The Power Waster

—adjustable electronic load for power supply testing

John Roos K6IQL
953 Valley High
Thousand Oaks CA 91360

Testing of bench power supplies, batteries, voltage regulators, or current limiters often requires application of an adjustable load to the circuit. After years of connecting haywire combinations of resistors together to test various power supplies, I determined that a really high-power adjustable electronic load would be a welcome addition to my test equipment. In short order the Power Waster was created, and during some three years it has proven most useful.

The load described in this article will handle the majority of amateur radio and microprocessor power supply tests. In addition, it has a number of other uses, such as constant-current battery charging.

Current drawn by the load is adjustable from 0 to 10 Amperes. Input voltages up to 30 volts are permitted at full current; that's 300 Watts dissipation! Heat sinking of the pass transistors is sufficient to permit 300-Watt operation for about ten minutes, at which point a thermal protection switch shuts the current off.

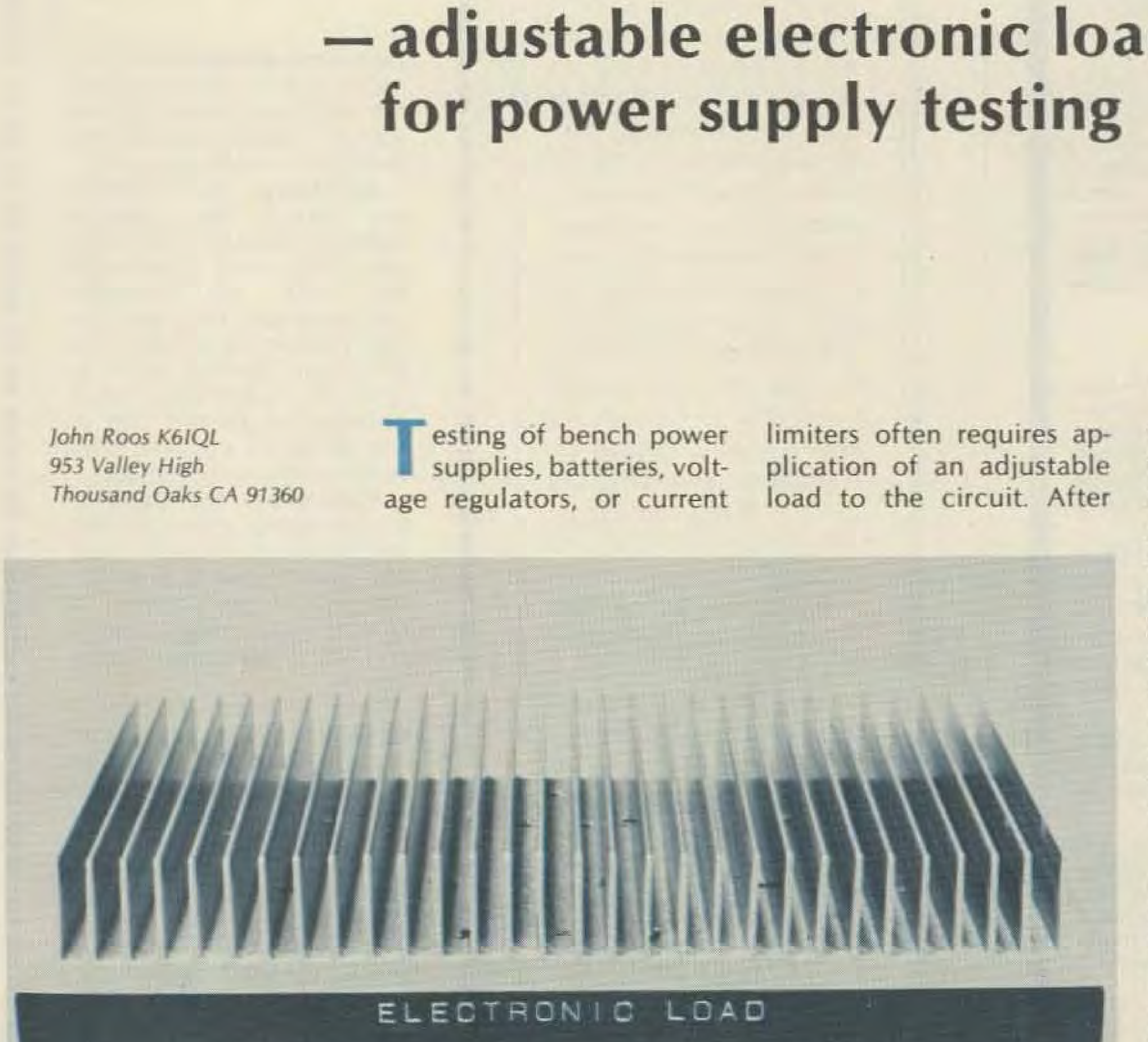

Photo A. The Power Waster. This electronic load is adjustable from 0 to 10 A and can dissipate up to 300 Watts. The unit is built upon a piece of heat-sink extrusion and has both reverse polarity and thermal overload protection.

