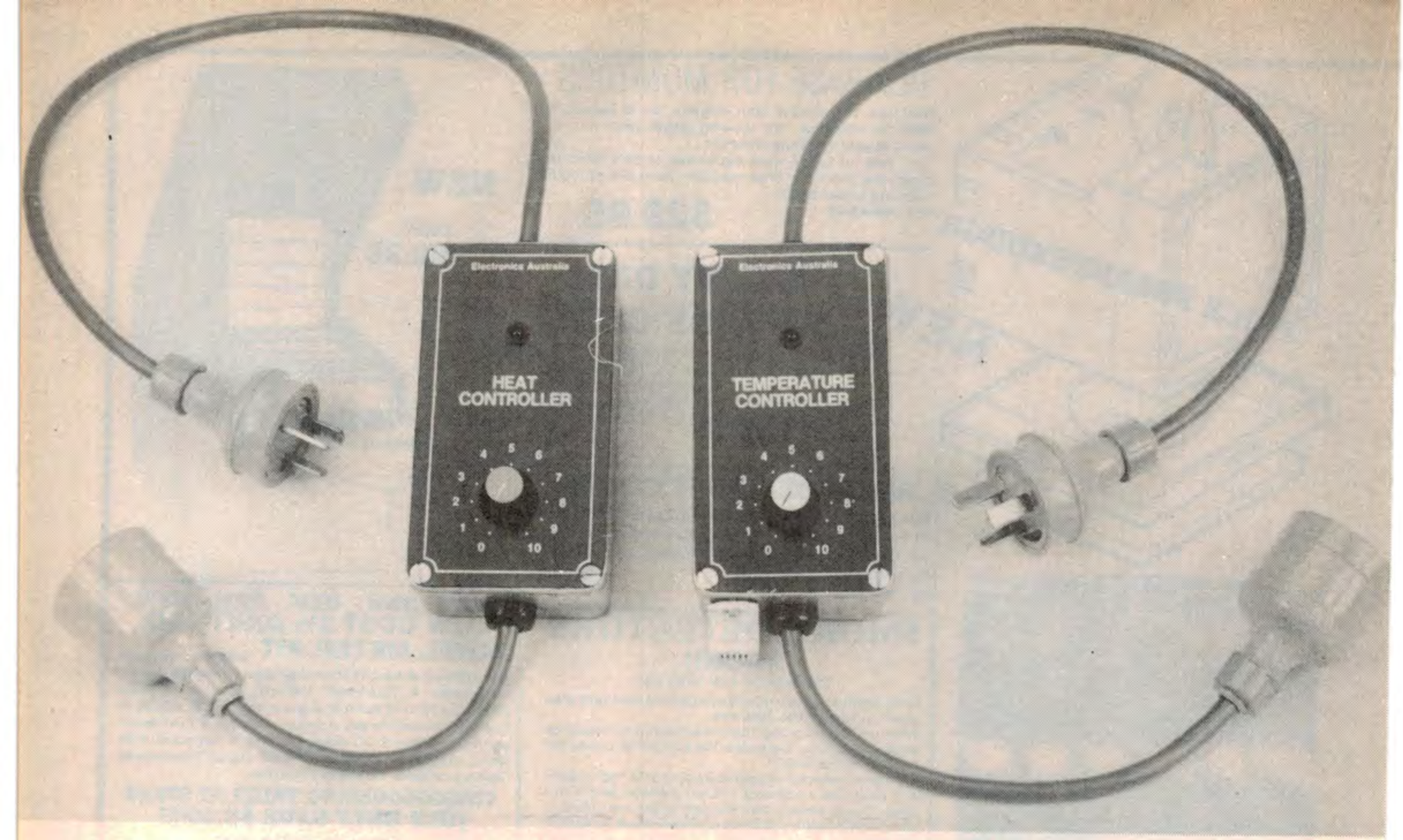


Save power: build these Heat Controllers

Winter is here and with it the problem of keeping warm without sending the power bill soaring. These new heat controllers can reduce the average power delivered to a heater and save you money.

by JOHN CLARKE

Two versions of this project will be described, one manually controlled and the other thermostatically controlled. The first version is designated as the "Heat Controller" while the thermostatically controlled version is called a "Temperature Controller". Both employ zero-voltage switching techniques to minimise radio frequency interference (RFI), and are capable of controlling loads up to 1200W.

