POND HEATER THERMOSTAT

A. R. WINSTANLEY

An essential winter accessory for pond fish enthusiasts. Ensures that fish will not suffer if the pond ices over.

THOSE readers who keep coldwater pond fish will know of the dangers which exist during wintertime, when low temperatures can give rise to ice formation on the fishpond. During summer, the oxygenating plants in the water provide a plentiful supply (hopefully) of oxygen which enables the fish to breathe.

In severe winters, no such oxygen is produced and so the pond's inhabitants rely on air entering the water from the surface. If the pond then freezes over, firstly the air supply to the fish is reduced if not cut off altogether, and secondly, toxic gases from decomposing material in the water can build up in the pond and poison fish.

Several tricks are employed by fish-keepers during icy weather to help the fish to breathe and gases to escape. A floating electric heating element is popularly used, the idea being that the warmth generated by the heater provides some local heating and keeps a small surrounding area – say 12 to 18 inches diameter – of water free from ice. The object is not to heat up the water to any extent but merely provide an air-hole in the ice.

FIT AND FORGET

Forgetting to switch the unit on during icy weather could result in thick ice formation with possible distress being caused to fish, and the build up of toxins and the lack of air can eventually be fatal to the pond's inhabitants. Conversely, leaving the heater continually switched on is wasteful and can only shorten the life of the heater.

Fish enthusiasts who own any expensive breeds such as Koi Carp will not wish to take any risks and even if you simply keep cheap and cheerful goldfish, you will certainly want to take precautions to protect them during harsh weather conditions. The Pond Heater Thermostat was designed as a "fit and forget" outdoor controller which monitors the ambient air temperatures and switches on the floating pond heater if the air temperature drops to near zero degrees Celsius.

The prototype unit has been of great success when used at the author's fish pond, and it reliably powers a nearby floating electric heater when the air temperature is just above freezing or colder. By using the Pond Heater Thermostat, it is no longer necessary to remember to watch weather forecasts and turn on the heater if frost or ice is looming.

In fact, the prototype has been operating very efficiently under very harsh weather conditions when temperatures have been measured as low as –8 degrees Celsius.

FISH AND CHIPS

Aquarists will know that the most common method of maintaining temperatures in a tropical fishtank is to use a bi-metallic strip thermostat immersed in the water. These are notoriously temperamental to set up at the desired switching point and their crude method of operation can be unreliable. Additionally they are generally uncalibrated.

The problem of detecting near-zero temperatures as required in our outdoor pond application is solved by employing a solid-state temperature sensing integrated circuit. In fact several types of device are available in this category, and one of the cheapest types, the well-established LM3911N is used in this design. A simplified block diagram of this device appears in Fig. 1.

HOW IT WORKS

The LM3911N is a highly accurate temperature measuring chip which is usable between –25° to +85° Celsius. The device comes in an 8-pin d.i.l. package which contains a temperature sensor, supply voltage reference and a comparator.

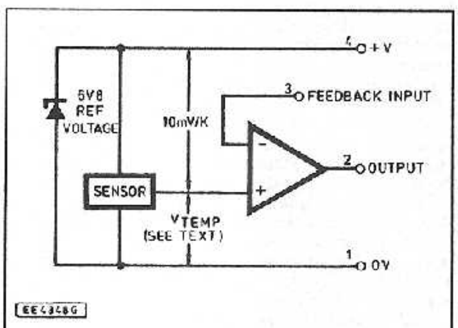


Fig. 1. Simplified structure of the LM3911 temperature sensor chip.

Its circuit utilises a pair of transistors operating at differing currents as the temperature sensor, and since the base-emitter voltages of the transistors vary by a tiny amount with temperature, the difference in the base-emitter voltages can be utilised to generate a temperature-dependent potential difference. The result is that the sensor is very stable and highly accurate.

