An RF-Proof 30-Amp Supply

Solid-state technology has made possible circuit miniaturization that was only dreamed about 20 years ago. This new technology has afforded the amateur community medium-power equipment compact enough to use in even the most cramped mobile environment. This equipment is normally designed to operate from a source of 13.8-V dc and is well-suited for direct connection to the automobile electrical system. In the interest of size and weight conservation, however, an ac-operated power supply (necessary for fixed-station operation), is not often built in. If home operation from the ac mains is contemplated, an external source of 13.8-V dc is required. Matching commercial units are often costly and are not normally designed for high-duty-cycle modes, such as RTTY or SSTV.

The power supply described here (Figs. 6 through 13), designed by George Woodward, W1RN, and built in the ARRL lab by Mark Wilson, AA2Z, boasts a 30-A continuous current rating. Cost of construction will depend on the builder's junk box, but should be significantly less than commercially available units. This design features complete output metering, overvoltage shutdown and foldback current limiting. Additionally, this supply exhibits excellent immunity to RF fields, even with the cover removed. During testing, a 5-W, 2-meter transceiver was keyed with the antenna just inches from the regulator circuitry, with no loss of regulation. Also, a 100-W HF transceiver was loaded into a piece of wire that was attached to a fluorescent bulb. There was enough RF present to illuminate the bulb, but the power supply performed perfectly when the bulb was brought near the output terminals.

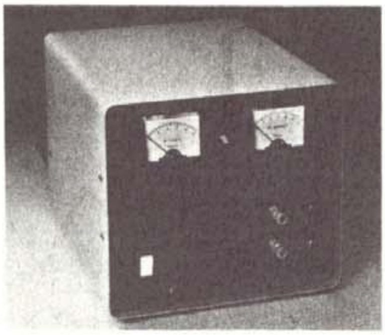


Fig. 6 — The completed RF-proof power supply features voltage and current metering and remote sensing.

Design Information

The schematic diagram of the RF-proof supply is given in Fig. 7. A custom transformer, available from Avatar Magnetics, is used in this design. The hefty 25.4-V center-tapped secondary, wound with a pair of no. 11 wires, is continuous-duty rated at 34 A. At full load, the secondary voltage is down only 100 mV from nominal. Transformer output voltage is an important consideration in high-power applications: If the transformer voltage is too high, the pass transistors dissipate excessive power because of the large voltage drop across each device. Conversely, low transformer output voltage can cause loss of regulation because of insufficient voltage differential across the regulator circuitry. A separate 15-V, 1.5-A secondary winding (connected to U3) powers the regulator and associated circuitry so that the high-current secondary voltage can be kept lower.

In high-current applications, a low-voltage condition can also be caused by marginal transformer current ratings. Under no-load conditions, the current through the transformer is low, hence the I × R drop through the secondary (from the dc winding resistance) is small. When the transformer is called upon to deliver more current, however, the voltage drop through the secondary increases, causing insufficient voltage at the rectifier and regulator circuits. This is not a problem with the AV-399 transformer used here!

C1, a 190,000-μF electrolytic capacitor, provides a clean dc waveform to the regulator and pass transistors. This high value is necessary to keep ripple to a minimum. The filtered secondary voltage is close to the desired output voltage to keep pass-transistor dissipation to a minimum. This, however, means that ripple must be minimized so that under load the input voltage remains above the desired regulated output voltage. The energy stored in this capacitor is tremendous, so a bleeder resistor must be used even though the voltage is low. The 1-kΩ resistor here draws 14 mA — not enough to heat up the inside of the already-warm cabinet, but enough to safely discharge C1.

The large value chosen for C1 places a high peak-current demand on the rectifiers. To charge this capacitor, several hundred amperes of peak current will flow through the rectifiers over short periods of each cycle. Peak-current demands must be considered carefully when selecting rectifiers and wiring for this portion of the circuit. D1 and D2 have surge-current ratings of 500 A and can handle 40 A continuously. These are stud-mounted rectifiers, and they require a substantial heat sink.

Voltage regulation is handled by a 723-type IC regulator, U1. This IC generates the reference voltage for the regulated output. R3, a 25-turn potentiometer, is used to set the output voltage to the desired value; the supply shown here was set to precisely 13.80 V.

U1 is capable of supplying about 150 mA — not enough to drive the high-current pass transistors. In this circuit, the output of U1 drives a control loop consisting of U2B and Q1. Almost any NPN Darlington that can handle 5 A or more will work for Q1. The 15-A 2N6576 used here was chosen because it was available locally.

Q1 drives four 2N3055 NPN power transistors (Q3-Q6). For best current balance and efficiency, these pass transistors should all be from the same manufacturing lot. A 0.1-Ω, 5-W spreading resistor is placed in series with the emitter lead of each 2N3055 to help balance current distribution. The emitter resistor values should be within 1% of each other. Matching can be accomplished by placing low-value (1.0- to 2.2-Ω), ¼-W resistors in parallel with each 0.1-Ω unit until the desired tolerance is obtained.