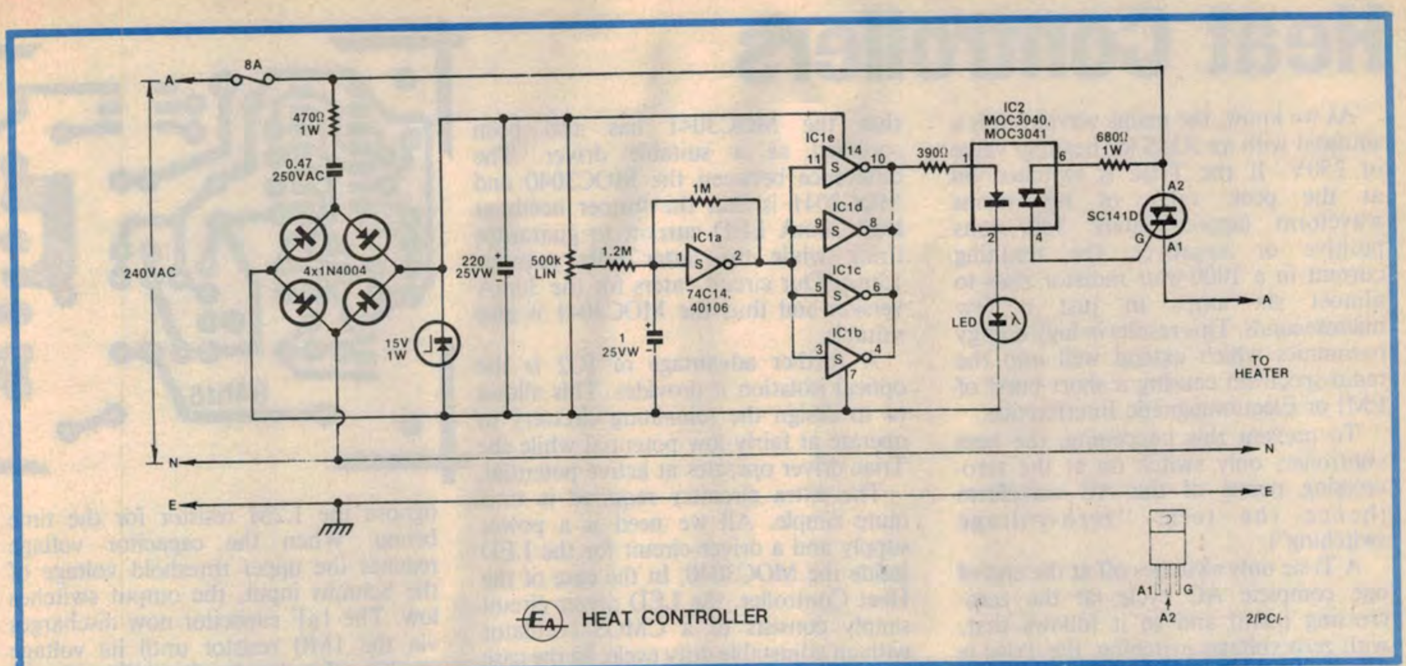
By far the most common application for heat controllers is with using electric radiators. Place a bar radiator, even a small 1000W type, in an average-size room and in a short time the temperature will become stiflingly hot. The heat can only be controlled by opening a window, (a wasteful approach) or by switching the radiator off.

This is where a heat controller is useful. It can supply power to the radiator in short bursts so that the room stays warm without becoming too hot.

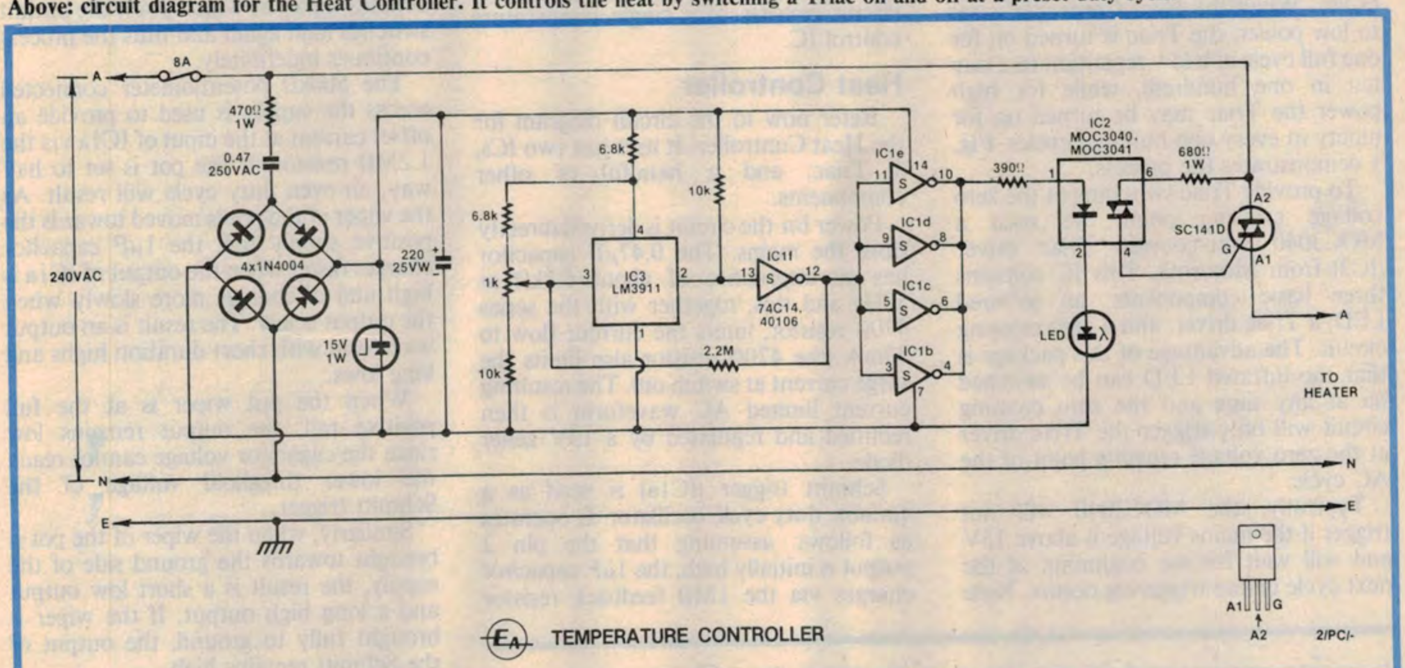
Similarly, a heat controller can be used with vertical grillers which have no built-in heat control. Normally, the only way the cooking temperature of these can be controlled is to open the side covers to release the heat — a very wasteful and imprecise method.