From the block diagram, it can be seen that the temperature sensor output is equal to 10mV/ degree Kelvin – directly equivalent to 10mV/ degree Celsius. (A brief explanation of the Kelvin scale of temperature measurement is given Table 1.) It can be seen that the temperature sensor is directly connected to the non-inverting (+) input of an operational amplifier.

REFERENCE VOLTAGE

Also on board the chip is a stable voltage reference working in a manner similar to a

Table 1: Kelvin Temperature Scale

The Celsius Scale of temperature measurement has an identical temperature interval to that of the Kelvin Scale. In order to convert from Kelvin to Celsius, it is necessary to "re-align" the two scales by a factor of 273 thus:

Freezing Point = 0 Degrees Celsius = 273 Degrees Kelvin

Steam (Boiling) point = 100 Degrees Celsius = 373 Degrees Kelvin

Therefore, Degrees K = Degrees C + 273

and, Degrees C = Degrees K – 273

Examples

+20 degrees Celcius = 293 degrees Kelvin
+5 degrees C = 278 degrees K
–2 degrees C = 271 degrees K

Zener diode. This reference voltage is used by the temperature sensor, and requires an external voltage-dropping resistor to be connected to pin 4 of the i.c., with the Zener forward current preferably kept to a minimum (1mA or less is recommended), in order that the self-heating effects of the i.c. are minimised – this helps to improve accuracy.

The reference voltage is typically 6·85V, and given that the potential at the sensor output varies by 10mV/degree Celsius as shown in the diagram, it means that the voltage at the non-inverting input (call it Vtemp) of the op.amp with respect to 0V is equivalent to:

Vtemp = (6·85–10mV/degree Kelvin) Volts.

For example, at an ambient temperature of +25°C., this equates to a temperature of 298 degrees Kelvin. The sensor output voltage at 10mV/ degree K is thus 2·98V as measured between the sensor output and the +6·85V reference rail. This is indeed confirmed in the manufacturer's data.

Using the above formula, Vtemp therefore typically equals 3·87V (6·85 − 2·98V) at a temperature of +25 degrees Celsius.

At a temperature of, say, +85 degrees, Vtemp typically equals 3·27V.

It can be seen therefore that, with respect to the 0V rail, the voltage at the op.amp non-inverting (+) input decreases as the i.c. temperature increases.

FEEDBACK

No mention has yet been made of the "feedback" input (pin 3) to the op.amp, which is actually the inverting input (–). By normal comparator action, when the non-inverting input has a higher voltage than the inverting input, then the output of the op-amp (pin 2) is *high*, and vice versa.

Looking at how this device can be used as a thermostat, in our application we want a simple on-off controller which can operate at a switching point of just above freezing – say +1°C.

Given that the non-inverting input is directly connected to the temperature sensor (and is not accessible), in order to act as a simple thermostat, an external reference voltage is set at the feedback input terminal by using a potential divider strapped across the 6·85V reference, (VR1 in Fig. 2).

The temperature control is set by the user so that the voltage at the inverting input of the comparator (pin 3) equals the voltage from the temperature sensor which will exist at the non-inverting input when the i.c. is at the desired switching temperature.

For example earlier we saw how, at a temperature of 25°C, the voltage (Vtemp) at the non-inverting input was 3·87V. By setting the preset control VR1 to this voltage also, the comparator will then be at the thermostat switching point of +25°C.

As the ambient temperature rises above this set point, the voltage at the non-inverting input of the comparator will decrease at a rate of 10mV/ degree Celsius. Pin 2 will therefore be low because the non-inverting input voltage is less than the inverting voltage.

Conversely when the ambient temperature falls, the non-inverting input voltage will rise until it exceeds the set point, as determined by VR1. Then the comparator output pin 2 will go high. Thus a simple on-off temperature controller can very easily be formed, using a simple potential divider to act as the temperature control point.

The only point to note is that it is necessary to set the external control quite accurately because an error of only 0·1V at pin 3 is equivalent to a temperature spread of 10°C.

