM723 regulator. Regulator's internal-reference voltage, V_{REF}, is clamped to ground; output voltage is thus adjustable from 0 to 12 V.

Dual Tracking Power Supply

A lab-quality power supply with one output voltage tracking the other; it features 0-50 volts and 2.5 amperes per output.

By David Bedrosian

A POWER supply is required in almost every electronic circuit, whether it is a small LED flasher or a high powered amplifier; this makes a power supply one of the most useful pieces of test equipment. To be able to fully test a circuit, the supply must put out enough voltage and current to properly run the circuit under test; as well, the supply must remain stable for all possible load conditions. To protect the circuitry under test, the supply must have a continuously variable output voltage down to zero volts, and must provide some form of current limiting. An added requirement when testing amplifiers which require dual polarity supplies (both positive and negative voltages with respect to ground) is that the supply must be capable of generating a negative voltage which tracks the positive voltage. If, for example, the output voltage is varied upward from 0 to plus 20 volts the negative supply must vary downward from 0 to minus 20 volts.

The power supply described in this article is a dual tracking supply capable of producing up to plus and minus 50 volts at an output current of up to 2.5A. The maximum current before limiting is adjustable between approximately 50mA and 2.5A for both the positive and negative outputs, using the two knobs on the front panel. The positive voltage is varied using a ten-turn potentiometer, and the negative voltage tracks the positive output with a ratio adjustable between 0 and 100 percent. Two LEDs on the front panel indicate when the supply is operating in the constant current mode, and two meters accurately monitor the output voltages and currents.

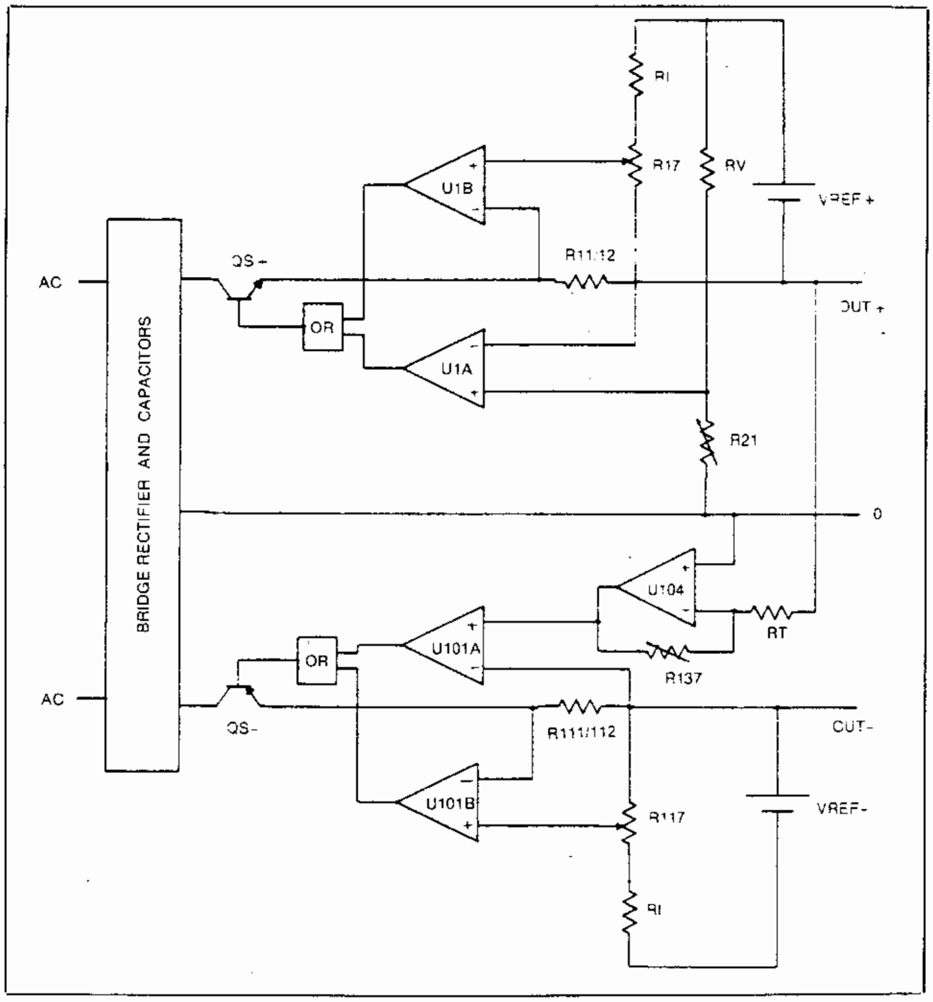
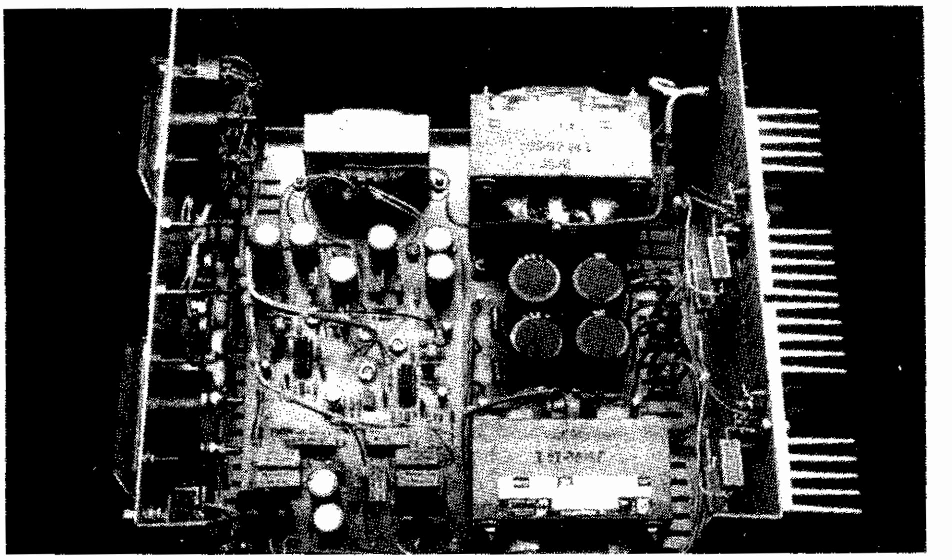


Fig. 1 The block diagram of the power supply.

The project also contains the necessary information to modify the existing circuit depending on the availability of parts and the requirements of the builder. The maximum output voltage and current values can be changed according to the transformers, transistors and heatsinks available; the negative supply can be made totally independent of the positive supply, or it can be omitted altogether.



The interior of the power supply unit.

Construction

The resistor values given in the Parts List are appropriate if the power supply is going to have the same output voltage and current as shown in this project, and if XFRMR1 and XFRMR2 put out between 50 and 60VAC under no-load conditions, and if the meters used to indicate voltage and current both require 100uA for full scale deflection. If the supply is going to be modified, refer to Parts Selection and Modification to determine the appropriate part values before beginning construction.

The circuit board designs shown are recommended to speed construction and minimize wiring errors. It is also recommended that resistors, diodes and transistors be tested before being soldered into place; this may seem time-consuming, but can actually save a considerable amount of time later if troubleshooting is required. Diodes will have a very high resistance in one direction and low in the other; transistors should have a high resistance between both the base and emitter leads and the base and collector leads in one direction, and a low resistance in the other. The resistance between collector and emitter will be high in both directions.

Construction begins with the main circuit board. First solder in the three jumpers and the IC sockets; the long jumper should be insulated. Next install all of the quarter and half watt resistors. The capacitors and power resistors can now be soldered in place; be sure to check

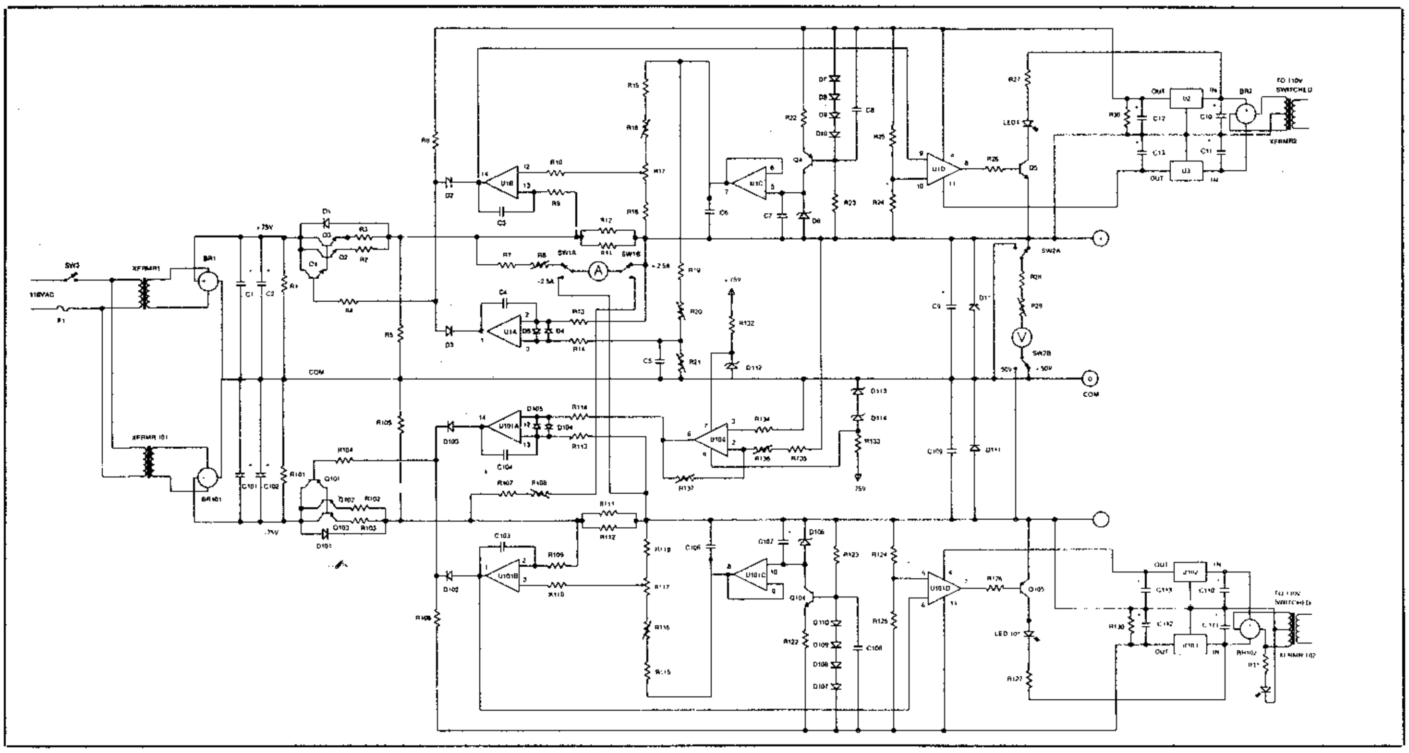


Fig. 2 The schematic of the power supply

the orientation of the electrolytic capacitors, as a reversal can cause serious circuit damage when power is applied. The 5W resistors should not have to dissipate more than one or two watts, and can therefore be mounted directly on the PCB. The seven trimpots are next soldered onto the board; provision has been made for both the upright and the flat types. If 25-turn upright trimpots are available (Bourns series 3299W) they can be used to allow for finer adjustment. The bridge rectifiers, diodes, and transistors can now be soldered into place. Note that the two bridges are oriented differently; look for the plus signs on the circuit board overlay to ensure correct insertion. Be sure to differentiate between zener diodes and the rectifiers. Before soldering in Q1 and Q101, attach a small heatsink to each device; silicone grease is not necessary and the heatsinks need not be insulated from the collectors as long as they don't touch any other metallic object (each heatsink is at the full input voltage of 75V, so beware). The op amps (U1, U101, and U104) should not be inserted yet; however, the voltage regulators (U2, U102, U3, and U103) can be soldered in place without heatsinks. This completes the assembly of the main circuit board.

The small circuit board should be completed next. This board may need to be modified if different sized capacitors are used for C1, C2, C101 and C102; otherwise assembly should be straightforward. After completing both boards, they should be thoroughly inspected for poor solder joints or bridges.

Construction now begins on the cabinet; the following description assumes the recommended Hammond cabinet is being used. Start with the back panel; drill holes for the fuseholder, the power cord (or connector), and the heatsinks. Temporarily mount the heatsinks and mark on the back panel where the power transistors will come through. The four power

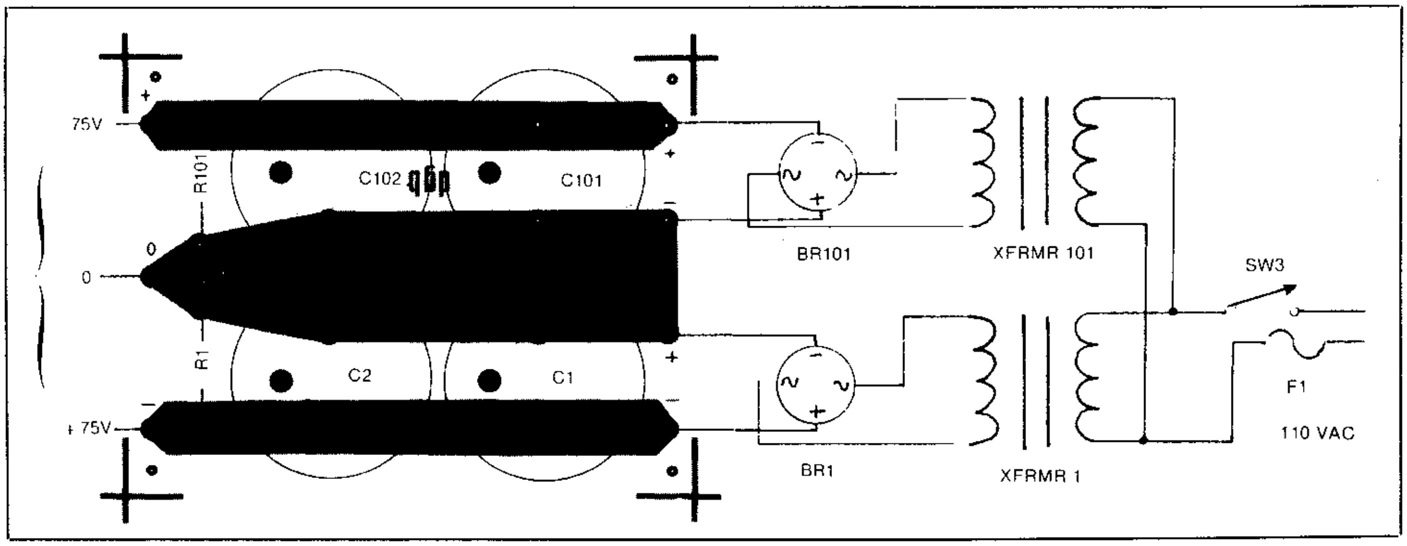
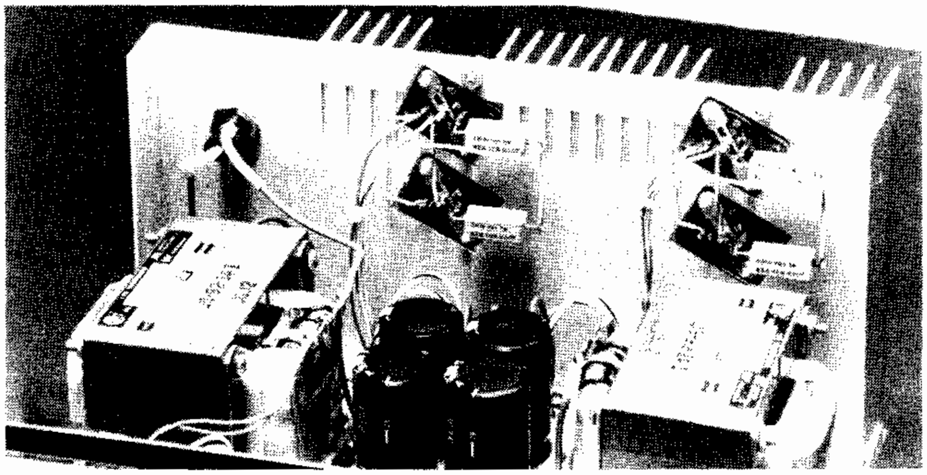


Fig. 3 Component location for the small printed circuit.

transistors should then be mounted; each transistor should then be isolated from the heatsink using a mica insulator with silicone grease on both sides. If transistor sockets are not used, the bolts holding the transistor must be insulated with a plastic sleeve and shoulder washer. The heatsinks can now be permanently fastened to the case, and the power transistors should be tested with an ohmmeter for possible shorts to the heatsink or cabinet.

The main power transformers, the large bridge rectifiers, and the small circuit board should be bolted to the bottom of the cabinet and wired with at least 18 gauge wire. The power cord ground lead should be attached directly to the cabinet with a ground lug between a bolt and the cabinet. The bridge rectifiers should be mounted directly on the cabinet, which will act as a heatsink; silicone grease is not required. Do not wire in the power switch yet; instead run two wires to the front cabinet of sufficient length to reach the power switch. The three wires to the main circuit board should not be soldered in place yet. The wiring in this section is critical, so be sure that all wires are mechanically sturdy and connected to the proper location.

