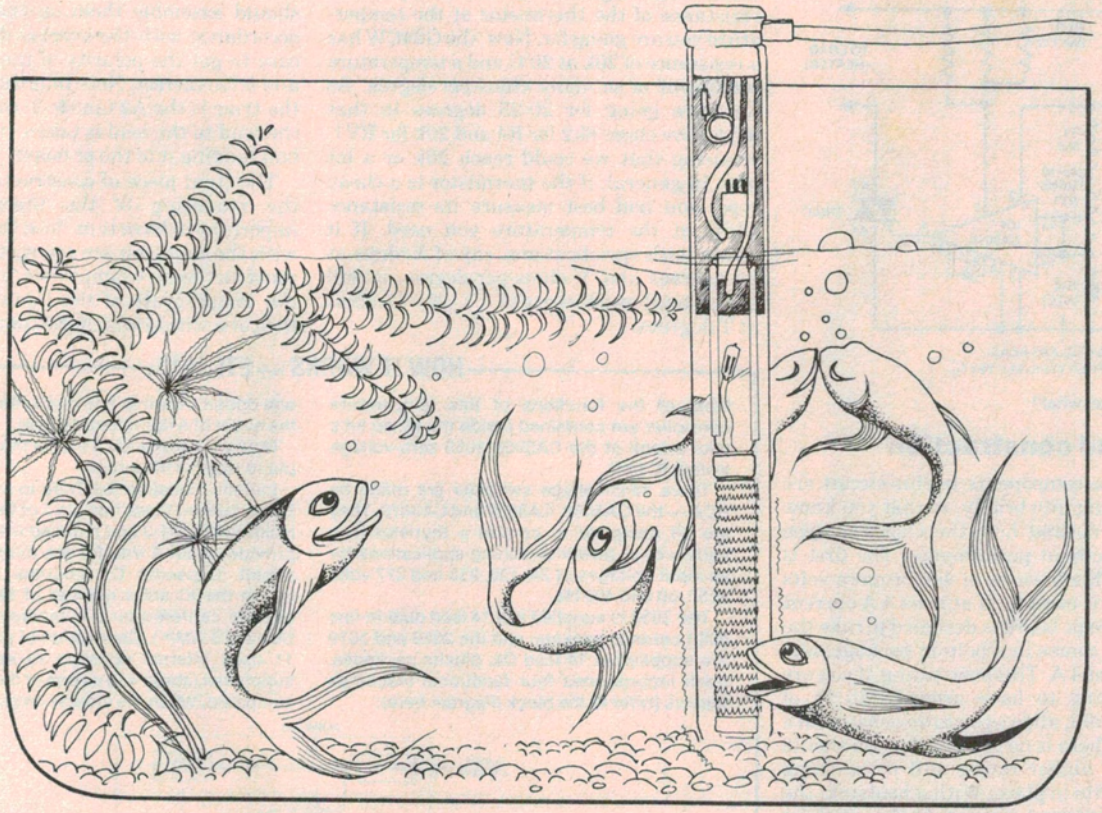


Immersible temperature controller features zero-crossing ac control

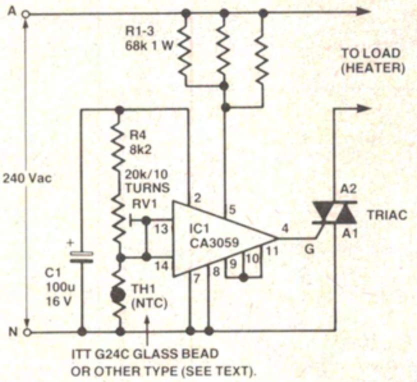
This simple to construct project has done sterling service as a temperature controller in a common fish tank heater but has wide application. It features a zero-crossing switch type controller to prevent RF interference to other appliances.