If you use a different heat sink or a higher input voltage, you will probably have to use additional pass transistors to keep the junction temperature to an acceptable level. See Chapter 6 for complete information on how to calculate the proper heat sink and number of pass transistors needed for your application.

Current limiting, provided by U2A, U2D and associated components, protects the supply from overcurrent damage. An operational amplifier, U2A, monitors the voltage across the current-sense resistor (R2) and reduces the regulator drive when output current exceeds 32 A. If a short circuit should appear across the supply output terminals, the overcurrent circuit activates, reducing output voltage to next to nothing at a current level selected by the fold-back resistor, R1.

R1 is actually made from two separate resistors in series. This makes it possible to change the value slightly (by experimenting with the smaller resistor) until the desired foldback current is obtained. With the value shown, fold-back current is limited to 3 A. This value was chosen so that the M1 deflects slightly so that the operator can tell that the problem is overcurrent of some kind rather than a loss of input voltage, yet it is low enough that wires won't melt. When the supply folds back, the OVERCURRENT lamp turns on, warning the operator of an overload.

A change in the value R1 as small as a few hundred ohms will make a significant difference, so resistor tolerances can affect the foldback current of your version of this supply. You may have to experiment with different resistors to get an acceptable foldback current. Of course, you can set the foldback current to any value you wish. Also, the value of V_{IN} has a profound effect, so if you use a different transformer and V_{IN} is much different from 20.5 V (the measured value of V_{IN} on the ARRL lab version), you should recalculate the

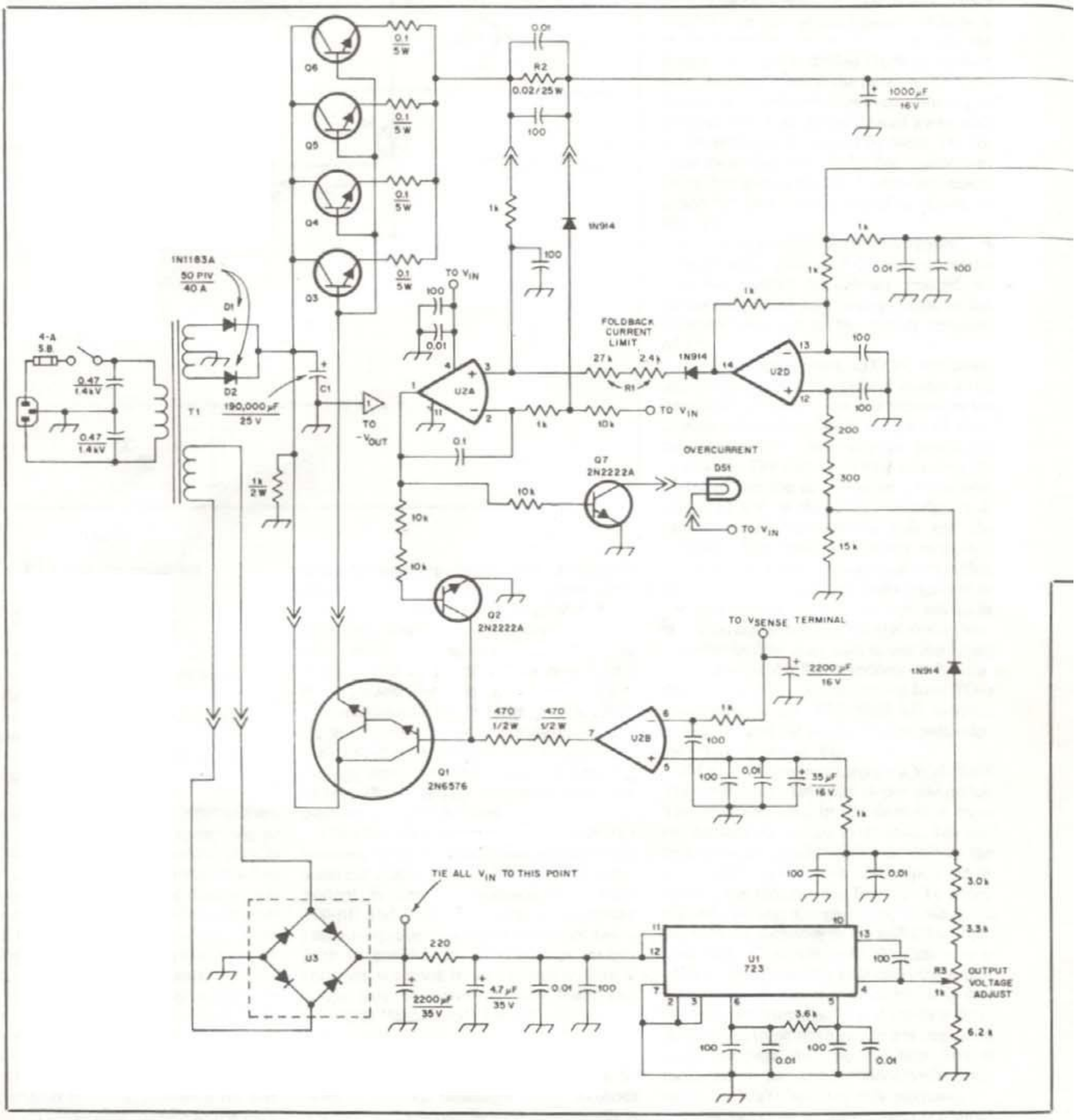
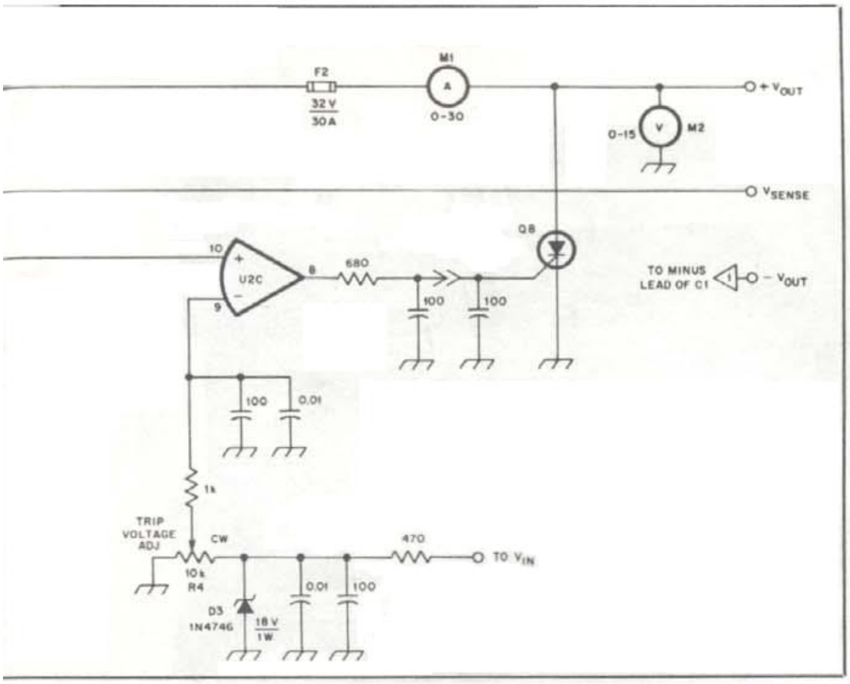