CIRCUIT DESCRIPTION

The full circuit diagram for the Pond Heater Thermostat is given in Fig. 2 and, as can be seen, is very simple.

The LM3911N, IC1, behaves as an on-off thermostatic controller. The circuit is mains powered, and uses a 12V step-down transformer T1 coupled with a standard full-wave bridge rectifier circuit (D1 to D4 and smoothing capacitor C1) to produce a d.c. supply rail of approximately 16V to 18V. The l.e.d. D5 is a power-on indicator.

The 18V rail is too high of course for direct operation of IC1 and so R2 is a series dropping resistor which limits the current to just 1mA for the internal reference voltage. The voltage at pin 4 is therefore about 6·8V (and this can be measured with a voltmeter).

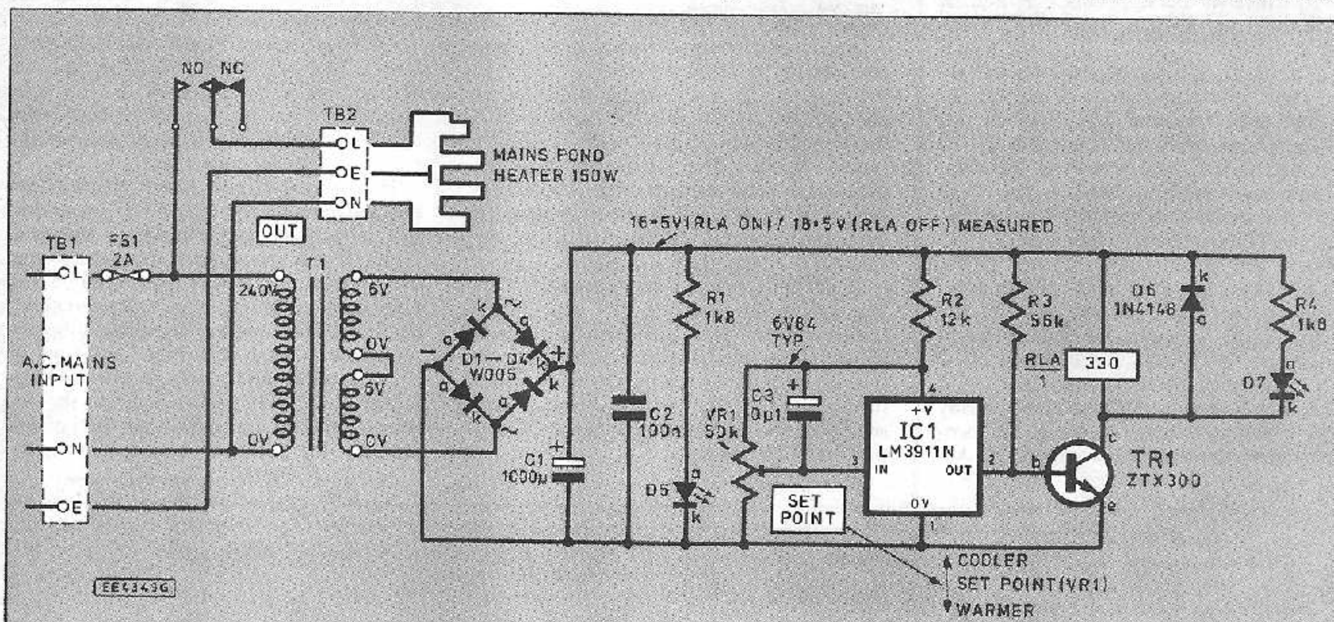


Fig. 2. Complete circuit diagram for the Pond Heater Thermostat.

Preset control VR1 is a 50kilohm 25-turn cermet trimmer, the wiper of which is connected directly to pin 3 (comparator feedback input) and is used to adjust the thermostat switching point. Capacitor C3 removes any noise and improves stability.