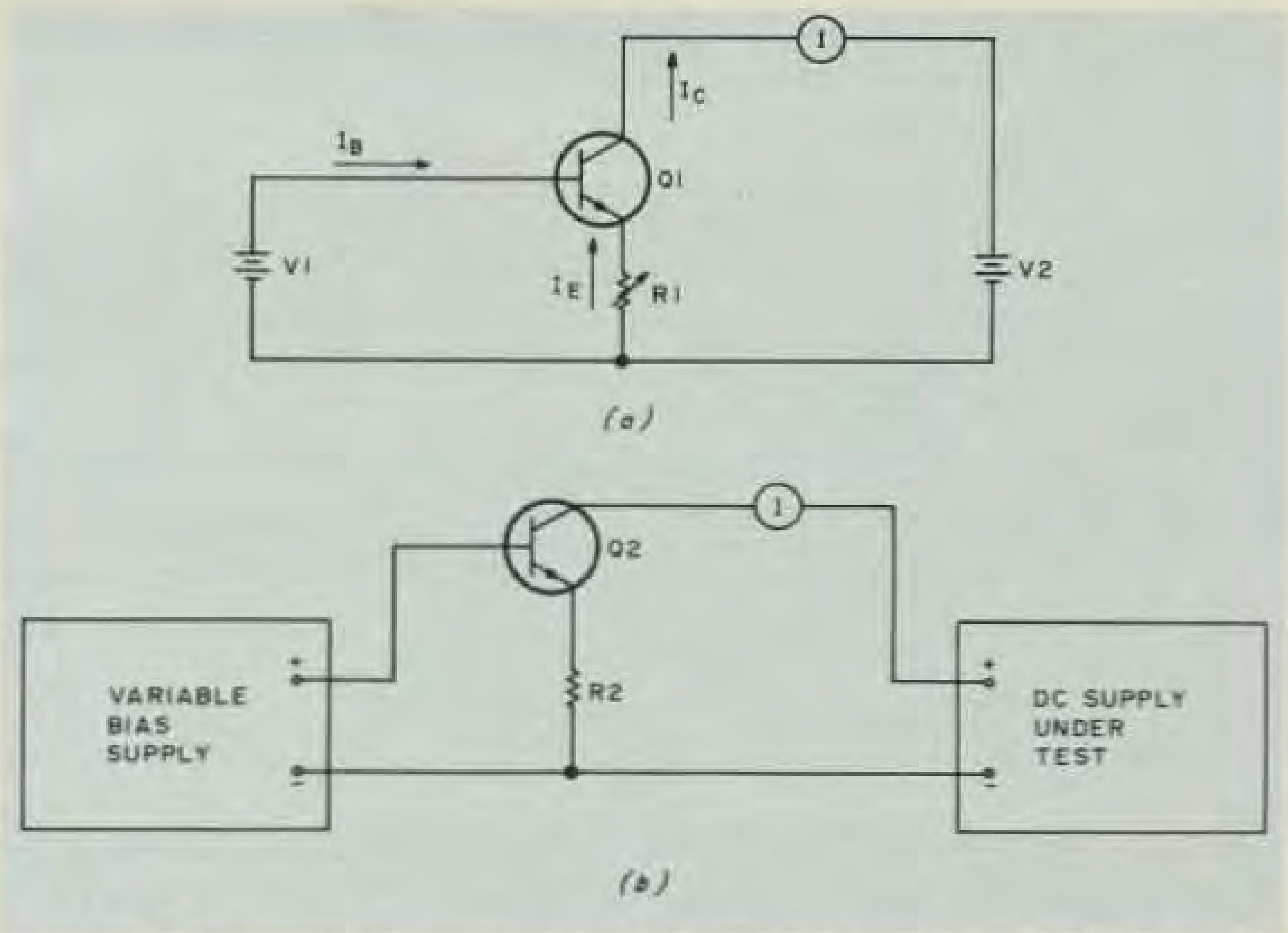

Fig. 1. Constant-current bias circuits. (a) A transistor with fixed base voltage. Collector current is set by emitter resistor. (b) Basic circuit of the electronic load. Emitter resistor is fixed, and both emitter and collector current are controlled with base-bias supply voltage.

At 100 Watts dissipation the heat sink is adequate for indefinite operation. By directing a small blower at the heat sink, I have run the load at 300 Watts for hours without difficulty.

Since I desired essentially self-contained operation, I included a small supply in the unit to bias the load transistors. Current is controlled by means of a front panel pot, and reverse polarity protection is included. A front-panel LED indicates operation of thermal shutdown circuitry. I took advantage of extra heat sink area to add two 8-Ohm, 50-Watt resistors. These are used for testing audio amplifiers or to increase the dissipation capability of the Power Waster circuit.

Circuit Operation

The simplified schematics in Fig. 1 are useful in understanding how the circuit operates. Commercial load boxes use current sensing and feedback to set the load current. My approach is simpler and uses the constant-current collector load-line characteristic of all bipolar transistors.

Fig. 1 shows the basic idea. The base of Q1 is biased at several volts from voltage source V1. The collector supply (V2) is greater than V1 by at least 1 volt. The voltage at the emitter of Q1 is one diode drop (0.7 V) below the base voltage, and the circuit is essentially an emitter follower. Emitter current is set by dividing the emitter voltage by R1. As R1 is decreased, the emitter current increases.

The collector current for any transistor is simply alpha (the common-base current gain) times the emitter current. As alpha is essentially equal to 1 for any modern transistor, we see that setting the emitter current also sets the collector current. And this is the point; the collector current is determined only by the emitter current. Collector voltage has almost no effect on the collector current, provided the transistor is kept from saturation or breakdown. Saturation occurs if the collector voltage becomes less than the base voltage. Breakdown will occur if any excessive voltage is applied.

