HIGH-SPEED **ELECTRONIC FUSE**

"Blows" within microseconds to protect sensitive components

BY CHARLES M. LENNY AND CHESTER DAVENPORT

FUSES, in many cases, blow too slowly to prevent damage in solid-state circuits. Power transistors, which are prone to thermal runaway when passing excessive currents, are especially vulnerable to slow-opening fuses. The electronic "fuse" shown in the schematic is a basic crow-bar circuit that operates in a hundred microseconds or so—more than fast enough to save low-power transistors—and can safely handle load currents up to 60 amperes.

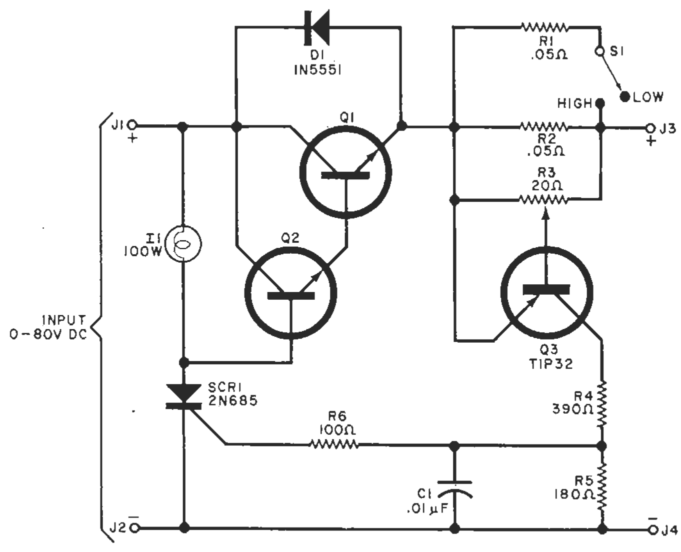
How It Works. When an overcurrent triggers *SCR1* into conduction, base drive is diverted from series-pass transistors *Q1* and *Q2*, which cut off and stop the flow of current to the load. Incandescent lamp *I1* has about a 10-ohm resistance when cold, and drops very little voltage. When *SCR1* fires, the lamp glows, and the filament resistance increases to about 100 ohms, minimizing the load on *SCR1* and acting as an indicator to show that the circuit has tripped.

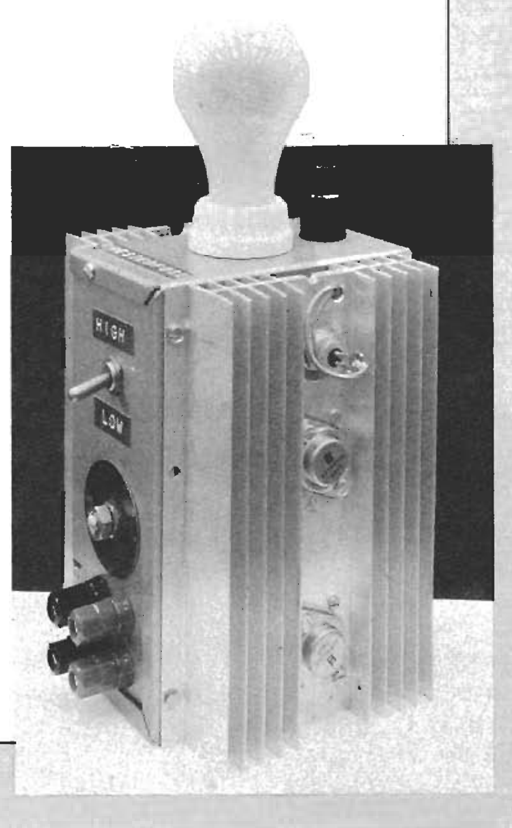
Potentiometer *R3* establishes the desired trip current. When the current passing through *R2* (and *R1* when *S1* is set to HI), exceeds the desired limit, transistor *Q3* turns on. The resulting positive voltage generated across *R5* turns on *SCR1*. Resistor *R6* limits the SCR gate current to a safe value. Diode *D1* permits operating the electronic fuse with an inductive load, removing any probability of punch-through of *Q1* or *Q2*.