Fig. 7 — Schematic diagram of the high-current, RF-proof power supply. All resistors are ¼-W, 5% types unless noted. Capacitors are monolithic ceramic types unless noted. Capacitors marked with polarity are electrolytic. Numbered components not appearing in the parts list are for text reference.

C1 — Electrolytic capacitor, 190,000 μF, 25 V (Sprague 194G025DJ2A or equiv.).
D1, D2 — Rectifier diode, 50 PIV, 40 A (1N1183A or equiv.).
DS1 — 12-V pilot light or LED with 680-Ω dropping resistor.
M1 — Dc ammeter, 0-30 A.
M2 — Dc voltmeter, 0-15 V.
Q1 — 5 A or greater Darlington transistor (see text).
Q3-Q6 — NPN power transistor (2N3055, 2N5303 or equiv.).
Q8 — 25-A SCR, TO-220 package (ECG-5550 or equiv.).
R2 — Five 0.1-Ω, 5-W resistors in parallel (see text).
R3 — Multiturn PC-mount potentiometer, 1 kΩ, 0.5 W.
R4 — Multiturn PC-mount potentiometer, 10 kΩ, 0.5 W.
T1 — Power transformer. Primary, 117-V ac; secondary, 25.4-V CT, 34 A and 15 V, 1.5 A (Avatar AV-399 or equiv. Available from Avatar Magnetics, 1147 North Emerson, Indianapolis, IN 46219).
U1 — Adjustable voltage regulator IC, 14-pin DIP package (LM723, MC1723 or equiv).
U2 — Quad 2-input operational amplifier (LM324).
U3 - Bridge rectifier, 50 PIV, 1.5 A.



value of R1 from the equation

$$R_{FB} = \frac{V_{IN}}{0.7 - (I_{FB} \times 0.02)} - 1$$

where

R_{FB} = the value of the foldback resistor in kΩ

V_{IN} = the regulator board supply voltage in volts

I_{FB} = the desired foldback current in amperes

This supply also includes a crowbar overvoltage protection circuit, consisting of U2C, Q8 and associated circuitry. Should the output voltage exceed the threshold — somewhere slightly above the desired output voltage — set by the parallel combination of D3/R4, Q8 will conduct, short-circuiting the output terminals of the supply. R4, a multi-turn potentiometer, is used to set the trip voltage. This lights DS1 and triggers the previously described overcurrent protection circuitry.

F2 is included in case of a drastic supply failure. Normally, the supply would fold back if a short circuit appeared at the output. Should something happen to the regulator board and the foldback current limiting circuitry fail to function, full supply current — in excess of 30 A — would be available at the output terminals. This is enough current to do serious damage to the load and/or interconnecting wires. F2 should blow if this happens.

