Construction project:

Low cost temperature probe

Here's an easy to build probe design which adapts a multimeter or electronic voltmeter into a general purpose thermometer. It's just the shot for measuring heatsink temperatures, how hot it gets inside your car, or whether little Johnny has a fever!

by HENK MULDER

Through the years, *EA* has presented quite a few different temperature probes and thermometers. This isn't too surprising when you realise that electronic components with their inevitable dissipation are closely related to temperature. Most engineers probably curse this relation, but still it's there and we live with it. In fact, for this project it's a blessing.

As years passed by, and technology developed, those thermometer projects became more and more elaborate. The last generation had a dual sensor and a digital readout. But for a lot of general-purpose temperature measurements, this kind of design can be "over-kill".

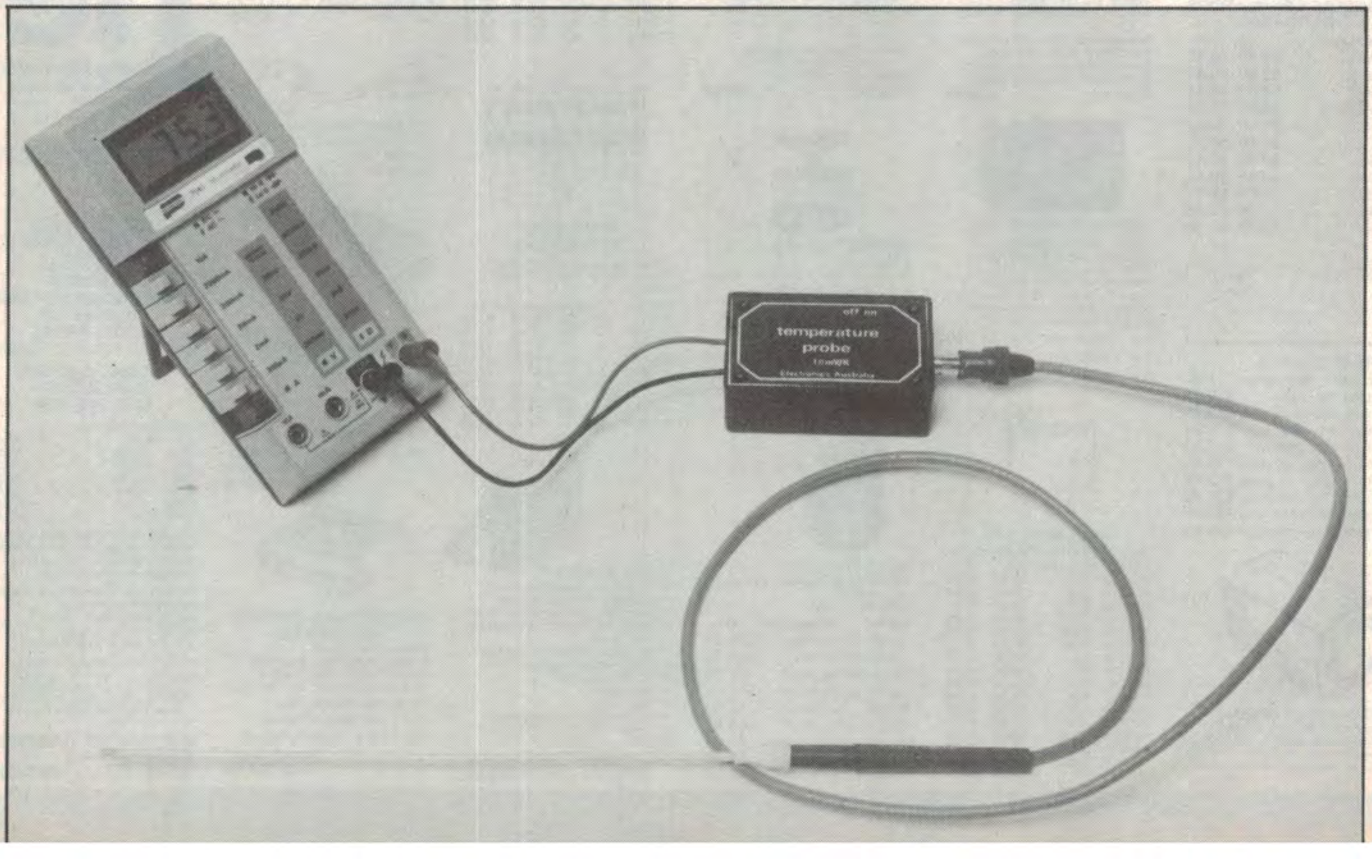
As an electronic hobbyist or perhaps a professional, you really don't need anything very fancy. You mainly want something for the odd occasion when you want to measure temperature as part of an integrated system.