Construction. At 60 amperes, resistors *R1* and *R2* can dissipate 45 watts each and should be provided with suitable heat sinking. A similar heat sink should be used for *Q1*, *Q2* and *SCR1*. These two heat sinks should be mounted on two exterior sides of the selected chassis. A socket for *I1* can be mounted on top of the chassis. Input and output power connectors *S1*, and *R3* can be mounted on an empty side as desired. The Solitron SDT96306 can handle 70 amperes at 325 volts. A 2N3055 that can handle 15 amperes at 60 volts is an acceptable substitute.

Calibration of *R3* is performed by using various resistive loads to draw specific currents, with *R3* adjusted so that the lamp glows when the specific current is reached. A dial plate on *R3* is used to identify the calibration points. Remember that the trip current must be within the pass transistor's rating.

Since the SCR is powered by dc, once it fires it will remain in the conductive state until the applied dc voltage is removed. This can be done either by installing a series switch in either of the supply leads or by turning off the driving power supply. ◇





PARTS LIST

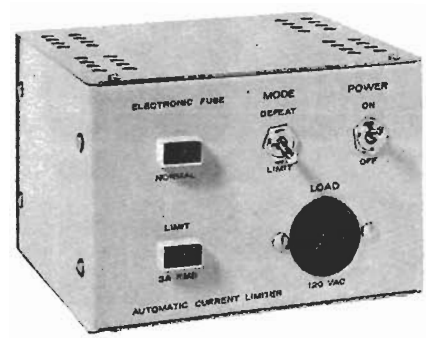
- C1—0.01-μF disc capacitor
- D1—1N5551 diode
- J1 through J4—5-way binding post, color coded
- I1—100-W incandescent lamp
- Q1, Q2—SDT96306 (70 amperes) or 2N3055 (15 amperes)
- Q3—TIP32 or any silicon transistor
- R1, R2—0.05-Ω, 50-W resistor

- R3—20-Ω, 5-W potentiometer
- R4—390-Ω, 10-W resistor
- R5—180-Ω, 1-W resistor
- R6—100-Ω, ½-W resistor
- S1—Spst switch
- SCR1—2N685 or similar SCR
- Misc.—Suitable heat sinks (2), socket for I1, enclosure, terminal strips, mounting hardware.

BUILD

10-μs Electronic Fuse

Protect your equipment with this fast-acting Electronic Fuse. Metal and glass fuses are simply not fast enough to protect sensitive semiconductors.



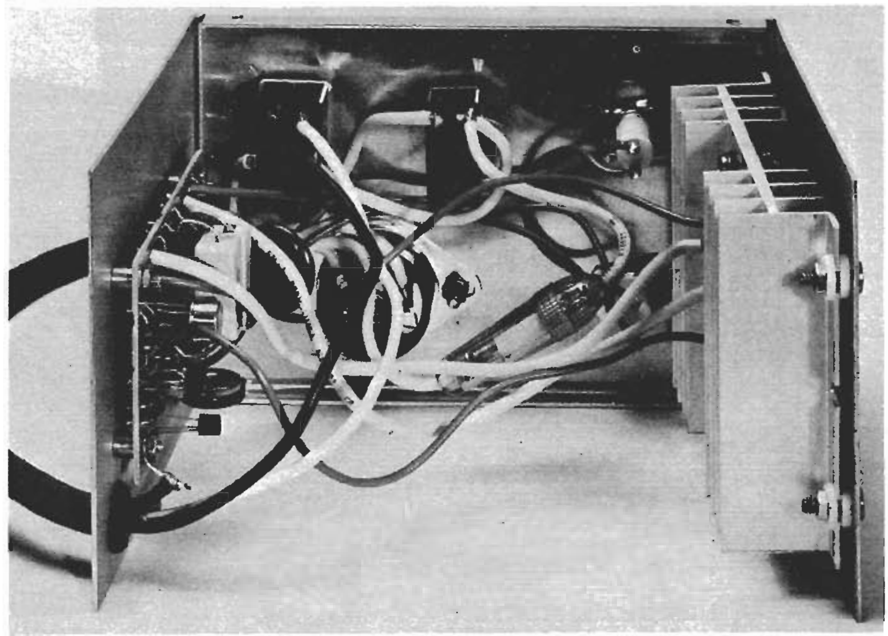
MITCHELL WAITE
and LARRY BROWN

BURNING UP A SET OF POWER TRANSISTORS can be an expensive and time consuming mistake. Such mistakes can easily occur by accidently changing the bias setting on an amplifier, shorting B+ to a transistor base, installing an NPN where a PNP goes, etc. How many times has your voltmeter probe slipped and shorted the B+ line? After you find a new fuse do you have the vague suspicion that the rectifier diodes got awful warm?