Jonathan Scott

IF THIS PROJECT did not run directly on 240 volts we would call it a simple project. It contains only one IC, a triac and very little else, yet it is a full zero-crossing switch system capable of controlling up to 1500 watts of heating power that may be employed to regulate the temperature of a room, a fish tank or a bowl of yoghurt-in-the-making. The latter two tasks are those for which it was first dreamed-up, but more ideas come to the mind the longer you think about it. The fact that it is a zero-crossing switch (see the panel on page 31) rather than a proportional phase control means that it will not generate any RF noise — no clicks or pops in the hi-fi, no buzzes or hums in radios.

The fact that it is quite small (it requires no heatsink for loads of 200 watts or less) makes it possible to include it in the innards of the heating device. For instance, we built one inside the narrow glass tube of an aquarium heater. It is cheap to build as it requires no transformer or mechanical relay mechanism. It can be adjusted to regulate to any temperature that the sensor can stand. In our case we wanted to regulate to a temperature in the 25-30°C region, but the unit will regulate over quite a wide range of temperatures with the correct resistor values, provided the pc board is not cooked along with the thing you are heating. This means of course, that the pc board and triac must be separated if you want to go over about 50°C or so. Varying things is covered later.

At this point, let us stress that the pc board *is operating at live mains potential* as the IC is designed to run directly on the mains without transformer isolation, so *be careful.* You should never touch any of the components while the circuit is plugged in, nor try to adjust the setpoint preset pot. Exercise extreme care when installing the circuit and ensure that it is mounted securely in a place where it is sealed away from prying fingers and poking utensils. While no less safe than the ordinary mains connection in whatever appliance you are using it with, it is significantly more tempting to approach this little fellow with a screwdriver or pair of pliers, so do try not to cost ETI any readers, especially yourself or your family. ▶



Circuit. Simple, what?

Parts and construction

Three of the components in this circuit are worth delving into briefly, so that you know what they do and how the choice of type affects the circuit performance. The first is the triac. This must be of 400 or more volts rating, and it must be of at least 4 A current rating as the pc board is designed to take the type which comes in a bolt-on package, and these start at 4 A. This over-rating, if you are only planning to have around 150 W of heater, as I did, allows you to dispense with a heatsink. There is no reason why you should not have a higher rating still if the thing physically fits in place. With a heatsink, the type we found most common at the suppliers (and used) is rated at 6 A and will thus run up to 1500 watts (6 A x 250 volts) of load.

The IC we have specified is a type CA3059, from RCA (distributed by AWA Microelectronics). There are three ZCS ICs available, one slightly more expensive which offers tighter specifications, of no use to us here. The other one, a CA3079, lacks a facility which is incorporated in the 3059, the device specified. This device has an 'automatic switch-off' facility for the heating element in the event that the temperature sensing thermistor goes either open circuit or short circuit. This means that if the connections to the sensor or the sensor itself fail, the system will not turn the heater on and overheat the controlled object. This adds a dollar or two to the price, but is quite worthwhile. The 3079 device must not be used in this circuit.

The thermistor you use will depend upon how much you wish to pay, how robust a component you need, and how you wish to connect it thermally to the load, as well as the temperature you are going for. We used both a cheap bead type, and an ITT G24CW. The latter is a small, but strong, glass bead type with a wide temperature range — but a $10-plus price tag! The G24CW is a professional type, but reliable and predictable. As we pointed out above, a failure of the thermistor is not likely to cause anything but a cooling of the load, so unless you are willing to pay the price and need the reliability, use a cheap type. It is only necessary to have a resistance of 10k to 60k at the regulated temperature. We used a type having a resistance of 47k at 20°C, costing $1 to $2 at a local supplier.

Once you have obtained the thermistor, it is necessary to select R4 and RV1 to suit. These must together be able to equal the resistance of the thermistor at the temperature you are going for. Now, the G24CW has a resistance of 20k at 20°C and a temperature coefficient of so many ohms-per-degree. As we were going for 20-25 degrees in that model, we chose 8k2 for R4 and 20k for RV1, ensuring that we could reach 20k or a bit less. In general, if the thermistor is a cheap type, you had best measure its resistance while at the temperature you need. If it comes with specifications, say of X ohms at 20 degrees and Y ohms-per-degree, it will have a total resistance of (X + Y (20 − T)) ohms at T degrees.