Then there are the many electric blankets which only have coarse three-position control. No matter what you do, the setting is always either too hot or too cool. A heat controller can provide a continuously variable setting so that the user can select just the right amount of warmth.

Although the two units employ similar circuits, they differ somewhat in their operation. The manual version (the Heat Controller) simply controls the duty cycle of "heat-on" to "heat-off". This can be adjusted using a rotary control knob from fully on to fully off, with continuously variable heat settings between these two extremes. Obviously, the setting does not directly relate to a particular temperature but to a percentage of the total power supplied to the heater.



Above: circuit diagram for the Heat Controller. It controls the heat by switching a Triac on and off at a preset duty cycle.



The Temperature Controller. IC3 switches the Triac on or off according to room temperature.

While the Heat Controller is suitable for all of the above applications, the Temperature Controller is the more practical for room temperature control. Basically, it automatically controls the radiator so that the temperature is kept to within a few degrees of a preset level. It does this by switching off the supply when the temperature reaches a preset level. When the room cools, it switches the radiator on again.

Similarly, the Temperature Controller can also be used to automatically switch on an electric blanket should the room temperature drop below a preset level, or off if the room temperature rises.

Physically, each unit is an in-line device housed in a small metal diecast case. Mains leads exit from each end of the case and are fitted with a three pin plug on one lead and a socket on the other. A knob on the lid provides the temperature control while a LED indicates whether the heater is switched on or off.

The Temperature Controller also has a small plastic housing mounted on one end of the case. This encloses an LM3911 temperature controller IC and serves to expose the IC, which is potentially at mains voltage, to the ambient air. At the same time, it isolates the IC from the case and this is important since the latter is prone to heating by the control circuitry.

How it works

Basically, both units contain a Triac, which can be considered as an electronic switch, and this is triggered to power the heater. In the case of the Heat Controller, the Triac is switched on and off at a preset duty cycle while the Temperature Controller switches the Triac on when the temperature is below a set level and off when the temperature rises above this level (although there is some hysteresis).

Heat Controllers

As we know, the mains waveform is a sinusoid with an RMS (or heating) value of 250V. If the Triac is switched on 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 microseconds. This results in high energy harmonics which extend well into the radio spectrum causing a short burst of EMI or Electromagnetic Interference.

To prevent this happening, the heat controllers only switch on at the zero-crossing points of the AC waveform (hence the term "zero-voltage switching").

A Triac only switches off at the end of one complete AC cycle (at the zero-crossing point) and so it follows that, with zero voltage switching, the Triac is turned on for integral numbers of AC cycles. When the Heat Controller is set to low power, the Triac is turned on for one full cycle at a low repetition rate (say ten in one hundred), while for high power the Triac may be turned on for ninety in every one hundred cycles. Fig. 1 demonstrates the process.

To provide Triac switching at the zero voltage crossing point, we used a MOC3040 opto-coupled Triac driver (IC2) from Motorola. This IC contains three basic components: an infrared LED, a Triac driver, and a zero crossing circuit. The advantage of this package is that the infrared LED can be switched on at any time and the zero crossing circuit will only trigger the Triac driver at the zero voltage crossing point of the AC cycle.

Typically, the MOC3040 will not trigger if the mains voltage is above 15V and will wait for the beginning of the next cycle before triggering occurs. Note that the MOC3041 has also been specified as a suitable driver. The difference between the MOC3040 and MOC3041 is that the former needs at least 30mA LED current to guarantee firing while the latter only requires 15mA. Our circuit caters for the 30mA version and thus the MOC3041 is also suitable.

A further advantage of IC2 is the optical isolation it provides. This allows us to design the remaining circuitry to operate at fairly low potential while the Triac driver operates at active potential.