But what about that old metal and glass fuse, doesn't it at least provide some protection for the semiconductors? Unfortunately, not always. A 25¢ glass and metal fuse just takes too long to melt and open. By the time it does (5–15 ms), thermal run-away could of easily ran away with $40 worth of your solid-state components.

The obvious solution to these problems is a fast-acting power switch in the AC line that cuts off current if the equipment shorts out. The Electronic Fuse is such a device. It can reduce operating current to zero within *10 microseconds* of being tripped.

The device to be protected, say an audio amplifier, is simply plugged into the 3-wire AC receptacle on the front panel of the Electronic Fuse. If the device isn't shorted, the NORMAL lamp glows indicating current drain is not excessive. If a short occurs, the Electronic Fuse will trip and cut off the AC-line current. When this happens, the LIMIT lamp lights indicating the fuse is in the current limiting mode.



INSIDE VIEW of the Electronic Fuse.

How it works

Referring to the block diagram in Fig. 1, the load (equipment to be protected) is connected in *series* with the AC line and the Electronic Fuse. A full-wave bridge circuit is connected between the AC line and the equipment load, with a current-sensing device and power switch connected across the bridge. The bridge conducts on each half-cycle of the line voltage. This produces a rectified 120-Hz pulsating DC waveform that appears across a current-level sensor circuit and the collectors of a three-stage Darlington transistor power switch. A resistor divider network, in the emitter leg of the Darlington circuit, applies a portion of the 120-Hz waveform to the gate of the SCR. A transistor in the gate circuit of the SCR reduces temperature drift.

As long as the current drawn by the equipment is less than 3 amps RMS, the SCR is off. With the SCR off, the Darlington power switch conducts, effectively shorting out the bridge circuit and allowing full current to flow in the load. With normal operation, there is less then a 5V RMS drop across the fuse. The NORMAL lamp is energized by the voltage across the load socket, while the LIMIT lamp remains extinguished.

When the load draws excessive current, the SCR conducts and the 3-stage Darlington power switch stops conducting. This effectively opens the series connection between the line and the load. When this happens, the voltage across the equipment drops to zero, the NORMAL lamp goes off and the LIMIT lamp lights indicating the fuse is

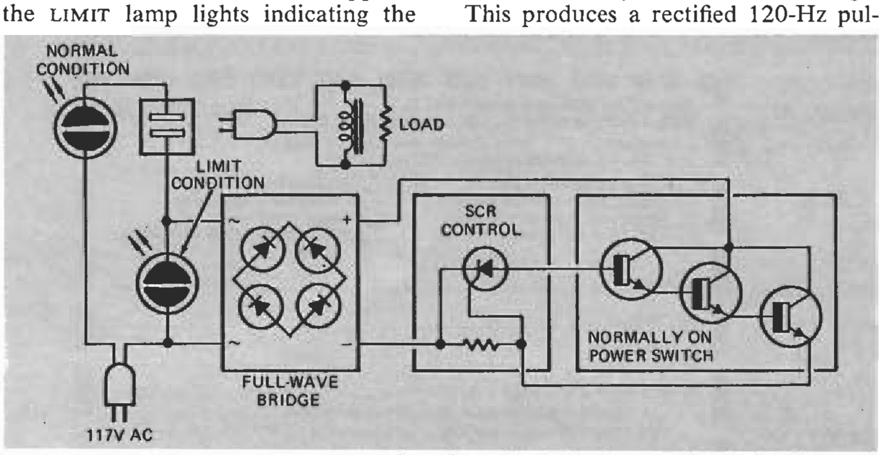


FIG. 1—ELECTRONIC FUSE is connected in series with the load to monitor the load current.