Remote sensing, another important feature in high-current supplies, is included. When heavy loads are connected through long cables, the voltage drop degrades load regulation. Remote sensing allows the drop associated with long cable runs to be included in the regulator feedback loop. For normal operation, a jumper wire must be connected between the $+V_{OUT}$ and V_{SENSE} terminals to complete the regulator feedback loop. The supply will not regulate if this jumper is omitted! To use the remote-sensing feature, remove the jumper wire between the $+V_{OUT}$ and V_{SENSE} terminals, and connect a wire between the V_{SENSE} terminal and the positive side of the load.

Care has been taken to make this design immune to the RF that floats around most amateur stations. Each RF-sensitive component is heavily bypassed with both 100-pF and 0.01-μF capacitors to ensure radio-frequency energy a low-impedance path to ground. In some places, several resistors are used in series, rather than a single unit, to break up long leads and potential "antennas" for RF.

Construction

One possible assembly method can be seen in Fig. 12, although other methods should perform just as well. The supply is built in a Hammond enclosure. T1, C1 and the regulator circuit board mount inside the cabinet. The heat sinks for Q3-Q6 and D1 and D2 mount on the exterior of the rear panel, with the fins vertical, to take advantage of natural convection cooling. Do not mount the heat sinks with the fins horizontal! See Chapter 6 for complete information on thermal design considerations.

Components that don't generate appreciable heat are contained on a double-sided PC board (Figs. 9 and 10). One side of this board is etched. The foil on the remaining side is unaltered, to act as a ground plane. All component leads that go to ground are soldered to the ground plane. Where a component lead is to pass through the board, the hole is drilled from the etched side, and foil around the hole on the component side removed to prevent shorting to ground. The foil can be cleared away with a 1/8-inch drill bit turned by hand. Do not clear away foil from holes for component leads that go to ground. A parts-placement guide for this circuit board is shown in Fig. 10.

To avoid ground loops, this supply uses a single-point ground. PC board common does not contact the cabinet; instead, all power supply grounds (except those on the primary) are tied to the minus terminal of C1.

The pass transistors, Q3-Q6, inclusive, are mounted on a Wakefield model 441K heat sink. In this version, the transistors are mounted directly to the heat sink with thermal compound, but without insulating hardware. The transistor case is tied to the collector, so the dc potential of the heat sink is 13.8 V. Wakefield insulating standoffs are used between the sink and the cabinet. The emitter current-spreading resistors are placed on terminal strips that are mounted on the heat sinks adjacent to each pass transistor. Connections are made by soldering directly to the transistor pins. Another builder may wish to use insulating hardware and/or TO-3 sockets. A full-size drilling template for mounting four TO-3 transistors on the Wakefield 441 is given in Fig. 11, and the wiring for the pass transistors is shown in Fig. 8.

D1 and D2 are mounted on a Wakefield 421K heat sink that bolts to the rear panel. The rectifiers used in the prototype have the cathode connected to the stud. The rectifiers are mounted "upside down" on the heat sink; that is, the anode pins point toward the chassis. See Fig. 13. To avoid exposed wiring, a copper strip is mounted between the cathodes of D1 and D2 and the heat sink. Connection to the cathodes is made to this strip. Use heat sink compound between the diodes and the copper strip and between the copper strip and the heat sink. As before, these devices are not insulated from the heat sink, so the heat sink is mounted on insulating standoffs manufactured by Wakefield for this purpose.

Q8 is mounted to the chassis on a small heat sink. Because the foldback current in this supply is limited to 3 A, only a small heat sink is required. If, however, you change the foldback current to a higher value, you must use a larger heat sink.

R2, the 0.02-Ω, 25-W current-sense resistor consists of five 0.1-Ω, 5-W resistors in parallel. The resistors used here have built-in mounting brackets, so long no. 4 machine screws are used to mount them to the chassis. The sand-type power resistors