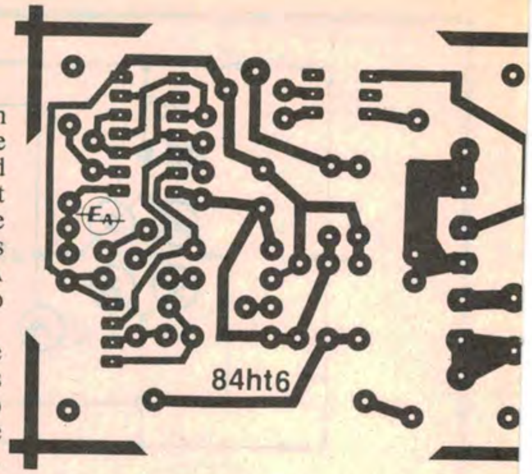
The extra circuitry required is thus quite simple. All we need is a power supply and a driver circuit for the LED inside the MOC3040. In the case of the Heat Controller, the LED driver circuit simply consists of a CMOS oscillator with an adjustable duty cycle. In the case of the Temperature controller, the driver circuit consists of a single temperature control IC.

Heat Controller

Refer now to the circuit diagram for the Heat Controller. It uses just two ICs, a Triac, and a handful of other components.

Power for the circuit is derived directly from the mains. The 0.47μF capacitor has an impedance of about 6.8kΩ at 50Hz and this, together with the series 470Ω resistor, limits the current flow to 33mA (the 470Ω resistor also limits the surge current at switch on). The resulting current limited AC waveform is then rectified and regulated by a 15V zener diode.

Schmitt trigger (IC1a) is used as a variable duty cycle oscillator. It operates as follows: assuming that the pin 2 output is initially high, the 1μF capacitor charges via the 1MΩ feedback resistor



(ignore the 1.2M resistor for the time being). When the capacitor voltage reaches the upper threshold voltage of the Schmitt input, the output switches low. The 1μF capacitor now discharges via the 1MΩ resistor until its voltage reaches the lower threshold of the Schmitt input, at which point the output switches high again and thus the process continues indefinitely.

The 500kΩ potentiometer connected across the supply is used to provide an offset current at the input of IC1a via the 1.2MΩ resistor. If the pot is set to half way, an even duty cycle will result. As the wiper of the pot is moved towards the positive supply rail, the 1μF capacitor charges faster when the output of IC1a is high and discharges more slowly when the output is low. The result is an output waveform with short duration highs and long lows.

When the pot wiper is at the full positive rail, the output remains low since the capacitor voltage cannot reach the lower threshold voltage of the Schmitt trigger.

Similarly, when the wiper of the pot is brought towards the ground side of the supply, the result is a short low output and a long high output. If the wiper is brought fully to ground, the output of the Schmitt remains high.

The 500kΩ potentiometer therefore varies the oscillator duty cycle and provides a range between a permanently high Schmitt trigger output to a permanently low ouput.

The output of the Schmitt trigger oscillator is buffered by paralleled Schmitt inverters IC1b-IC1e, which together supply the necessary 30mA LED current for the MOC3040. An external LED connected in series with the MOC3040 LED indicates when the IC is firing the Triac.

When the Triac driver is activated, current flows between the gate and A2 of the mains switching Triac (SC141D) via a 680Ω 1W resistor. A 1W resistor is necessary for its 400V rating, although the actual dissipation is less than ¼W.

