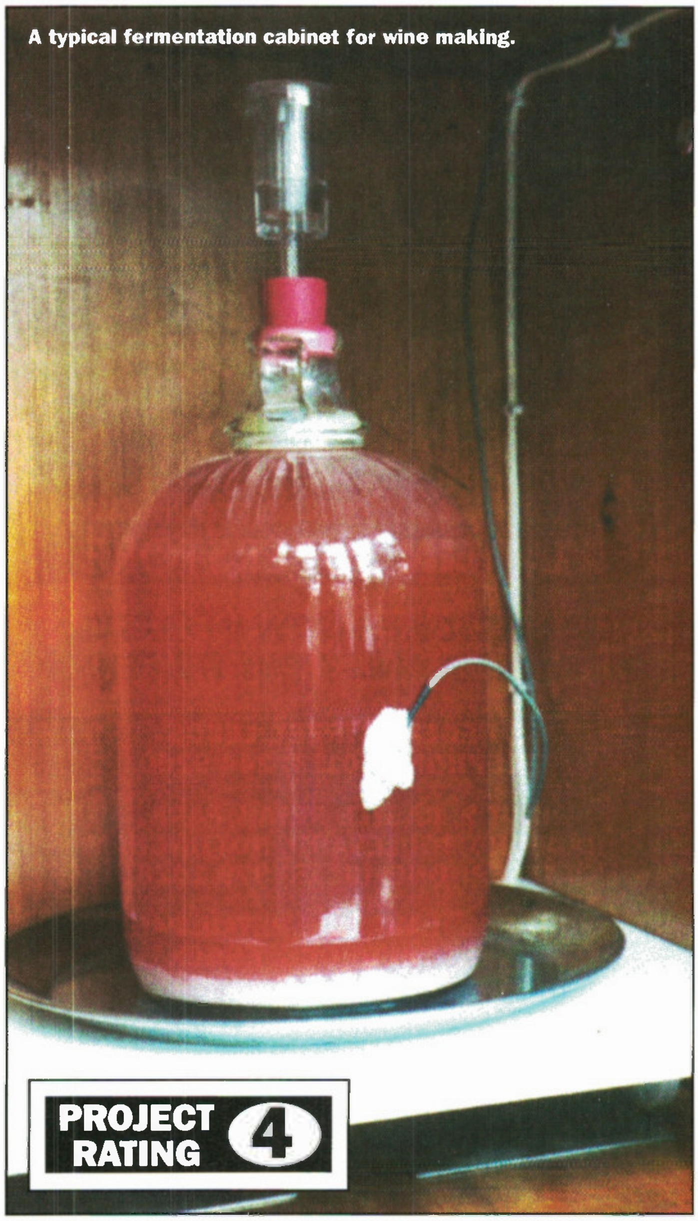
PROJECT

Heater TEMPERATURE CONTROLLER

by Raymond Lee BSc (Hons.)

The motivation for this project came from having been given some wine making equipment as a Christmas gift. In order that fermentation proceeds properly, the liquid needs to be maintained at a temperature of 20 to 25°C. Traditionally, many people use airing cupboards, but ours is small and often filled with clothes, and there is no certainty of temperature stability. The rest of the house in winter months is generally much cooler than the ideal range.



A typical fermentation cabinet for wine making.

As I enjoy woodwork as well as electronics, I built a cabinet large enough to hold a 2-gallon bucket, or 2 demijohns with airlocks side by side, on a shelf. Beneath the shelf is a space large enough to fit two batten lampholders with a pair of candle lamps which act as the heat source. I then required some control electronics to control the power to the lamps. This is the circuit that I devised to do the job.

The first prototype was built on stripboard mainly with components I had in stock, but I have subsequently designed a PCB layout, and the parts list includes all Maplin stock codes.