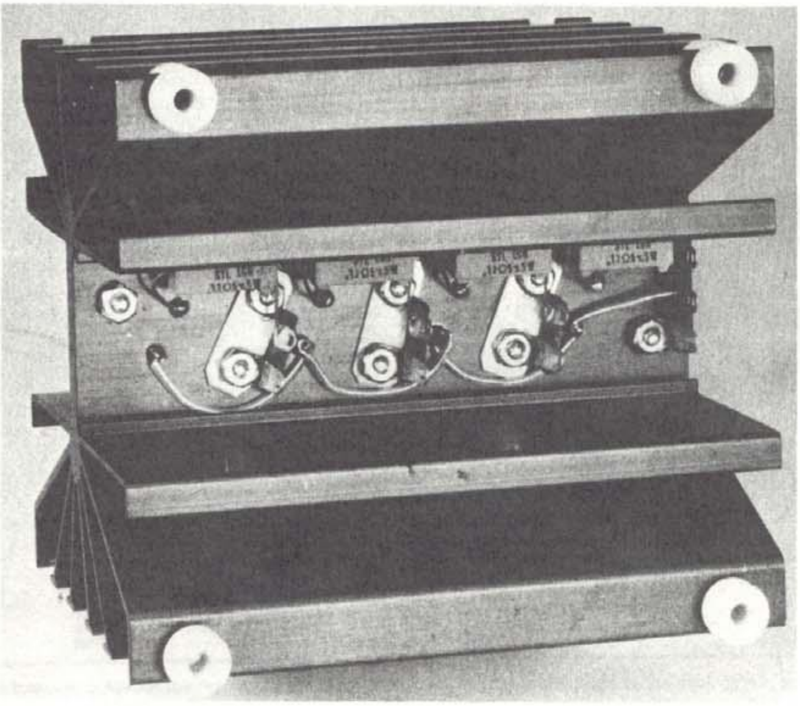


Fig. 8 — Connections to Q3-Q6 are made on the underside of the heat sink.

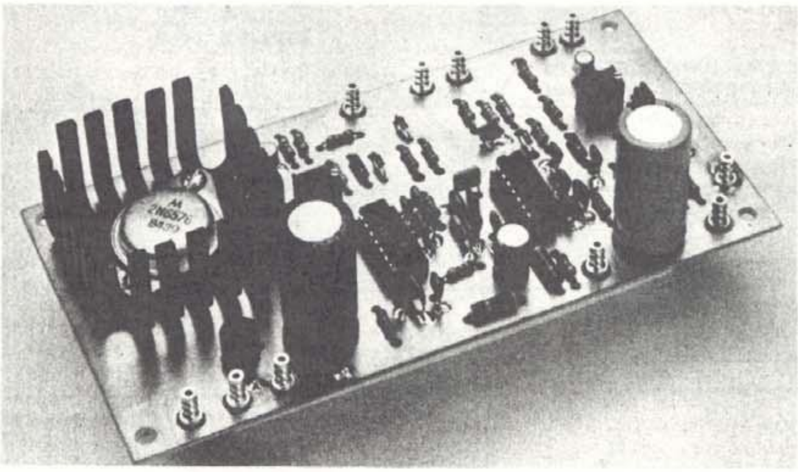


Fig. 9 — The regulator circuitry is mounted on a double-sided PC board. Component leads that connect to ground are soldered to the ground plane on top of the board. Copper foil is removed from the component side of the board where leads pass through to traces on the other side. See text and Fig. 10.

(like those used at the emitters of Q3-Q6) are much more common; the best way to mount sand-type resistors is between two terminal strips.

Liberal use of terminal strips simplifies the wiring and troubleshooting, should it be necessary. In a supply of this current capability, it is imperative that you use wire heavy enough for the job. If you choose a different cabinet and/or layout from the one shown here, try to keep the high-current runs between T1, D1, D2, C1 and Q3-Q6 as short as possible. Even no. 12 wire is rated for only 23 A continuous in applications such as this, so no. 10 is in order here. No. 10 wire can be difficult to obtain and work with, so you can do what we did in the prototype supply: Use several pieces of smaller wire for each run. The high-current secondary wires from T1 connect directly to the anodes of D1 and D2; the center tap connects directly to the C1 minus terminal. Three pieces of no. 12 wire are used between the rectifiers and C1. A separate length of no. 14 wire is used between the collector of each pass transistor and C1. Likewise, a separate piece of no. 14 is used between the emitter of each pass transistor and R2. Three no. 12s are used between R2 and M1, and between M1 and the positive output terminal. Likewise, three no. 12s are used between C1 and the negative output terminal. This may seem like overkill, but at 30 or more amperes, I × R losses in even short lengths of hookup wire are significant. The rest of the wiring is low current, so any no. 22 or larger hookup wire may be used.

Testing and Setup

After construction has been completed, it will be necessary to adjust the output voltage and crowbar threshold point before using the supply as a power source. All that is needed is an accurate voltmeter (preferably a digital voltmeter, if available) and a screwdriver to turn the OUTPUT VOLTAGE and TRIP VOLTAGE potentiometers. Remember to install the jumper between $+V_{OUT}$ and V_{SENSE}.

For initial setup, temporarily replace R2 with a resistor of approximately 0.5 Ω. This resistor can be made from several low-value, 1-W resistors in parallel. The actual value is not critical; the purpose is to prevent unnecessary fireworks by limiting supply current to around 1 A for initial testing and setup. Also, disconnect the gate of Q8 from U2C.

Before applying power to the regulator board and pass transistors, verify the operation of T1, D1, D2 and C1. No-load voltage on C1 should be approximately 18 V. Remove power and connect the pass transistors and the regulator board. Begin with R4 fully counterclockwise (for maximum trip voltage) and R3 fully clockwise (for minimum output voltage).

