A zero-voltage switching heat controller

for minimum electromagnetic interference

Winter is almost upon us and with it the problem of keeping warm without sending the power bill soaring. This versatile zero-voltage switching heat controller provides continuously variable control of heating appliances without the radio interference problems common to more conventional phase control circuits.

DESIGN by JOHN CLARKE

While the Triac has proved a boon for light dimmers and in many other power control applications, conventional phase-controlled Triac circuitry generates considerable electromagnetic interference. By contrast, this zero-voltage switching power control circuit does not generate interference and is suitable for controlling radiators and other heating appliances.

Conventional phase-controlled Triac circuitry controls the power of the AC mains by varying the point at which the Triac is triggered into conduction. For low power operation, the Triac is triggered late in each half-cycle of the AC mains waveform, while for high power, the Triac is triggered early in each AC half-cycle. Fig. 1 demonstrates the principle.

The term "phase-control" refers to the fact that the phase of the Triac trigger pulses is varied with respect to the phase of the AC waveform.

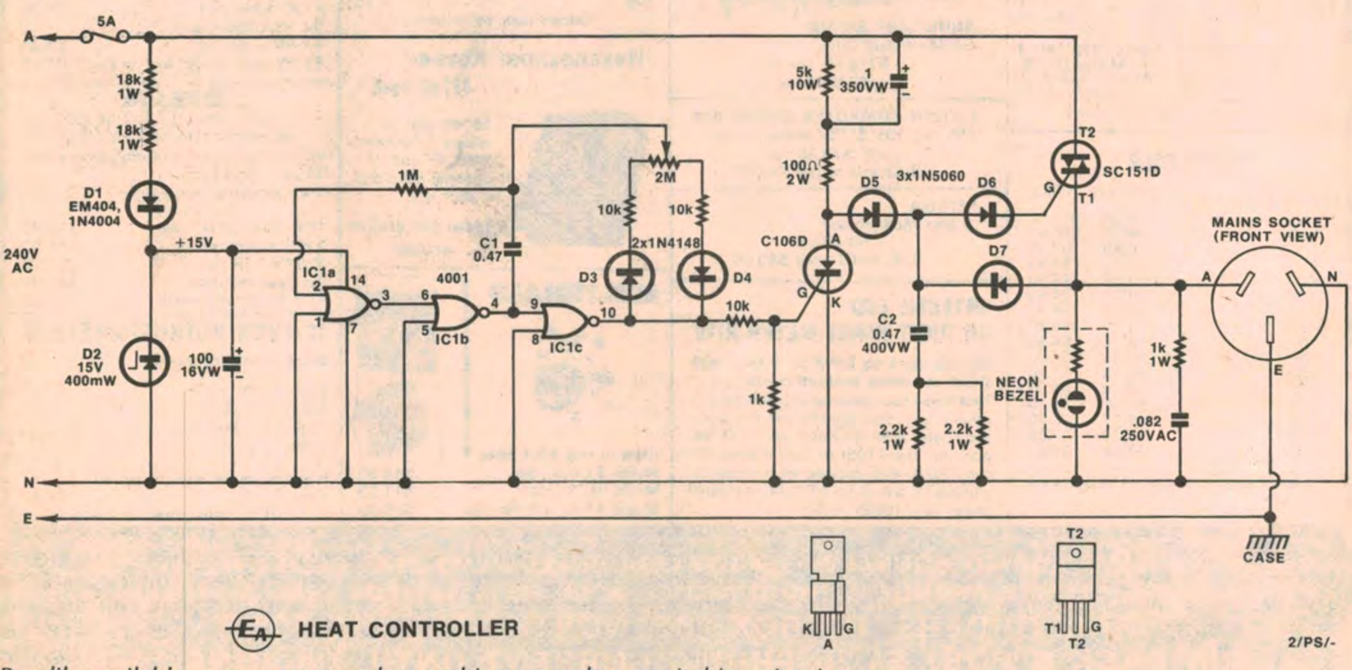
The one big problem with phase-controlled Triac circuitry is that it generates considerable EMI (electromagnetic interference) or, as it used to be called, RFI (radio-frequency interference). By either name, the problem is the same. The EMI occurs because the Triac switches at any point in the AC waveform and thus generates peak currents with very fast rise-times in the load and wiring.