How it Works

Referring to the circuit diagram shown in Figure 1, IC1, a quad op-amp, provides the heart of the circuit, with IC1c driving the opto triac IC2, effectively acting

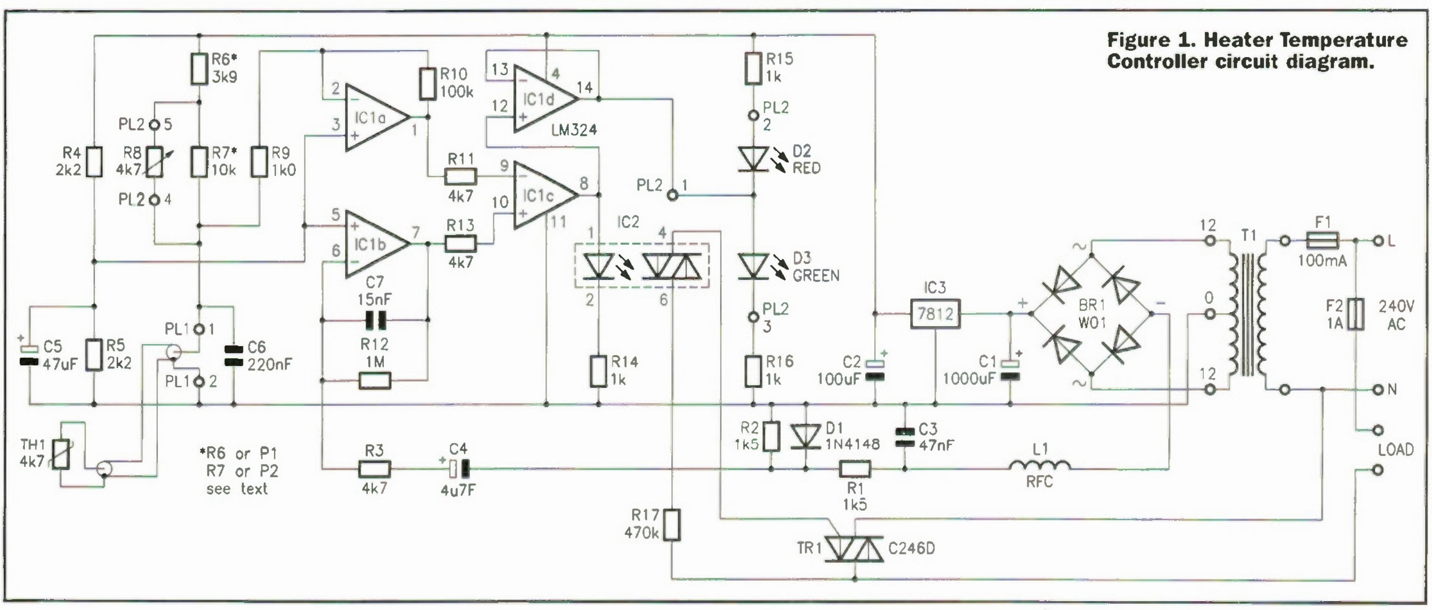


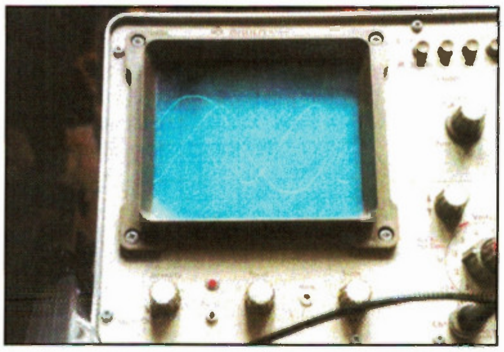
Figure 1. Heater Temperature Controller circuit diagram.

as a phase control lamp dimmer depending on temperature.

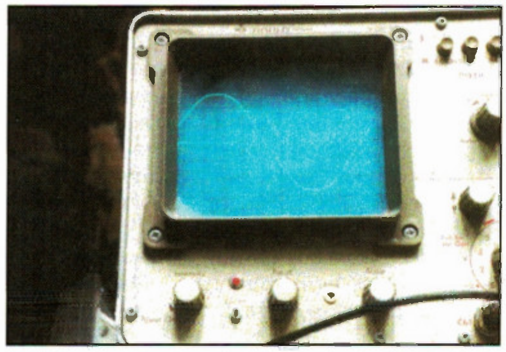
The transformer T1 feeds a conventional bridge rectifier but only the positive side is used to provide a DC supply, via the 12V regulator IC3. The negative side provides full-wave rectified sine waves, which pass first through an RF filter (L1 & C3) to remove any spikes and RF, then through a clipping circuit comprising R1, R2 and D1. The resulting waveform is a short duration positive-going pulse around the zero-crossing point of mains.

This pulse is passed via C4 to IC1b, which is arranged as an integrator, resistor R12 being present to provide a DC path so that the output waveform sits at mid rail. Resistors R4 & R5 and capacitor C5 provide a mid-rail reference for IC1a & 1b. IC1a is used as a bridge balance comparator. R6-8 form the upper arm of the bridge, TH1 the lower arm.