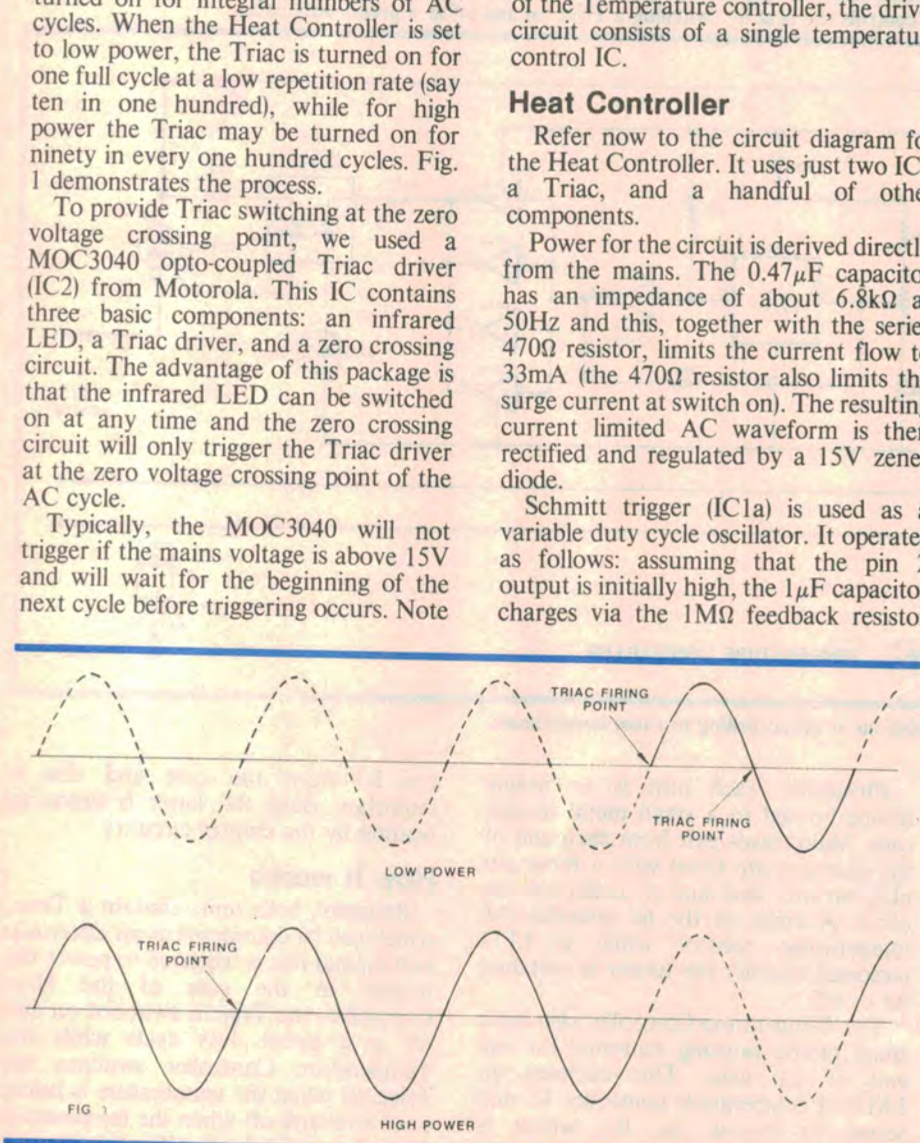
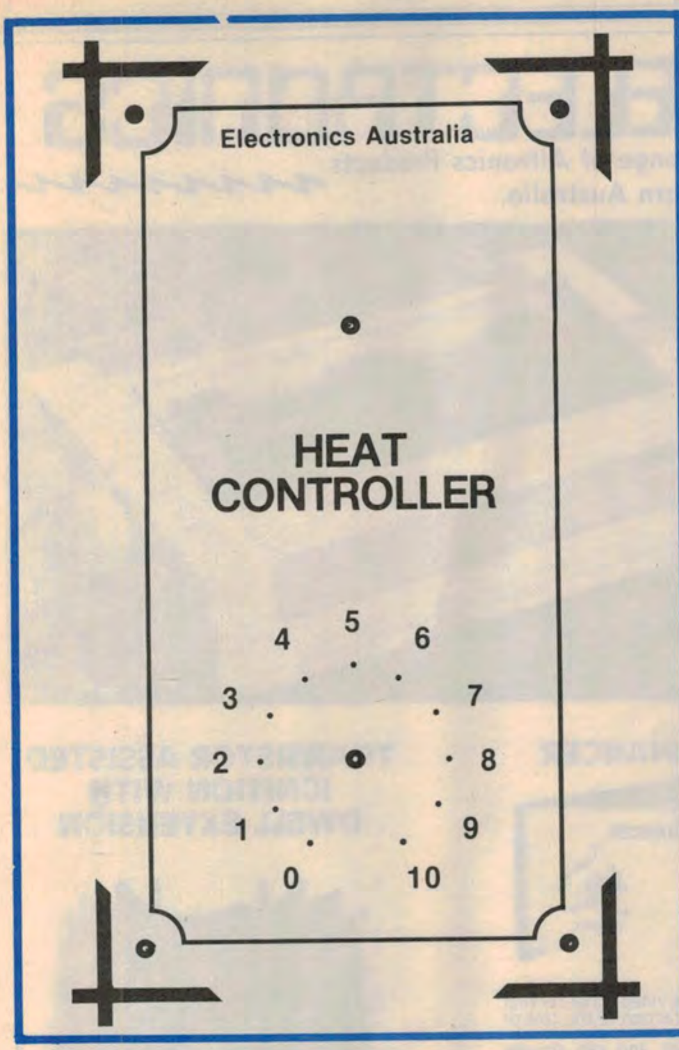
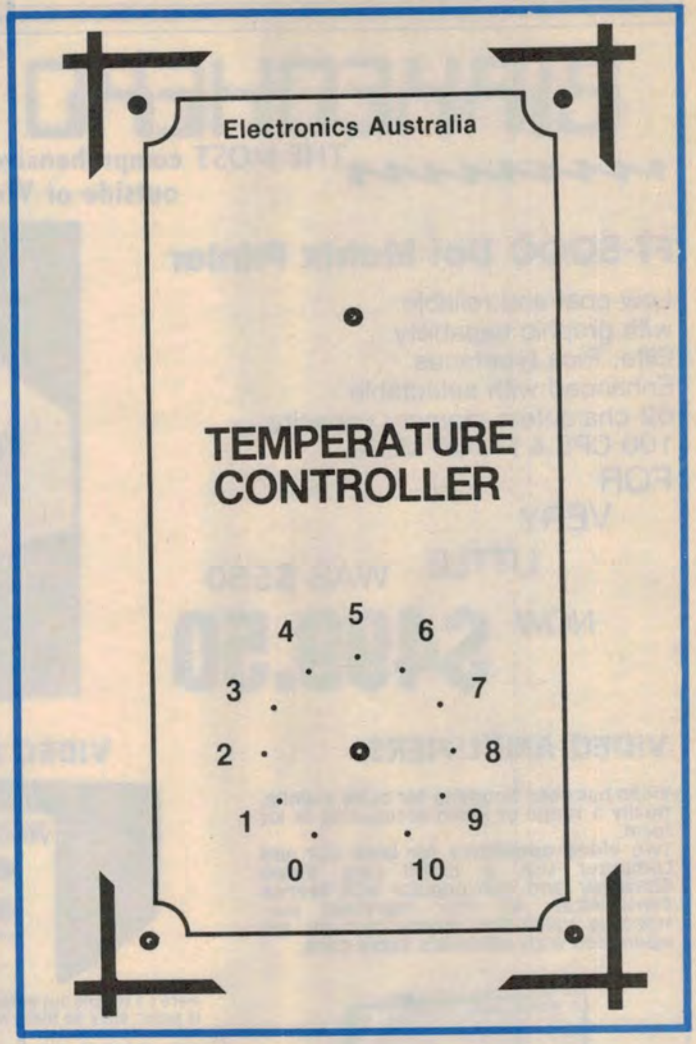