If, for example, the Triac switches at the peak value of the mains waveform, approximately 340 volts positive or negative, the resulting current in a 1000-watt radiator rises to almost six amps in just a few micro-seconds. Since this happens on every AC half-cycle, the resulting high-energy harmonics become an irritating loud buzz when reproduced by broadcast and shortwave receivers.

It is possible to suppress Triac generated EMI but effective suppression is very difficult to obtain over a wide frequency range. It is far better to avoid the problem altogether. This can be done by the technique known as "zero-voltage switching". This method involves turning on the Triac at the zero-crossing point of each AC half-cycle. In this way, the Triac generates negligible interference when it turns on.

The "zero-voltage" switching method also implies that the Triac is turned on for integral numbers of successive AC cycles. For lower power, the Triac is turned on for one full AC cycle with low repetition rate (say, one in 20) while for high power, the Triac may be turned for nine out of ten AC cycles. Fig. 2 demonstrates the process.

Naturally, this method of power control is only suitable for resistive loads such as radiators and other heating



Readily available components make up this zero-voltage switching circuit.

appliances. It is not suitable for light dimming because the lights would flash!

Zero-voltage switching Triac circuitry is often designed around special-purpose integrated circuits but our design uses readily available, off-the-shelf components. Our design is based on a circuit originally developed by General Electric and published in that company's SCR Manual which was reviewed in our December 1979 issue.

Now refer to the circuit diagram. Forget the components to the left of the C106D SCR for the moment. The heart of the circuit is the SC151 Triac, the C106D SCR and the diodes D5 to D7. Now consider that the SCR is not receiving a gate signal and so cannot conduct.

At the beginning of a positive AC half-cycle, the voltage at the Triac terminal T2 rises and so feeds a current to the Triac gate via the 1uF capacitor, 100 ohm resistor and diodes D5 to D6. Thus the Triac turns on very early in the positive AC half-cycle.

As the Triac conducts and applies a positive voltage to the load, diode D7 conducts and charges C2. Then, at the beginning of the next AC half-cycle (which happens to be negative) C2 is discharged via D6 into the gate of the Triac to turn it on immediately.

In this way, whenever the Triac is turned on for a positive half-cycle, conduction in the negative half-cycle automatically follows.

So with the three diodes, D5 to D7 and associated capacitors and resistors, the Triac will begin conduction at the beginning of a positive half-cycle and continue until the end of the following negative half-cycle. The silicon controlled-rectifier (SCR) C106D is used to switch the Triac on for integral numbers of AC cycles.

When the SCR turns on, it bypasses any gate current to the Triac which would otherwise flow through D5. If the SCR is switched on at some time during an AC cycle, the Triac will remain in conduction for the remainder of the cycle. However, if the SCR remains on for successive AC cycles the Triac remains off.

So the means for switching the Triac on for integral numbers of AC cycles is provided merely by feeding a low frequency square wave, of variable duty cycle, to the gate of the SCR. This square wave is generated by a CMOS oscillator comprised of a 4001 quad two-input NOR gate and the components associated with D3 and D4.

Since one input of each NOR gate is tied to the negative supply, the gates actually work as inverters. The three inverters are wired in a variation of a standard triple-inverter oscillator. The time-constant of the oscillator is defined by the value of C1 and the value resistance between C1 and the output of IC1c.