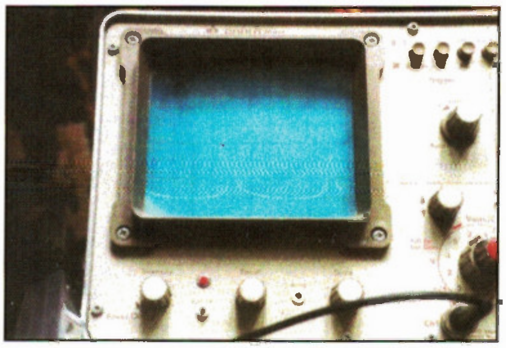
When the bridge is balanced, the output of IC1a is also at mid-rail. A very small increase in temperature will cause the output to go positive, IC1a having a voltage gain of 100. IC1c acts as a comparator, one input being fed with the 4V sawtooth waveform, the other with the DC level from the bridge amplifier. As the thermistor decreases in value (rise in temperature), so the point at which IC1c switches gets higher up the sawtooth, i.e., later in the mains waveform. If it gets too high, the output never changes so there is no drive to the opto triac. Conversely, if the temperature falls, the switching point gets earlier and if too cold, stays high giving a permanent drive to the opto triac. IC1d is a buffer to drive a visual indication of the state of balance, with a Green LED indicating on state and red indicating off state. In the control range, the relative brightness of the LEDs give an idea of the switching point, and hence, the amount of power being delivered.



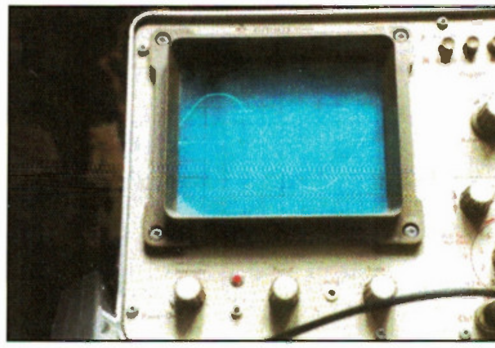
Oscilloscope traces showing output of IC1 pin 7, with mains reference waveform via 24V transformer, to show phase relationship (Y-scale=1V/cm, X-scale=2ms/cm).



Oscilloscope traces showing output of IC1 pin 8 – opto-isolator drive with load light bulbs glowing dimly, with mains reference waveform via 24V transformer (Y-scale=5V/cm, X-scale=2ms/cm).



Oscilloscope traces showing junction of R1, D1, R2, C4 (Y-scale=0·2V/cm), X-scale=2ms/cm).



Oscilloscope traces showing junction of L1, C3, R1 (Y-scale=5V/cm), X-scale=2ms/cm).

Temperature Range Calculation and Setting

The bridge circuit has an upper arm maximum with the values shown of 7k1, and a lower limit of 3k9 (4k7 in parallel with 10k = 3k2). The thermistor value is quoted at a temperature of 25°C (which is 298K), the value at other temperatures being given by the formula:

$$Rt_1 = Rt_2 \times e^{\left(\frac{B}{T_1} - \frac{B}{T_2}\right)}$$

Where B is the temperature coefficient, T1 and T2 the temperatures in Kelvin, and Rt1 and Rt2 the resistance of the thermistor at those temperatures.

Rearranging gives:
B for the 4k7 bead thermistor is 3,977, so:

$$\left(\frac{1}{T_1} - \frac{1}{T_2}\right) = \frac{\log_e\left(\frac{Rt_1}{Rt_2}\right)}{B}$$

Gives a minimum temperature of 16·1°C using the equation:

$$\frac{1}{T_{min}} = \frac{\log_e\left(\frac{7{\cdot}1}{4{\cdot}7}\right)}{3{,}977} + \frac{1}{298}$$

and a maximum temperature of 29·2°C using the equation:

$$\frac{1}{T_{max}} = \frac{\log_e\left(\frac{3{\cdot}9}{4{\cdot}7}\right)}{3{,}977} + \frac{1}{298}$$

The minimum and maximum as measured with the wine thermometer when calibrating were 17°C and 31°C respectively, which is quite close to the theoretical values. The difference is probably due to component tolerances.