The constant-current collector load line is a useful property. If the voltage across R1 is small compared to the collector supply, a lot of power can be controlled and will be quite independent of the collector supply voltage. If a relatively low base-bias voltage is used, most of the power will be dissipated in the transistor and relatively little in R1.

As useful as this circuit is, there are some disadvantages. The main problem is that R1 must be a variable resistor capable of handling the entire load current. In a practical circuit, this becomes a 0.2-Ohm pot rated for 10 Amperes, which is an expensive item.

By arranging the circuit as indicated in Fig. 1(b), things become a bit easier. Resistor R2 is a fixed high-power resistor. The base supply is made variable. Since the circuit is essentially an emitter follower, the emitter voltage follows the base voltage. Increasing the base bias increases the emitter voltage and the emitter current through R2. This increases the collector current to the desired value.

Within limitations, the collector current is set solely by the base-bias voltage and the value of R2. These limitations are: The collector supply must be at least one volt more than the max-

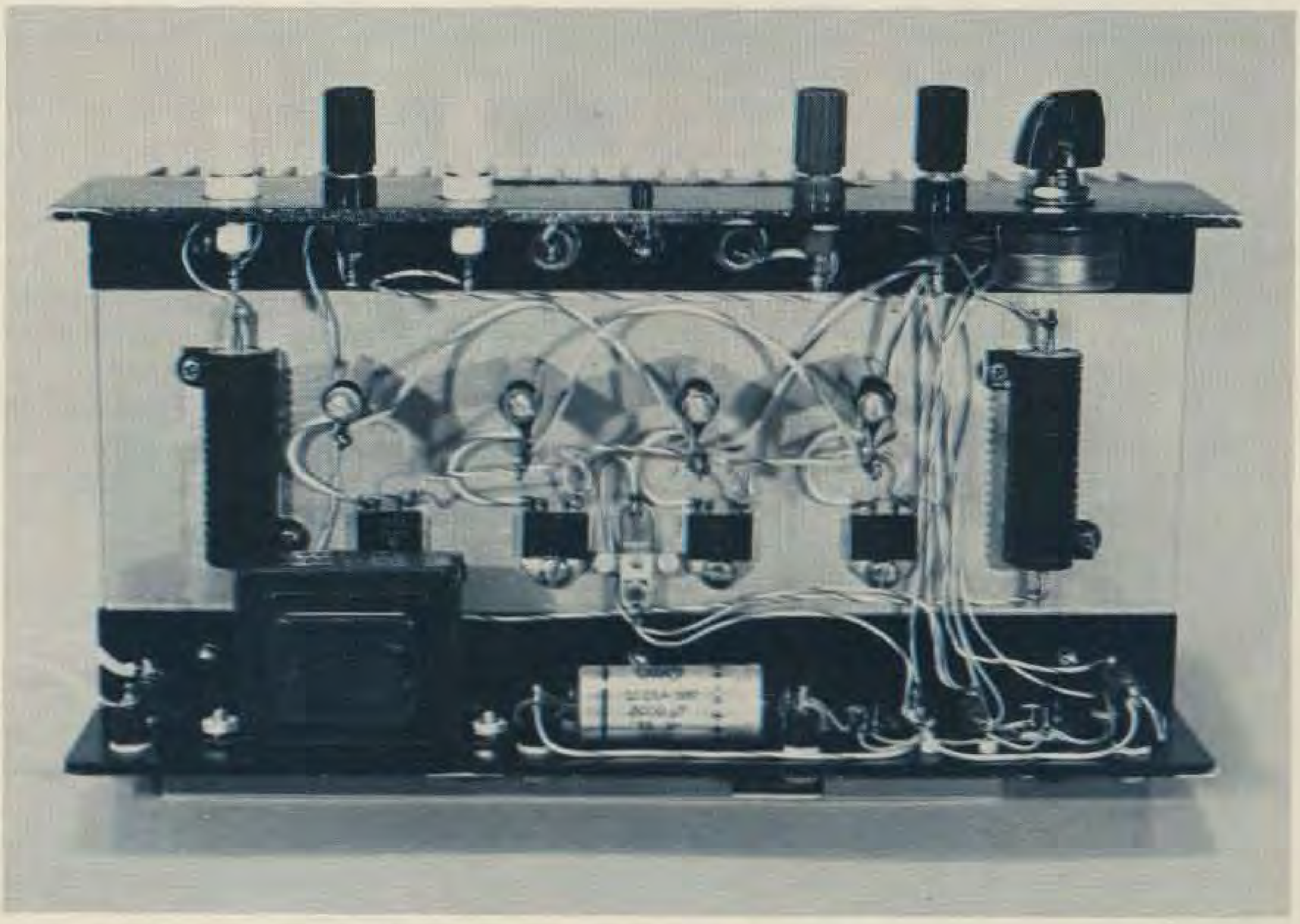

Photo B. Interior view of the Power Waster. Four TIP 35C load transistors are mounted to the heat sink. The thermal switch is located between the two center transistors. A U-shaped chassis is formed from the heat sink and two pieces of aluminum angle stock.