The oscillator works as follows: Since

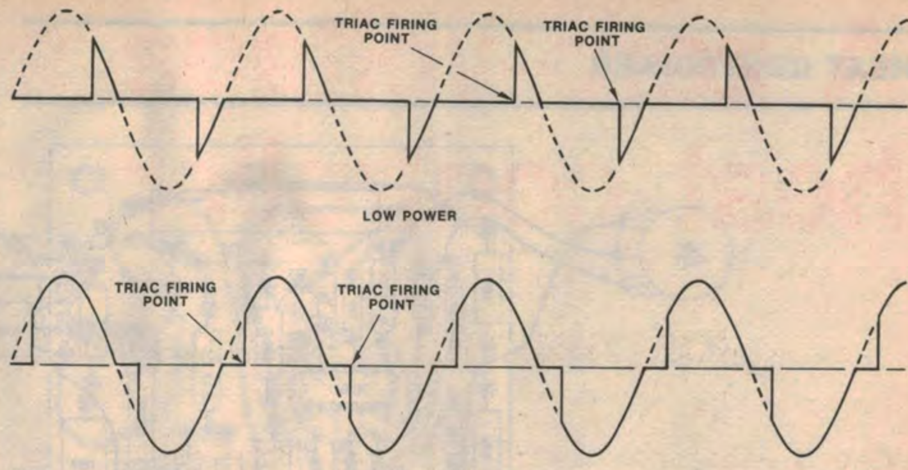


FIG. 1

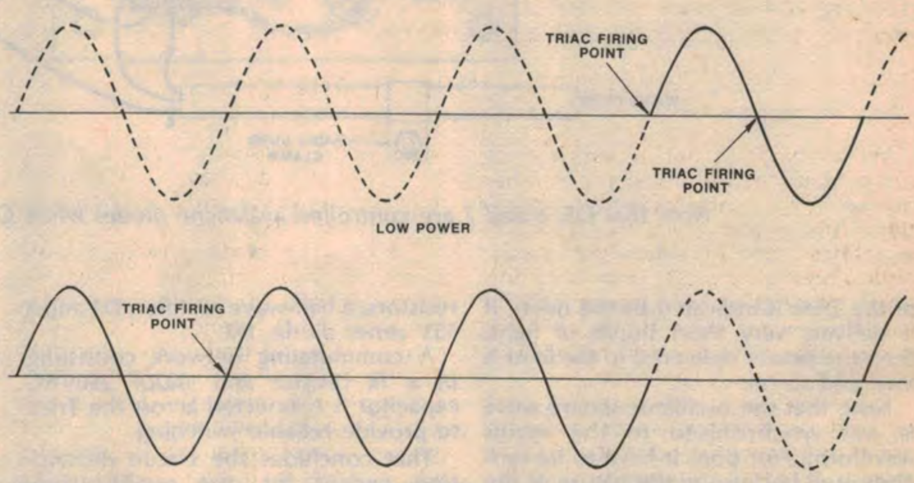


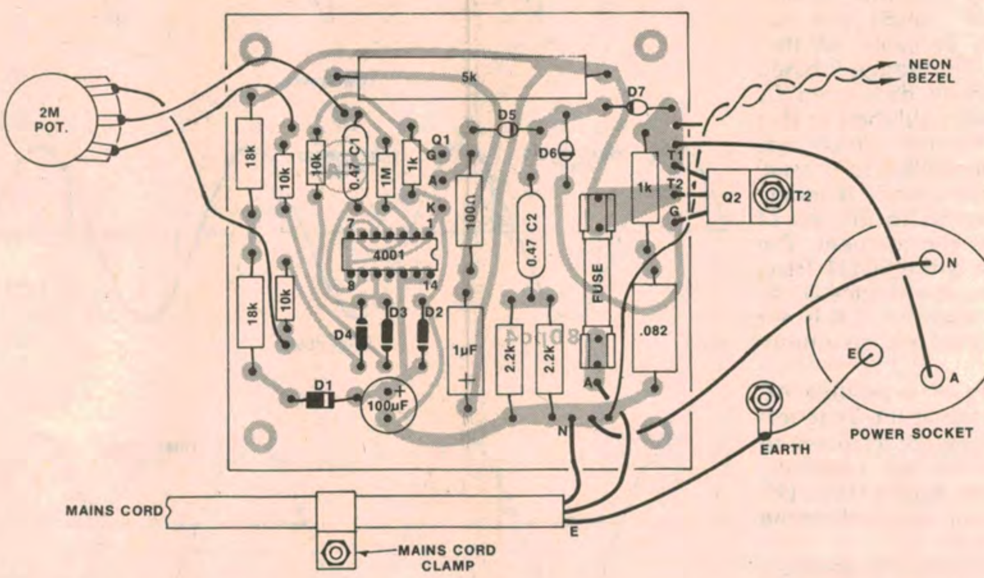
FIG. 2

Figs. 1 and 2, above, show the difference between phase-controlled and zero-voltage switching Triac circuits. At right is the prototype Heat Controller.

each inverter has a change in polarity between input and output, the capacitor C1 will be charged alternately in one direction and then the other, forcing all the inverters to change state (from low to high or high to low) simultaneously. For example, when the output of IC1c is high and its input is low, C1 will charge towards the positive supply to the point where the input of IC1a is pulled high enough to force all inverters to change state.

When C1 charges towards the positive supply it is fed via diode D3; when charging in the other direction it is fed via D4. Thus it is possible to vary the duty cycle of the generated square wave by changing the setting of the two megohm potentiometer.

When the potentiometer wiper is set at midtrack, the oscillator waveform will be approximately square (ie, 50% duty cycle) and the Triac will turn on for roughly 10 cycles in every 20 of the AC waveform and thus apply roughly half power to the load. The duty cycle



Note that D5, 6 and 7 are controlled avalanche diodes while C2 is rated at 400VW.

of the Triac is indicated by the neon. If it delivers very short bursts of light, then the power delivered to the load is low, and so on.

Note that the oscillator square wave is not synchronised to the mains waveform. Nor does it have to be synchronised because of the nature of the Triac switching circuit which automatically ensures that the Triac switches on for whole AC cycles.

Power requirements of the CMOS oscillator are provided directly from the mains via two 18k dropping resistors, a half-wave rectifier, D1 and a 15V zener diode, D2.