Different temperature ranges could be obtained by altering the resistor values in the upper arm, although care should be exercised if the maximum is more than 30°C, due to internal dissipation in the thermistor, as at balance, it will always have 6V across it, and the power dissipated will rise in proportion to the square of the voltage. It may be preferable to use a higher value thermistor, e.g. 15k, if the circuit is to control to a higher temperature. The potentiometer and resistors around it would need to be altered accordingly.

A side effect of a resistor in parallel with a potentiometer is to make the scale non-linear, so ideally, choose a potentiometer closest to the value required to give the range needed, and then trim with a higher value resistor in parallel. If it was required to set the end limits to specific values to cover a precise temperature range, R6 & R7 could be replaced with trim potentiometers (P1 & P2). If only a single fixed temperature was required, the next lowest preferred value to the calculated value with a small trim potentiometer in series could be used in place of R6-8.

Construction

Figure 2 shows the PCB legend and track details. The prototype was constructed on a piece of stripboard cut to a suitable size to fit the plastic box, this being held in place by the plastic PC carrier strips supplied with the box. After drilling holes for the transformer such that it fitted at one end of the box, all the smaller components were fitted and wire links where required. N.B., all the strips around the opto triac were broken over two holes to provide adequate mains isolation. Warning: Mains electricity can be lethal, so double-check that there is no continuity to any other part of the circuit!

If using the optional box to house the controller, the corners of the circuit board will need to be carefully cut away to allow it to fit around the pillars which hold the lid. The circuit board is held in place in the box by PCB adaptors which clip to the board near the transformer, and slot into the box guides. The adaptors will need trimming to length so that the lid holds it all in place. Otherwise, mounting holes can be drilled in the corners to mount it in an enclosure of your choice. If mounting in a metal enclosure, this will need adequate insulation from the live end of the circuit board and should be earthed.

All the small components should be fitted to the circuit board first. Start with the resistors, then add the choke, diode D1, fuse holders and capacitors, taking care to note the polarity of the electrolytic capacitors. Then add ICs, bridge rectifier and triac, again observing orientation. Finally, fit the plug headers, terminal blocks and transformer.

The PCB layout includes pads to fit the vertical type trim potentiometers. Suitable values for the original design temperature range would be 4k7 for P1 and 22k for P2. In this case, R6 & R7 would be omitted.

The control potentiometer and two LEDs were fitted to the lid of the box and wired through short pieces of hook-up wire back to the stripboard. The thermistor was wired to a length of screened cable (to prevent pickup of stray signals), with heatshrink sleeving placed over the junction of the inner and one thermistor wire before a longer piece was fitted over both this and the junction of the screen and other wire, leaving just the bead of the thermistor exposed.

The control potentiometer and two LEDs should be fitted to the lid of the box and wired to the 5-pin connector. When positioning them, care should be taken to ensure that they will not foul on the transformer, and should be away from the mains end of the circuit board.

The thermistor is wired to the 2-pin connector using screened cable to prevent pickup of interference. Heatshrink sleeving is placed over the junction of the inner and one thermistor wire before a longer piece is fitted over both this and the junction of the screen and other wire, leaving just the bead of the thermistor exposed. If it was intended to be used in a damp environment the end could then be sealed with a suitable sealer, or epoxy resin, but this would reduce the responsiveness of the thermistor slightly.

Testing

With all components fitted to the circuit board, check that there are no shorts and that there is no continuity between the live side and the control side of the board. Temporarily remove fuse F2 but ensure both covers are in place before testing.

Before connecting the mains to the triac, it is preferable to check the operation of the rest of the circuit. If possible, wire to the terminal block via an isolating transformer, but take great care as mains is potentially lethal.

If you are using potentiometers P1 & P2, check that these are set to maximum resistance before powering. If no faults are found, power up and check that 12V is present on the regulator output, and that the mid-rail junction of R4 & R5 is at 6V.

If you have a scope, check the waveform at the output of the integrator IC1, pin 7. If this is present and only one of the LEDs is lit, check the voltage at pin 1 and see if it can be adjusted to about 6V by the temperature control. This should be possible, assuming the thermistor is at a temperature between the control range limits. If not, warm or cool the thermistor to bring it within range. The red LED indicates too hot, the green, too cold. When both are lit, the circuit is within the control range, and varying the thermistor temperature slightly will cause the brightness of the LEDs to vary, according to whether it was warmed or cooled; note, it is very sensitive. Assuming all is working, the mains connections to the triac circuit can now be made by inserting F2, and the load connected. If this circuit is being used to control a non-radiant heater, you may like to use a light bulb as a load initially to check that the triac is functioning correctly.