FIG 1

How zero-voltage switching works. The Triac turns on and off at the zero-voltage crossing points.





Heat Controllers

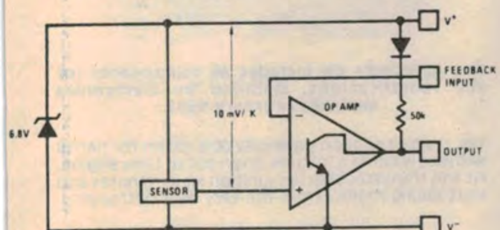


Fig. 2: block diagram of the LM3911 temperature controller IC.

Temperature Controller

The Temperature Controller circuit incorporates most of the circuitry of the Heat Controller, the main exception being the Schmitt trigger oscillator. The additional circuitry comprises inverter IC1f, temperature controller IC3, and a few associated components.

IC3 is a National Semiconductor temperature controller IC designated the LM3911. It supplies an output voltage of 10mV/degree Kelvin. Internally, it consists of a temperature sensor, an operational amplifier and a stable voltage reference (see Fig. 2). The internal op amp is used as a comparator which changes state when the temperature reaches a preset point.

The voltage at the input, pin 3, determines the temperature at which the comparator changes state. If the voltage at pin 3 is 2.73V negative with respect to pin 4, then the comparator output will be low for temperatures above 0°C and high for remperatures below this. For each 10mV change on pin 3, the triggering point for the comparator changes by 1°C. For example, 2.98V on pin 3 will switch the comparator at 25°C.

A 1kΩ potentiometer is used to vary the voltage on pin 3 (so that the temperature can be set), while the 6.8kΩ and 10kΩ resistors limit the voltage swing from about 2.66 to 3.13V. The 6.8kΩ resistor from pin 4 to the 15V supply is for current limiting the internal voltage reference.

The comparator output is open collector and so a 10kΩ resistor is necessary to pull up the output to the full 15V rail when pin 2 is high. IC1f inverts the comparator output to provide the correct logic sense while the 2.2MΩ feedback resistor provides a small amount (about 4°C) of hysteresis. This is necessary to prevent oscillation at the trigger point and means that, in practice, the temperature will vary over a 4°C range.

The remainder of the circuit functions in exactly the same manner as the Heat Controller, with the output of IC1f driving buffers IC1b-IC1e. These in turn drive the MOC3040 optocoupler and the SC141D Triac.

Construction

Assembly is straightforward but take care with the mains wiring to ensure personal safety. The printed circuit board used is the same for both circuits and is coded 84ht6 (66 x 54mm). This is mounted inside a metal diecast case (65 x 120 x 40mm), to which is fitted a Scotchcal front panel.

Begin by installing the parts on the PCB according to the appropriate layout diagram. Fit PC stakes to the external wiring points and make sure that you install the polarised components correctly. The Triac is mounted on the

Heat Controllers

copper side of the PCB so that it can be bolted to the bottom of the case for heatsinking.

Fig. 3 shows the Triac mounting details. Bend the leads at right angles, close to the Triac body, then mount the device so that its bottom surface is exactly 6mm below the bottom surface of the PCB. Do not trim the Triac leads at this stage as some adjustment may be necessary later on.

Work can now begin on the diecast case. Spray the Scotchcal label with a clear lacquer, then carefully affix it to the front panel. The case can now be drilled to accept the various parts using the wiring diagram and the Scotchcal label as a guide. Deburr all holes before mounting the hardware and check that the Triac mounting hole is free of metal swarf.

The Triac must be isolated from the case using two mica washers and an insulating bush. Temporarily position the PCB on 6mm spacers inside the case and check that the Triac body lies flat against the bottom of the case. When everything is correct, smear both sides of the mica washers with heatsink compound and bolt the Triac to the case using a machine screw and nut (Fig. 3).

It is a good idea to use a multimeter to check that the Triac is indeed isolated from the case. If the meter registers a short circuit, remove the PCB assembly and locate the fault before proceeding.