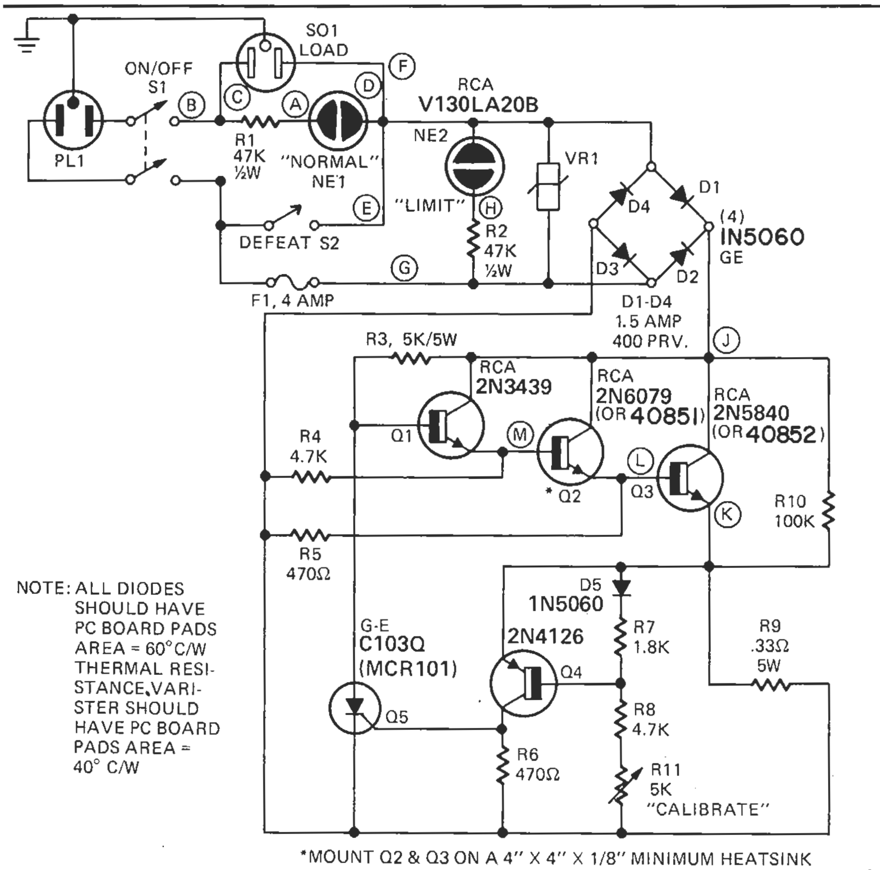


FIG. 2—ELECTRONIC FUSE trips when load draws more than 3-amps. The fuse can be adjusted to trip at lower values of load current by selecting different values of resistor R9.

PARTS LIST

R1, R2—47,000 ohm, ½-watt, 10%
R3—5000 ohm, 5-watt, 10%
R4, R8—4700 ohm, ¼-watt, 5%
R5, R6—470 ohms, ¼-watt, 5%
R7—1800 ohms, ¼-watt, 5%
R9—0.33 ohms, 5-watt, 10%
R10—100,000 ohm, ¼-watt, 5%
R11—5000 ohm trimmer
Q1—2N3439 transistor
Q2—2N6079 transistor
Q3—2N5840 transistor
Q4—2N4126 transistor
Q5—SCR (G-E C103Q or equal)
D1-D5—1N5060 diode
VR1—Varistor (G-E V130LA20B or equal)
S1—DPDT toggle switch, 3 amp
S2—SPST toggle switch, 3 amp
NE1, NE2—neon pilot lamps, panel mount
F1—4 amp in-line fuse
SO1—3-wire AC socket
PL1—3-wire AC plug and cord
Misc. PC board, heatsink for Q2 and Q3 (Thermalloy 6500B-6 or equal), Teflon spacers, mica insulators for transistors, hardware, etc.

Note: A complete kit of all parts including drilled and screened enclosure, drilled and solder-plated PC board, and all components is available from Cal Kit, P.O. Box 38, San Rafael, CA 94901. Order #EF-2, $63.95. Board only, order #EF-1, $4.95. All prices postpaid and insured. California residents add 6% sales tax.

in the current-limit mode. Note that the fuse monitors the current during each ½ cycle of the line current and proceeds to shut down on each ½ cycle as long as the over-current condition persists. In order to use the fuse with highly inductive equipment (such as tape recorders and phonographs), a varistor is inserted across the bridge. Its purpose is to damp out the large-amplitude voltage spike these loads can cause.

The Electronic Fuse triggers at 3 amps RMS or 4.25 amps peak when used with a resistive load. Most audio amplifiers with transformer/diode power supplies draw less than this amount and will not falsely trigger the fuse. Small black-and-white televisions as well as most test equipment will operate properly when connected to the fuse. However, large color TV's often will not work. This is because the power supply draws a large current pulse on each cycle that is greater than 4.25 amps peak. In general, wattage ratings are rather poor indicators of whether the fuse will trip falsely. This is due to the fact that wattage ratings are calculated on an RMS basis while the power supplies draw current in pulses. The acid test is to plug the unknown load in and see if it causes the fuse to trip. If it does, its too big.