The front panel can now be drilled and all parts should be mounted. Only the power switch should be wired at this time to allow for testing of the main power supply. With a 3A slo-blo fuse installed, apply power to the supply and measure the voltage at the output of the small circuit board (the voltmeter leads can be clipped across R1 and R101). If no voltage is present or it is very low, measure the AC voltage to the input of each bridge; they should have about 55VAC each to their inputs, depending on which transformer is used. If there's a problem, check the wiring and fuse.



The rear panel, showing the transistor and emitter resistor mounting.

With approximately plus and minus 75VDC at the output of the small board, the power supplies on the main board can be tested. Mount XFRMR2 and XFRMR102 in the cabinet and wire their primary windings to the switched 115VAC connected to XFRMR1 and XFRMR 101. Temporarily connect the secondary windings to the main circuit board and run three wires from the small circuit board to the main board for 0, plus 75, and minus 75V. Apply power to the circuit and measure the voltages at U1, U101, and U104. The voltage at pin 4 of U1 with respect to the positive output (clip onto the outside end of R11 or R12) should read 12V plus or minus 0.5V, the voltage at pin 11 should read -12V plus or minus 0.5V, and the voltage at pin 5 should be 6.2V. The voltage at pin 4 of U101 with respect to the negative output should be (clip onto the outside end of R111 or R112) should read 12V, the voltage at pin 11 should be -12V, and the voltage at pin 10 should be -6.2V. Pin 7 of U104 should be at about 4V with respect to ground (clip onto the inside lead of R1 or R101) and pin 4 should be at -55V, again with respect to ground.

The main board should be removed from the cabinet and the ICs inserted. Suitable length wires should be soldered to the main circuit board for connection later to all of the front panel parts, the power transistors, the small circuit board, and the low voltage transformers. The wires to the power transistors, the small circuit board, and the output binding

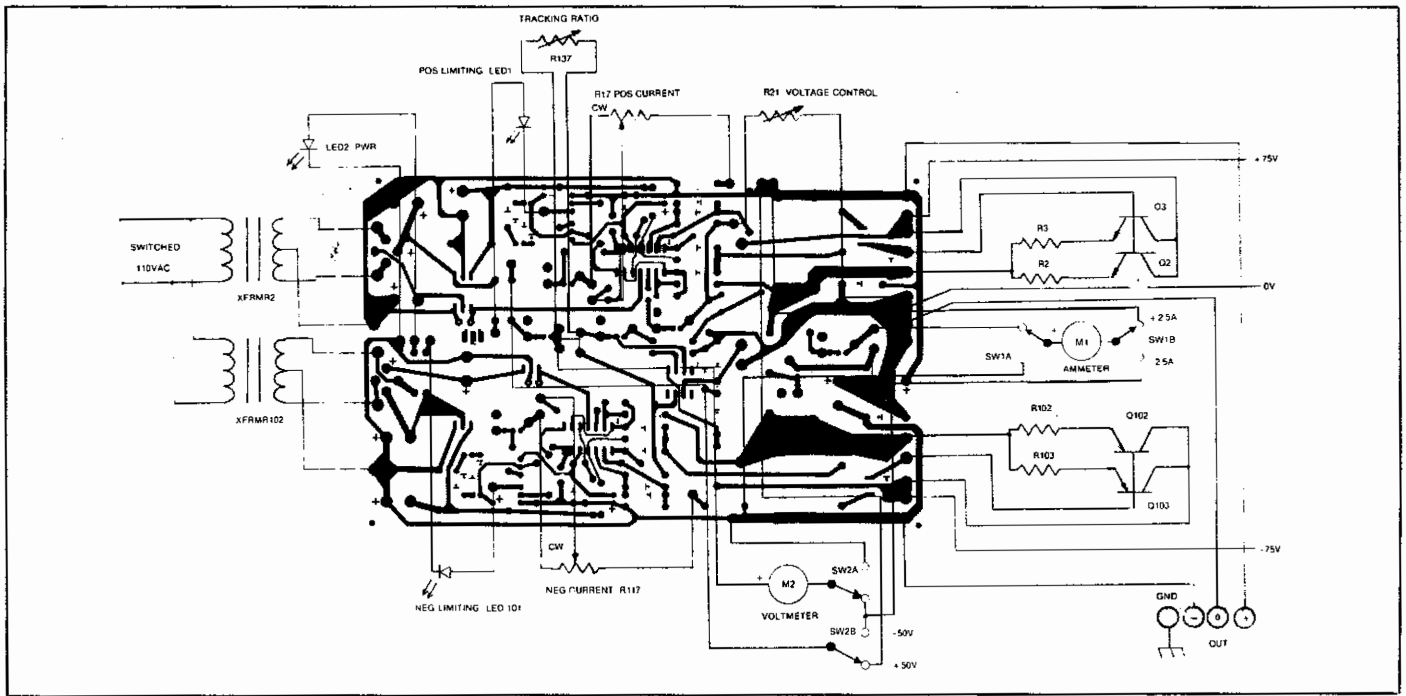


Fig. 4 The wiring points for the main printed circuit.

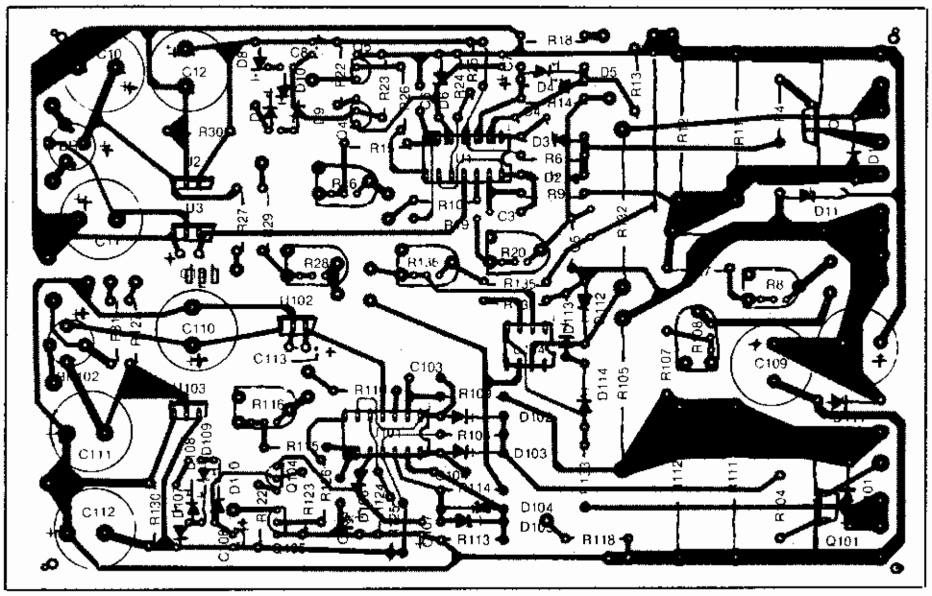


Fig. 5 The component location for the large printed circuit.

posts should be 18 gauge or larger; all other wires can be a lighter gauge. The main circuit board can now be fastened to the cabinet and the wiring can be completed. The chassis ground binding post is wired directly to the cabinet using a ground lug. The 0R2 5W resistors (R2, R3, R102, and R103) can be attached directly to the emitter terminals of Q2, Q3, Q102, and Q103. The voltage control pot, R21, and the tracking ratio pot, R137, should both be wired so that clockwise rotation gives maximum resistance.

The final step in constructing the power supply is to replace the voltmeter and ammeter scales with the ones shown; these scales should work well for most 2.5" meters.

Testing and Adjustments

Before turning the supply on, check that both M1 and M2 are zeroed, and then connect an external voltmeter between the positive and the ground binding posts. Switch on the power supply and turn the voltage control pot clockwise; the output voltage should increase. Set the output voltage to exactly 25V and adjust R29 until M2 reads 25V; be sure SW2 is in the +50V position when making this adjustment. Turn the output voltage up to 50V and see that M2 also shows 50V. If the output voltage will not go up to 50V, adjust R20 until it does; this trimpot should be set to give an output voltage about 1 or 2 volts above 50V with the voltage control pot fully clockwise. Turn the voltage back down to 25V and connect the external voltmeter to display the negative output voltage; also switch SW2 to the -50V position. Turn the tracking pot clockwise; the output voltage should become more negative. With the tracking pot set fully clockwise, adjust R136 until the output voltage is exactly 25 percent (100 per cent tracking). Turn the positive output up to 50V and check that the negative voltage goes down to -50V; if the output will not go this low, the negative supply to U104 is not negative enough and D114 must be changed; refer to the Part Selection section. The tracking ratios can be adjusted to 25, 50, 75, and 100 percent and appropriate markings added to the front panel.

To set the current limiting, adjust the positive output to about 2V and connect a ammeter between the positive output binding post and the ground binding post; be sure the ammeter is set to a current range greater than 2.5A. The positive output current limiting LED should be on. Turn the positive current limiting pot clockwise; the current should increase; set the pot at 1/2 rotation and adjust R16 until the output current is approximately 1.3A. Also adjust R8 until M1 reads the same value as the ammeter (SW1 must be in the +50V position). Turn the current limiting pot fully clockwise and adjust R16 for a current output of 2.5A. The same procedure should be followed for the negative supply, adjusting R116 for a maximum output current of -2.5A and adjusting R108 so that M1 displays the correct current. Lines can be added to the front panel for both current control pots to indicate plus and minus 1, 2, and 2.5 amperes. This completes the testing and adjustment of the power supply.

Troubleshooting

If the op amp supply voltages or the reference voltages are not present, refer to Table 1 for assistance in locating the problem. If all of the required voltages are present but the supply does not function properly, use the schematic and carefully measure the voltages around the circuit. The voltage between the inverting and non-inverting terminals of each op amp should be 0V within a few millivolts unless the output of the amp is saturated to +12 or -12V. The output voltages of U1C and U101C should be equal to the collector voltages of Q4 and Q104 respectively. The output voltages of U1A and U101A should be within 1 or 2 volts of the positive and negative outputs respectively when the supply is operating in the constant voltage mode. The outputs of U1B and U101B should be approximately equal to the respective output voltages when operating in the constant current mode. The voltage across R21 should be the same as the positive output voltage, and the output of U104 should be the negative of this voltage. The base voltages of Q2 and Q102 should be within 1 volt of the respective output voltages.

Part Selection and Modification

If some of the recommended parts are not available, or if the supply does not fulfill the requirements of the builder, the existing circuit can be modified quite easily.

The most expensive components are the transformers and are the most likely to be substituted; the transformers selected, however, will greatly affect the available output voltage and current. Choose a transformer that has an AC output current approximately 1.5 times the required DC output current, and an AC voltage several volts above the required DC output voltage. Operating a transformer above its maximum rating for long periods of time will cause the transformer to overheat, and is not recommended.

The selection of the power transistors and the heatsinks should be based on the output rating of the supply. The MJ15003 and MJ15004 transistors used will work well for most configurations with currents up to 10A and voltages up to 100V; however, as the current and voltage ratings are increased, the size of the heatsinks must be increased. The maximum power dissipated by each pair of transistors is equal to the product of the maximum output current and the collector voltage. For this supply, the maximum power dissipation is about 200W (75V x 2.5A) for each pair of power transistors. If the temperature rise is to be kept to 100 degrees C, the heatsinks must have an efficiency of 0.5W/deg C in free air convection; alternatively, smaller heatsinks could be used with a cooling fan. Instead of the MJ15000 series transistors, a pair of 2N3055s and a pair of MJ2955s can be used for Q2, Q3, Q102, and Q103 respectively if the input voltage to these transistors is kept below 50V.

If the power supply's voltage or current ratings are changed, the formulas

HOW IT WORKS

It's best to refer to the block diagram. The AC input is converted to plus and minus 75V by the bridge rectifiers and the filter capacitors, and applied to the collectors of Qs+ 1 and Qs–. Ignoring the negative supply, the base of Qs+ is driven by U1a if the supply is operating in the constant voltage mode, or U1b if it is in the constant current mode. Vref sets up a constant current through RI and R17 and through RV and R21; the current through R21 produces a voltage directly proportional to the resistance of R21. U1a attempts to keep this voltage and Vref equal by generating an error signal proportional to the difference between the voltages. If the load resistance decreases and the output voltage drops, U1a increases the conductance of Qs+, causing the output voltage to return to its previous level. Similarly, an increase in output voltage causes U1a to reduce the drive to the base of Qs+. The output regulation is very good because the high gain of U1a produces a large error signal for even very small input voltage differences.

Op amp U1b compares the voltage at the wiper of R17 to the voltage across R17/R12, the latter voltage being proportional to the output current. If the output current increases past a certain point, the output of U1b goes negative and reduces the drive to Qs+, reducing the output current. The OR circuit selects the lower of the two output voltages from U1a and U1b to drive the base of Qs+. This causes the supply to operate in the constant voltage mode until the output current exceeds the value set by R17, at which time U1b will take over and switch the supply to constant current.

To provide the negative supply with tracking, the positive supply voltage is inverted by U104 and applied to U101a. The gain of U104 can be varied between 0 and -1 by adjusting R137, thus giving a tracking range of 0 to 100 percent. The output of U101a is an error signal which tries to maintain a constant voltage. The current limiting operates in the same way as the positive supply, except that the OR circuit now selects the higher of the output voltages from U101a and U101b.

The operation of the negative half is much the same as the positive. Referring to the schematic, Q2 and Q3 are the pass transistors and Q1 is the driver; resistors R2 and R3 help compensate for differences between transistors. The base current for Q1 comes from the OR circuit, D2, D3, and R6; this circuit selects either U1a or U1b as controller, depending on which has the lower output voltage. The high gain of the op amps ensures a sudden transition; the drive current actually comes from R6.

The reference voltage is provided by D6 and constant current source Q4, which is biased by D7–D10 and R22. C8 provides a soft start when the supply is switched on. The reference voltage is buffered by U1c.

The reference voltage generates a constant current through R21; the developed voltage is compared to the output and any difference controls U1a. R20 allows adjustment of the current through R21 and C5 stabilizes the voltage; C4 provides extra compensation against oscillation.

The voltage at the non-inverting input of U1b is taken from the wiper of R17; when the voltage across resistors R11/R12 exceeds the voltage set by R17, the output of U1b will drop from 12V to a voltage which will maintain the current at the limiting value.

The plus and minus 12V for the bias circuitry is provided by XFRMR2, U2 and U3. This voltage is referenced to the positive output because the outputs from the op amps must swing around the power supply output voltage. C13 prevents oscillation, and C12 and R30 are included to prevent the supply from putting out its full voltage when first switched on. The negative supply requires that the positive 12V come on first, so C112 and R130 are added to the negative regulator.

C9 and C109 improve the overall stability of the power supply. D11 and D111 protect the supply from an accidental connection of another power supply wth the opposite polarity. D1 and D101 protect the supply if it is turned off with another power supply of the same polarity still connected.

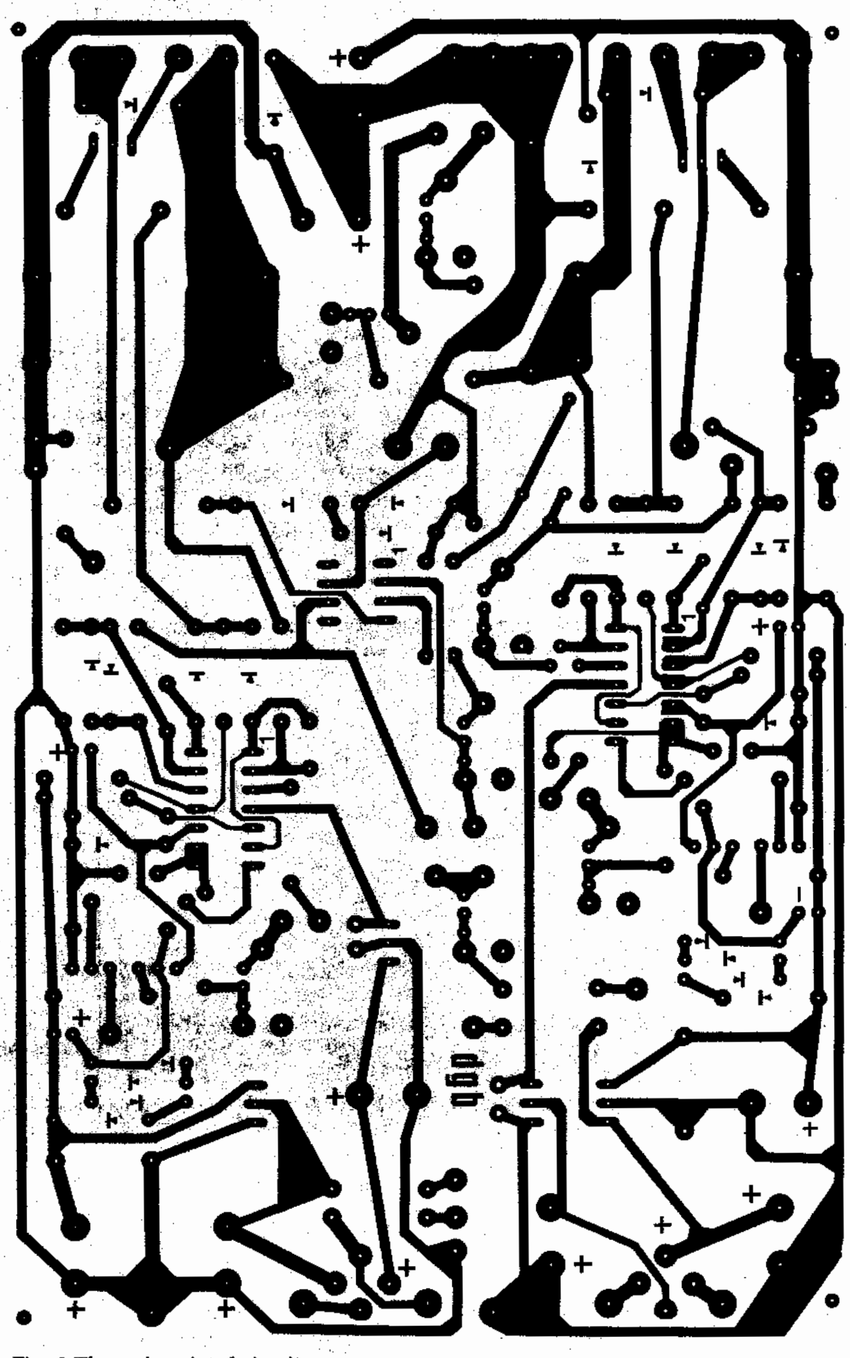
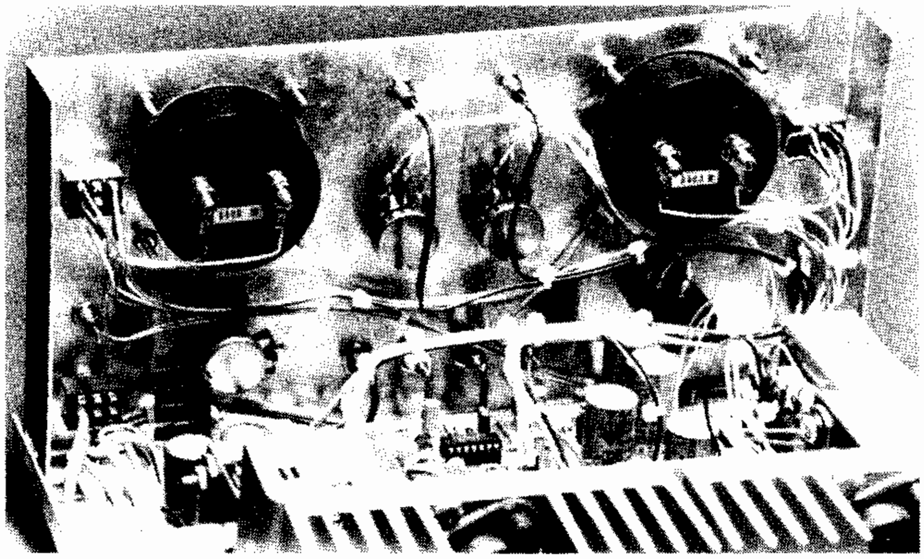