The output of the i.c. drives a simple transistor switch TR1 which is used to control a mains-rated relay RLA. Diode D6 removes back e.m.f. when the relay de-energises, in order to protect the transistor and chip.

Preset VR1 is adjusted to the desired set point, which in this application should be no more than +1°C – equivalent to setting a voltage at pin 3 of about 4·11V or so (but this setting depends on the actual Zener reference voltage of readers' individual units – see later).

When the i.c. temperature exceeds +1°C, therefore, the voltage present at the comparator non-inverting input is *less than* 4·11V and so the comparator output is low, near 0V. The transistor switch is off.

When the ambient temperature drops, the non-inverting (+) input of the comparator is sent more positive, towards the internal 6·85V reference, until the set point voltage of 4·11V is exceeded, when pin 2 goes high, switching on the transistor.

This then completes the circuit to relay RLA which operates and closes the normally-open mains-rated contacts RLA1. These directly switch on the mains (L) supply to the floating heating element which is connected via terminal block TB2. The l.e.d. D7 also illuminates to indicate that the heater has switched on.

Resistor R3 is required in order to shunt an internal resistor which is present at the comparator output, and enables more base drive current to flow into the transistor TR1.

The thermostat will cycle quite happily like this, turning the heater on and off according to the ambient temperatures detected by the integrated circuit.

SOAK TIME

One further practical aspect to take into account is the fact that the "die" or chip within the i.c. is, of course, embedded in the plastic resin of the dual-in-line package. This can slow down the reaction of the i.c. slightly because it takes time for the ambient temperature to soak through to the silicon chip itself – especially when the device is mounted flush on a printed circuit board and the changes in temperature are slight.

In practice this can be adjusted out by trial and error, trimming VR1 accordingly to advance the point at which IC1 would trigger. This compensates for any temperature lag. It is also necessary to use a multi-turn preset for VR1 because the i.c. is very sensitive, and a 25-turn preset makes setting up much easier.

The prototype was quickly set up and was adjusted once only, and has been in successful operation for many months. It starts to power the heater on and off when the temperature is just above freezing, and the heater is hard on at sub-zero levels.

CONSTRUCTION

***Important Safety Notice:* Constructing this unit involves making MAINS connections. Any reader who is not certain of being able to build it safely is strongly advised to seek professional advice. If necessary, a qualified electrician should carry out the fixed installation work.**

The Pond Heater Thermostat is designed for outdoor use in harsh weather and the circuit itself is constructed on a single-sided glass-fibre printed circuit board size 130mm x 70mm. This is available from the *EPE PCB Service* code 856.

The printed circuit board (p.c.b.) topside component layout and full size underside copper foil master pattern is shown in Fig. 3. If you are tempted to produce your own p.c.b., make sure you keep to the published design i.e. large "ambient sink" plane and large tracks for mains voltages. All connections to IC1 (pins 1 to 4) are on one side of the d.i.l. package, but pins 5 to 8 are electrically isolated from the integrated circuit. In order that the i.c. can monitor the ambient temperature more