Calibration

In order that this was not too lengthy, I laid the wine thermometer and thermistor on the top heat spreader plate with the thermometer bulb and thermistor in close physical contact, and a generous blob of petroleum jelly over both. This was then covered by a strip of wide sticky tape. It only took around 3 or 4 minutes for the temperature to stabilise, indicated by both LEDs being on to a similar extent. I started at the coolest setting, turned the knob a fraction at a time and made a mark to correspond with each mark on the thermometer. As a check, when I reached the maximum setting, I then turned it down a fraction at a time, checking that the marked values corresponded to the thermometer readings.

In other applications, it may be worth using a digital thermometer with an external probe, e.g. aquarium thermometer (RJ79L), placing the probe and thermistor in close proximity into or onto the device to be controlled.

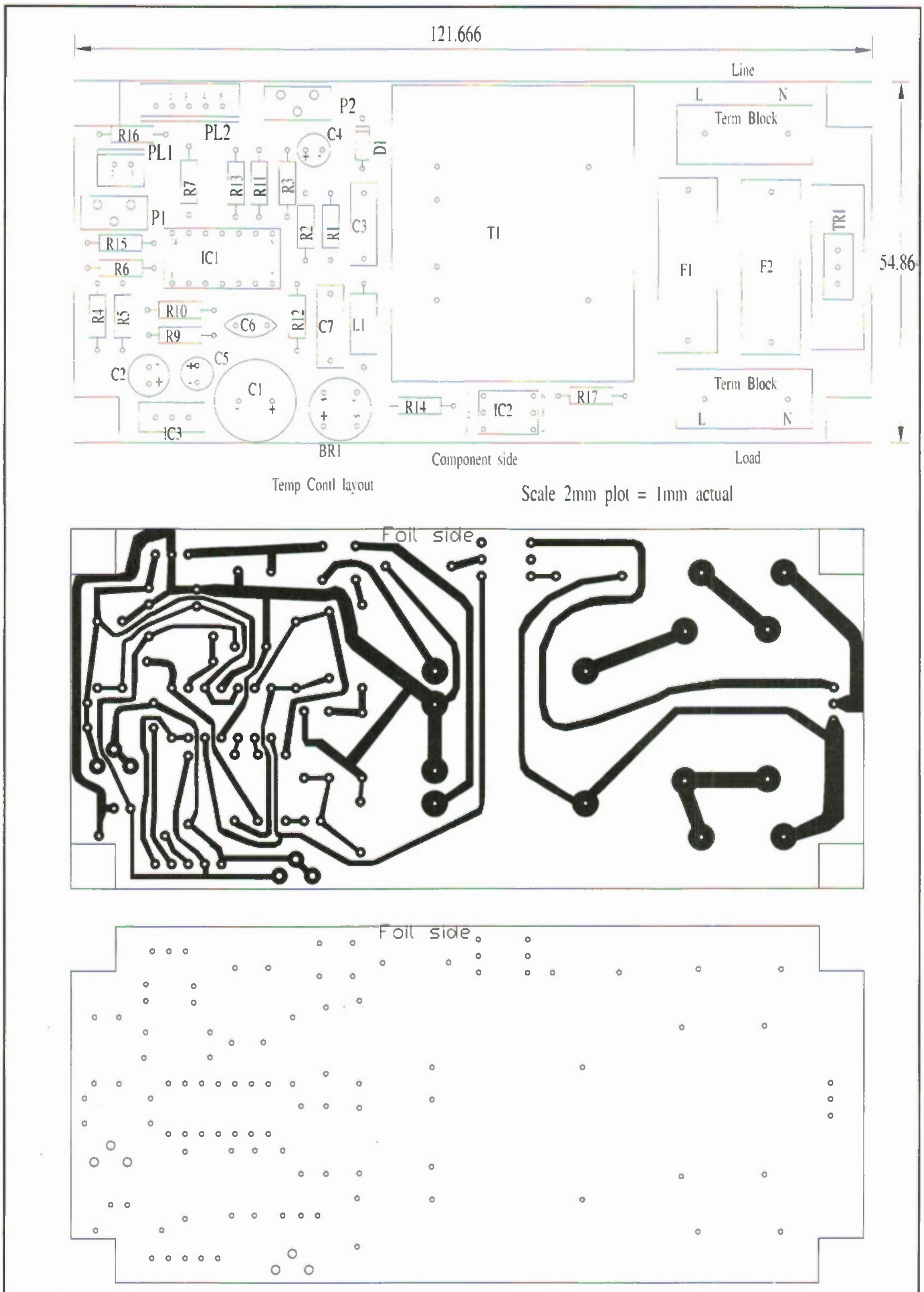
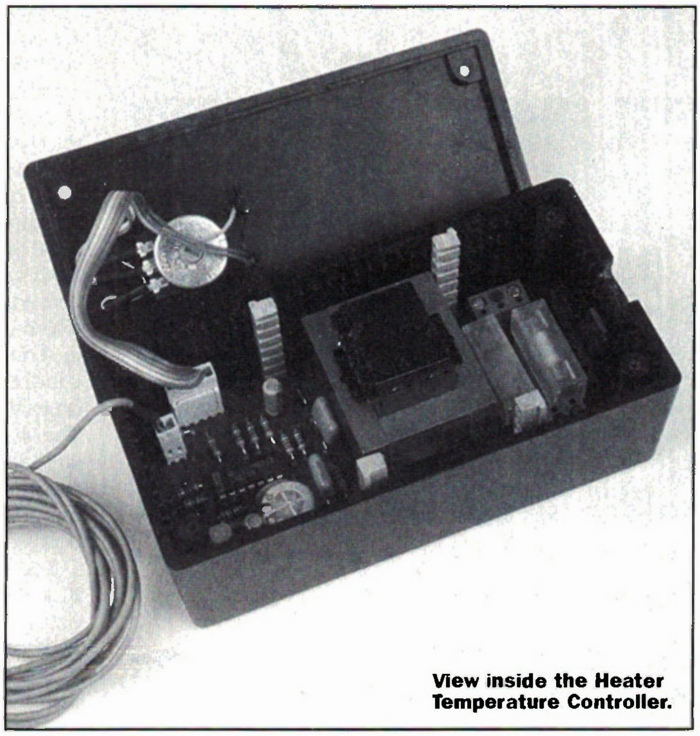
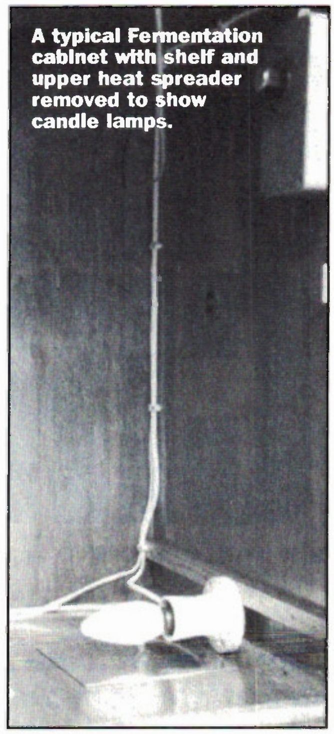