Fig. 6 The main printed circuit.



The front panel, showing the meter and control wiring.

given in Table 2 can be used to calculate the new resistor values. This table also includes the formula to calculate new series resistors for the meters if the recommended ones are not used. In the table, Vmax and Imax are the maximum output voltage and current of the supply, respectively. Imeter is the current required for the full-scale-deflection of the appropriate meter.

A change in the output voltage also requires a change in the zener diodes D113 and D114. Choose two 1W zeners that sum to approximately 5V more than the maximum output voltage. Note that the MC1436 has a maximum supply voltage of 60V. R133 must also be changed in order that each zener diode dissipates about 200mW.

R133 = 4 x Vz x (Vsupply - Vz)

where Vsupply is the magnitude of the negative input voltage from C101 and C102, and Vz is the sum of the zener diode voltages of D113 and D114.

The voltage reference diodes D6 and D106 are temperature compensated zener diodes; however, ordinary 6.2V (1N4735) zener diodes can be used with some loss of temperature stability. The current through these diodes should be increased by decreasing R22 and R122 to 75R.

If the negative supply is to be fully independent of the positive supply, U104 and its associated circuitry can be replaced with a duplicate of R19, R20, R21 and C5 off pin 8 of U101. If the negative supply is not required, all the 100-series parts can be deleted.

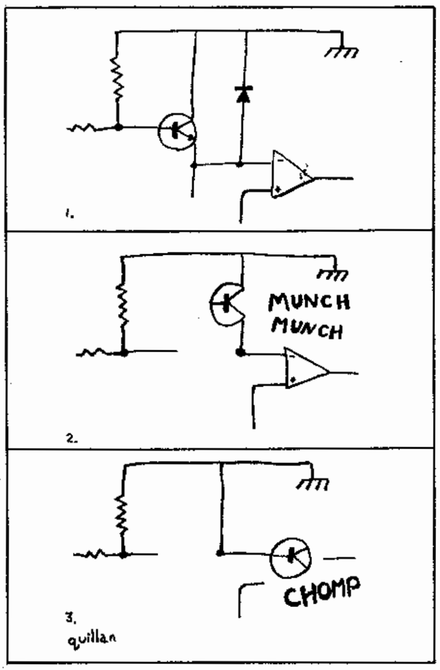
The 10-turn potentiometer (R21) can be replaced with one or two single-turn pots; if two pots are used, one should have a value of 50k for coarse voltage adjustment, and the other in series should be 1k for fine adjustment.

There are many other options available to the user, such as providing terminals for remote sensing when long leads are used, or replacing XFRMR1 and XFRMR101 with one larger transformer; however, these are left to the ambitious builder.

Use

Using the power supply is very easy; the maximum output currents are set on the current limiting pots (this can be done by shorting the output of the supply and adjusting the current limiting pot until the desired current is reached). If there is a problem with either load, assuming both positive and negative supplies are being used, the current limiting circuit will override the voltage control pot and keep the current constant. As the output voltage is increased, the output current also increases until the limiting current is reached. At this point the output voltage will not go any higher because the current would not remain constant. If the resistance of the load decreases, the output voltage will also decrease to keep the output current constant. With a short circuit, the output voltageis zero.

When the positive supply is current limiting, the negative supply will be limited to the output voltage of the positive supply regardless of the operating mode of the negative supply (the negative supply voltage can go below this voltage, of course). In other words, the magnitude of the negative supply can never exceed the magnitude of the positive supply.



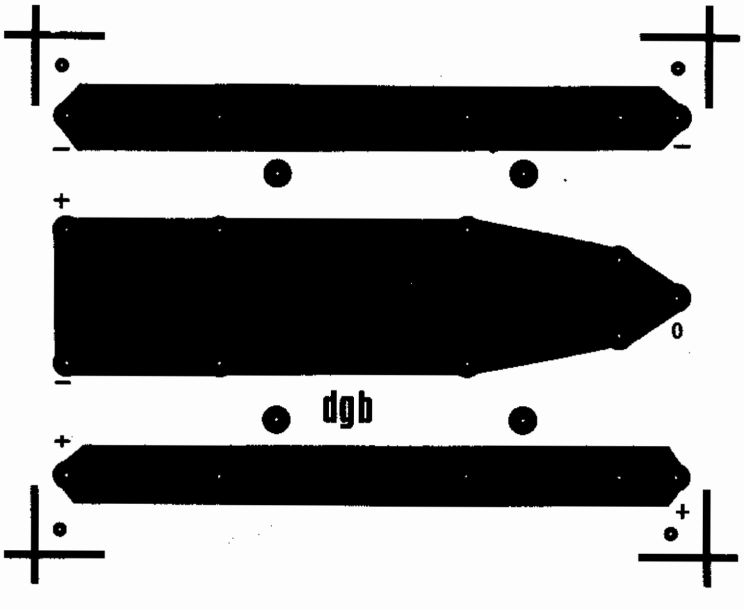


Fig. 7 The small printed circuit for the capacitors.

PARTS LIST

Resistors (All resistors 1/4W unless otherwise noted)
- R1, R101 .... 10K 1W
- R2, R102, R3, R103, R11, R111, R12, R112 .... 0R2 5W
- R4, R104 .... 47R
- R5, R105 .... 2K7 5W
- R6, R106 .... 2K7
- R7, R107 .... 680R
- R8, R108 .... 5K trimpot
- R9, R109, R13, R113, R134 .... 1K
- R10, R110, R14, R114, R26 R126, R135 .... 10K
- R15, R115 .... 10K
- R16, R116 .... 50K trimpot
- R17, R117 .... 1K pot
- R18, R118 .... 10R
- R19 .... 4K7
- R20 .... 5k trimpot
- R21 .... 50K ten turn pot Bourns # 3540S-1-503
- R22, R122 .... 270R
- R23, R123 .... 2K2
- R24, R124, R25, R125 .... 47K
- R27, R127 .... 470R 0.5W
- R28 .... 270K
- R29 .... 500K trimpot
- R30, R130 .... 1K 0.5W
- R31 .... 200R 0.5W
- R132 .... 3K3 5W
- R133 .... 4K3 0.5W
- R136 .... 50K trimpot
- R137 .... 50K pot

Capacitors
- C1, C101, C2, C102 .... 2200u 100V
- C3, C103, C4, C104 .... 470p
- C5 .... 470n
- C6, C106 .... 100n
- C7, C107 .... 1u 25V
- C8, C108 .... 47u 25V
- C9, C109 .... 100u 100V
- C10, C110, C11, C111, C12, C112 .... 100u 25V
- C13, C113 .... 4u7 tant.

Transistors
- Q1 .... TIP31C
- Q101 .... TIP32C
- Q2, Q3 .... MJ15003
- Q102, Q103 .... MJ15004
- Q4, Q105 .... 2N3906
- Q5, Q104 .... 2N3904

Diodes
- D1, D101, D11, D111 .... 1N4004
- D2 - D5, D102 - D105, D7 - D10, D107 - D110 .... 1N914
- D6, D106 .... 1N821A
- D112 .... 1N4731 (4.3V 1W)
- D113 .... 1N4757 (51V 1W)
- D114 .... 1N4731 (4.3V 1W)

Integrated Circuits
- U1, U101 .... LM324
- U2, U102 .... LM7812
- U3, U103 .... LM7912
- U104 .... MC1436

Miscellaneous
- BR1, BR101 .... KBPC602 (6A 200V)
- BR2, BR102 .... WO2M (1A 200V)
- XFMR1, XFMR101 .... 50V @ 3-4A Hammond # 167-P50
- XFMR2, XFMR102 .... 20VCT @ 0.3A Hammond # 166-F20
- LED1, LED101 ... green panel mount LED
- LED2 .... red panel mount LED
- M1, M2 .... 100uA 2.5" panel meter
- SW1, SW2 .... DPDT switch
- SW3 .... SPST switch
- Cabinet .... Hammond # 1426Q
- 4 binding posts
- 4 knobs
- 2 small TO-220 heatsinks
- 2 large TO-3 heatsinks
- 2 14 pin IC sockets
- 1 8 pin IC socket
- 4 TO-3 transistor sockets
- 1 panel mount fuse holder
- 1 5A slo-blow fuse

■

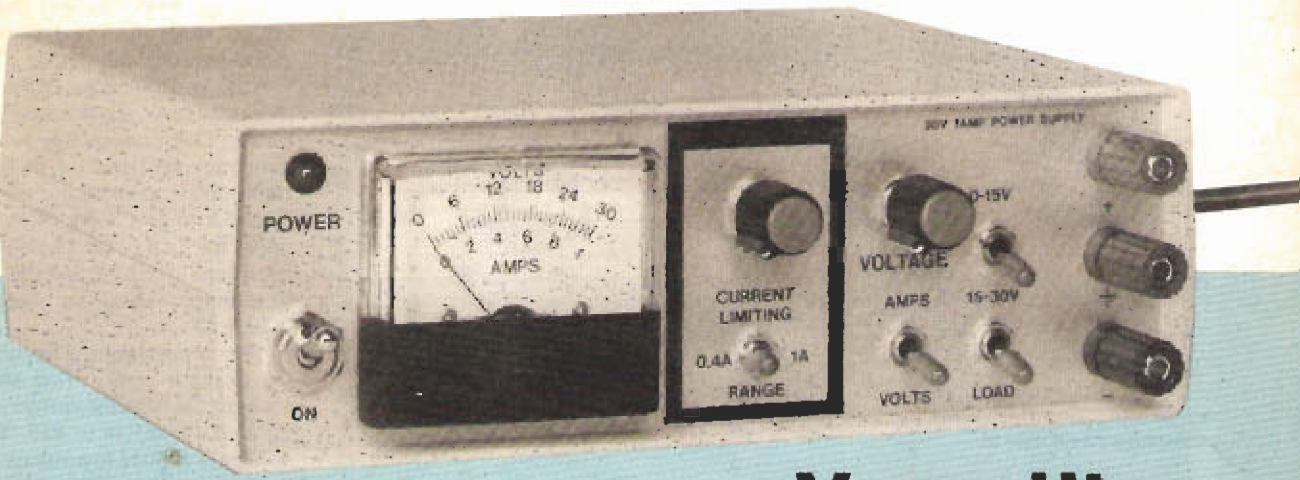
continued from page 17

For Your Information

```
F8A8 8D FF 9F            STA OUTPORT
F8AB C9 FF               CMP #$FF           ;QUIT IF BYTE IS $FF
F8AD D0 F3               BNE OPTEST
F8AF 60                  RTS
F8B0             ;**** COMMAND TABLE 'CTABLE'
F8B0             ;
F8B0             ;SUBROUTINE INDICATED WILL BE EXECUTED WHEN CORRESPONDING
F8B0             ;COMMAND BYTE IS RECEIVED:
F8B0             ;(NOTE: ALL COMMAND BYTES MUST BE EVEN)
F8B0             ;
F8B0 FF E2       CTABLE  DBY EXEC-1         ;$00
F8B2 F8 69               DBY RRAM-1         ;$02
F8B4 F8 8F               DBY SRIOT-1        ;$04
F8B6 F8 A1               DBY OPTEST-1       ;$06
F8B8             ;
F8B8             ;
F8B8             ;**** SUBROUTINE 'EXEC'
F8B8             ;
F8B8             ;MAPS RAM ADDRESS SPACE TO $F800-$FFFF AND PERFORMS
F8B8             ;INDIRECT JUMP TO ($FFFC) I.E. HARDWARE RESET VECTOR
F8B8             ;LOCS. $DFF7-9 OVERWRITTEN IN RAM
F8B8             ;
FFE3                     ORG $FFE3
FFE3                     OBJ $0FE3
FFE3 A9 6C       EXEC    LDA #$6C           ;OP-CODE FOR 'JMP ($FFFC)'
FFE5 8D F7 DF            STA $DFF7          ;TO END OF RAM AT $DFF7
FFE8 A9 FC               LDA #$FC
FFEA 8D F8 DF            STA $DFF8
FFED A9 FF               LDA #$FF
FFEF 8D F9 DF            STA $DFF9
FFF2 A9 80               LDA #$80           ;CLEAR MODE BIT THEREBY
FFF4 8D FF BF            STA TXPORT         ;MAPPING 2K RAM
FFF7             ;INTO $F800-$FFFF, AND DISABLING ROM
FFF7             ;AT THIS POINT ROM IS DISABLED AND INDIRECT JUMP IN RAM
FFF7             ;WILL BE EXECUTED
FFFA                     ORG $FFFA
FFFA                     OBJ $0FFA
FFFA             ;SET NMI,RESET & IRQ VECTORS TO 'RESTART'
FFFA 00 F8 00            ADR RESTART,RESTART,RESTART
FFFD F8 00 F8
0000                     END
```

```
DARK ROOM TIMER ROM
0000: 3E CF D3 03 3E 80 D3 03 3E CF D3 02 3E 0F D3 02
0010: 0E 30 79 E6 0F 59 57 CB 3A CB 3A CB 3A CB 3A 06
0020: 3C 3E 00 D3 00 DD 21 21 00 DB 00 E6 0F FE 0F 20
0030: 03 C3 FA 00 DD 21 7A 00 3E 60 D3 00 DB 00 E6 0F
0040: FE 0F 28 0B FE 07 CA D0 00 F6 60 08 C3 FA 00 3E
0050: 50 D3 00 DB 00 E6 0F FE 0F 28 06 F6 50 08 C3 FA
0060: 00 3E 30 D3 00 DB 00 E6 0F FE 0F 28 06 F6 30 08
0070: C3 FA 00 DD 21 21 00 C3 FA 00 08 D9 4F D3 00 E6
0080: 0F 47 DB 00 E6 0F B8 28 08 DD 21 21 00 D9 C3 FA
0090: 00 06 00 21 C5 00 7E FE FF 28 07 B9 28 0C 23 04
00A0: 18 F4 DD 21 21 00 D9 C3 FA 00 78 D9 CB 21 CB 21
00B0: CB 21 CB 21 B1 4F 3E 00 D3 00 DB 00 E6 0F FE 0F
00C0: 20 F8 C3 12 00 57 6E 5E 3E 6D 5D 3D 6B 5B 3B FF
00D0: 3E B0 D3 00 AF B9 20 02 16 0A 05 20 0F 06 3C 1D
00E0: 7B B2 CA 12 00 FE FF 20 03 1E 09 15 DD 21 DA 00
00F0: DB 00 E6 08 CA 21 00 C3 FA 00 21 1A 01 7A 85 6F
0100: 7E D3 01 DB 01 E6 80 28 FA 21 1A 01 7B 85 6F 7E
0110: D3 01 DB 01 E6 80 20 FA DD E9 3F 06 5B 4F 66 6D
0120: 7D 07 7F 6F 3F 29
```

Probotics, Toronto's personal robot user's association, will hold its first robot contest in the afternoon of Saturday, October 26, 1985. The contest will be open to robots which will have been designed and built by members of the club, and prizes will be awarded in each of two categories. The first category is for robots that can learn their way through a maze; the robot making a second pass in the shortest time wins. The second is for speech-recognition systems. Robots are required to be able to tell left from right when one of the words is spoken, which is more than some people can do. Robots must be home-built; anyone who feels that their robot has too little design and too many commercial parts should contact Probotics prior to the contest. A third category, that of robots which must negotiate the Don Valley Parkway at rush hour, has been eliminated. Write to Probotics, 38 Arlene Crescent, Scarborough, Ontario M1P 3L9.