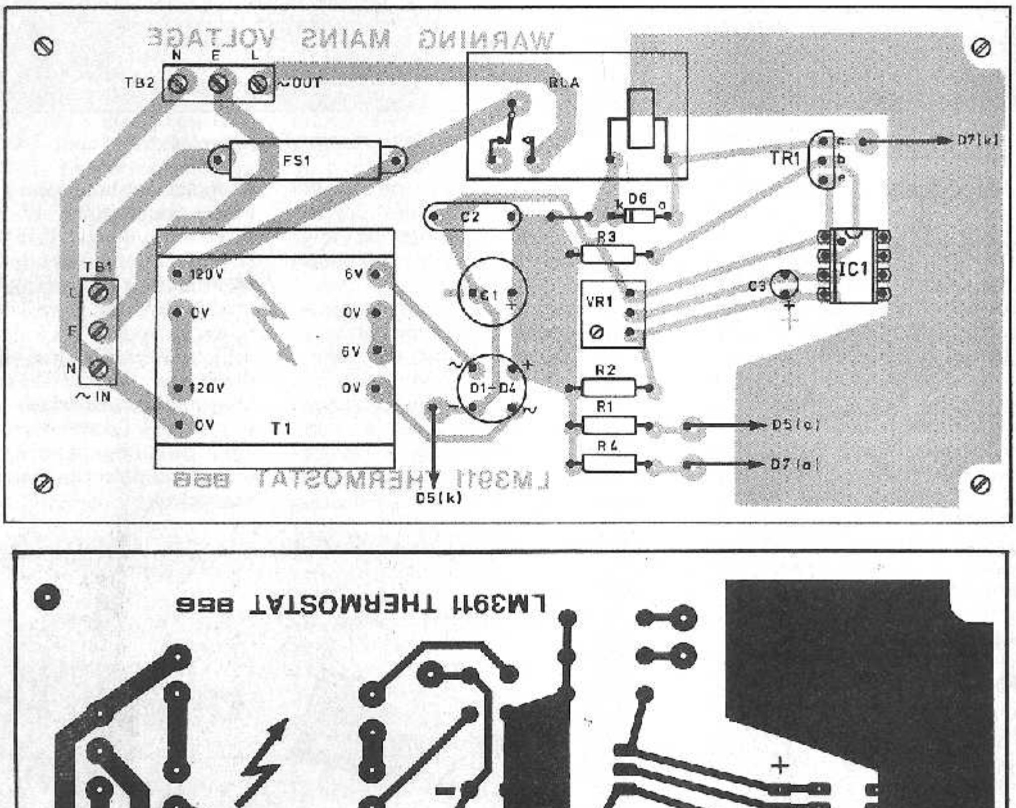


Fig. 3. Printed circuit board component layout and underside copper foil master pattern (full size). Note the large area of copper which act as a heatsink (cold) for the i.c.

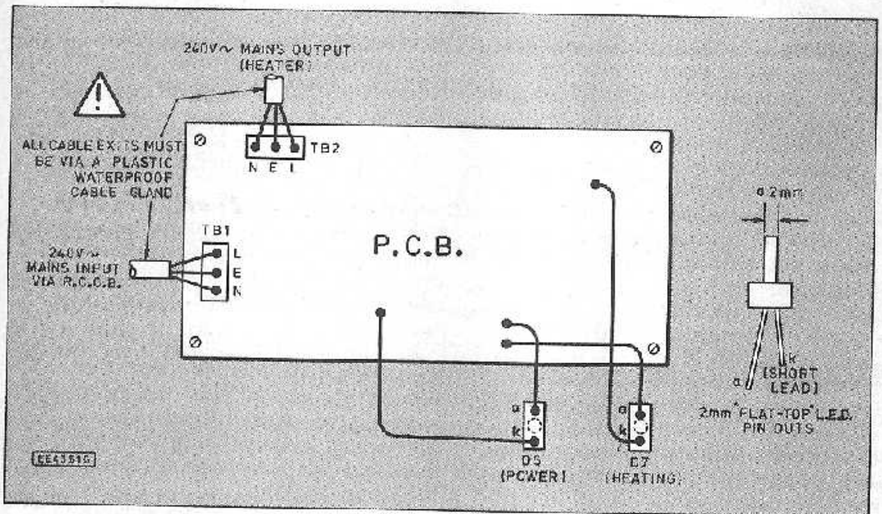


Fig. 4. Wiring from the circuit board to the power-on and heating l.e.d.s.

effectively, a large area of copper foil acts as a simple heatsink, monitoring the surrounding heat level, and this is soldered directly to pins 5 to 8 of the chip. This helps the surrounding heat (or cold) to soak through to the i.c. die.