A more subtle limitation of the Electronic Fuse is the possibility that a hefty charged filter capacitor in the

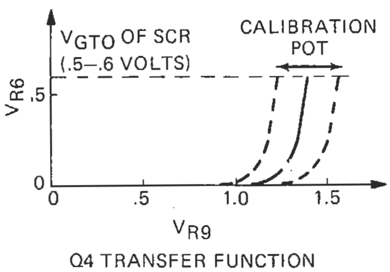


FIG. 3—TRANSFER CHARACTERISTIC of the temperature compensated inverter amplifier.

power supply of the equipment connected to the fuse can store enough energy to damage the transistors in spite of the fact that the fuse is limiting. The danger here will depend on the size of the charge on the filter capacitor, the type of transistor, the degree of heat-sinking, and the type of power-supply. Normally, filter capacitors are expensive components and a consumer product will generally use the smallest possible value consistent with good fil-

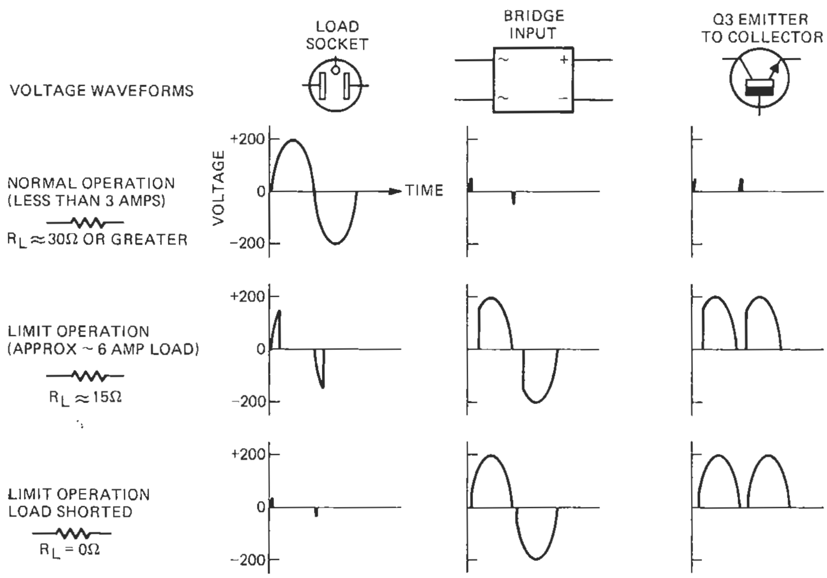


FIG. 4—VOLTAGE WAVEFORMS of the Electronic Fuse during normal operation, current-limit operation and when the load is shorted.

tering. But this isn't really such a big worry, because when a set of new transistors are installed, the amplifier is off and the filter capacitor is not charged. If a short exists, then as the equipment is turned on the fuse will trip long before the filter capacitor has time to charge. (The typical technician gets around this problem by using a Variac and an ammeter in series with the equipment load. The line voltage is increased and the ammeter is carefully monitored. A sudden rise in the current as the voltage is increased indicates a short. As quick as possible the technician switches the Variac off, but often he is too late and the damage is permanent.) In over 1½ years of service, the fuse has "saved" many replacement transistors from biting the dust. In most cases, devices that are normally on and develop shorts will be protected from damage.

The electronic fuse is not only restricted to high current (3 amp RMS) operation, it also may be used to protect low-current devices such as portable phonographs and low-power (5-15 watt) audio amplifiers. For example, to protect the components of a 120-volt, 12-watt amplifier, first calculate the current level that will trip the fuse. This is found from the equation:

$$I_{RMS} = P_{max}/120 \text{ volts}$$

For the example cited above; $I_{RMS} = 12/120 = 100$ mA. Now adjust the fuse to limit at this current by calculating the proper resistance of R9 (see Fig. 2):

$$R9 = 1/I_{RMS} \ (R9 \leqq 10 \text{ ohms})$$

For our example, $R9 = 1/.1 = 10$ ohms. To check the power rating for R9, use the formula:

$$P = 1.96/R9$$

The power consumption of R9 is: $P = 1.96/10 = .196$ watts. Thus R9 should be a ¼ watt resistor.