Versatile Bench Top Power Supply

Here's a high-performance power supply to help get your designs off of the drawing board and on to a PC board!

GREG SWAIN AND FRANCO UBAUDI*

EVERYONE WHO WORKS WITH ELECTRONICS needs a power supply, but a commercially-produced variable-voltage current-limited power supply can take quite a chunk out of your pocketbook. So we decided to find a better way. Our power supply provides any voltage between 3 and 30 volts, at any maximum current you desire less than 1000 mA. In addition, our supply provides short-circuit protection, load switching, and switchable voltage/current metering. Further, all parts are readily obtainable and inexpensive, and the supply is easy to build and calibrate.

One feature that really sets our design apart is that it's capable of providing a full amp of power over most of its range of output voltage. Many comparable power supplies can provide one amp of current, but only over a restricted range of output voltage.

Output voltage is selected by means of a range switch with two positions: 3–15 and 15–30 volts. A potentiometer varies voltage continuously throughout the selected range. Similarly, current limiting is selected by a switch providing ranges of 150–400 and 400–1000 ma., and by a potentiometer that allows current to be varied continuously over the selected range. Actually, both current and voltage ranges overlap slightly to ensure that there are no gaps in output.

*Adapted with permission of *Electronics Australia*

The graph in Fig. 1 illustrates the high performance you can obtain from our power supply. As you can see, maximum load current (one amp) is maintained up to 27 volts, after which the load curve falls away due to transformer losses. Other specifications include load regulation that is better than 0.2% from zero to full load, and output ripple that is less than 2-mv rms.

Design considerations

Initially we considered using an LM317 three-terminal variable-voltage regulator as the basis for our supply, but we soon ran into difficulties. Despite various approaches, we were unable to come up with a cost-effective circuit that would deliver one amp over the entire voltage range. The problem was thermal limiting in the LM317 with a high input voltage and a low output voltage. Another drawback was that an additional op amp was required to provide current sensing for the current-limiting circuitry, and that would have increased both cost and complexity of the circuit.

So we rejected the LM317 and adopted the LM723. It requires a current-boosting transistor, but it has built-in current limiting. The guts of the 723 are shown in Fig. 2. It consists of a series-pass transistor, an error amplifier and a voltage reference. The error amplifier compares a portion of the output voltage with the internal reference voltage and continually regulates the base current that is applied to the series-pass transistor. That's what provides regulated output.

The 723's built-in series-pass transistor can deliver a maximum of 150 mA of current, so, in order to obtain more current, an external power transistor is required.

One particularly useful characteristic of the 723 is its built-in current-limiting circuitry. When output current reaches a preset value, the current-limit transistor turns on and that reduces the base drive to the series-pass transistor. The output voltage is thereby reduced.

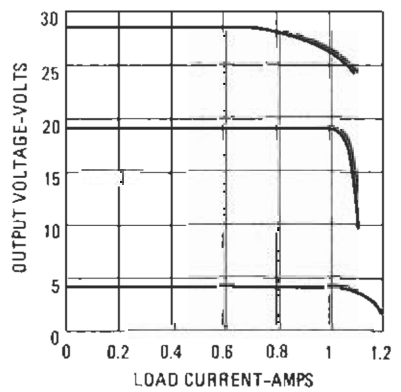


FIG. 1—POWER SUPPLY CAN SUPPLY ONE amp of current all the way to 27 volts, where output drops to about 0.75 amp.

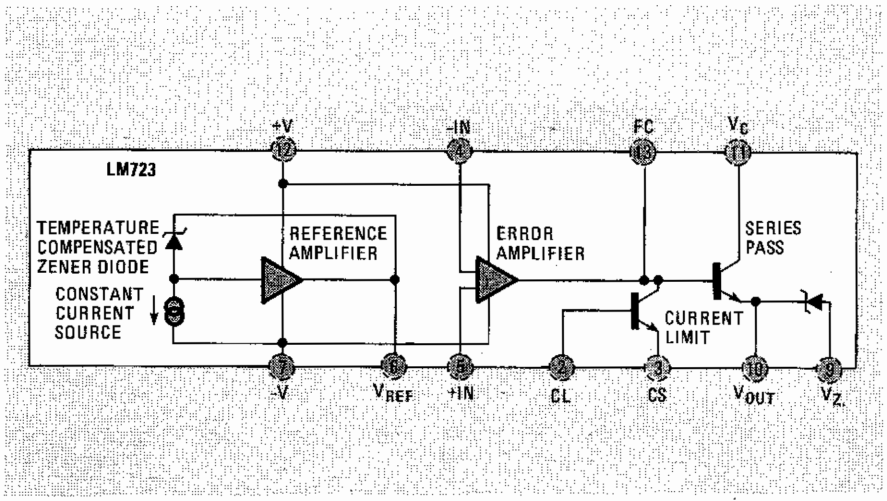


FIG. 2—THE LM723 REGULATOR has most of the circuitry necessary for a complete current-limited power supply built right in.

Circuit details

The schematic of the complete power supply is shown in Fig. 3. A tapped transformer drives a diode bridge (D1–D4) and two 2500-µF filter capacitors (C1 and C2). That provides a no-load voltage of 37 or 47 volts, depending upon the position of switch S2-a. The unregulated DC is then fed to a pre-regulator stage composed of Q1 and D5. Those components protect IC1 (the 723) from an over-voltage condition; the 723 can't handle more than 40 volts.

The LED (LED1) and its 2.2K current-limiting resistor (R1) provide on/off indication. The current through the LED varies slightly according to the transformer tap selected, but that's of no real consequence.

The series-pass transistor in IC1 drives voltage-follower Q2, which provides current amplification. That transistor can handle lots of power. It has a maximum collector current of 15 amps and a maximum V_{CE} of 70V, both of which are more than adequate for our supply.

Heat dissipation could have been a problem when drawing high current at low voltage. We solved that problem by switching the secondary winding of the transformer. For outputs greater than 15 volts, S2-a selects the 30-volt tap on the transformer, and for outputs less than 15 volts, S2-a selects the 24-volt tap.

Voltage regulation

Now let's examine in detail how the voltage-regulator section works. The error amplifier in the 723 is connected as a non-inverting amplifier with variable gain. The input to that amplifier is fixed at about 2.8 volts by R3 and R4, which are fed by the 723's internal reference voltage. Capacitor C3 is included to reduce output noise.

On the 0–15V range, switch S2-b is closed, so feedback resistance—the resistance between the output of the supply and the inverting input of the error amplifier—can be varied between 100 and 5000 ohms. That corresponds to an amplifier gain ranging from 1.1 to 6.1, and that corresponds to an output voltage ranging from 3.1 to 17.1 volts. With switch S2-b open, the gain of the amplifier is adjustable from 5.8 to 10.8, and that corresponds to an output voltage ranging from 16.2 to 30.2 volts.

The current-limiting circuit depends on the position of S3. That switch causes load current from the emitter of Q2 to flow through either R14 or R15. The resulting voltage is applied to a voltage divider network composed of R12 and R13. The voltage developed at the junction of those two resistors depends on the setting of front-panel control R13, CURRENT LIMIT. That voltage is then applied to the current-limiting transistor in the 723.

In the interests of economy, we elected to use a single meter and to switch between measuring voltage and current. It would be nice to have a separate meter for each, but cost is prohibitive. Meters are expensive, and a larger case, which is also more expensive, would be necessary to provide the necessary front panel area.

Our metering circuit is straightforward. When measuring voltage, the parallel combination of a R16 and R17 provides an effective resistance of 30K. That resistance is in series with the one-mA moving-coil meter, so it can measure a maximum of 30 volts full scale. When measuring current, the meter is shunted by the 0.5 ohm resistance provided by the parallel combination of R5 and R6. Trimmer potentiometer R7 is used to adjust the meter for accurate readings.

There's not much else to the circuit. Capacitor C6 prevents switching transients from being delivered to the output, and D6 protects the power supply from an accidentally-applied reverse voltage—from a charged capacitor, for example. Capacitor C5 ensures stability of the supply under all conditions.

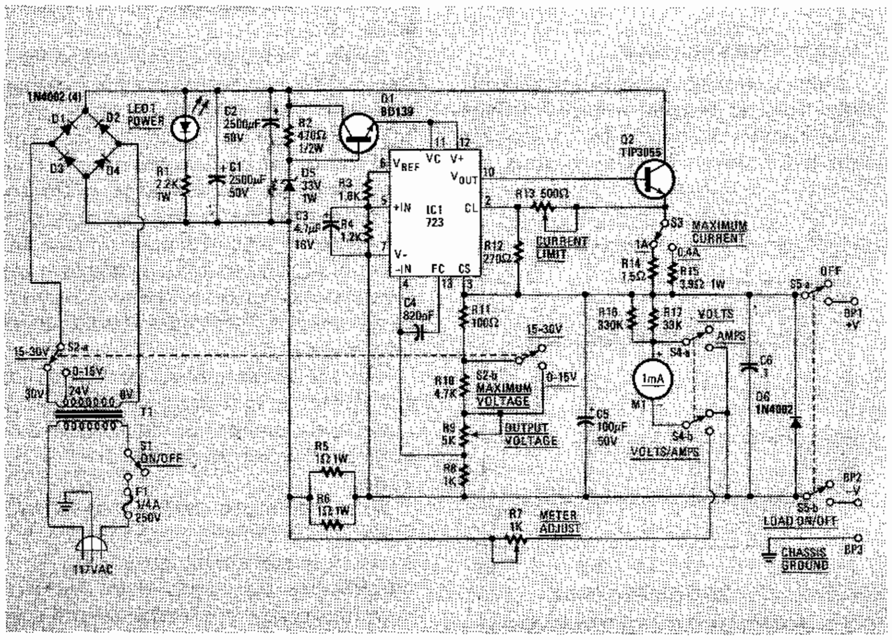


FIG. 3—SCHEMATIC DIAGRAM OF OUR POWER SUPPLY shows how the LM723 can be put to good use with little more than a current-amplifying transistor (Q2).

Construction

Except for the front-panel switches, potentiometers, etc., and the power transformer, all components are mounted on a PC board that measures about 4⅛ × 4⅜ (inches). A foil pattern for the board is shown in "PC Service."

No special procedure need be followed when assembling the PC board, although the job will be much easier if the lower-profile components are installed first. Refer to the parts-layout in Fig. 4 to install all components; be careful to install IC1, the diodes, the transistors, and the electrolytic capacitors in the correct orientation. Also, mount transistors Q1 and Q2 without trimming their legs; the full length will be necessary if you use the heat sink arrangement shown in Fig. 5.

The power supply is housed in an attractive plastic instrument case that measures about 7⅞ × 6⅜ × 2¾ (inches). If you purchase the kit from the source mentioned in the parts list, you'll receive special front and rear panels.

The layout of the front panel is shown in Fig. 6. Note that, if you use a different meter than the one specified in the Parts List, you'll have to alter the drilling dimensions accordingly. The kit includes *Scotchcal* artwork that you can affix to the front panel and then spray with a hard-setting clear lacquer to protect the artwork, which can then be used as a template.

PARTS LIST

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

R1—2200 ohms, ½ watt
R2—470 ohms, ½ watt
R3—1800 ohms
R4—1200 ohms
R5, R6—1 ohms, 1 watt
R7—1000 ohms, trimmer potentiometer
R8—1000 ohms
R9—5000 ohms, panel-mount potentiometer
R10—4700 ohms
R11—100 ohms
R12—270 ohms
R13—500 ohms, panel-mount potentiometer
R14—1.5 ohms, 5 watts
R15—3.9 ohms, 1 watt
R16—330,000 ohms
R17—33,000 ohms

Capacitors

C1, C2—2500 µF, 50 volts, electrolytic
C3—4.7 µF, 16 volts, electrolytic
C4—820 pf, ceramic disc
C5—100 µF, 50 volts, electrolytic
C6—0.1 µF, ceramic disc

Semiconductors

IC1—LM723 voltage regulator
D1–D4, D6—1N4002 rectifier
D5—1N5257B, 33 volts, 1 watt, Zener diode
Q1—BD139 or ECG373
Q2—TIP3055

Other components

F1—¼-amp, 250-volt fuse
M1—0–1 mA panel meter
S1—SPST power switch
S2, S4—DPDT switch
S3—SPDT
S5—DPST
T1—117 VAC primary, 0-24-30 volt secondary, 1 amp (Altronic A6672)

Miscellaneous

Line cord, heatsink, mica insulators, silicone grease, PC board, case, binding posts, knobs, solder, wire, etc.

Note: A complete kit of parts, including case, is available for $49.95 from Imtronics Industries, Ltd., 11930 31st Court, St. Petersburg, FL 33702. Florida residents must add appropriate sales tax.

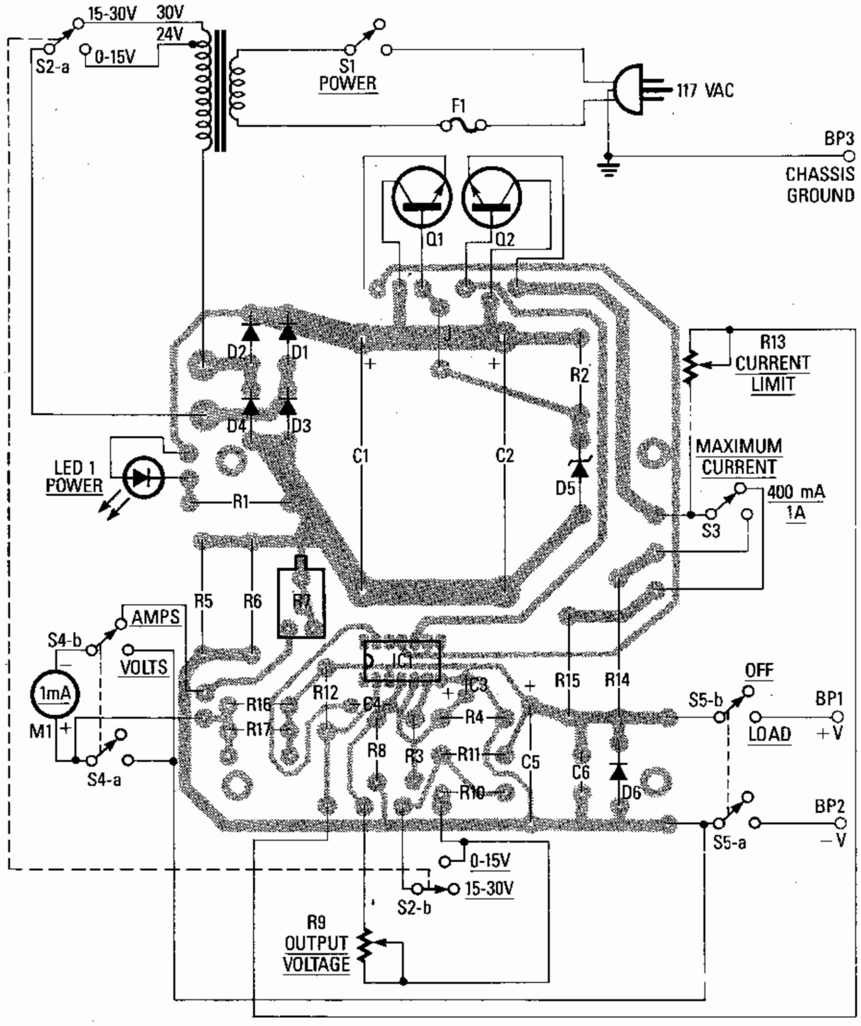


FIG. 4—ON- AND OFF-BOARD COMPONENTS are mounted and wired as shown here.

You'll also have to drill holes in the rear panel for the fuse holder, the power cord, and the heatsink. But, don't drill the heatsink holes yet.

Secure the PC board to four internal mounting posts using self-tapping screws, and bolt the power transformer to the case using machine screws and nuts. Include a solder lug under the nut nearest the rear panel.

Use medium-duty hookup wire (16 gauge) for all wiring that carries the full supply current, and light-duty hookup wire for the potentiometer, the meter, and the LED.

Install the rear panel and then mark the positions of the holes for the power transistors. Drill those holes, and then you can use the rear panel as a template for drilling the heatsink mounting holes. The heatsink may have to be trimmed to fit the rear panel. Both transistors must be insulated from the rear panel using mica washers and insulating bushings. Smear heatsink grease on all mating surfaces, including the rear of the heatsink, and then bolt the assembly together using machine screws and nuts as shown in Fig. 7. Finally, use an ohmmeter to make sure that there is no conductivity between the metal tabs of the transistors, and the rear panel, or the heatsink.

Anchor the 117 VAC power cable to the rear panel with a cable clamp. Solder the "hot" 117 VAC lead to the fuseholder, the neutral wire to the power transformer, and the ground-wire to the solder lug beneath the transformer. In addition, separate ground leads should be run to both the rear and the front panels.