In fact National Semiconductor suggest that a d.i.l. heatsink is bonded to the package to improve thermal transfer even more, but the author could not successfully locate a suitable type.

This printed circuit board has been specially designed to fit a weatherproof and frostproof plastic box, RS type 507-933, which measures 160mm x 80mm x 55mm. It is rated down to −20°C and so should be quite shatterproof at sub-zero temperatures. The box incorporates p.c.b. mounting bushes which are utilised to carry the p.c.b. shown, using M3 screws.

All parts including the mains-voltage section are p.c.b. mounted for maximum reliability. Other parts may not fit the p.c.b. so check before purchasing.

Construction starts by fitting the smaller, lighter components to the board in accordance with Fig. 3. Observe carefully the polarity of the bridge rectifier, electrolytic capacitors and transistor. Note that you should solder the i.c. directly to the board as shown without using a socket.

Follow on with the relay, mains terminal blocks and finally the mains transformer. An insulated cover fuseholder is recommended for FS1.

The lid of the plastic box needs to be drilled to take the two light-emitting diodes, and here 2mm diameter "flat-top" types were used on the prototype. Two 2mm diameter holes were drilled in the lid and the l.e.d.s are a tight, waterproof push fit giving a very neat effect.

They are connected to the board with flying leads, and it must be ensured that the lead-outs will not touch or interfere with the p.c.b. once the lid is screwed down. Other types of l.e.d. can be used but it may be necessary to seal them with silicone sealant to prevent water seeping in.

It is also necessary to drill the box to accept a mains cable input, 6A three-core cable is suitable and this ***MUST*** be fitted through the box using a plastic cable gland with sealing washer to make the cable entry waterproof. Similarly a cable exit is needed for the heating element, which will probably also use 6A three-core cable. Again

COMPONENTS

Resistors

R1	1k8
R2	12k
R3	56k
R4	1k8

All 0·25W 5% carbon film

See SHOP TALK Page

Potentiometer

VR1	50k 25-turn cermet preset

Capacitors

C1	1000µ radial elect. 25V
C2	100n polyester
C3	0µ1 tantalum bead, 35V

Semiconductors

D1 to D4	W005 50V 1A bridge rect.
D5, D7	2mm flat top l.e.d. (2 off – see text)
D6	1N4148 signal diode
TR1	ZTX300 *npn* transistor
IC1	LM3911N temperature sensor i.c.