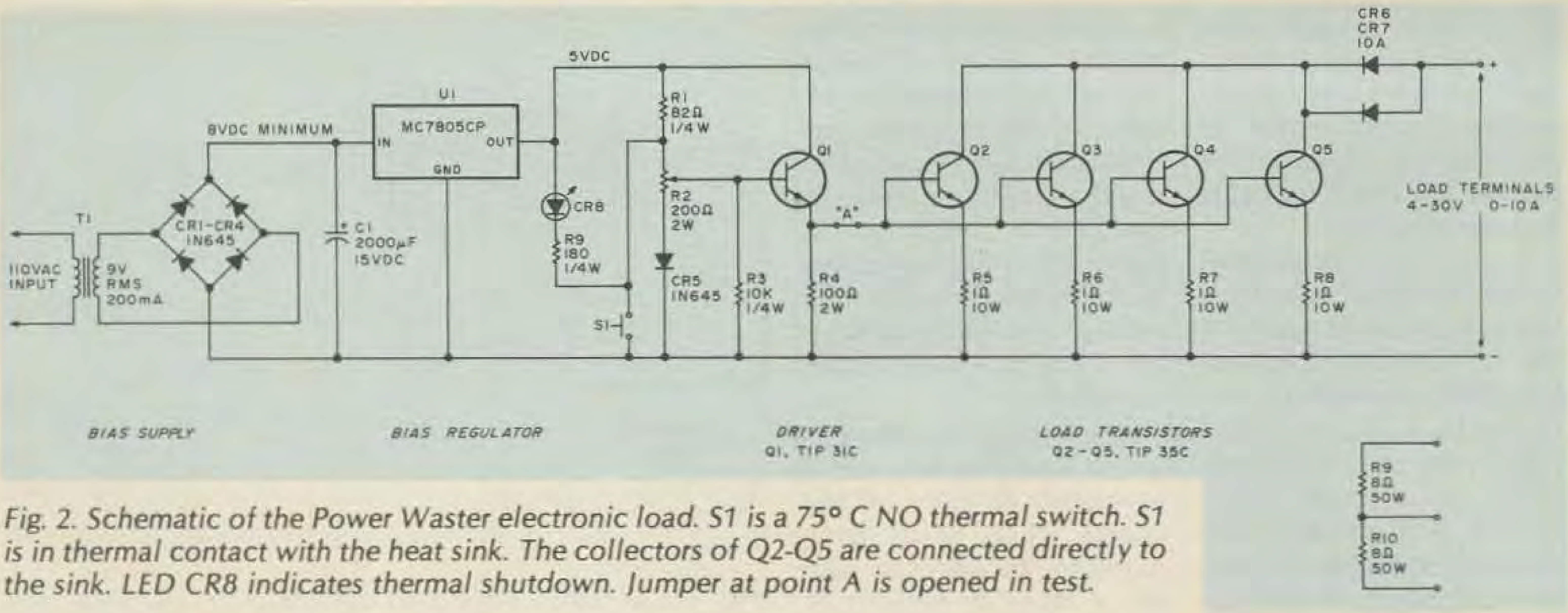

Fig. 2. Schematic of the Power Waster electronic load. S1 is a 75° C NO thermal switch. S1 is in thermal contact with the heat sink. The collectors of Q2-Q5 are connected directly to the sink. LED CR8 indicates thermal shutdown. Jumper at point A is opened in test.

imum base-bias voltage, and must be less than the transistor breakdown voltage for the current drawn.

In addition, it is assumed that the base-bias supply is capable of supplying increasing current to the transistor base as the collector current increases. The base current will be the transistor collector current divided by beta, the common emitter current gain. Beta will vary from 10-50 for practical power transistors.

To convert these ideas into the final design, I had only to add a base-bias supply, circuit overload, reverse polarity protection, and to increase the number of load transistors to handle the required power. The result is shown in the schematic diagram.

Power is dissipated in the pass element (consisting of Q2, Q3, Q4, and Q5 connected in parallel). Four TIP 35C transistors are used in order to safely handle the 10-Ampere maximum load current. Each pass transistor has a 1-Ohm resistor in the emitter which corresponds to R2 of Fig. 1. In addition to setting the collector current for a given base voltage, these resistors also equalize the load distribution between the four pass transistors and help to keep the load current constant as the transistor temperature increases.

Variable base voltage for the load transistors is obtained from emitter follower Q1 which operates from a 5-volt regulated supply. This circuit consists of transformer T1, the bridge rectifier (CR1-CR4), C1, and an MC7805CP three-terminal regulator chip (U1).

The base of emitter follower Q1 is connected to a variable voltage divider consisting of R1, the pot (R2), and diode CR5. R1 and CR5 limit the driver base voltage range to approximately 0.8 to 4 volts. An additional 0.8-volt offset in the base-emitter junction of Q1 results in a driver output voltage range of 0 to 3.2 volts. Restricting the drive voltage to 3.2 V sets the maximum current the load will draw to 10 A. CR5 was included to compensate for the change in the base-to-emitter threshold voltage of Q1 as the temperature changes. In use, this simple bias supply has proven completely adequate. There is very little drift in load current as the temperature increases.

Some additional features are worthy of mention. Diodes CR6 and CR7 provide reverse polarity protection. A thermal switch (S1) shorts the base-bias supply and turns the current off if the heat-sink temperature becomes excessive. An over-temperature shutdown is indicated by illumination of the LED (CR8).