We recommend that you use heat-shrink tubing over all 117 VAC connections to the fuseholder, the transformer, and the power switch. That will prevent you from being shocked while doing the testing and calibration discussed below. Use wire with thick insulation for the 117 VAC circuit, and do not use a miniature metallic switch for POWER switch S1.

Shown in Fig. 8 is a meter scale you can use to replace the scale that comes with the meter. Being careful not to bend the meter's needle, gently pry the plastic

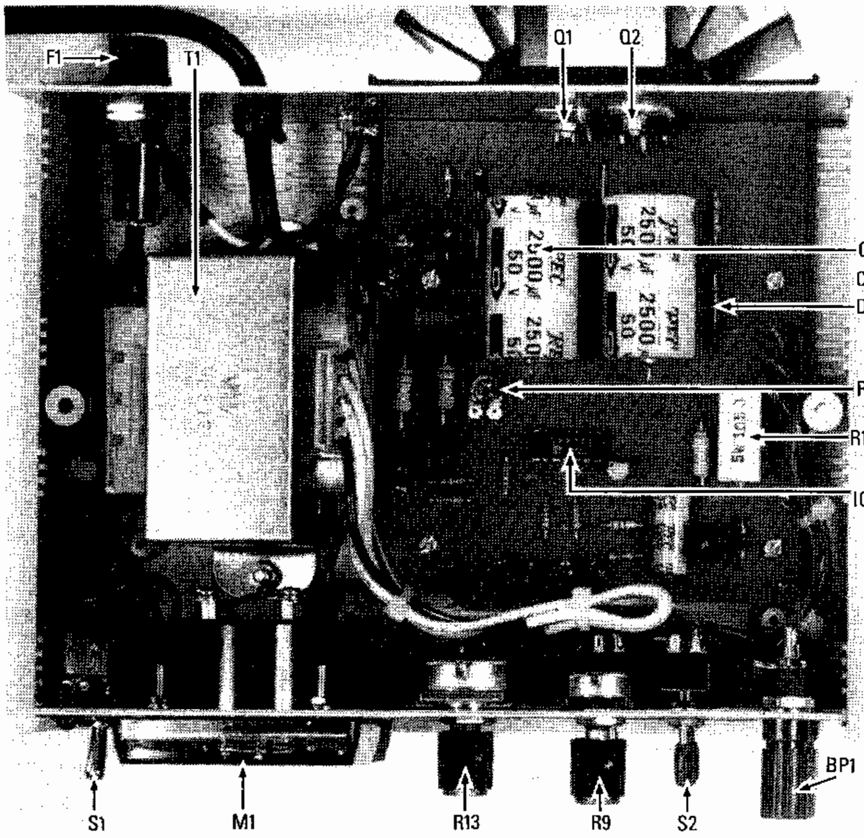


FIG. 5—INTERNAL VIEW OF THE POWER SUPPLY reveals its neat, clean, design.

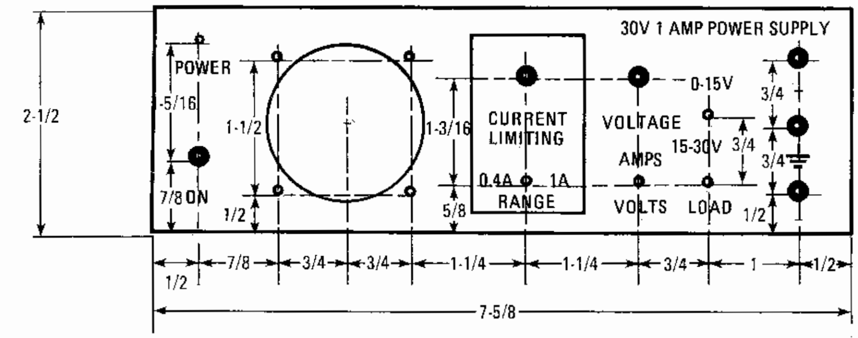


FIG. 6—DRILL THE FRONT PANEL OF THE POWER SUPPLY according to the dimensions shown here.

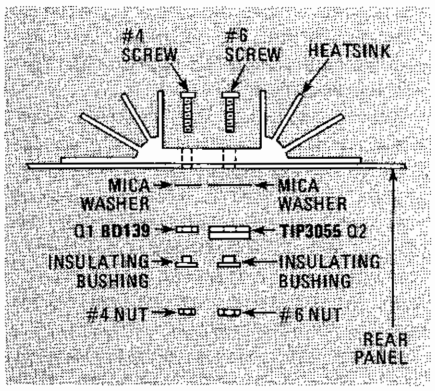


FIG. 7—ATTACH Q1 AND Q2 to the rear panel and the heatsink as shown here. Use heatsink grease on all mating surfaces.

cover off the meter and glue an enlarged copy of our scale over the present one.

Testing and calibration

Connect a voltmeter across the output binding posts, turn the supply on and close the LOAD switch. If all is well, the POWER LED will light up and you will be able to vary the output voltage from three to 30 volts using the RANGE switch and the OUTPUT VOLTAGE control.

Verify that the voltage reading on the supply's meter and on your meter are identical. Note that we left room on the PC board for an additional trimmer resistor that, if used, would parallel R16 and R17. You can install an additional high-

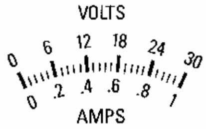


FIG. 8—ENLARGE OR REDUCE THIS METER SCALE to fit the meter you use, and then glue our scale over yours.

valued resistor there to increase the accuracy of the voltage displayed by the meter, if necessary. Just use Ohm's law to calculate the appropriate value.

Assuming all is well, open the load switch, select the 0–15 volt range, and then turn the OUTPUT-VOLTAGE potentiometer fully counter-clockwise. Now set the CURRENT-LIMIT control to the middle of its rotational range, the CURRENT-LIMIT switch to the one amp range, and the VOLTS/AMPS switch to amps. Now connect a one-amp ammeter directly across the output binding posts and close the load switch.

Your meter should indicate a current of about half an amp, although the supply's meter may show something different now. Adjust the CURRENT-LIMIT control so that the multimeter reads 1A, and then adjust trimmer resistor R7 so that the supply's meter reads the same.

Finally, vary the CURRENT-LIMIT control and verify that the meter reading corresponds closely to that on the multimeter throughout its range.

Applications

Why is adjustable current limiting useful? First, it protects the power supply in case its output is inadvertently short-circuited by improper circuitry. Second, it helps prevent that circuitry from being damaged by excessive current due to a fault condition.

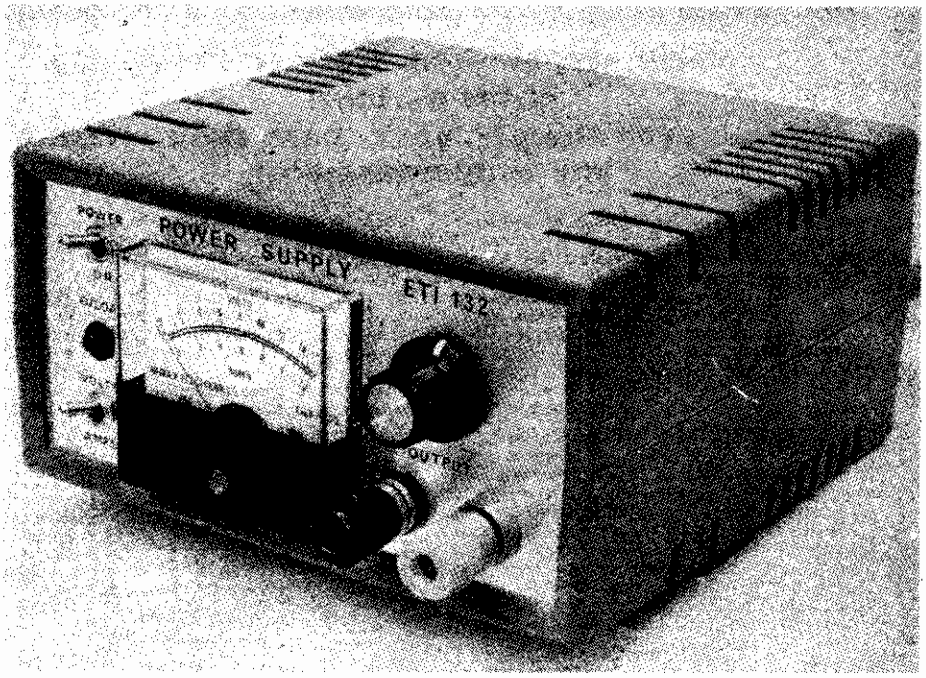
Why is a separate LOAD switch useful? It allows you to remove load voltage without turning the supply off. The latter can cause switching transients that might damage the power supply, the circuit under test, or both.

So, when testing out an untried circuit, turn the LOAD switch off, and the voltage and current controls all the way down. Connect the supply to your circuit, turn the LOAD switch on, and gradually increase output voltage to the required voltage. Next set the meter to measure current and turn the CURRENT LIMIT control up *slowly* while monitoring the meter. If the needle of the meter seems to jump at all throw the LOAD switch quickly. But if the needle moves smoothly as you rotate the control, most likely the circuit has no severe power-related problems. In other words, you're not likely to fry anything! So now you're ready to start the real work—testing and troubleshooting your circuit. But that's another article. **R-E**

EXPERIMENTERS' POWER SUPPLY

Versatile, two version bench supply — no workshop is complete without one!

THIS ECONOMICAL POWER SUPPLY gives the full range 0 to 15 V. In addition this supply features metering (or you can use the calibrated scale on the second version if you don't have a spare meter) to enable accurate setting of voltage or current.



Construction

Commence by assembling the pc board with the aid of the component overlay diagram. The main filter capacitor C1 is normally a chassis-mounting type, but we mounted this satisfactorily by passing the lugs through the large holes in the pc board, bending them flush with the copper and soldering. Check the polarity of the capacitor before fitting, as it cannot be seen later. The transistor Q3 is fitted, along with its heatsink, with the two mounting screws. No insulation is used between the transistor and the heatsink but pass a small piece of tubing over the base and emitter leads where they go through the heatsink, to prevent shorting. If the meter is not required RV3, RV4 and R10 are not used.

The front and rear panels can now be drilled. Note that the mounting bracket of the transformer has to be cut back about 12 mm on one end to allow it to fit easily.

Assemble the front and rear panels and wire the unit according to Fig 3.

The wires to and from the power switch can pass the pc board via the chamfer on the lower left hand side. Other wires from the pc board to the front panel can be connected onto the copper side of the board.

SPECIFICATION

Output Voltage	0-15 V variable
Output Current	0-1 A
Current Limit	approx 1.2 A
Load regulation	35 mV 0 to 1 A load
Line regulation	20 mV 220 to 260 V input
LED indication of current overload	

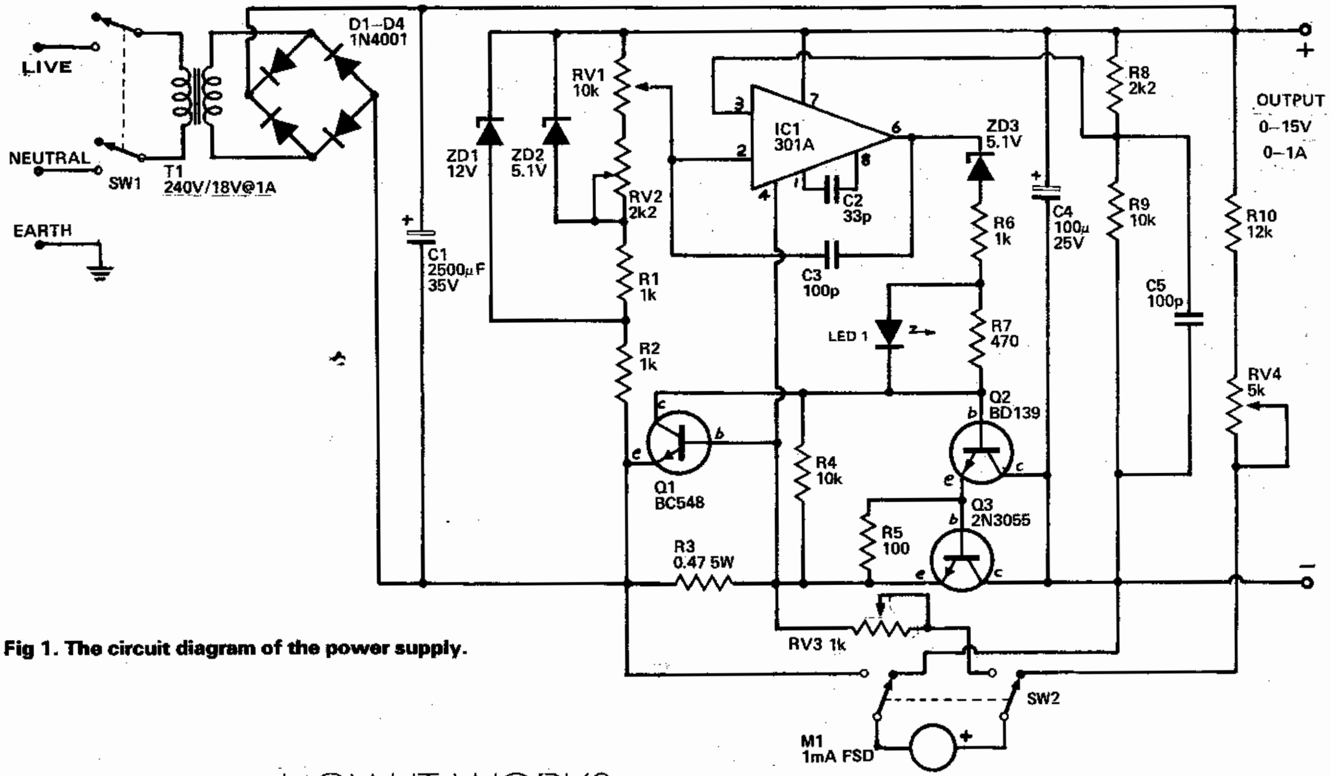


Fig 1. The circuit diagram of the power supply.

HOW IT WORKS

The 240 V mains is reduced to 18 V in T1. This 18 V ac is then rectified by D1-D4 and filtered by C1 to give about 25 volts dc (on no load). The voltage reference for the supply is ZD2, which gives about 5 V dc. However, due to the large variation in voltage across C1 (caused by load changes) additional regulation is used, incorporating ZD1, and the two circuits give the stability required.

The regulator is a 'series-pass' type with the positive rail common and the negative rail variable. We have done it this way to achieve outputs down to 0 V. The comparator IC (LM301) cannot work with its input less than about 2 volts above the negative rail, but it can work with the inputs at the positive supply rail. However this will not work with all types of op amp – so do not substitute the 301 with a 741 or similar.

The output of ICl controls the output transistors, Q2 and Q3. A level-shifting zener ZD3 is used in the output of IC1 as its output cannot swing low enough. The output voltage is divided by R8 and R9 and is taken to IC1 which compares it to that set on RV1. IC1 then adjusts the drive to the output stage until the two voltages are the same. RV2 is used to compensate for variations in the voltage of ZD2.

In the event of an overload the voltage drop across R3 will forward-bias Q1, which will bypass current away from the output transistors. This causes the output voltage to fall, the comparator sees this error, and the output of IC1 goes to the positive supply rail (trying to compensate). Q1 however will continue to bypass any extra current, holding the output current constant at about 1.2 A. However, the additional current out of IC1 will forward bias LED 1 and it will indicate the overload.

With such high gain in the circuit additional frequency stability is needed and C3 and C5 provide this. For metering, we simply use a 1 mA movement meter and measure the voltage across the output (via R10 and RV4) and across R3 (current).

Setting Up

1. Without Meter – With this version we rely on the potentiometer to be linear. In practice it is not linear at the two ends of its travel. Calibration is done by adjusting the knob position and RV2.

Set the output to one volt and position the knob to read one volt. Now turn the knob to 15 V and adjust RV2 to give 15 V output. Recheck the 1 V setting and repeat the procedure, if necessary.

2. With Meter – Connect the output to an accurate voltmeter and turn the pot to maximum. Adjust RV2 to give 16 V. Adjust RV4 until the meter reads 16 V (with RV2 switched to volts). Now connect a load and an ammeter. Set 1A on the ammeter and then adjust RV3 until the power supply meter reads 1 A. ▷

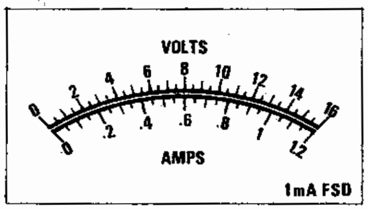


Fig 2. The meter scale used.