Miscellaneous

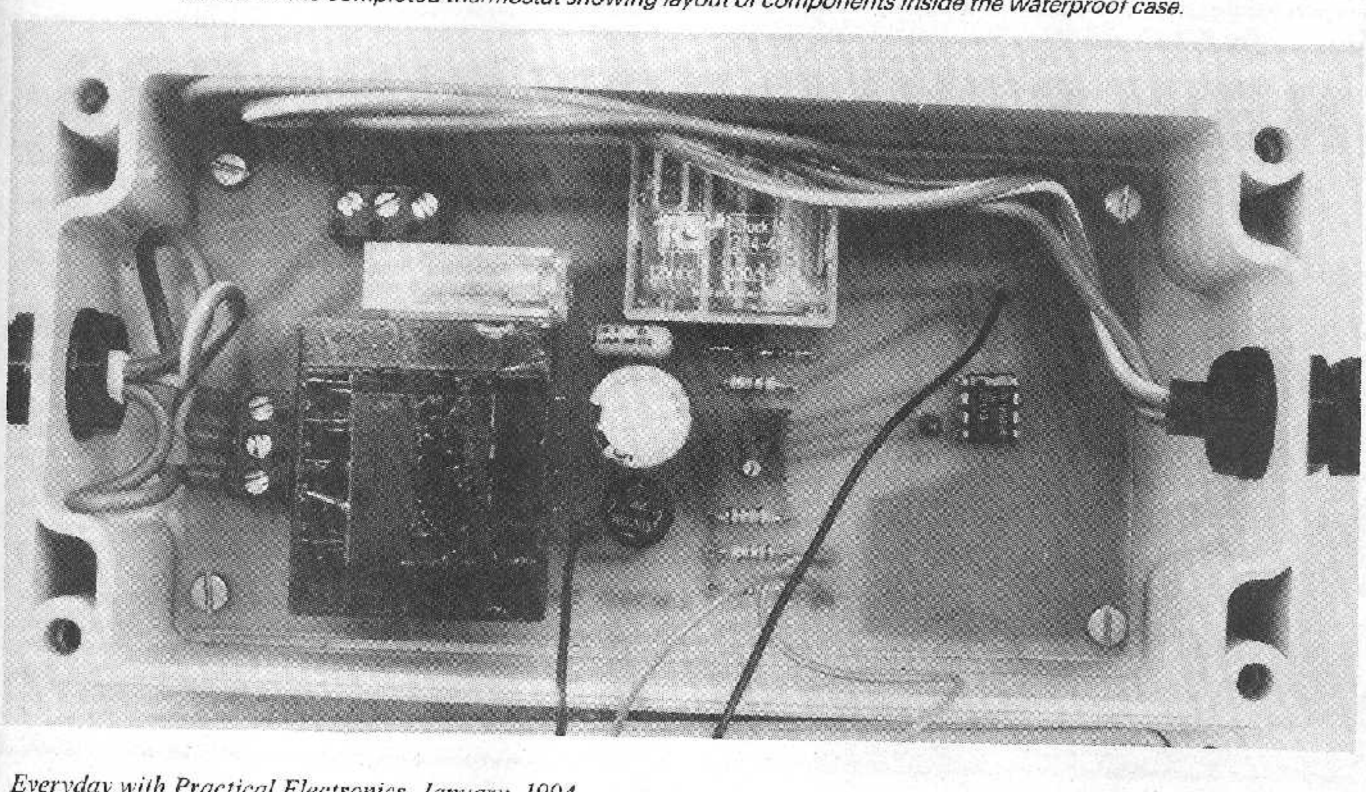
RLA	12V 330ohm coil flatpack relay, with s.p.c.o. contact rated at 8A 250V a.c.
T1	3VA p.c.b. mounting mains transformer, with 0V-6V, 0V-6V secondaries
FS1	20mm p.c.b. insulated fuseholder, with 2A quick-blow fuse
TB1, TB2	3-way p.c.b. mounting screw terminal block, mains rated (2 off)

Weatherproof ABS box, size 160mm x 80mm x 55mm; cable-sealing glands (2 off); 6A 3-core mains cable, length as required; connecting wire; M3 x 10mm pan-head screws for p.c.b. mounting (4 off); solder etc.

Printed circuit board available from the *EPE PCB Service*, code 856.

Approx cost guidance only **£30** *excl. Heater*

Interior of the completed thermostat showing layout of components inside the waterproof case.



a weatherproof cable gland *MUST* be employed.

The mains flying leads are connected to the appropriate screw terminal blocks – taking great care to ensure that stray strands of wire do not short adjacent terminals. It is ***essential*** that the earth continuity is maintained, so that the metal case of the heating element is properly connected to the mains Earth (E) input.

TESTING AND CALIBRATION

After construction is complete, the best way to test the unit is to power it up using a d.c. bench power supply rather than connecting it to the mains. Clip an 18V d.c. supply across the positive and negative leads of the bridge rectifier.

By rotating VR1 with a trimming tool it should be possible to make the relay (and l.e.d. D5) turn on and off. This confirms that the comparator and temperature sensor are working. Then trim VR1 so that the thermostat will switch at +1°C. It is possible to calibrate this point to a certain extent by taking a few test readings, preferably with a DMM (digital multimeter).