Turn the supply on. M2 should deflect upscale 10 to 12 V. If the voltmeter does not indicate any output voltage, or if the OVERCURRENT lamp is illuminated, quickly turn the supply off, unplug the line cord and check for wiring errors. If all is well, connect a voltmeter across the supply output terminals and slowly rotate R3 clockwise until the meter reads 13.8 V. Do not be surprised if you have to turn R3 many turns; the adjustable voltage range of this supply has been preset by the fixed resistors, and R3 is intended for trimming the supply voltage to the desired output, rather than for large voltage excursions. Connect a resistive load of approximately 15-Ω across the supply output terminals. This should draw approximately 1 A, and M1 should deflect slightly. Short-circuit the supply output terminals through a meter capable of reading approximately 0-1 A. Supply voltage should drop drastically, the foldback current through the ammeter should be less than 500 mA and DS1 should light to indicate OVERCURRENT. The

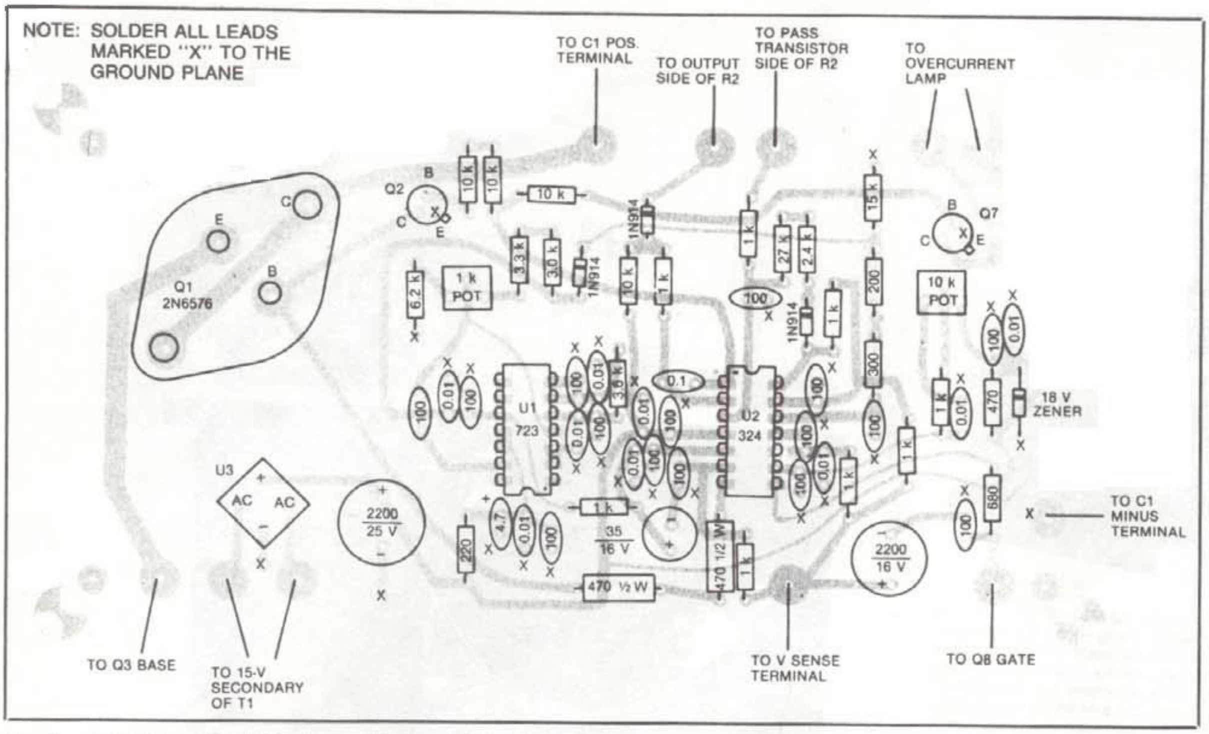


Fig. 10 — Parts-placement guide for the regulator board. A full-size etching pattern appears at the back of this book.

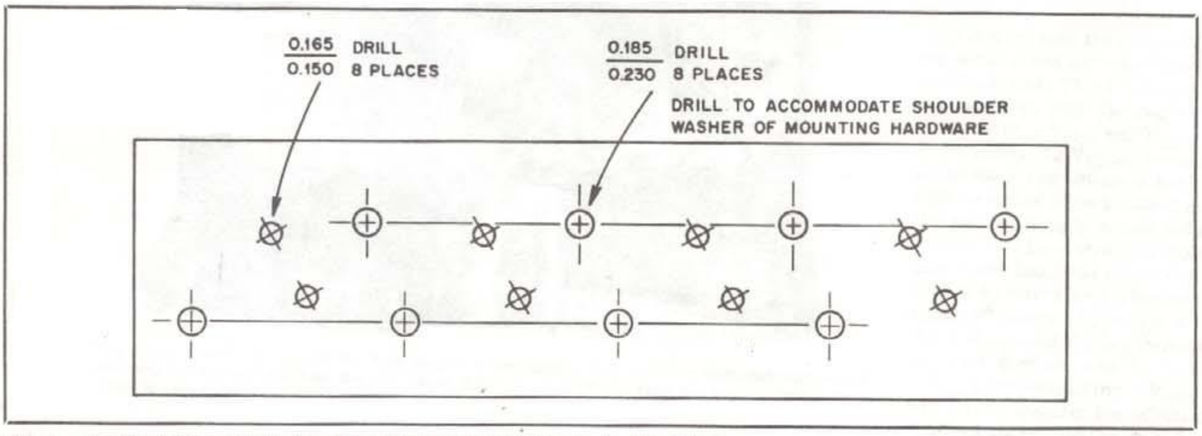


Fig. 11 — Full-size drilling template for the Wakefield 441K heat sink. See text for details.

foldback current should be less than half of the maximum supply current (set to approximately 1 A by the temporary R2).