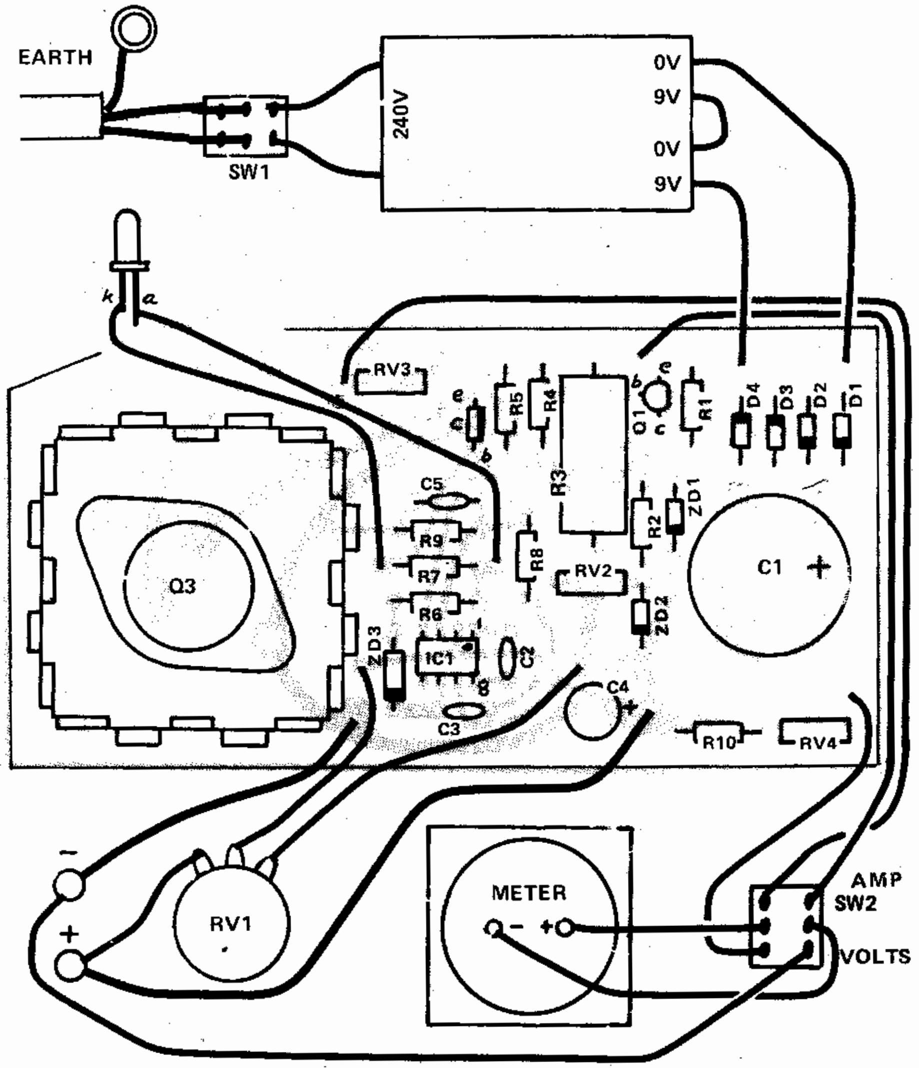
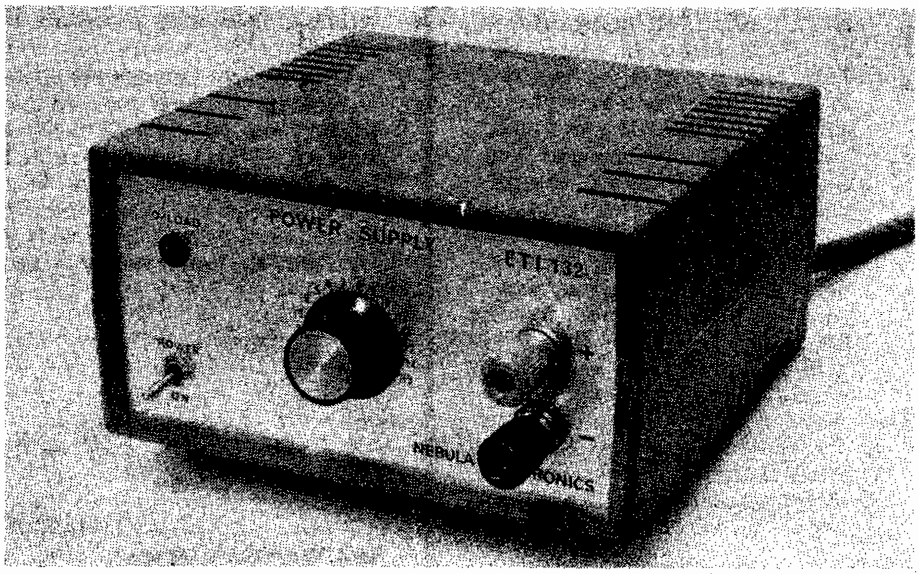


Fig 3. The component overlay and interconnection diagram.



PARTS LIST

Resistors

R1,2,6	1 k	½ W 5%
R3	0R47	5 W 5%
R4,9	10 k	½ W 5%
R5	100	" "
R7	470	" "
R8	2k2	" "
R10 *	12 k	" "
RV1	10 k lin rotary	
RV2	2k2 Trim	
RV3 *	1 k "	
RV4 *	5k "	

Capacitors

C1	2500 µ electrolytic
C2	33 p ceramic
C3,5	100 p "
C4	100 µ 25 V electrolytic

Semiconductors

D1-D4	Diodes 1N4001
ZD1	Zener 12 V 400 mW
ZD2,3	Zener 5.1 V 400 mW
LED1	TIL 209 with clip

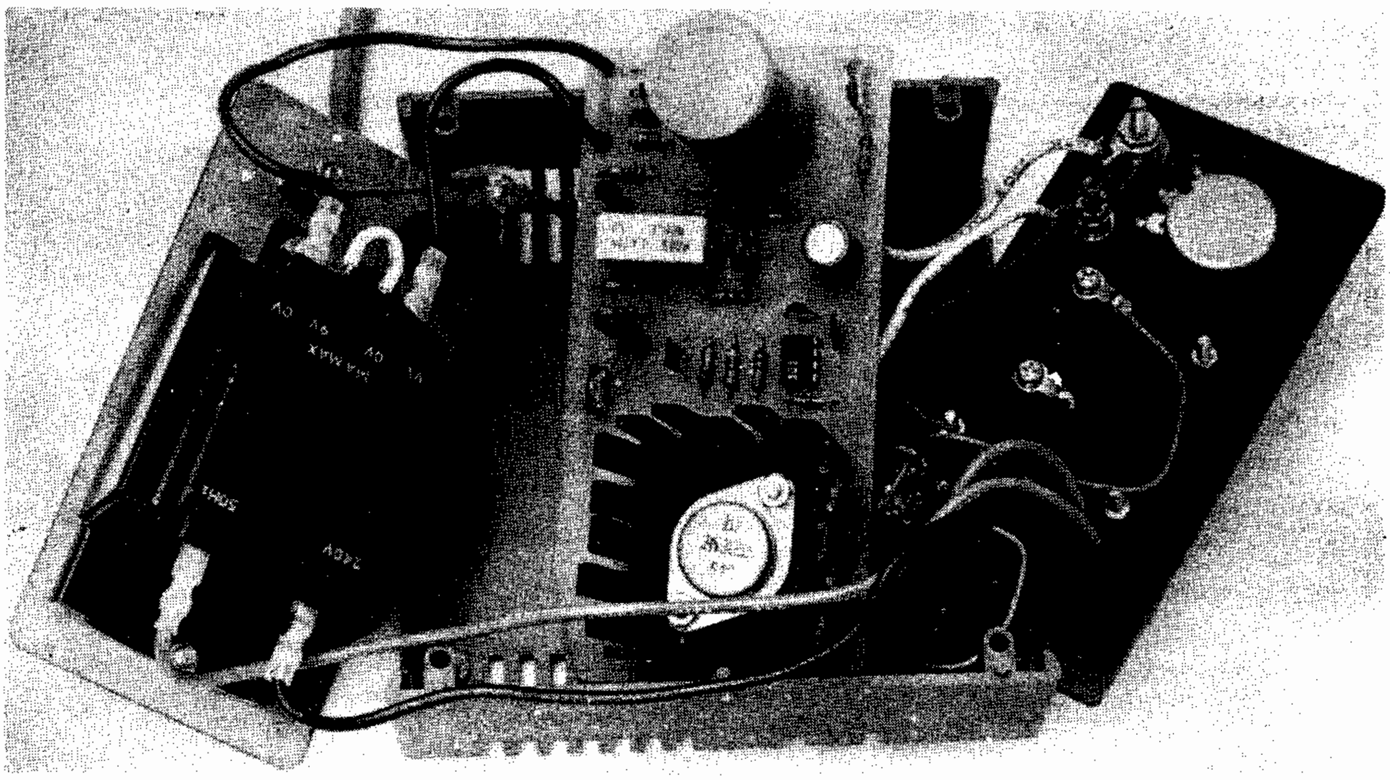
Q1	Transistor	BC548
Q2	"	BD139
Q3	"	2N3055
IC1	Integrated circuit LM301	

Miscellaneous

PCB ETI 132
Transformer 240 V – 18 V 2A

Case
Power cord and clamp
Heat sink
Two 2 pole 2 position 240 V Toggle switches
Two terminals
Meter 1 mA FSD *
Knob

*If meter is not required delete RV3, RV4, R10, the meter and one switch



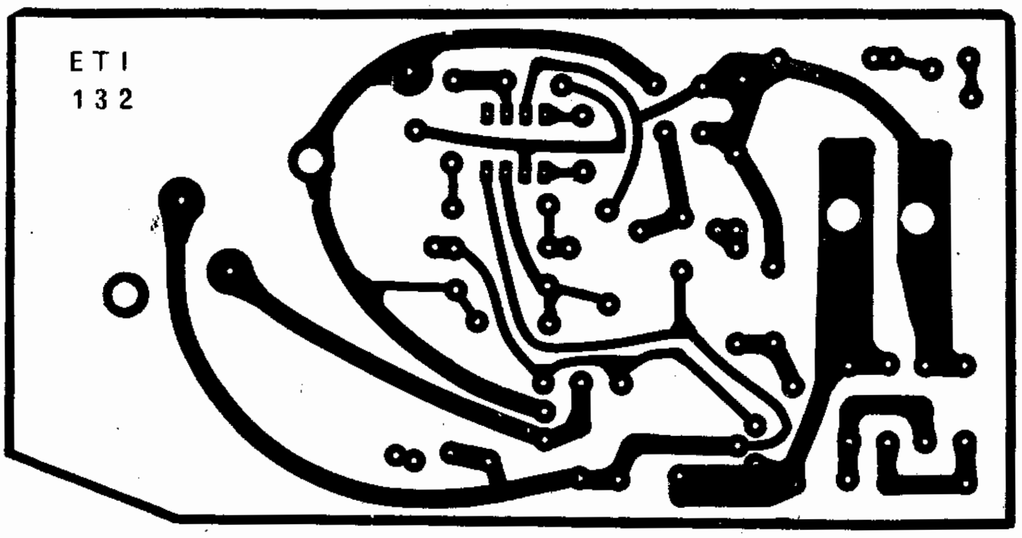
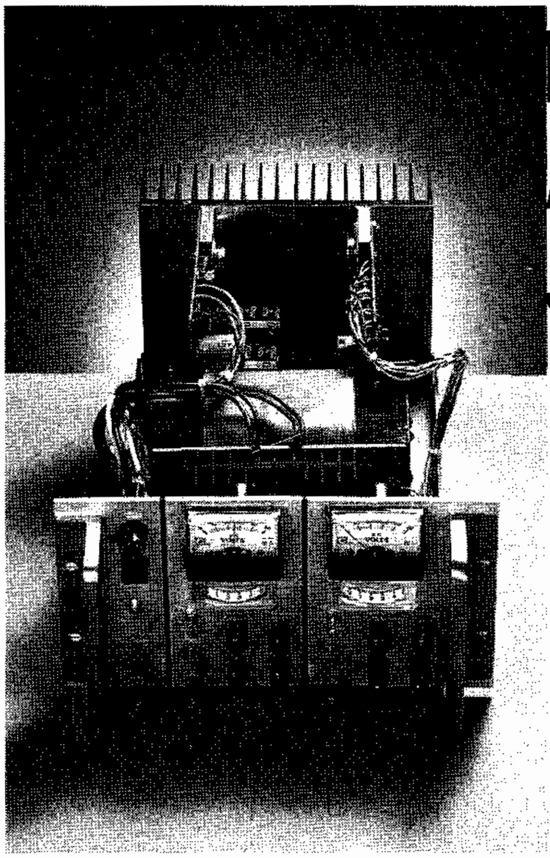


Fig 4. Printed circuit layout Full size 132 x 66 mm.

BUILD THIS

UNIVERSAL LABORATORY POWER SUPPLY



This universal power supply offers high performance and flexibility at low cost.

REINHARD METZ

WHILE NUMEROUS BENCH POWER SUPPLIES have emerged over the years, few combine the performance, flexibility, and low cost of the version described here. This article describes a well-regulated, modular, lab-grade power supply with dual 0–50-volt, 0–5-amp DC supplies, and a single 5-volt, 3-amp DC supply. It uses two identical custom PC boards, one for each 50-volt supply. There's also a customized heat sink with space for both PC boards that minimizes point-to-point wiring in the 50-volt supplies. However, because of the modular design, you can customize the configuration as needed. See Table 1 for a performance summary.

Circuit description

Figure 1 is the schematic of the power supply. The value of the design lies in the use of IC1, an LM317HVK adjustable series-pass voltage regulator, for broad-range performance. The "HVK" suffix specifies the high-voltage version of the regulator. The remainder supplies voltage-setting and current-limiting functions. The input to to IC1 comes from the output of BR1, which is filtered by C1 and C2 to about +60-volts DC, and the input for current-sense comparator IC2 comes from BR2, which also acts as a negative bias supply for regulation down to ground.

The purpose of IC1 is to maintain the OUT terminal at 1.25- volts DC above the ADJ terminal. The current drain at the ADJ terminal is very low (nominally 25 μA) and, as a result, R15 and R16 (the coarse and fine voltage adjustments) and R8 form a voltage divider, with 1.25 volts appearing across R8. The bottom end of R16 connects to a −1.3-volt reference level generated by D7 and D8, letting the R8-R15 divider set the output voltage all the way down to ground when R15+R16=0 ohms. In general, the output voltage is determined by:

$$(V_{OUT} - 1.25 + 1.3)/(R15 + R16) = 1.25/R8.$$

Thus, the maximum value from each variable supply board is:

$$V_{OUT} = (1.25/R8) \times (R15 + R16) = 50.18 \text{ volts DC.}$$

Using potentiometers R15 and R16 to control the voltage, V_{OUT} ranges from 0–50 volts DC. As current demand increases, the drop across R2 increases, and at about 0.65 volts (which corresponds to about 20 mA), Q1 and Q2 turn on, becoming the main current path. Also, R3 and R4 ensure that Q1 and Q2 share the load equally. Current limiting is provided by IC2. Its noninverting input uses the output voltage as a reference, and its inverting input is connected to the

TABLE 1—PERFORMANCE SUMMARY

Characteristic	Capability
Number of supplies	2 (fully floating)
Voltage range	0–50 VDC
Current range	0–5 A
Coarse vs. fine control ratio (both current and voltage)	1:10
Voltage regulation	0.01% line, 0.1% load
Current limiter	0.5%

NOTE: (a) There's a current-limiting LED;
(b) Has internal +5 VDC, 0–3 A supply.

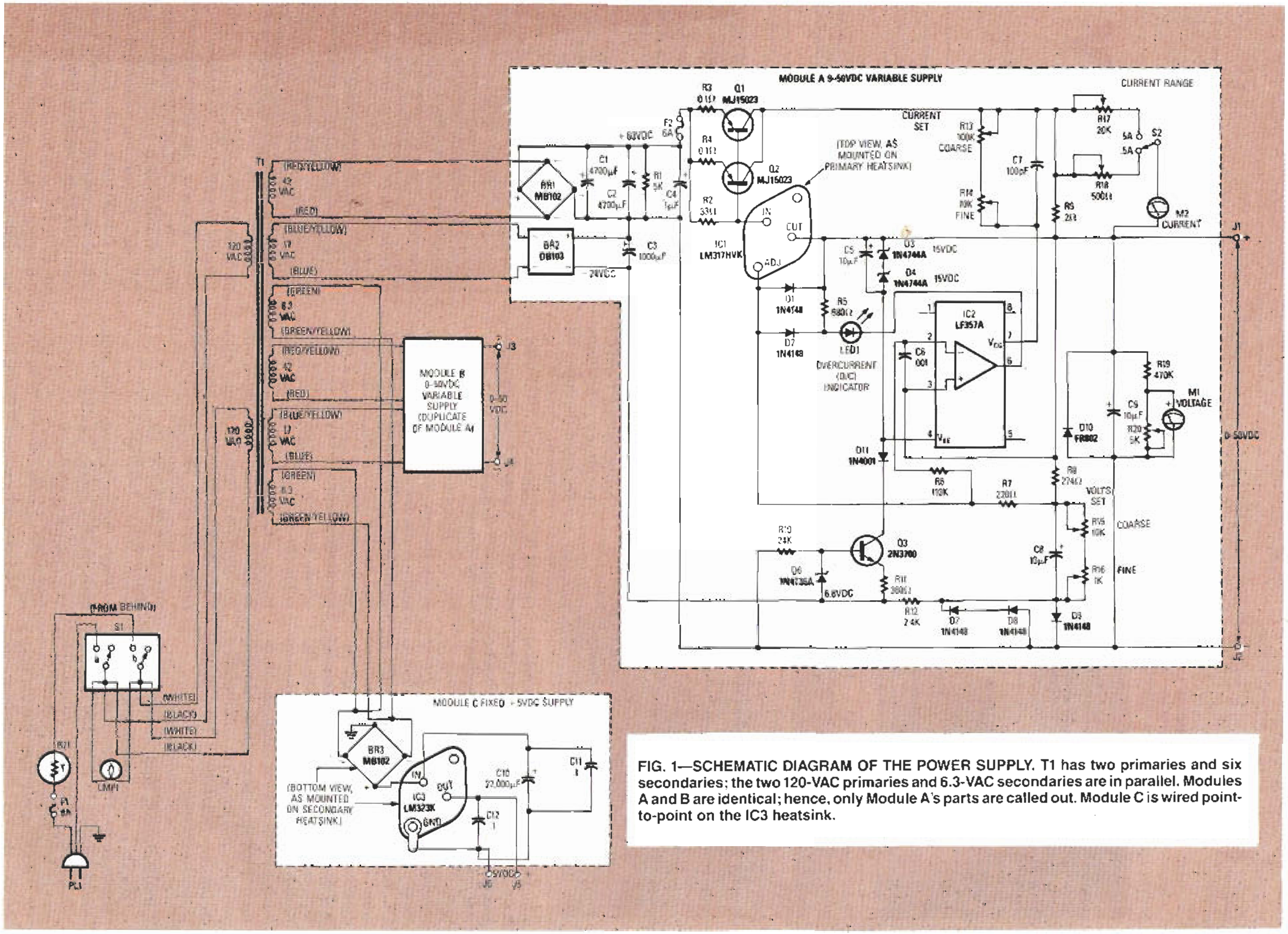


FIG. 1—SCHEMATIC DIAGRAM OF THE POWER SUPPLY. T1 has two primaries and six secondaries; the two 120-VAC primaries and 6.3-VAC secondaries are in parallel. Modules A and B are identical; hence, only Module A's parts are called out. Module C is wired point-to-point on the IC3 heatsink.