R4 provides a return path to the transistor emitters for collector-to-base leakage current. This assures that they will actually turn off when the base-bias voltage is removed. R3 is there for safety in case the wiper of R2 opens. This is the usual method of failure for pots. Inclusion of R3 assures a path from base to emitter for the collector-to-base leakage current of Q1. In its absence, failure of R2 could cause the load to pull more than 10 A and damage something. With R3 included, the circuit just shuts off.

A series-connected pair of 8-Ohm, 50-Watt resistors is also mounted on the heat sink of the electronic load. These are provided to increase the dissipation capability of the unit and, in addition, are handy for testing audio amplifiers.

Power Rating

While the nominal input capability of the Power Waster is 10 A at up to 30 V, it may be operated at higher voltages if the proper conditions for safe operation are understood. In this section, I will explain how the nominal power rating is derived.

All high-power transistors have a "safe area" of operation, in which no damage will occur. Fig. 3 is a safe-area curve for a single TIP 35C. This is a plot of maximum-permitted collector current as a function of collector voltage. Operation at any point in the region below and to the left of the curve will not damage the transistor. Combinations of voltage and current above and to the right of the curve will certainly destroy the transistor.

It is interesting that the power dissipation capability is not constant. At a Vce of 5 V, a current of 25 A is permitted. That's 125 Watts. But if the voltage is increased to 50 volts, only 1 Ampere is allowed, providing a dissipation capability of only 50 Watts! The successful designer of high-power transistor circuits stares long and hard at the safe area curves before picking a final configuration!

When I designed the Power Waster, I tried to be conservative so that it could really take abuse without failure. Thus, four TIP 35C transistors were used. In Fig. 4, the composite safe-area curve for the four devices in parallel is shown. This is Curve B. Curve A indicates the "rated" operating envelope for the Power Waster. Only at the 10 A and 30 V point does the "rating" curve approach the safe-area curve.

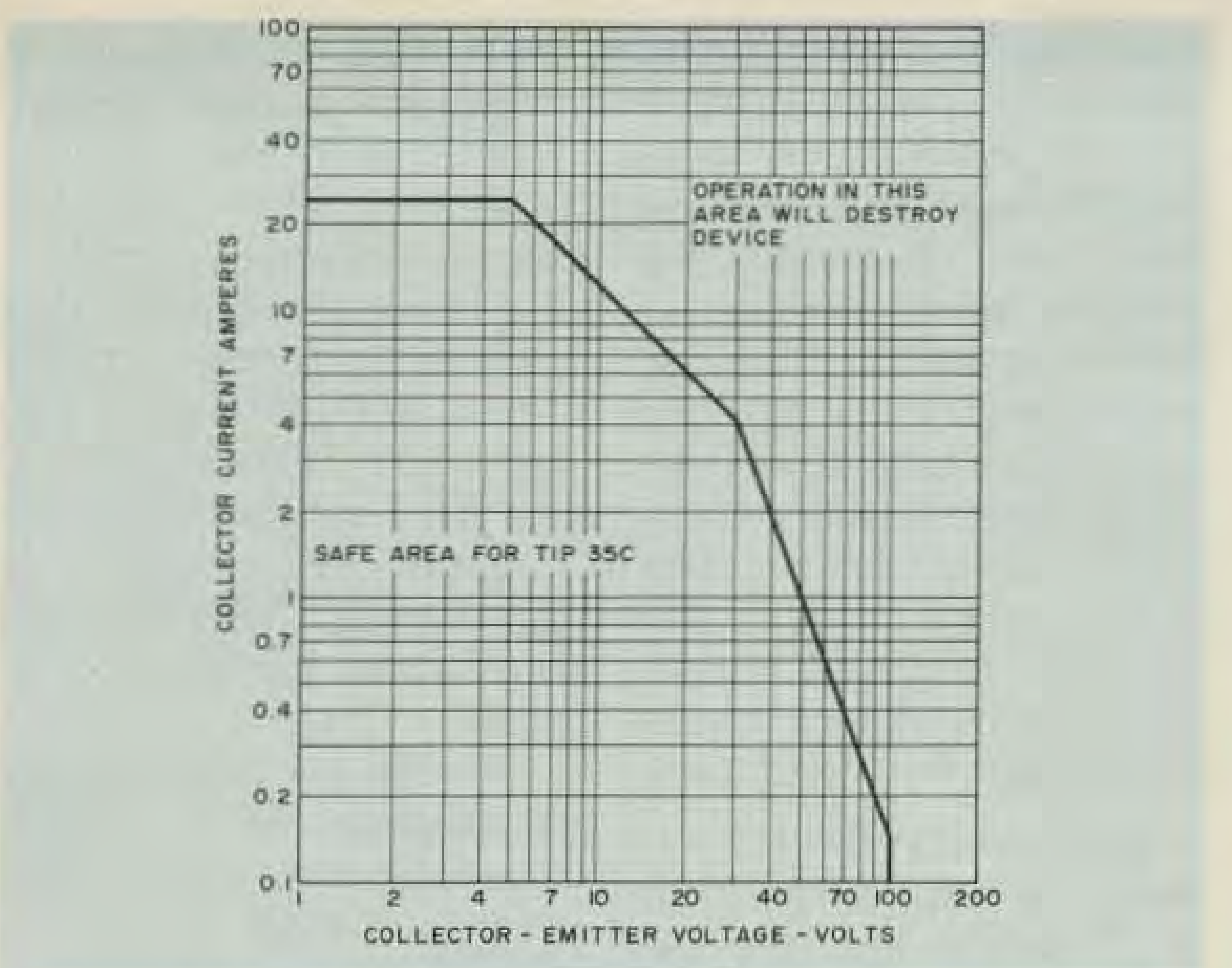

Fig. 3. Safe-area curve for TIP 35C. Safe operation is limited to the area below and to the left of the curve. Operation beyond the safe area will destroy the transistor.