So, having selected these components, you should assemble them on the pc board in accordance with the overlay diagram. Take care to get the polarity of the IC, capacitor and triac correct. Note that the metal flag of the triac is the A2 (anode 2) connection, and the lead to the load is taken via a lug on the bolt holding it to the pc board.

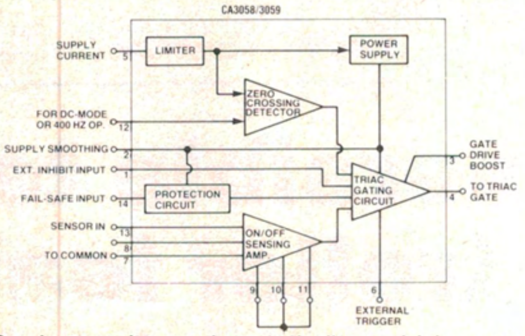
The final piece of constructional detail is the mounting of the thermistor. It is important to have it in close thermal contact with the item you are trying to heat. In our constructional example we are regulating the temperature of the liquid surrounding the tube within which the controller and the

HOW IT WORKS — ETI-1511

Most of the functions of this temperature controller are contained inside the IC, so let's take a look at the CA3058/3059 zero-voltage switch IC first.

Three zero-voltage switches are made by RCA — the CA3058, CA3059 and CA3079. They are all designed to control a thyristor in a variety of ac power switching applications for ac input voltages of 24, 120, 230 and 277 volts at 50, 60 and 400 Hz.

The 3058 is supplied in a 14 lead dual-in-line (DIL) ceramic package and the 3059 and 3079 are supplied in 14 lead DIL plastic packages. Each incorporates four functional blocks as follows (refer to the block diagram here):



1. Limiter-Power Supply — permits operation directly from an ac line.
2. Directional On/Off Sensing Amplifier — tests the condition of external sensors or command signals. Hysteresis or proportional-control capability may easily be implemented in this section.
3. Zero-Crossing Detector — synchronises the output pulses of the circuit at the time when the ac cycle is at zero voltage point; thereby eliminating radio-frequency interference (RFI) when used with resistive loads.
4. Triac Gating Circuit — provides high-current pulses to the gate of the power controlling thyristor.

In addition, the CA3058 and CA3059 provide the following important auxiliary functions:
1. A built-in protection circuit that may be actuated to remove drive from the triac if the sensor opens or shorts.
2. Thyristor firing may be inhibited through the action of an internal diode gate connected to Terminal 1.
3. High power dc comparator operation is provided by overriding the action of the zero-crossing detector. This is accomplished by connecting Terminal 12 to Terminal 7. Gate current to the thyristor is continuous when Terminal 13 is positive with respect to Terminal 9.

Because the CA3079 does not incorporate the built-in protection circuit, the CA3058 or CA3059 have been specified for this project. If the project is used to control a fish tank heater, one doesn't want to boil one's finny friends in the event of a thermistor failure!

Now we know what's inside the IC, how is it put to work in the circuit?

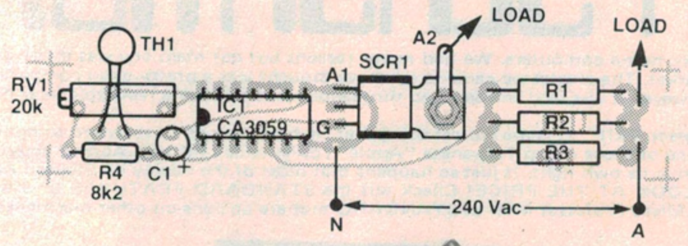
Initially, consider the Triac to be turned off. Some current flows into pin 5 of the IC and this is limited by R1-3 and rectified within the IC to provide about 8 Vdc for the operation of the circuit. Capacitor C1 smooths this supply. Inside the IC are a number of separate sub-circuits centered on a comparator ('ON/OFF SENSING AMP'). Connection of pins 9, 10 and 11 uses internal resistors to establish half supply rail (about 4 V) as one of the levels to be compared. When the voltage on pin 13 exceeds half rail potential the comparator activates a circuit which turns the triac on at the next supply zero, and each subsequent zero until the voltage falls below half rail.