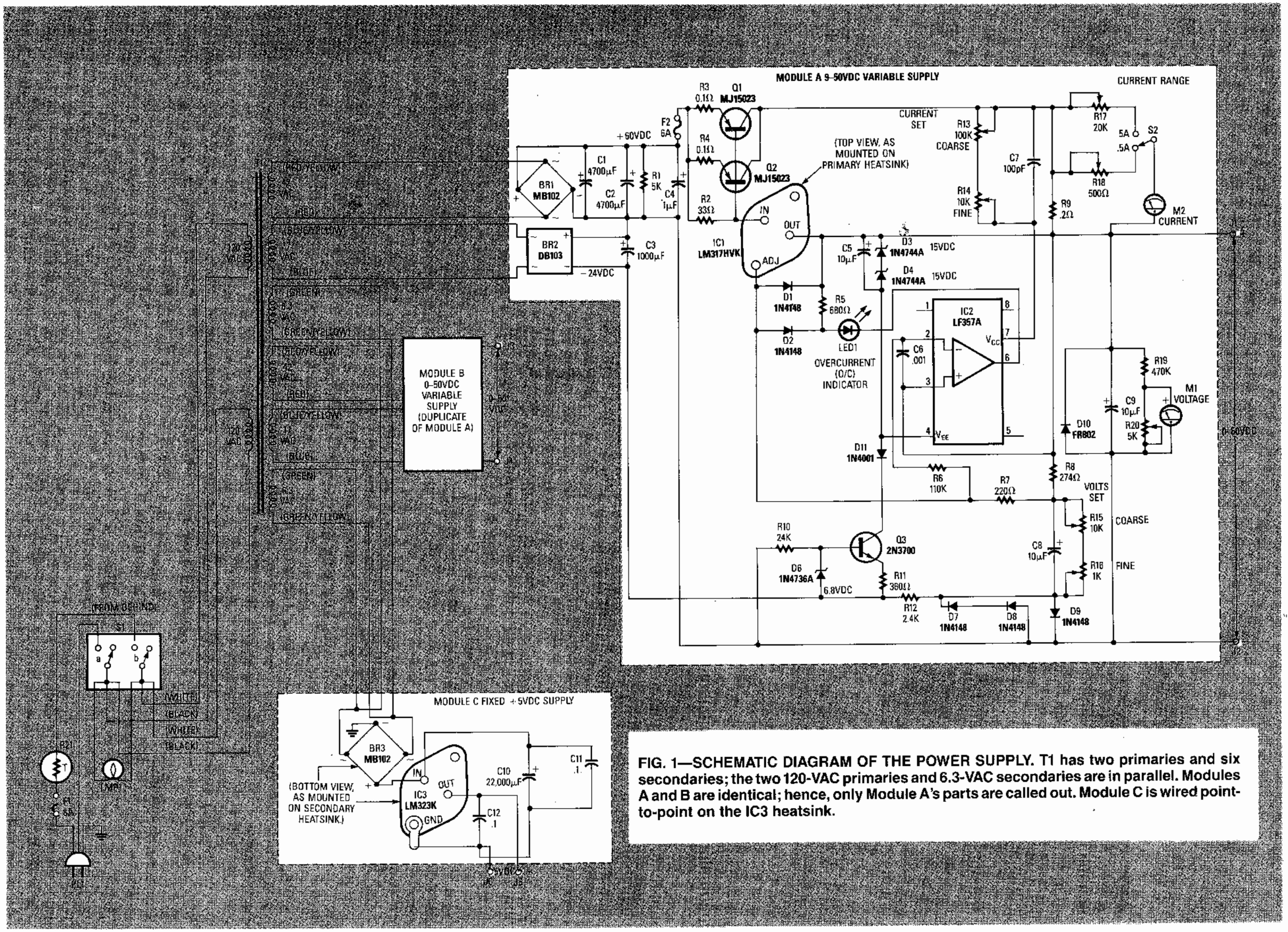


FIG. 1—SCHEMATIC DIAGRAM OF THE POWER SUPPLY. T1 has two primaries and six secondaries; the two 120-VAC primaries and 6.3-VAC secondaries are in parallel. Modules A and B are identical; hence, only Module A's parts are called out. Module C is wired point-to-point on the IC3 heatsink.

voltage divider created by R6 and current-limit potentiometers R13 and R14.

The drop across R6 is about 1.25 volts, the reference voltage mentioned above as being the difference between the OUT and ADJ terminals of IC1. Current from Q1 and Q2 flows through R9, creating a drop across R13 + R14. Thus, IC2 trips when the drop across R9 creates current through R13 and R14, causing the voltage at the non-inverting input to exceed V_{OUT}.

That sets the current limit point at: $(I_{OUT} \times 0.2)/(R13 + R14) = 1.25/100K$; $I_{OUT} = 0$–5 amps. That corresponds to a range of about 0–5 amps. At the current limit point, IC2's output goes low, pulling the ADJ lead down via D2 and lighting LED1. Additional current for D5 is provided by R5. As the ADJ lead is pulled low, the output follows, until the output current drops to a level corresponding to the setting of R13 and R14.

Since the output voltage can be anywhere from 0–50 volts, the power supply for IC2 must track that range using D3, D4, and Q3. Next, D9 ensures that the output voltage doesn't rise when the supply is shut off, while D10 protects against supply back-feeding. Finally, M1 monitors voltage and M2 monitors current. The power supply is modular; each PC board is used for one 50-volt supply, and includes all parts other than those for the front panel and the 5-volt supply. Since a dual 50-volt version may be popular, T1 accomodates two supplies and the 5-volt supply, and a custom heat sink for the two PC boards is available.

Construction

The transformer is mounted on a 6- × 5- × 1-inch L-bracket in the center of the supply, and the heatsinks for IC1 and BR1 go on the back of the transformer bracket. A 6- × 8- × 6- × 11-inch U-shaped cover of 1/16-inch aluminum completes the assembly. Complete all drilling and preparation before assembly, but install only the transformer and its bracket for now, to make wiring easier for you.

Next, assemble the PC board(s) for the 50-volt supplies; Fig. 3 shows the parts placement diagram. Install all components except Q1, Q2, and IC1. Check resistor values as you go, and mount the heat sink for BR1 before installation. Don't forget to observe polarities on all the electrolytic capacitors. Use the alignment holes with 6-32 screws for the PC board(s). Install Q1, Q2, and IC1, using mica insulators, heat sink compound, and 6-32 screws. Check for shorts from

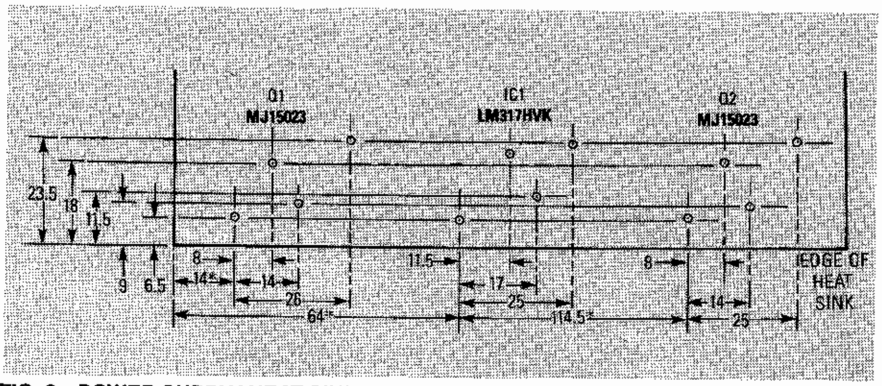


FIG. 2—POWER SUPPLY HEAT SINK LAYOUT. All marked dimensions are in millimeters, all mounting holes are 1/4-inch in diameter, all lead holes are 3/16-inch in diameter, and add 3 mm to all dimensions with an (*) to align the PC boards.

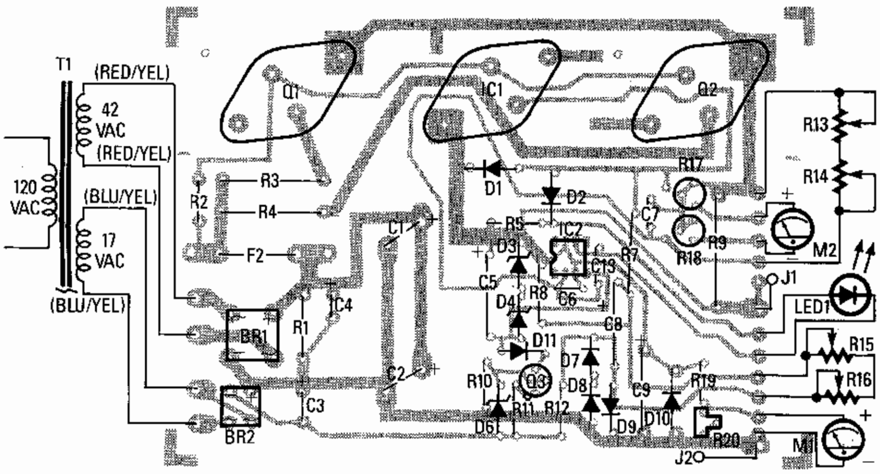


FIG. 3—PARTS PLACEMENT DIAGRAM FOR 50-volt supply. Only one primary and the two relevant secondaries of T1 have been depicted, for brevity.

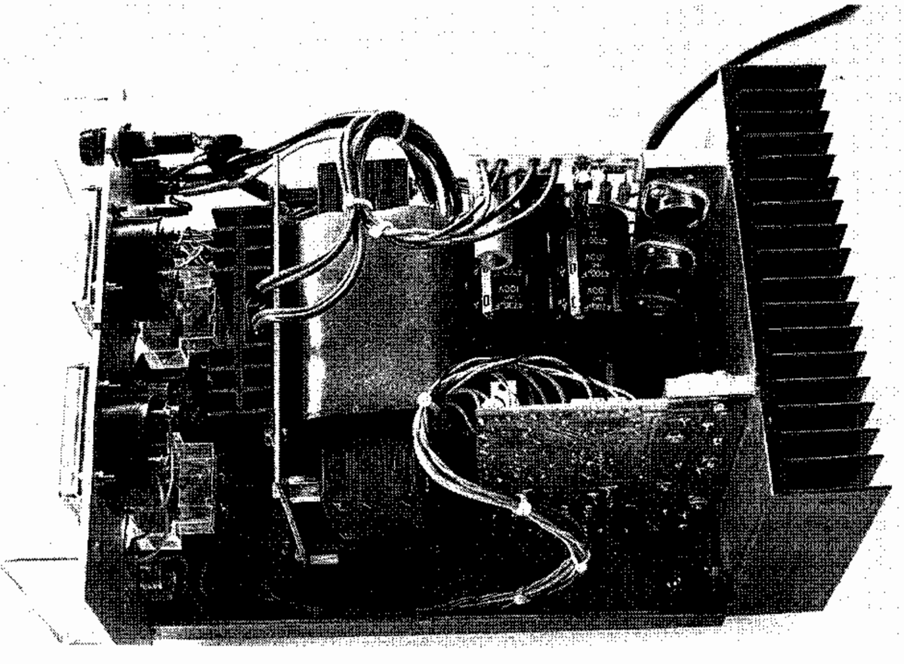


FIG. 4—PROTOTYPE OF THE POWER SUPPLY. Note the custom PC board heatsink at right, and how S1, F1, LMP1, and R21 are wired.

PARTS LIST

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

R1—5000 ohms, 1-watt
R2—33 ohms
R3, R4—0.1, 3-watt
R5—680 ohms
R6—115,000 ohms, 1%
R7—220 ohms
R8—274 ohms, 1%
R9—0.2 ohm, 5-watt
R10—24,000 ohms
R11—360 ohms
R12—2400 ohms
R13—100,000-ohm potentiometer
R14, R15—10,000-ohm potentiometer
R16—1000-ohm potentiometer
R17—20,000-ohm PC-board-mounted potentiometer
R18—500-ohm PC-board-mounted potentiometer
R19—470,000 ohms
R20—5000-ohm PC-board-mounted potentiometer
R21—thermistor in-rush protector (Keystone KC003L)

Capacitors

C1, C2—4700 µF, 100 volts (Panasonic P6430)
C3—1000 µF, 50 volts, Panasonic P6272
C4—1 µF, 63 volts
C5—10 µF, 500 volts
C6—0.001 µF, ceramic disc
C7—100 pF, mica
C8, C9—10 µF, 50 volts
C10—22,000 µF, 16 volts (Panasonic P6420)
C11, C12—0.1 µF, ceramic disc

Semiconductors

IC1—LM317HVK adjustable, series-pass, high-voltage regulator
IC2—LF357A JFET input, 8-pin DIP comparator
IC3—LM323K 5-volt DC regulator in TO-3 case
D1, D2, D7, D8, D9—1N4148 germanium diode
D3, D4—1N4744A, 15-volt, 1-watt Zener diode
D6—1N4736A, 6.8-volt, 1-watt Zener diode
D10—FR802 8-amp, 100-volt fast-recovery silicon rectifier (TO-220 package)
BR1, BR3—MB102 10-amp, 200-volt bridge rectifier
BR2—DB103 1-amp, 200-volt bridge rectifier
Q1, Q2—MJ5023 or ECG68 PNP silicon transistor
Q3—ECG128 or 2N3700 1 watt general purpose NPN silicon transistor
LED1—yellow light-emitting diode

Other components

F1—8-amp fast-blow fuse
F2—6-amp fast-blow fuse
T1—600 VA transformer; 120-volt AC primary; two 42-volt, 5-amp secondaries; two 17-volt, 250-mA secondaries; and one 7-volt, 3-amp secondary
PL1—120-volt AC pilot light
M1—50 mA meter (GC Electronics 20-1110)
M2—100 µA meter (Jewell 81T)
S1—120-volt, 10-amp DPST switch
S2—SPDT switch
J1, J3, J5—red banana jack
J2, J4, J6—black banana jack

Miscellaneous: 8-inch wide × 6-inch high × 11-inch deep aluminum case with ⅛-inch predrilled aluminum plate as front panel (including holes for handles) and 8- × 11- × 3/32-inch steel plate with a 1-inch lip on the bottom, two front-panel-mounted case handles, 6- × 8- × 3-⅛-inch dual-supply main heatsink, heatsink for 5-volt DC regulator with TO-3 case, heat sink for BR1, 3-wire power cord, knobs, four rubber feet, panel-mounted fuse holder (for F1), two PC-board mounted fuse clips (for F2), PC board (Digi-Key #F040), three TO-3 transistor insulator kits, silicone grease, wire, solder, etc.

NOTE: The following parts are available from A&T LABS, P.O. Box 552, Warrenville, IL 60555; plated PC board with parts placement silkscreen, $19.00; 600 VA custom dual-supply transformer (T1), $66.00; custom dual-supply main heatsink, $42.00; LM317HVK (IC1), $8.00; MJ4502 (Q1 and Q2), $6.00; M1, $16.00. Send check or money order, except for COD orders via UPS in the U.S. If you don't order T1, add 5% shipping and handling for U.S., and 10% for Canada. If you order T1, add 12% for U.S., and 17% for Canada; Illinois residents add 6.75% sales tax.