Figure 2. PCB legend and track.

> **Important Safety Note**
>
> It is important to note that mains voltage is potentially lethal. Details of mains wiring connections are shown in this article, and every possible precaution must be taken to avoid the risk of electric shock during maintenance and use of the final unit, which should never be operated with the box lid removed. Safe construction of the unit is entirely dependent on the skill of the constructor, and adherence to the instructions given in this article. If you are in any doubt as to the correct way to proceed, consult a suitably qualified engineer.
>
> The circuit has no earth, having been designed to go in a plastic box and having no exposed metal accessible. It comes into the double-insulated category, there being at least one insulating layer plus an air gap, between any part carrying mains potential, and the accessible parts. A fuse (F2) in the feed to the load is included on the PCB layout, and a separate fuse (F1) to the transformer as well.
>
> Great care should be exercised when testing, as mains is potentially lethal.



View inside the Heater Temperature Controller.



A typical Fermentation cabinet with shelf and upper heat spreader removed to show candle lamps.

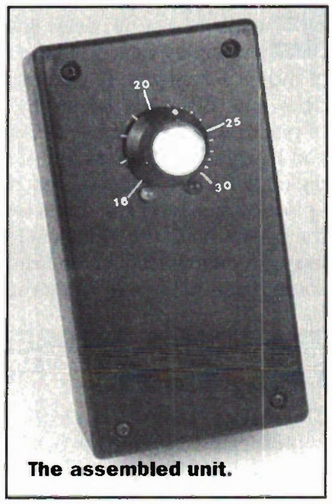
Other Uses

The prototype was designed with the purpose of producing a controlled heater for wine making, but could be used for any application requiring close temperature control where the ambient temperature may vary. In my application, I found that simply fastening the thermistor to the demijohn with Blue-tac maintained the temperature of the fermenting wine to within 1°C of the setting, even when the room temperature was varying by 10° or more (cold nights to sunny winter afternoons). The brightness of the lamps was a good indication of how cold it was.

This could also be used with a submersible heater for tropical fish, or photographic developing work. If the thermistor were enclosed in a sealed thin tube or suitably encapsulated, it could be placed directly into the liquid whose temperature it was required to maintain. In these kind of applications, it may be necessary to provide a bigger heatsink for the triac, depending on the power rating of the heater. The prototype has a small piece of 16-gauge aluminium bolted to it, but with the 80W load, barely seems to get warm, so a clip-on heatsink is specified for the PCB version. However, the triac is rated to 16A, so could drive a substantial heater with adequate heatsinking.

In such an application, the circuit board would need to be mounted in a different enclosure, and may need an earth to provide suitable protection.

The PCB design, by including header plugs and pads for trim potentiometers, should allow for most applications that might require a controlled heater, and by tailoring the choice of thermistor and bridge balance resistors, most domestic and several industrial applications should be covered. ELECTRONICS



The assembled unit.

PROJECT PARTS LIST

RESISTORS: All 0·6W 1% Metal Film (Unless Stated)

R1,2	1k5	2	(M1K5)
R3,11,13	4k7	3	(M4K7)
R4,5	2k2	2	(M2K2)
R6*	3k9	1	(M3K9)
or P1*	4k7 Vertical Enclosed Preset Potentiometer	1	(UH02C)
R7*	10k	1	(M10K)
or P2*	22k Vertical Enclosed Preset Potentiometer	1	(UH04E)
R8*	4k7 Linear Potentiometer	1	(FW01B)
R9,14-16	1k0	4	(M1K0)
R10	100k	1	(M100K)
R12	1M	1	(M1M0)
R17	470Ω	1	(M470R)

* See Text for Details

CAPACITORS

C1	1,000μF 35V Radial Electrolytic	1	(FF18U)
C2	100μF 25V Radial Electrolytic	1	(FF11M)
C3	47nF Polyester	1	(BX74R)
C4	4μ7F 63V Radial Electrolytic	1	(FF03D)
C5	47μF 25V Radial Electrolytic	1	(FF08J)
C6	0μ22F Ceramic Disc	1	(JL01B)
C7	15nF Polyester	1	(BX71N)

SEMICONDUCTORS

IC1	LM324	1	(WF26D)
IC2	Opto Triac	1	(QQ10L)
IC3	LM7812	1	(AV17T)
BR1	W01 Bridge Rectifier	1	(AQ95D)
TR1	C246D Triac	1	(QL14Q)
D1	1N4148	1	(QL80B)
D2	5mm Red LED	1	(WL27E)
D3	5mm Green LED	1	(WL28F)

MISCELLANEOUS

T1	12-0-12V 6VA Transformer	1	(YJ54J)
TH1	4k7 Thermistor	1	(FX21X)
L1	100μH choke	1	(WH41U)
F1	T100mA Glass Fuse	1	(CZ87U)
F2	T1A Ceramic Fuse	1	(DA11M)
	Fuse Holders	2	(DA61R)
	Fuse Covers	2	(DA62S)
	Clip-on Heatsink	1	(FG52G)
	Terminal Blocks	2	(JY92A)
	5-way PCB Header Plug	1	(FY93B)
	2-way PCB Header Plug	1	(RK65V)
	5-way Socket Housing	1	(BH66W)
	2-way Socket Housing	1	(HB59P)
	PCB Terminal Strip	1	(YW25C)
	M2 Knob	1	(RW89W)
	Heatshrink Sleeving	1	(BF89W)
	Screened Cable	As Req.	(XR13P)
	Hook-up Wire	As Req.	
	Solder	As Req.	

OPTIONAL

	Plastic Box PX2	1	(YU53H)
	PCB Adaptors	4	(YR72P)

The Maplin 'Get-You-Working' Service is not available for this project.

The above items are not available as a kit.