You might want to monitor several 'hot spots' in your car engine compartment, for example, or similarly check the temperature of a power transistor heatsink in various kinds of electronic systems. There are also many applications where you would like to measure temperature as part of normal system operation, and do a bit more with it than just reading it out.

For those people we designed this general purpose temperature probe. It uses easy-to-get components, and can be used with almost any conventional multimeter or electronic voltmeter — whether analog or digital. It's also suitable for building into other projects, where they require temperature sensing.

Essentially this circuit converts tem-

The temperature probe is shown here with an experimental sensor. It uses an ordinary multimeter as display.



perature into voltage; 10mV per degree with 0V for 0°C. It has been tested from –20°C to 120°C, but might well operate beyond these values. The accuracy within this range is approximately 1%.

The probe is designed to run from a 9V battery, but could also be run from a stabilised 9V DC power supply.

As we didn't have an "inbuilt" application for the temperature probe, we built the prototype into a small project case and turned it into an add-on temperature probe for a multimeter.

A diode as sensor

One of the possibilities for sensing temperature is using ordinary silicon or germanium diodes as sensors. The voltage/current characteristics of such diodes, or PN-junctions in general, are strongly temperature dependent. When you run a constant current through a diode, then the voltage across the diode decreases with increasing (junction) temperature.

This temperature/voltage relation happens to be close to linear and is about 2mV/K, where "K" stands for Kelvin, the unit of absolute temperature measurement (0K = –273°C). The figure of 2mV/K might vary slightly for various diodes.

The linearity of this phenomenon makes such diodes excellent temperature sensors. The temperature range is limited to the maximum and minimum operating temperature of the diode.

Circuit details

Using an ordinary diode as a temperature sensor, it doesn't take very much circuitry to build a temperature probe.

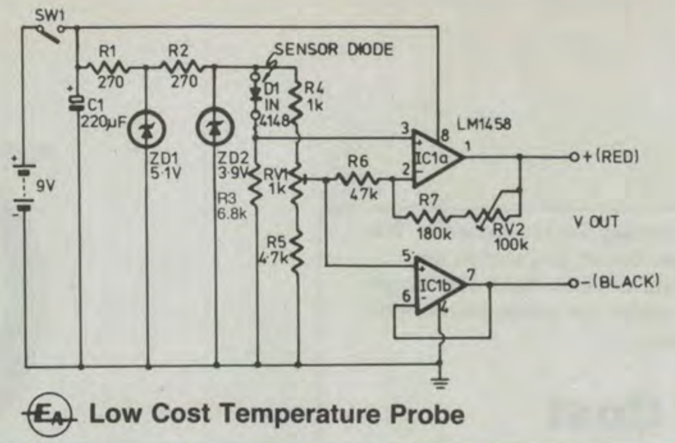
Given: a silicon diode with a range of 0.75V to 0.55V for 0°C to 100°C. Wanted: a temperature probe with a range of 0V to 1V for 0°C to 100°C.

This means that the voltage of the sensor diode has to be shifted (-0.75V) and amplified (-5 times). Hence the circuit as shown in the circuit diagram.

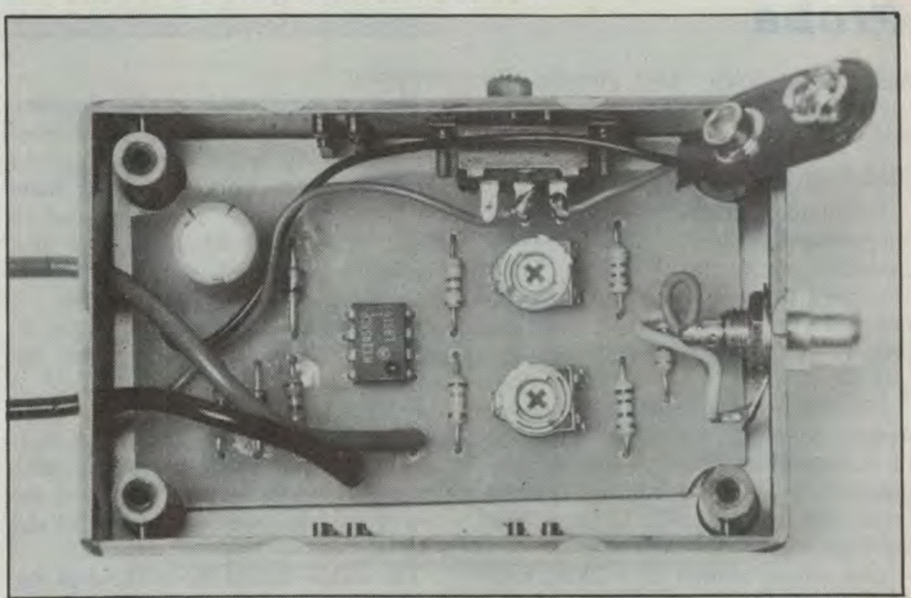
The circuit can be divided into three major parts; a voltage reference, a Wheatstone bridge and an amplifier.