A commutating network consisting of a 1k resistor and .082uF 250VAC capacitor is connected across the Triac to provide reliable switching.

That concludes the circuit description except for one qualification. Because of the Triac gate current requirements of typically 50 milliamps or more, the Triac does not switch at the zero-voltage point at the beginning of the positive half-cycle. The switching voltage is actually closer to 15 volts. While this is not ideal, the EMI delivered by the Triac is negligible compared with a phase-controlled circuit.

APPLICATIONS

Well, what are the uses for this circuit? As we remarked earlier, it is applicable to heating appliances. For example, it can be used to provide continuous heat control for electric radiators. It is particularly handy for reducing the output of a single-bar 1kW radiator, which, when used in a small room, can quickly produce a stifling atmosphere. Our heat controller allows the radiator to be set for a comfortable temperature without power wastage.

Similarly the heat controller can be used with vertical grillers which have no built-in heat control. Normally the only way the cooking temperature of these vertical grillers can be controlled is by opening the side covers to release the heat — a very wasteful and imprecise method.

Then there are the many electric blankets which have only a coarse, two or three position heat control, often either too hot or too cool. Our heat controller can provide a continuously variable temperature setting, so that the user can select just the right amount of warmth.

CONSTRUCTION

We built our heat controller into a diecast box. This provides rugged and safe construction as well as a heat sink for the Triac. Note that plastic boxes cannot be used for this project.