The temperature sensor IC (Temperature Controller only) is mounted inside a small plastic case scrounged from an electronic buzzer. The buzzer mechanism and the plastic film are both removed and the IC affixed

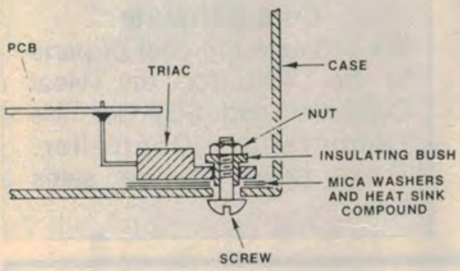
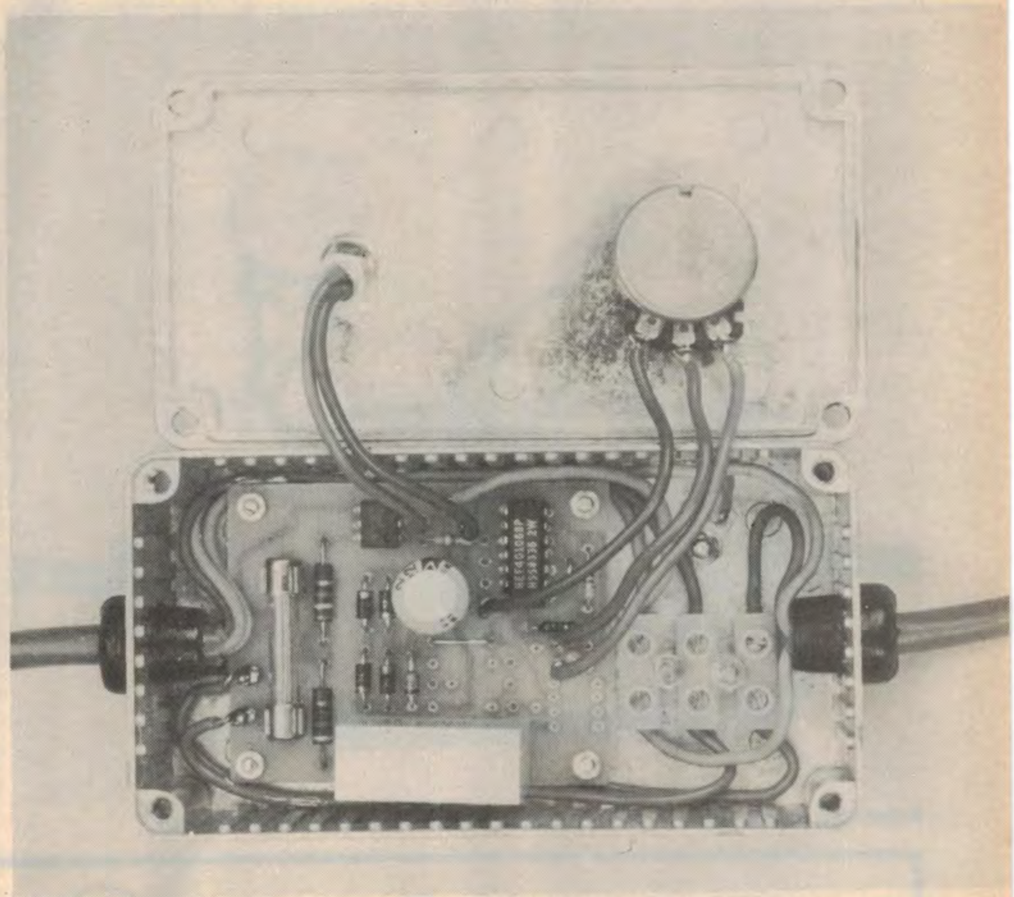
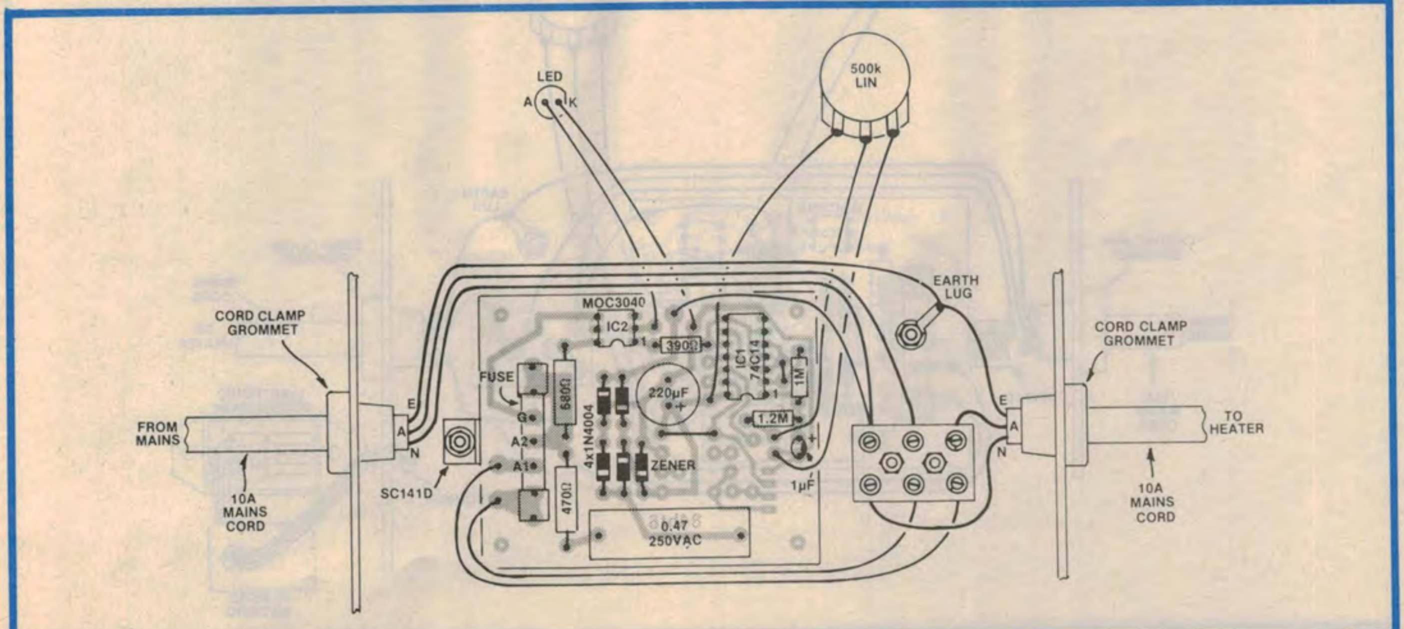