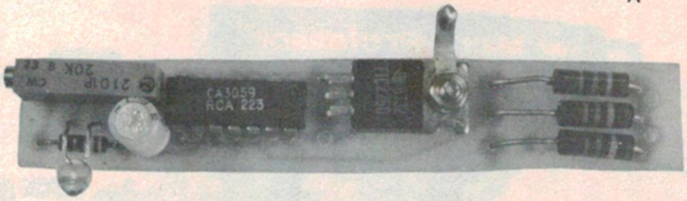
Clearly then, RV1/R4 must be selected so that they add up to the resistance of the sensing thermistor at the temperature for which it is desired to regulate. Thus, when the temperature reaches the preset point, the voltage across TH1 corresponds to half rail potential on pin 13.

Pin 14 allows the protection circuit to detect when TH1 goes either open circuit or short circuit by looking at the voltage at the junction of R4 and TH1. If this voltage nears the dc supply rail or the local common (N), there has been a failure, and the firing of the triac is inhibited until the condition is removed.

The supply dropping resistors R1-3 are used instead of a single resistor purely for size considerations. All that is required is that they deliver 10 to 50 milliamps to the IC's rectifier-regulator.

The sensing thermistor must be a negative temperature coefficient type (NTC), as its resistance must drop with increasing temperature in order to reduce the voltage on pin 13 as the temperature is brought towards the setpoint. There is sufficient excess supply current to allow it to draw at least one milliamp if necessary. Thus, any of the common small bead types with a few kilohms of resistance at the setpoint may be used. The total permissable sensor resistance range is 2k to 100k.



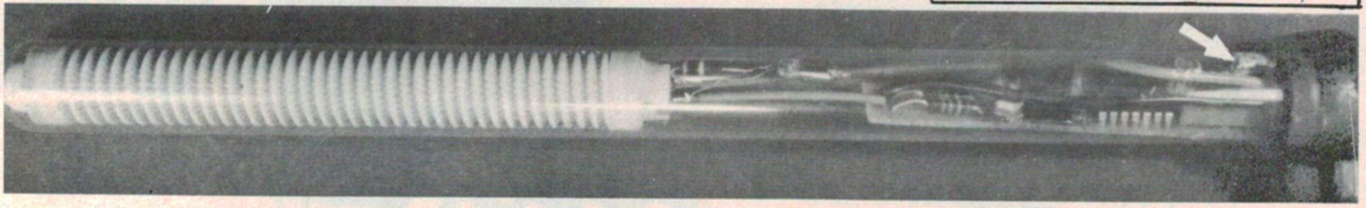


PARTS LIST — ETI-1511

Resistors	all ½ W, 5% unless noted
R1, 2, 3	68k, 1 W
R4	8k2 (see text)
RV1	20k, 10-turn trimpot
Capacitors	
C1	100u/16 V tant.
Semiconductors	
IC1	CA3059
SCR1	6A/400 V triac, e.g: TIC226D or similar
Miscellaneous	
TH1	thermistor to suit application, e.g: ITT G24C glass bead type (see text)

ETI-1511 pc board; solder lug; hookup wire; heating element, etc.