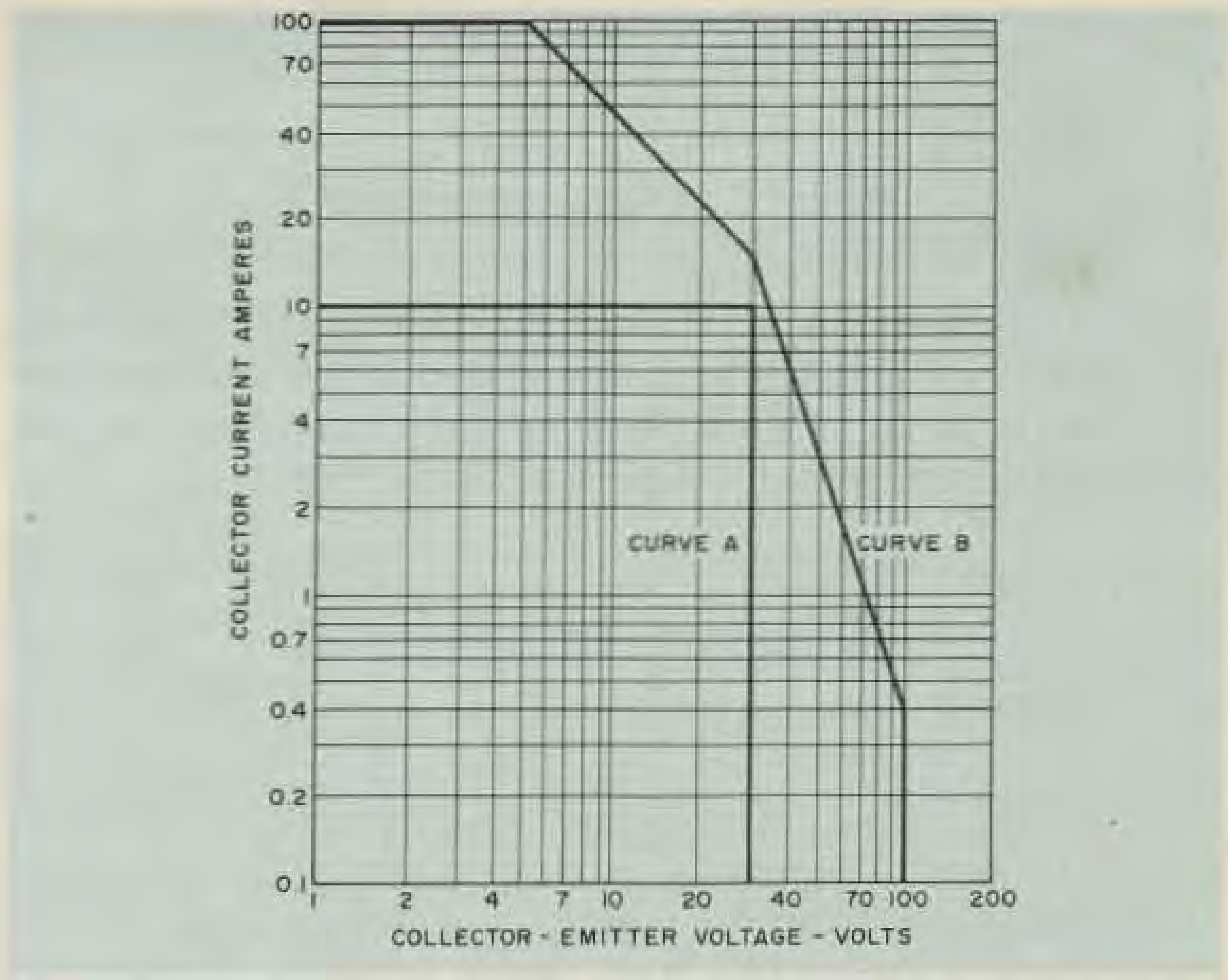

Fig. 4. Operating areas for the electronic load: Curve A indicates the rated operating area for the load. Curve B shows the composite safe area of the four TIP 35C transistors used as the load element. The rated operating area (Curve A) is well inside of the safe area.

At all other combinations of current and voltage, the power dissipation is comfortably inside of curve B.

This conservative design assures that the unit will never fail as long as the 10 A and 30 V maximums are observed.

Construction

Construction of the electronic load can take almost any form because of the non-critical nature of the circuit. In most cases, the shape of the heat sink will determine the final configuration. In order to dissipate 300 Watts, a sink having a thermal resistance of 0.1° C per Watt is required. This is a truly massive piece of metal. I elected to depend upon thermal inertia to permit short tests of up to ten minutes duration and to let the thermal cutout act if things got too hot. Continuous operation is obtained by directing a small blower at the heat sink.