A DEFEAT switch on the front panel of the Electronic Fuse is used to override normal operation and apply line current directly to the equipment. This is useful when you are making a test and can't tolerate the 5-volt drop across the fuse or when you expect large current surges and don't want the fuse to limit.

Circuit description

When the Electronic Fuse isn't in the current-limit mode, current flows from the AC line, through the equipment load, the full-wave bridge rectifier, 3 stage Darlington and back to the AC line (see Fig. 2). Diodes D1 through D4 make up the bridge rectifier and conduct on alternate cycles of the 60-Hz line voltage. This produces a 120-Hz pulsating DC voltage that is applied across the collector and emitter of the Darlington circuit. Resistor R9, in the emitter leg of the final stage of the Darlington (Q3) develops a voltage waveform that follows the instantaneous load current.

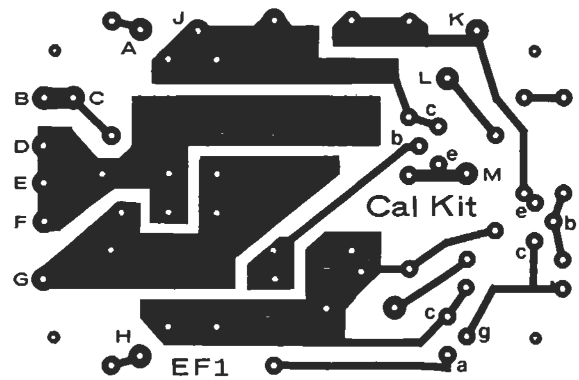


FIG. 5—FOIL PATTERN of printed circuit board.

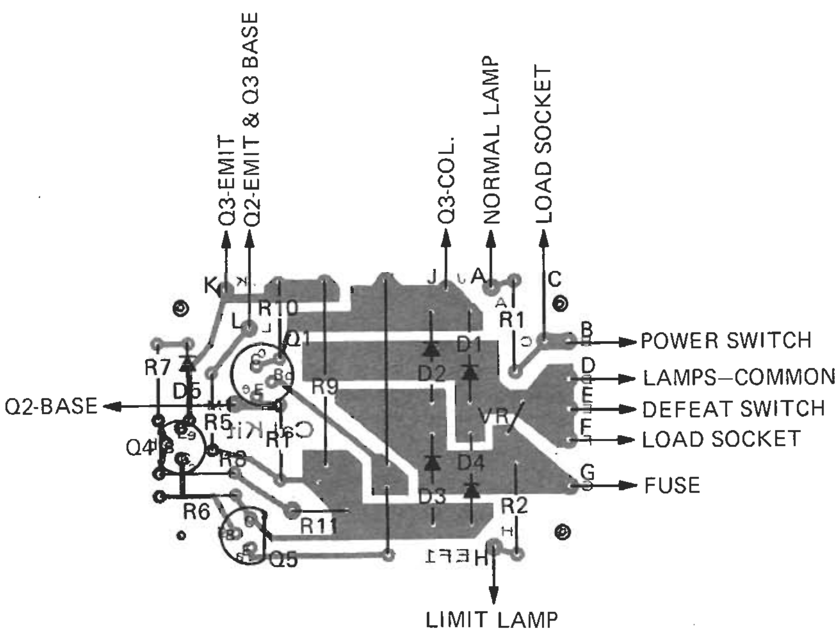


FIG. 6—COMPONENT PLACEMENT diagram for the Electronic fuse.

Transistor Q4 and its associated components make up a temperature-compensated inverter amplifier that senses when the voltage across R9 reaches the trip-point of the fuse and triggers SCR Q5. When the SCR conducts, the base voltage of Q1 is lowered, thus turning it off. This in turn shuts off Q2 and Q3. The voltage across R10 produces positive feedback that turns Q1, Q2, and Q3 off in under 10 microseconds.

Any inductive spike or transient due to the fast switching speeds is absorbed by varistor VR1. A varistor is similar in operation to two back-to-back Zener power diodes and produces excellent low-cost protection for the switching transistors. Trimmer R11 is used to adjust the trip point of the fuse by adjusting the threshold voltage of the temperature-compensated inverter amplifier. This stage may appear rather strange at first. What is odd is that V_{cc} for Q4 is developed from the same signal used to trigger Q4. The overall operation of Q4 is such that it functions like a diode with an adjustable offset. The transfer function of Q4 shows this more clearly (see Fig. 3).