Next, set the crowbar to fire at the desired voltage. Connect a voltmeter to the lead that will be used to connect the 680-Ω resistor on the regulator board to the gate of Q8. Set the voltmeter to a convenient range above 20 V (the value of V_{IN}). There should be no voltage present at this point until the crowbar trips. Rotate R3 until the supply output voltage reaches the desired trip voltage. A trip voltage of 14.5 V was selected for the prototype supply. Next, adjust R4 until the crowbar trips and the voltmeter indicates the value of V_{IN}. The crowbar is now set to fire at 14.5 V. Turn R3 until the supply voltage drops below the trip voltage (the voltmeter will return to zero) and connect the gate lead to Q8. Turn R3 to increase supply voltage until the crowbar trips. This time, Q8 will fire, shorting the supply output. The supply should go into foldback current limiting and behave as it did when you shorted the output terminals as described above. Remove power and turn R3 to reduce the supply output voltage below the trip point. Apply power again and adjust R3 until supply output voltage returns to 13.8 V, or whatever you want the output voltage to be for normal operation. This completes initial testing.

Now it's time for the real smoke test. Turn off the supply and remove the temporary resistor used at R2; install the 0.02-Ω unit. Locate some low-value resistors to test the supply at various current levels. We started testing the prototype with a 5-Ω,

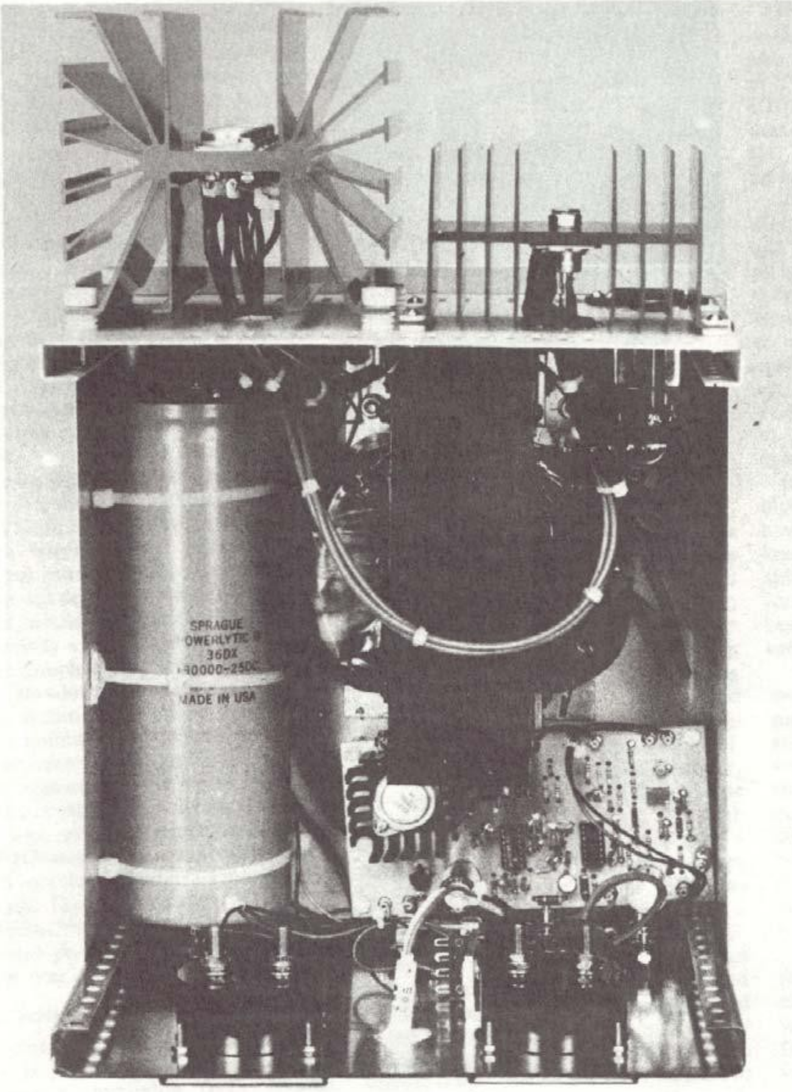


Fig. 12 — An internal view of the high-current power supply. The rectifiers and pass transistors are mounted to heat sinks on the rear panel. Parts are arranged to keep the high-current runs as short as possible.