I used a 5″ × 11″ piece of heat-sink extrusion having 32 one-inch-high fins as a chassis. To this I fastened a pair of 0.75″ × 2″ pieces of angle to form a U-shaped chassis with the fins on top. All parts are mounted on the underside of the extrusion, and the front and rear panels are formed by the pieces of angle. Vertical fins are more efficient, of course, but since a cooling fan is required to obtain the full power rating, this arrangement is quite convenient.

Parts located on the front panel include the three binding posts for the 8-Ohm resistors (R9 and R10). These are at the left end of the panel. Next is the LED over-temperature indicator. Adjacent to the LED are the input terminals for the electronic load. The load current adjustment pot, R2, is on the extreme right end of the panel.

Mounted directly to the underside of the heat sink are the two 8-Ohm resistors, the four emitter resistors for the load transistors, and transistors Q2 through Q5. The thermal switch (S1) is located in the center of the sink. Two reverse-polarity protection diodes (CR6 and CR7) are also mounted directly onto the heat sink near the center of the front panel. All parts are mounted to the sink by threaded holes tapped directly into the extrusion. The cathode ends of CR6 and CR7 are connected to the sink via threaded mounting holes. In the same way, the collectors of Q2-Q5 are screwed directly to the sink. Thus, the connection from the polarity protection diodes to the transistor collectors is via the heat sink itself. Fastening the transistors to the sink without insulating wafers puts the entire chassis at the potential of the positive supply input.

Normally, I would have insulated the transistor collectors from the sink but there is a good reason for not doing so. The thermal impedance of the transistor junction to case is 1° C per Watt. Most insulating wafers have a thermal resistance of at least 0.5° C per Watt. If a wafer were used, the resistances are summed to yield a thermal resistance of 1.5° C per Watt. The junction temperature would rise by fifty percent! Instead, I elected to have the positive supply input on the sink and to exercise caution in using the unit. The low voltages involved certainly pose no shock hazard.

On the rear panel are located: the power transformer, bridge rectifier, filter capacitor, 5-volt regulator, and the driver transistor (Q1). The transformer is located at the left end of the rear panel. The filter capacitor is in the center of the panel as is the bridge rectifier, which is hidden by the capacitor in the photograph. Adjacent to the filter capacitor is the 5-V regulator and the driver circuit components. U1 and Q1 are both fastened to the rear panel for cooling. All small parts such as resistors, capacitors, and diodes are mounted with push-in Teflon terminals. Threaded standoffs are used for the larger components.

Not everyone who wishes to build this circuit will be able to find a heat sink similar to the one I used. One approach is to use four smaller sinks and to mount a load transistor on each. A suitable configuation would use four Wakefield Engineering type NC-423 heat sinks. Individually, these units have a thermal resistance of 0.8° C per Watt so the resistance of the combination would be 0.2° C per Watt. Such an arrangement would permit inputs of about 150 Watts without forced-air cooling.

Testing

A few simple tests prior to using the load will prevent damage to it, or to the circuit being tested. First, break the circuit between

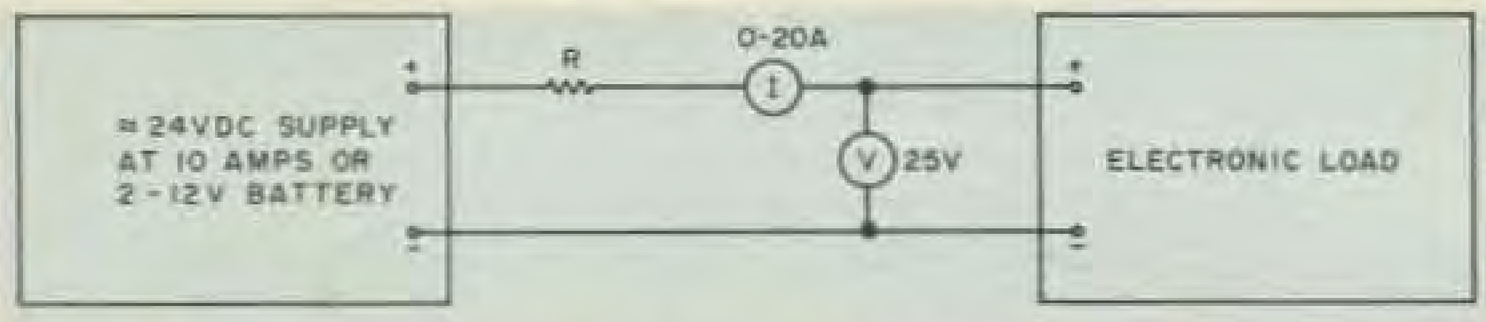

Fig. 5. Testing the Power Waster. A high-current supply such as a pair of 12-V batteries is connected to the load via current-limiting resistor R. The resistor should be chosen to limit the current to a few Amperes for the initial tests.