The circuit is rated for loads up to

PARTS LIST

1 PCB coded 80pc4, 88mm x 87mm
1 diecast aluminium box, 118 x 93 x 56mm, Eddystone 6908P or similar
1 neon bezel
1 mains socket
1 mains plug and three core flex
1 grommet to suit mains cord
3 small grommets
1 cable clamp
1 solder lug
4 rubber mounting feet
4 8mm brass standoffs
2 mica washers and one insulating bush for Triac
2 PC fuse-holder clips
1 5-ampere fuse type 3AG
1 plastic knob
nuts, bolts etc

SEMICONDUCTORS
1 x IN4004 400V PIV, 1A silicon diode
3 x IN5060, A14D, 400V PIV 2.5A controlled avalanche diodes
2 x IN4148 small signal diodes
1 x IN965 400mW 15V zener diode
1 x C106D SCR
1 x SC151D TRIAC
1 x 4001 quad two-input NOR gate

RESISTORS
(¼W unless specified otherwise)
1 x 1M, 2 x 18k/1W, 3 x 10k, 1 x 5k/10W, 2 x 2.2k/1W, 1 x 1k, 1 x 1k/1W, 1 x 100 ohm/2W, 1 x 2M linear pot.

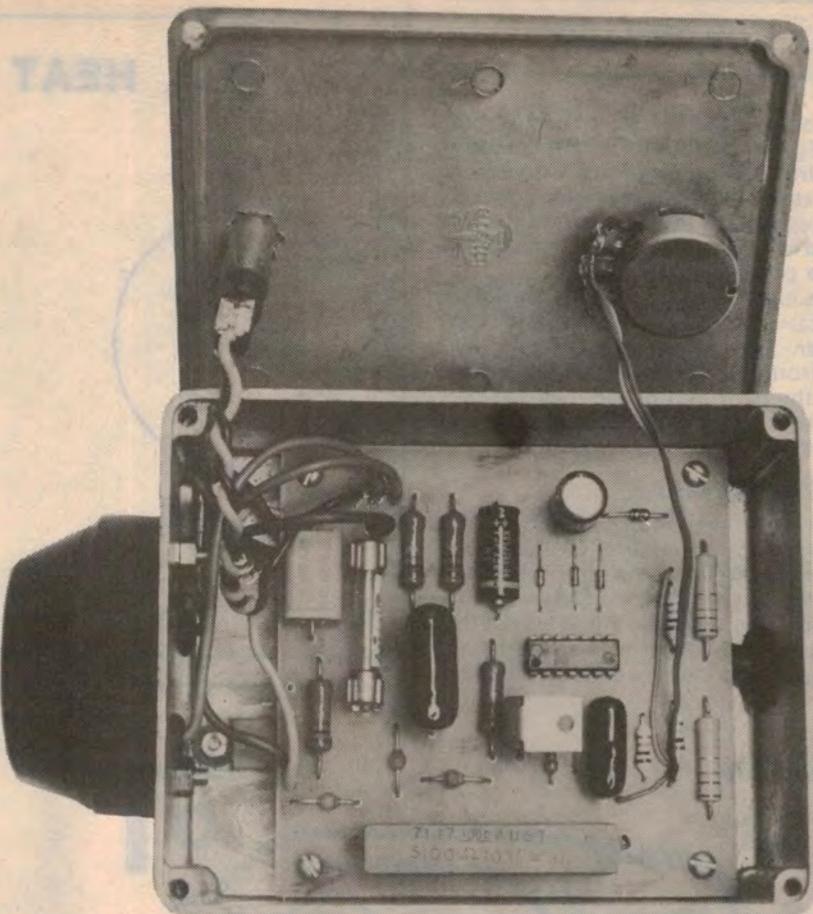
CAPACITORS
1 x 100uF/16VW electrolytic (PC-mounting)
1 x 1uF/350VW electrolytic (pigtail type)
1 x 0.47uF/100VW metallised polyester
1 x 0.47uF/400VW metallised polyester
1 x 0.082uF/250VAC polycarbonate

1.2kW in the form that we have built it. With a better heatsink for the Triac and a 10-amp fuse, the circuit could control loads up to 2.4kW.