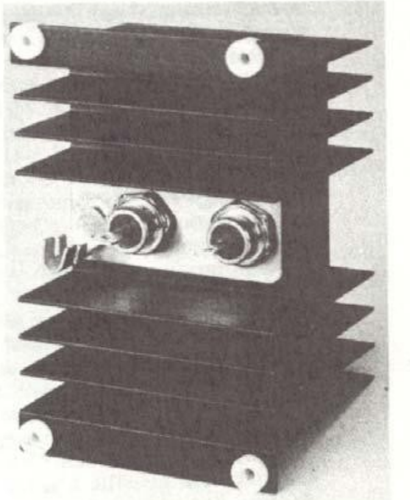
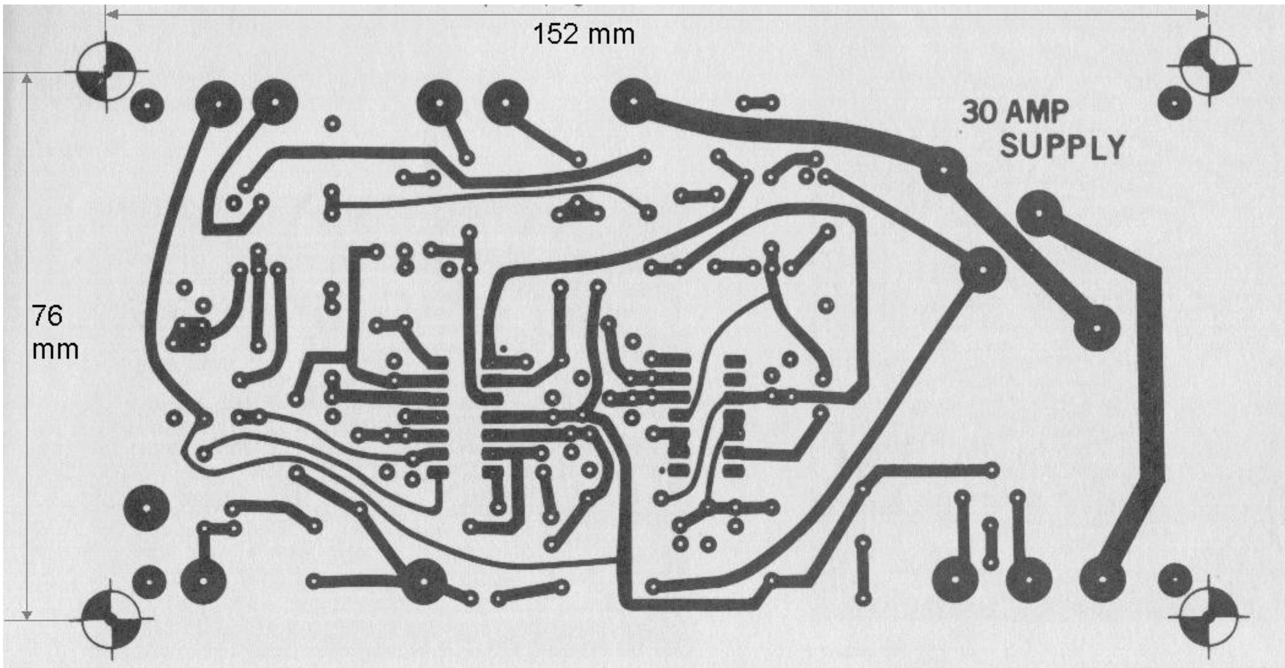


Fig. 13 — D1 and D2 are mounted to the heat sink with the anode posts pointing toward the chassis. The cathodes are connected by a copper strip that is sandwiched between the devices and the heat sink. Connection to the cathodes is made to a lug that is soldered to the copper strip. See text.

200-W resistor (approximately a 3-A load) and added additional similar resistors in parallel until we reached the desired current level. To make a full-current test of the supply, you'll need a combination of resistors that totals approximately 0.5 Ω at 450 W. If you don't have access to suitable power resistors, automobile headlights are an excellent, commonly-available high-current 13.8-V load. At some point in your testing, you'll notice that although the supply voltage at the output terminals of the supply is still holding steady at 13.8 V, the voltage at the load will be somewhat less than that because the drop in the connecting wires is not included in the regulator feedback loop. This is where remote sensing comes into play. Disconnect the jumper between the $+V_{OUT}$ and V_{SENSE} terminals and connect the V_{SENSE} terminal directly to the load. The voltage at the load should now be within a few hundred millivolts of the no-load supply output voltage.

After you have verified supply performance under load, you should verify that the foldback current level is indeed the desired value. Reconnect the jumper wire between the $+V_{OUT}$ and V_{SENSE} terminals. Screw up your courage and briefly short the $+V_{OUT}$ terminal to the $-V_{OUT}$ terminal. M1 should indicate the selected value of foldback current (in this case, 3 A) and M2 should indicate almost no voltage. If this is not the case, you will have to experiment with different values for the smaller of the two resistors that make up R1. Try changing the value a few hundred ohms at a time until you reach the desired foldback current.

Congratulations! The supply is now ready to use.



Chapter 27, Fig. 10