It is best to adjust your setting to take account of the tolerance of the Zener reference voltage because yours may not be precisely 6·85V, so you can get a good idea of the setting required at VR1 wiper for your unit by using this simple formula, which is based on the voltage divider effect present at the comparator non-inverting input:

$$V_{temp} = V_z - 2{\cdot}74V$$

where Vtemp is the voltage at pin 3 (the switching voltage for +1°C operation) – you will trim this with VR1, and

Vz is the reference voltage of your unit (measured at pin 4 (+) and pin 1 (0V) – this should be between 6·55V and 7·25V).

N.B. 2·74V represents the temperature sensor output voltage at a temperature of +1°C (i.e. 10mV per degree Kelvin).

Measure the reference voltage of your i.c. then calculate the setting you need for your own unit and trim this with VR1, monitoring the potential at pin 3 of IC1. For example, if you measure a reference voltage of 6·25V at pin 4, you will need to trim VR1 so that pin 3 measures roughly 3·51V. A reference voltage of 6·85V for instance would require VR1 to be trimmed to 4·11V.

Using this simple method you will be able to easily set up your unit on the bench so that it will start to switch just above freezing point.

Even using a high impedance DMM it was found that the meter loaded the circuit slightly, and in view of the high sensitivity of the LM3911, the simple calibration procedure will enable you to position VR1 at approximately the correct setting. However, you will still probably need to make one or two trial and error fine adjustments *in situ* to finalise the setting up.

If no test equipment is available, then you will have to adjust VR1 by trial and error. If you use the "trial and error" method, take great care to keep clear of mains components, and to keep water out of the box when the lid is removed.

You could for instance, test your unit by using a cool box filled with ice packs to simulate near-freezing conditions. A mercury thermometer will be of help also.

INSTALLATION

If you are satisfied that the device operates correctly, the Pond Heater Thermostat can be installed outdoors perhaps by securing the box to a wall or a nearby fixture. It will be seen that the wall-mounting holes in the weatherproof box are outside the sealed compartment, and it is therefore not necessary to seal the box mounting screws. However, ensure that the lid is secured evenly but *do not overtighten* the screws as the bushes may be damaged.

It is recommended to connect the mains power to your Pond Heater Thermostat through an Earth Leakage Circuit Breaker/Residual Current Device (ELCB/RCD) for maximum protection.

It is important to remember that floating heater elements must not be powered unless they are in water – do not operate them unless they are submerged or they could be seriously damaged. Floating them in a nine litre (two-gallon) bucket of water will be quite adequate if you power up the unit indoors.

The siting of the Thermostat is quite important, and you need to bear in mind any likely windchill or sunlight which might affect the operation slightly. It is best to locate the unit in a sheltered spot as near to the pond as possible. It will be simple to compensate for any local conditions by adjusting the Set Point preset VR1 as necessary.

In normal operation you will hear the relay switch on and off (with l.e.d. D7 turning on and off) as the thermostat responds to changing temperatures. A slight relay "chatter" may be evident at times but this is normal and there is no need to be concerned.

Larger pools may use several heaters and it should be possible to connect up to two extra heaters from the same circuit as the unit could comfortably handle up to 500 Watts. Each cable exit from the box *MUST* employ a sealing gland.

LOW VOLTAGE HEATERS

Presumably on the grounds of improved safety, it is now possible to use a low voltage heating element which is powered from the mains via a heavy duty (typically 50VA) step-down transformer, which itself is situated under cover. It should be perfectly feasible to use these low voltage systems also with the Pond Heater Thermostat, by connecting the mains (primary) of the transformer in place of the mains heating element, at TB2.

A low voltage heater has not been tested with the prototype shown, and the only potential problem may be noise or spikes generated by the step-down transformer when RLA1 switches it off. It might be a good idea to carefully wire a 240V varistor (mains transient suppressor) across the Live and Neutral connections at TB2, i.e. in parallel with the transformer unit. It is still important to protect yourself from the mains-voltage side of the circuit by using an ELCB/ RCD trip. □