Fig. 3: Triac mounting details. The Triac must be fully insulated from the case.



Above is a view inside the Heat Controller while below is the wiring diagram.



to the grill inside the case using epoxy resin. Mount the IC off centre so that pins 1-4 are not accessible from outside the case, as these pins can float at mains potential.

The remaining four pins are not electrically connected and so are quite safe.

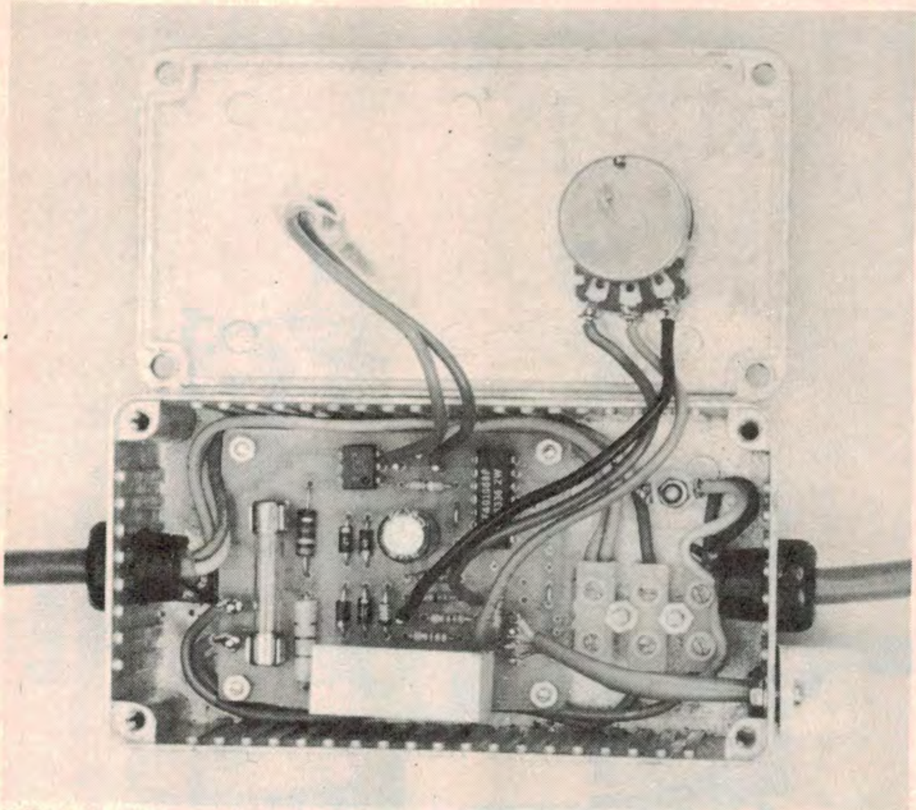
Note that all internal wiring except for the leads to the temperature sensor should be run using mains rated cable. The four leads to the temperature sensor are run using rainbow cable and should all be sheathed in plastic tubing.

Take care with the mains wiring and make sure that you wire the plug and socket correctly. The brown lead goes to the active pin, the blue wire to the neutral pin, and the green/yellow wire to the earth pin. Lead length will depend upon the application but, as a guide, we used a 750mm length for the plug lead and a 250mm length for the socket lead.

Testing

Testing involves little more than plugging the unit into a mains outlet and applying power. In the case of the Heat Controller, the indicating LED should flash on and off with a duty cycle determined by the setting of the control knob. On the Temperature Controller, the LED should come on at a certain position as the control knob is advanced and extinguish when the control is turned back a few degrees from this position.

Just one final point. While these units have been rated for 1200W they can handle higher loads provided there is adequate heatsinking for the Triac. In practice, this means building the unit into a larger diecast case and increasing



Follow this photograph and wiring diagram to build the Temperature Controller.

Cost Estimate

We estimate the cost of parts to be $33 for the Heat Controller and $37 for the Temperature Controller. These prices include sales tax.