Price estimate **$14 — $16** (less element)



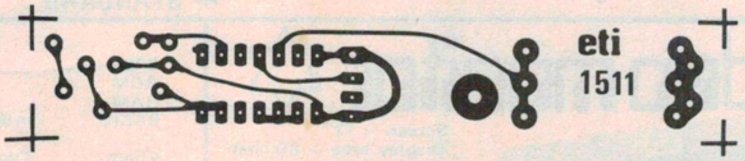
Naked and clothed. At top is the naked pc board (approx. life size) to compare with the component overlay. The lower picture shows the completed immersible temperature controller made from a common fish tank heater. The arrow shows the positioning of the thermistor sensor.

heater are immersed. It is thus only possible to regulate the tube temperature, as we cannot put the (live) sensor in the liquid. The sensor was pressed against the tube and seated in a blob of thermal compound of the type used for mounting transistors on their heatsinks. This meant that it was held at the temperature of the outside as much as possible, rather than at the temperature of the heater and controller themselves. In general, the limitation of keeping the sensor in the same container as the rest of the controller is the one responsible for the accuracy of the system. This method, used in small appliances and ordinary aquarium heaters, gives about two degrees accuracy if the liquid is well mixed and convects freely past the tube. Our controller, limited by the same problem, gives little improvement: the only advantage comes from the fact that the sensor is a small piece of solid which can be pressed to the glass firmly, whereas the mechanical (bi-metallic strip) type of temperature sensor cannot be so positioned. In a larger container it can be separated by some distance and placed wherever you need, and it will give fractional degree accuracy.

As the design of the housing is largely up to the individual constructor, there is very little to say about the physical makeup of the project. If you are copying the format shown in the pictures, assembly is rather straightforward. The only point to note is that you will have to take particular care to see that the tube is sealed against the accidental entry of liquid. Here, Silastic or a similar silicone sealant comes in very useful.

It is necessary to set the preset pot before sealing up the immersible tube. This is done by carefully setting the system up with water coming up to the point on the tube above where the sensor is located. Then, allow a couple hours of undisturbed operation and measure the liquid temperature with a thermometer. Adjust the preset pot (mains unplugged!) and repeat. If you measured the thermistor beforehand, while at the correct temperature, you can adjust the pot/R4 combination to give you that resistance straight away and there should be no need to make a second adjustment of the pot. If at some later stage you wish to change the set point, Silastic is easy to peel away and you can reseal the tube when the adjustment is made and checked.

We do not advise you to leave an access hole to permit adjustment of the pot because, firstly, someone might try and do that with the power on *(poof!)* or more likely the liquid will find a way of invading the tube and quietly ruining the components. ●



THE ZERO CROSSING SWITCH (ZCS) TECHNIQUE

In normal phase control switching the switching element, an SCR or Triac, is triggered into conduction at some time during each half cycle. The moment of switching is varied, so that the duration of the applied voltage pulse, which corresponds to the fraction of the cycle left at the point of triggering, is varied. This is a simple and direct method which does vary the applied power fairly smoothly (see Figure 1). Unfortunately, the sudden application of voltage tends to produce a lot of electromagnetic radiation due to the sudden current change in the load circuit. This is responsible for a lot of radio frequency interference, or RFI.

In ZCS the switching element is only allowed to change to the conducting state when the supply voltage is crossing the zero-voltage point — hence the name. This means that there are no sharp voltage transitions across the load, and so no RFI. The penalty paid is that only whole half cycles are applied to the load. The system is thus not readily applicable to lighting applications as the lights flicker badly due to the relatively long periods between conduction and isolation (see Figure 2).

For applications where the system has sufficient inertia, such as heating, this system is by far the superior technique. As the required functions are available within a single, relatively cheap, IC it is practicable to build a ZCS system with almost the same ease as a proportional system.

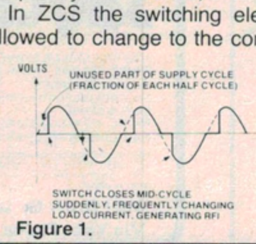


Figure 1.

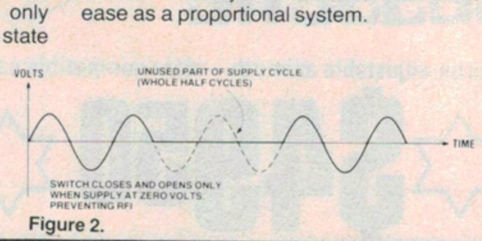


Figure 2.