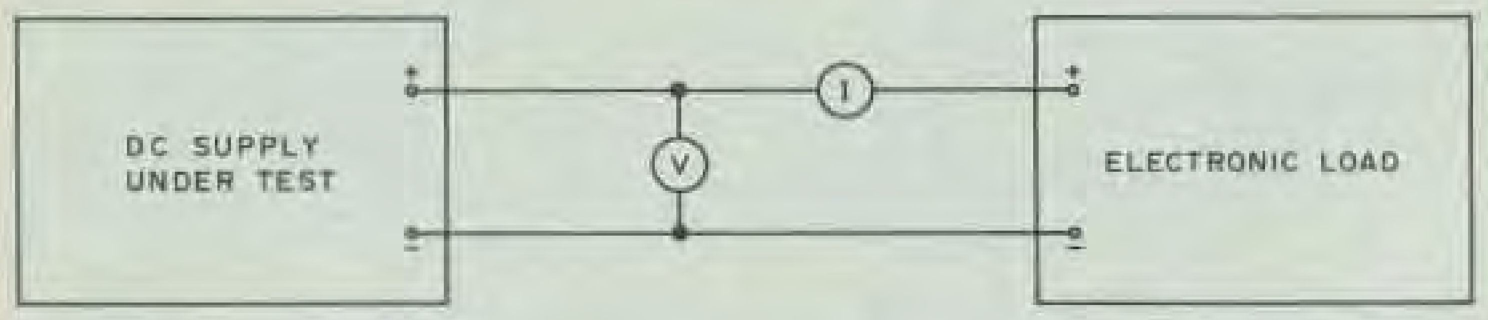

Fig. 6. Using the load to evaluate a power supply. Increasing current is drawn from the supply, and the regulator performance is measured. The load also may be used to ensure proper current-limiter operation.

the driver transistor (Q1) and the load transistors (Q2 through Q5), at point A in Fig. 2. Apply 110 V ac to the power transformer and verify that the voltage is variable from about 0 to 3.5 V as R2 is rotated. Zero volts should occur at the extreme counterclockwise position of R2. This is the zero current setting.

Reconnect the circuit at point A. Then arrange a high-current test setup similar to Fig. 5. Resistor R is chosen to limit the current to 3 or 4 A under short-circuit conditions. Two automobile headlamps in series may be used for this resistor. Set the current control pot (R2) at minimum (CCW position) and turn on the supply and the bias supply in the Power Waster.

Increase the current setting until 2 A is drawn by the load. Measure the voltage drop across R5 through R8 and assure yourself that the voltages are about equal. About 0.5 V should appear across each resistor for a 2-A load. If no voltage appears, then the associated transistor is not drawing any current.

Next, advance the current control. The load current should increase smoothly until the voltage at the load input terminals drops well below 5 V. At this point the load transistors will saturate and the current will be set by resistor R.

The next step is to test the current-limiting feature to verify that the load current is limited to about 10 A. Reduce R in value so that for the supply voltage present under load, about 15 A may be drawn. Again increase the load current from zero with R2. The load should current limit at 9 to 11 A if the same parts values were used.

If all of the above tests were successful, the electronic load is ready for use.

Applications

My purpose in building the electronic load was to enable rapid test of power-supply circuits. The 10-A and 30-V input capability will suffice for almost the entire range of solid-state supplies found in amateur equipment. After I built the load, a number of other applications surfaced. Some of these are worthy of mention.

The performance of a voltage regulator is easily plotted by using the load, connected as indicated by Fig. 6. The regulator is connected to the load via an ammeter. A voltmeter is connected across the output of the supply. By increasing the load current and noting the meter reading, the internal resistance of the regulator may be found, and the percent regulation as a function of load determined. If the supply has a current limiter, the current-limiting point may be found by slowly increasing the load current until the voltage drops. The smooth control of current afforded by the electronic load makes these tests easy.

At times it is desirable to know if a surplus transformer of questionable ancestry can meet a given requirement. Of particular concern is the "overhead" voltage requirement. This is the input voltage required to maintain a regulator in operation (at full load) subtracted from the output voltage.

Typical three-terminal regulators require a 3-volt overhead to function properly. If all circuit parameters are known, it is easy to determine if a certain transformer, rectifier, and filter capacitor will work. If junkbox parts are used, the calculation is often difficult or impossible. It takes only a few minutes to connect up the unregulated supply parts and apply the expected load current using the Power Waster. The unregulated voltage and ripple may be measured, and the suitability of the components determined.

Battery charging is another application. All batteries must be charged from a current source so the charging current is held constant as the battery terminal voltage increases. To use the load as a battery charger, simply connect it in series with a source having a voltage at least 4 V greater than the full-charge voltage of the battery. Then place the combination in series with the battery and dial up the desired charging current.

One final application is protection of high-power transistors during tune-up. The electronic load is placed in series with the supply and programmed for the maximum current that you feel is safe for the amplifier under test. At currents less than the setting, the load saturates and the voltage drop across it is quite small. This is especially true at the lower currents.

Should the amplifier try to draw excessive current, the maximum will be limited to the set value. Response is very rapid. Current limiting occurs in about a microsecond and in the case, is much faster than a normal power-supply current limiter. So effective is this method of protection that I have built it into several solid-state transmitters.

Conclusion

Electronic loads are common in professional labs where power supplies are developed. Many are built from scratch, but also they are sold by commercial test equipment manufacturers. Such devices permit evaluation of supplies prior to connecting them to their intended (and often very expensive) loads.

In writing this article, I have attempted to describe the application and operation of a little-known but very useful piece of test equipment. While my Power Waster is certainly austere as compared with the professional units, it will definitely do the job. The basic design could be modified to include meters and an internal cooling fan. If this were done, the complete unit could be packaged in a well-ventilated box where the heat sinks would be better protected from accidental contact.

I welcome comments or questions from anyone wishing to either duplicate or modify the circuit. ■