Most of the components are mounted on a printed circuit board measuring 88 x 87mm and coded 80pc4. To avoid component overcrowding on the PCB, do not use components with ratings higher than specified in our parts list. Note that some holes on the PCB may require enlarging to take the pigtails of the SCR, and the fuseholder.

Mount the 10W resistor a couple of millimetres above the board to avoid charring the board, as it runs quite hot. If PCB fuse holders are difficult to obtain, the fuse can be soldered into the circuit with stiff tinned copper wire. Mount the resistors and capacitors first, then the diodes and SCR. Take care in handling the CMOS integrated circuit, and solder the power supply pins first (with the soldering iron barrel connected to the negative supply line on the PCB) to allow the internal static protection circuitry to take effect.

Clamp the power cord securely to the bottom of the box. The screws holding the cable clamp and the Triac should be kept as short as possible to prevent them shorting to the PCB and



For safety's sake, a diecast box is recommended for this project.

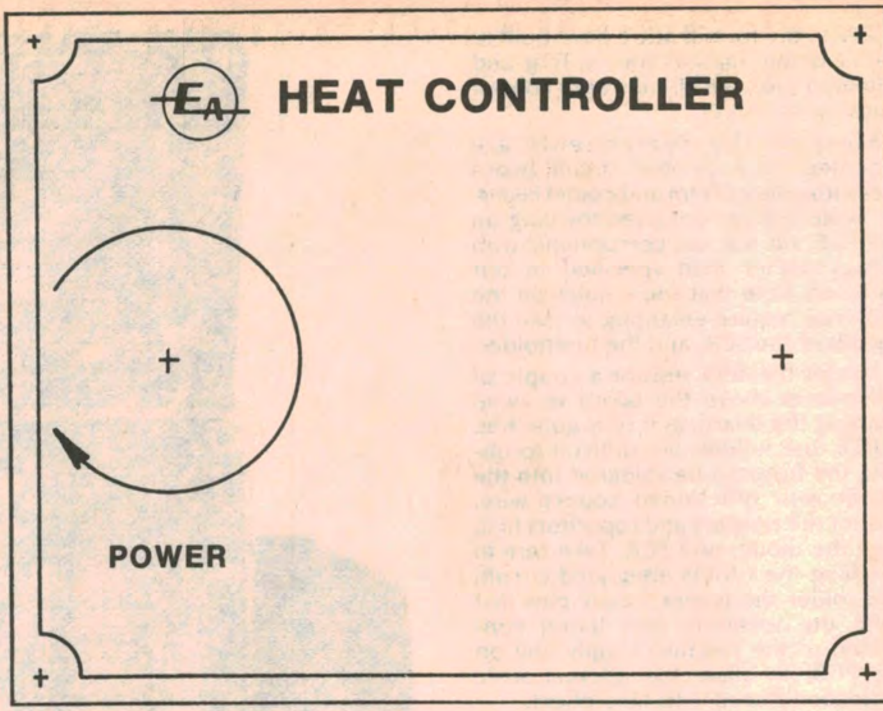
HEAT CONTROLLER

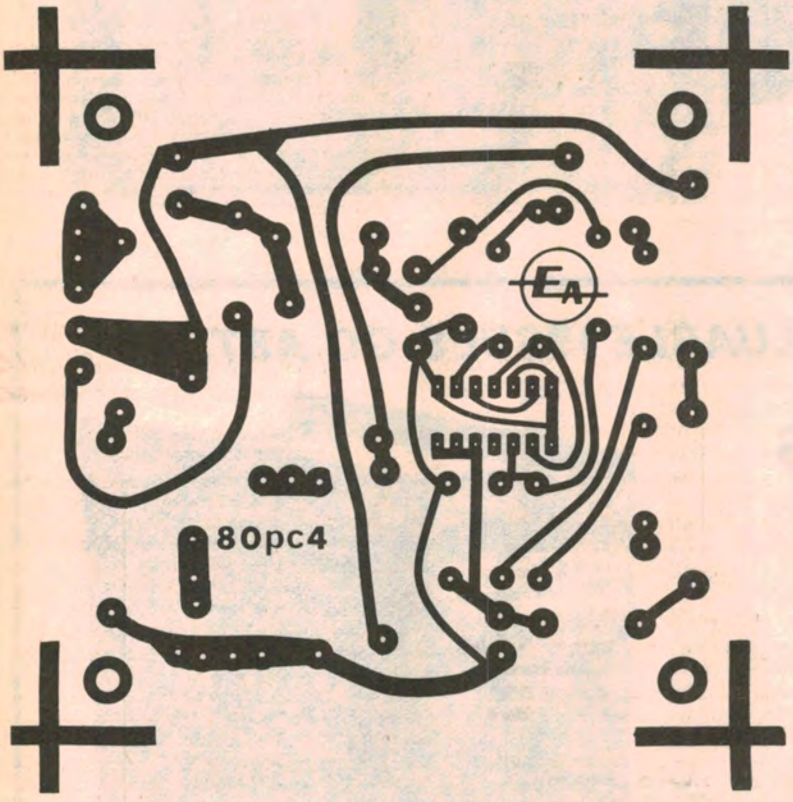
the neon, respectively. It is important to use grommets for the mains cord and the wires passing through the case from the externally mounted mains socket. The neon bezel should be mounted on the lid of the box, clear of the Triac end of the printed circuit board.

The earth lug should be secured to the case with a nut, bolt and lock washer. The green or green/yellow wire from the mains cord and the wire from the earth pin of the mains socket must be connected to the earth lug and be securely soldered at this point.

MOST IMPORTANT