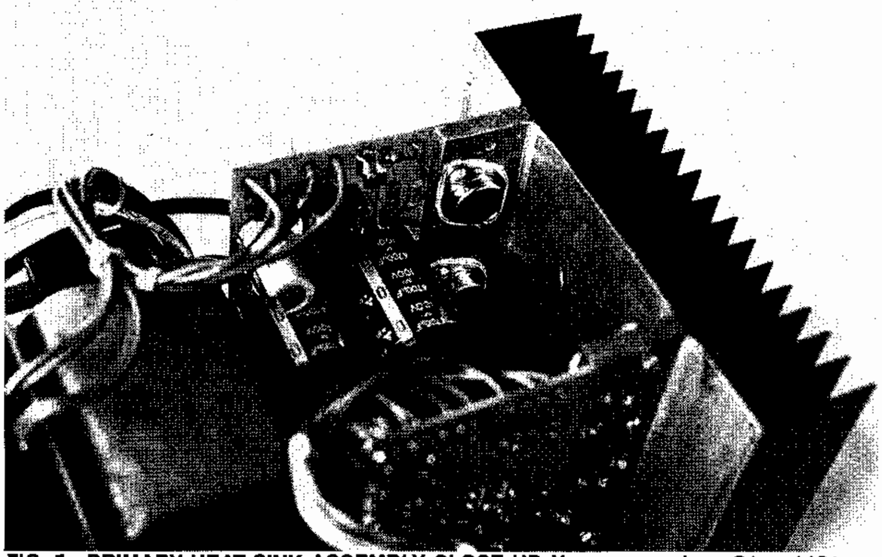


FIG. 5—PRIMARY HEAT SINK ASSEMBLY CLOSE UP. You can see how Q1 and IC1 are attached, the silicone grease used for heat transfer, and how the heatsink is attached to the PC boards. The mica insulators aren't clearly visible from this perspective.

Q1, Q2, or IC1 to the heatsink. Note that BR1 and BR3 have different pin connections than BR2.

A variety of meters can be used with this design. Sensitivity differences are compensated with PC-board-mounted resistors and potentiometers. The values in the parts list call for 50 µA/2500 ohms for M1, and 100 µA/700 ohms for M2. In most cases, panel meters require some faceplate disassembly or removal to mark them for 50 volts and 5 amps DC at full scale. Assuming sensitivities of I_V and R_V for M1 and I_I and R_I for M2, the resistor values are:

- R19 = $25/I_V$, R20 = $2 \times R_V$.
- R17 = $2 \times (1.0_I - R_I)$, for 5 amps full-scale.
- R18 = $2 \times (0.1/I_I - R_I)$, for 0.5 amp full-scale.
- R18 = $2 \times (0.2/I_I - R_I)$, for 1 amp full-scale.

Proceed with the point-to-point wiring from the PC board to the front panel. Those wires should all termi-

continued on page 69

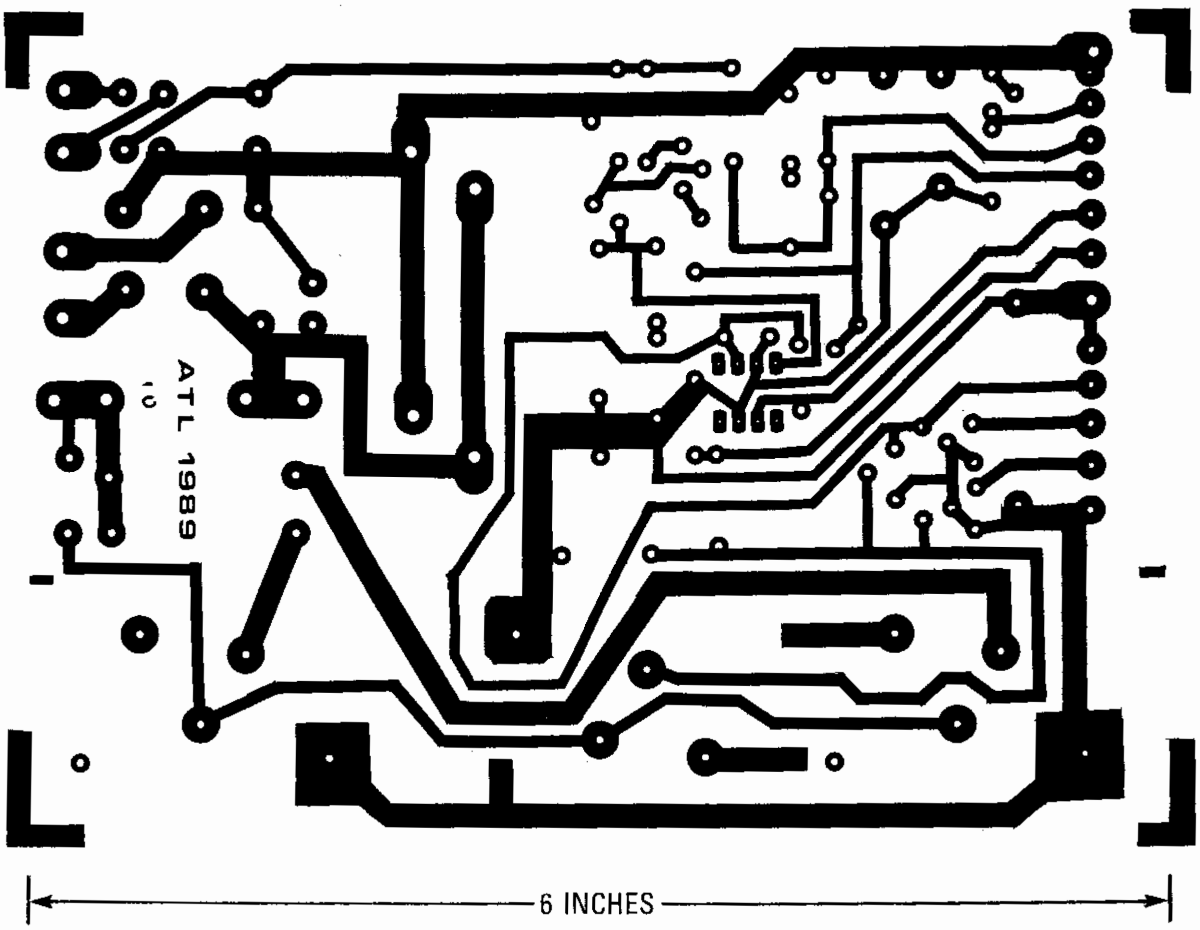
POWER SUPPLY

continued from page 34

nate in a row on one end of the PC board. Figure 4 shows the general chassis layout, and Fig. 5 shows the juncture between the PC boards and the custom heatsink close up. Use 16-gauge or heavier wire for the leads to J1–J4, and twisted pairs to R13-R14 and R15-R16. If you're including the 5-volt supply, install BR3, C10, C11, and IC3 with the secondary heatsink using point-to-point wiring. Connect T1, wire the primaries, and mount the primary heatsink and front panel. You should now be ready to turn on the supply.

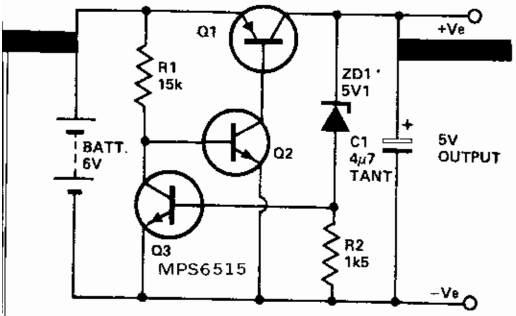
Checkout

Install F1 and F2, apply power, and check for +60 volts DC across C1 and C2. Check for a bias supply of −25



UNIVERSAL POWER SUPPLY FOIL PATTERN.

RVICE



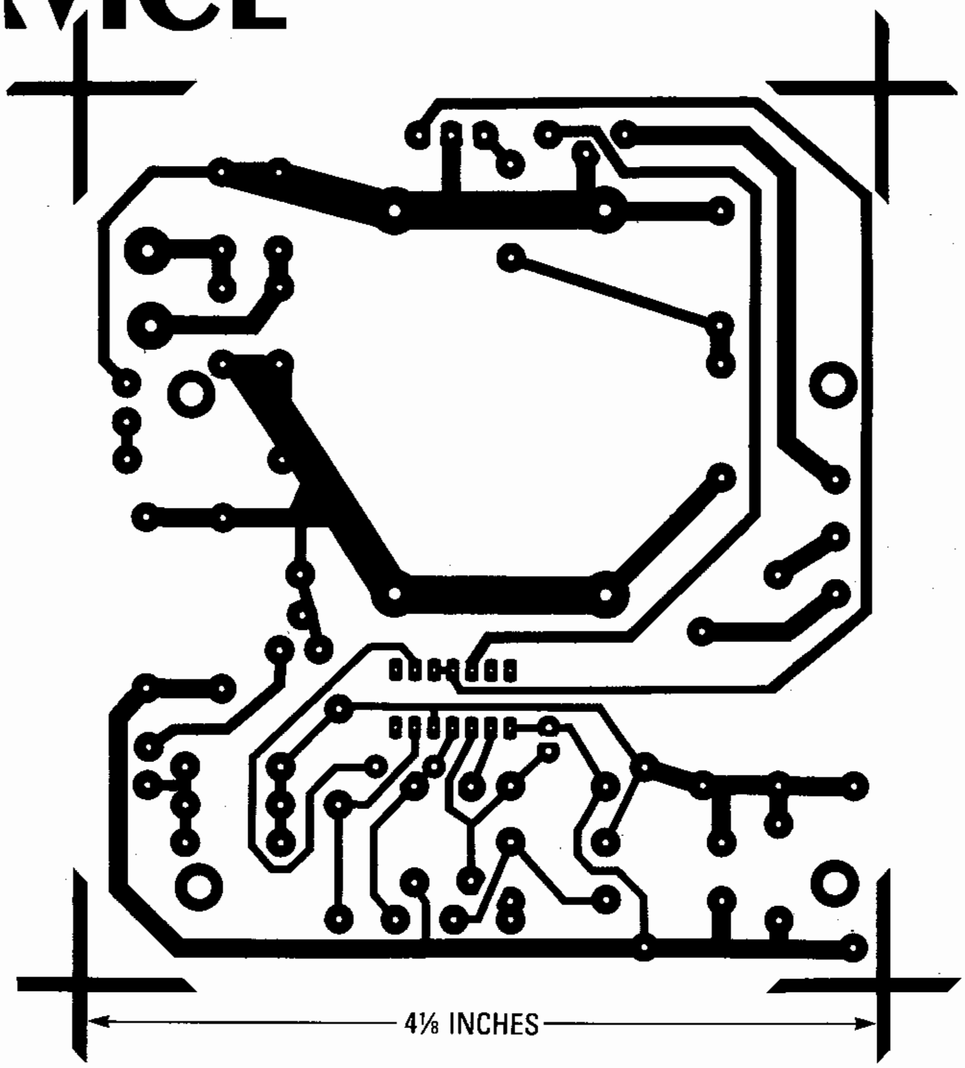
Q1. Any PNP power transistor

Stabiliser For Battery Supplies

The accompanying circuit, is useful when voltage sensitive devices (such as TTL ICs) must be battery operated. It uses very little power from a good battery; whilst with a flat battery, the output voltage is within 0.1V of the battery voltage.

ZD1 should be selected to obtain approximately the desired output voltage; for fine trimming, R2 may be selected between 470 ohms and 3k3. With the components shown, the output voltage varies less than 2% for battery voltages from 5V to 8V and output currents from zero to 200 mA. For higher currents, R1 may need to be decreased.

Always use a power transistor for Q2 or it will overheat when the battery is nearly flat. Both Q1 and Q2 should have a current gain of as least 40, while the gain of Q3 should be as high as possible.



IF YOU WISH to etch your own board for the 30-volt power supply, use this pattern.

SWL's" on page 59 in this issue.

OUT OF TUNE

Experimenter's Short-Proof Power Supply (*February, 1968, page* 54). In Fig. 1, the solder dot at the junction where the base of *Q2*, the collector of *Q3*, and the collector of *Q4* meet was accidentally omitted. This is a common point for these three transistors and their associated components. The printed circuit board in Figs. 2 and 3 is correct. —30—

1 megahertz. Naturally, a faster clock is needed if bigger numbers are to be multiplied. The number of clock pulses required to multiply two n-bit numbers (where n includes the sign bit) is 2n(n–1). Additionally, larger numbers will mean more registers in the multiplier circuitry and more counters in the control-signal circuitry. (Some minor circuit changes must also be made.)

There is a useful rule of thumb to keep in mind to minimize modification when the multiplier is expanded. Choose the factor 2(n–1) to be the nearest larger integer power of 2 and then set the extra bits introduced in the multiplicand and the multiplier to zero. □

Regulating supply voltage all the way down to zero

by Brother Thomas McGahee
Don Bosco Technical School, Boston, Mass.

Precision monolithic voltage regulators make it fairly easy to design a high-performance power supply with a minimum of external components. These regulators have one general fault, however—they cannot regulate to any voltage lower than their reference, which is usually about 7 V. Sometimes, a voltage divider can be used to reduce the reference voltage, but if the reference voltage is reduced below approximately 2 V, good regulation can no longer be maintained.

The circuit shown in the figure, on the other hand, allows the reference voltage to be adjusted all the way down to the offset voltage of the regulator's internal op amp. REGULATOR$_1$ and its associated circuitry form a bias supply that provides a voltage of about –7 V for the V$^-$ terminal of the main regulator (REGULATOR$_2$). Since the noninverting input of this regulator is connected to the common ground of the circuit, its reference voltage appears to be +7 V with respect to this V$^-$ terminal.

There will be a 7-V drop across resistors R$_2$ and R$_3$. When R$_1$ is set to its minimum value, the circuit's output voltage will be equal to the reference voltage. If the output is measured with respect to the V$^-$ terminal of REGULATOR$_2$, it will be 7 V. But if it is measured with respect to the common ground, it will be zero.

The maximum voltage available at the output is determined by the value of resistor R$_2$. For the component values shown here, the maximum voltage may be set anywhere from 16 to 39 V. But voltages above 30 V will not be regulated very well because the supply is using a 24-V transformer (T$_2$).

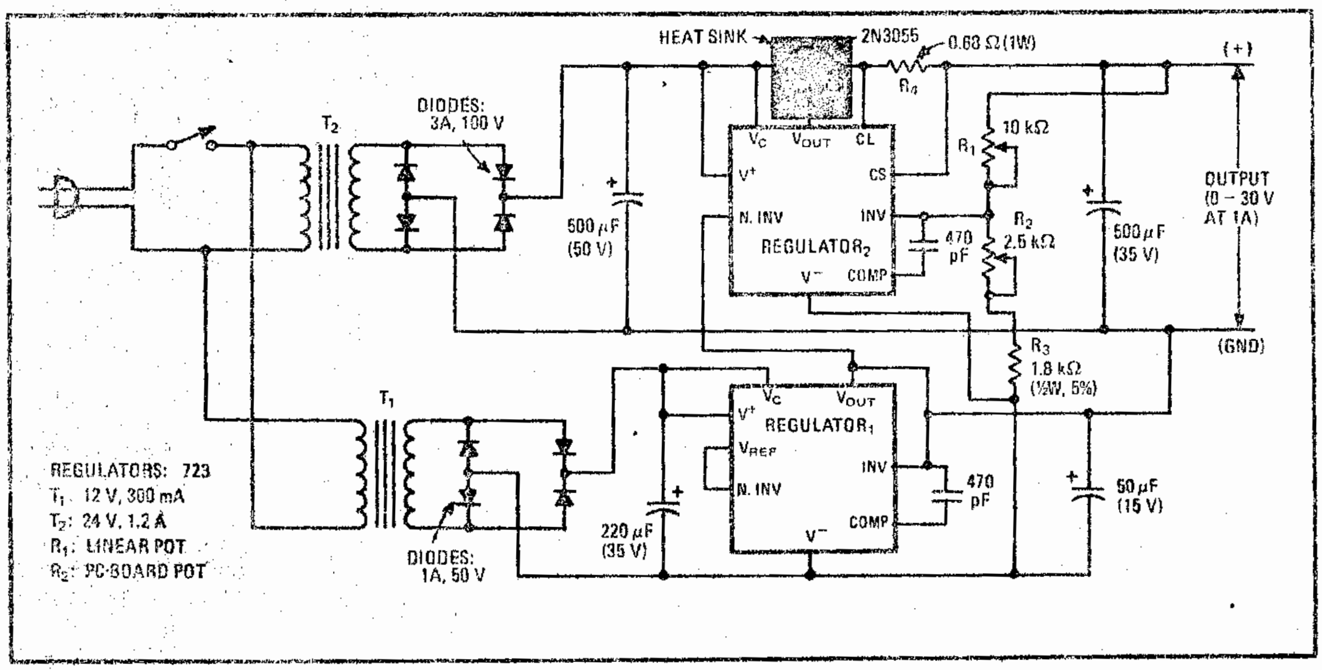
The equation for the output voltage is:

$$V_{OUT} = R_1 V_B/(R_2 + R_3)$$

where V$_B$ is the absolute value of the bias voltage (7 V in this case). The bias supply normally will be producing about 12 milliamperes of current. Under worst-case conditions, however, it may be required to provide a maximum of 40 mA. Transformer T$_1$, therefore, should be a 12-V unit capable of supplying at least 50 mA (since REGULATOR$_1$ will require some current itself).

The transistor at the output of REGULATOR$_2$ boosts the circuit's output current. Resistor R$_4$ acts as the current-limiting resistor. □

Designer's casebook is a regular feature in Electronics. We invite readers to submit original and unpublished circuit ideas and solutions to design problems. Explain briefly but thoroughly the circuit's operating principle and purpose. We'll pay $50 for each item published.



Variable supply. This power supply, which employs two IC voltage regulators, produces a regulated output voltage of between 0 and 30 V. REGULATOR$_1$ provides the bias voltage for REGULATOR$_2$ so that the latter device can operate with respect to a common ground. The lowest regulated output voltage, then, is approximately zero, rather than the reference voltage of REGULATOR$_2$.