The voltage waveforms of the Electronic Fuse shows what happens as the fuse goes from normal operation to the current-limiting condition. The voltage waveforms are shown in Fig. 4.

Construction

There are a number of ways to construct the circuit—Vector board, point-to-point wiring, etc. However, a printed circuit board (see Fig. 5) will allow the varistor and diodes to be heat-sinked by the copper foil. A finished board is available from the supplier shown in the parts list. The component placement for the printed-circuit board is shown in Fig. 6.

The diodes should be heat-sinked at 60° centigrade per watt and the varistor at 40° centigrade per watt. Mount the 5-watt resistors, R9 and R3, as far from transistors Q4 and Q5 as possible. Power transistors Q2 and Q3 are mounted on a sheet of 4 × 4 × ⅛"

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ELECTRONIC FUSE

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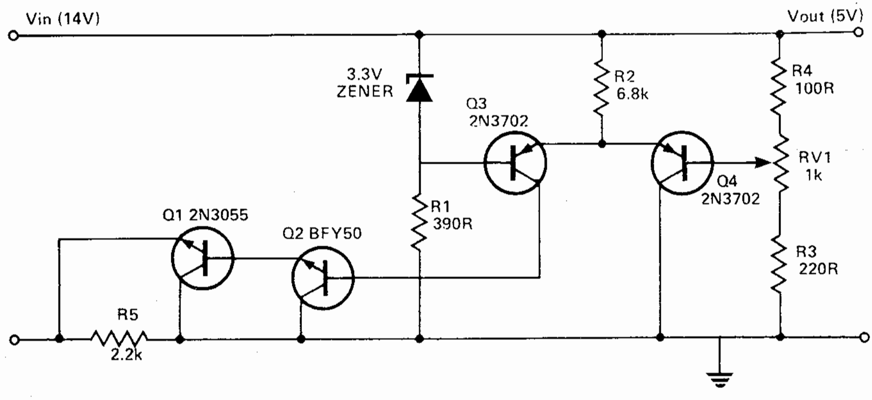
aluminum. Even better is a commercial heat sink like the one described in the parts list. Use number 16 gauge wire with 300 volt insulation for connecting between the board and the controls and transistors. For safety use a 3-wire type AC receptacle and plug. Use a well ventilated enclosure to keep the internal temperature below 75° centigrade.

Calibration

A convenient calibration procedure is to plug incandescent lamps totaling 350 watts into the fuse with the fuse switched OFF. Adjust trimmer R11 to its approximate midpoint position. Turn the fuse ON. After about 2 to 5 seconds, the lamps should come on (the delay is due to the thermal lag in the filaments). Adjust the trimmer until the lamps just turn off. What you have done is adjusted the fuse to "trip" at a 350-watt 3-amp RMS load. The final test is to remove about 50 watts of lamps and see if the remaining lamps turn on without causing the fuse to trip. **R-E**

VOLTAGE REGULATOR AND ELECTRONIC FUSE

This circuit improves on those previously published (Tech-Tips, April and September 1975) in that current cut-off is achieved, it is self-resetting once that overload is removed and it is an efficient voltage regulator. Choose Z to be about $2/3V_{out}$ and R_1 to supply enough current for stabilization of the Zener voltage. Choose R_2, which determines the cut-off current, I_{max} such that $I_{max}R_2 = (V_Z - 0.5) \times (\beta Q1+Q2)$ and the values of R_3, RV_1 and R_4 so that the base of Q4 is at the same voltage as the base of Q3 and a large current (100 times) passes down the resistor chain compared to the base current of Q4 which is $(V_Z - 0.5)/R_2\beta Q4$. Altering RV1 gives fine control over V_{out}. R5 (200 ohms to 2.2k) allows switch-on under no load conditions. Component values are given for a 5V supply with a 2A cut-out. For low current applications, Q1 can be a BFY50 with Q2 omitted.



Circuit Ideas

Two terminal circuit breaker

The unit functions by sensing a load current across the base-emitter junction of the output transistor (voltage sensing requires a third terminal). Resistors R_1 and R_2 control the off and on times respectively provided V_{cc} and I_{load} do not change. The capacitor undergoes a small amount of reverse bias (~ 0.7V). Good tantalum capacitors will stand this and, unofficially, so will most electrolytics with voltage ratings above 16V.

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