The most important aspect of the construction procedure is mounting the Triac. The heat sink tab of the Triac is at mains potential, and must be insulated from the box. Fig. 3 shows the correct method of mounting the Triac. We used two mica washers with heat sinking compound on each surface. The hole for the mounting screw must be deburred to keep the heatsink surface flat and to prevent possible "punch-through". Check the insulation with a meter. Attempting to operate the controller with faulty insulation will blow the fuse.





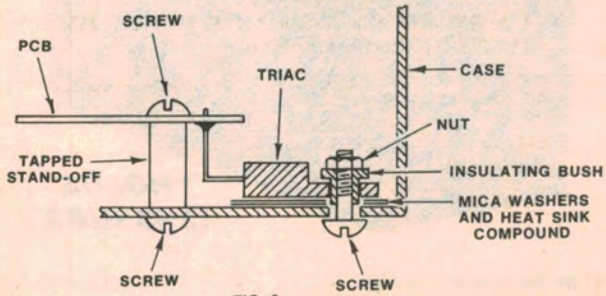


FIG. 3

Shown on this page is the artwork for the front panel and printed circuit board. Fig. 3, at left, shows the Triac mounting details.

When construction is complete, check the PCB board for component orientation and check the wiring for errors and shorts to the case. A meter is helpful here. With a fuse in place, the Heat Controller is ready to be used. Switching on the power should cause the neon to flash on and off, and adjusting the potentiometer should vary the ratio of on-time to off-time. Connecting a resistive load to the controller will allow heat control which is directly proportional to the duty cycle of the neon.

> We estimate that the current cost of parts for this project is approximately
>
> **$27**
>
> including sales tax.

Overall the Heat Controller works very effectively. No radio interference could be detected from our prototype. When driving a radiator, the heater bar could be seen to glow more strongly in time with each pulse of power, but the heat level remained steady. At half power the radiator bar did not glow but emitted a steady warmth.

Remember that, as presented here, the Heat Controller is only suitable for loads up to 1.2kW. Bigger loads can be accommodated by mounting the Triac on a better heat sink.