The voltage reference consists of C1, R1, R2, ZD1 and ZD2. Firstly, the 9V from the battery is scaled down to 5.1V by R1 and ZD1. This voltage is scaled down further by R2 and ZD2 to 3.0V.

Only 3.0V from a 3.9V zener diode? Yes, that is possible. In order to save battery power, we've deliberately kept the current in the zener diode low. The result is that the voltage over the zener diode is lower than specified. But the stabilising effect still works quite well.



The circuit comprises a voltage stabilisation network, a wheatstone bridge (with the sensor diode) and a bridge amplifier.



The temperature probe has two adjustments, one for 0°C and one for 100°C.

This two-step voltage stabilisation is necessary as the supply voltage for the Wheatstone bridge should not vary more than a few millivolts. Knowing that the battery voltage drops substantially with age, the battery voltage therefore needs some thorough stabilisation.

Of all the possible values for zener diodes, the 3.3V and 3.9V types provide the lowest effective temperature coefficients in this circuit. We suspect this is because the small negative temperature coefficient of the diode itself (at this voltage) may balance temperature effects in the op-amps.

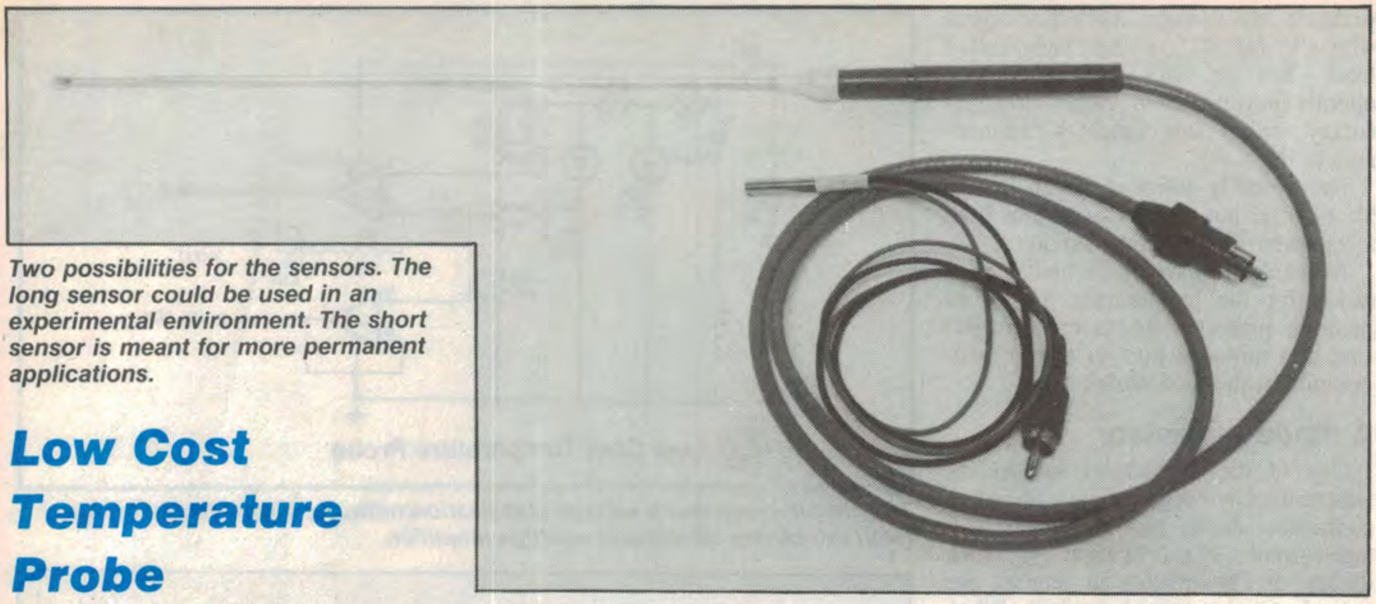
Capacitor C1 compensates for the increasing source resistance of the battery as it ages.

The Wheatstone bridge itself is formed by D1 (the sensor diode), R3, R4, RV1 and R5. The trimpot is adjusted so that the voltage between the cathode of the diode and the wiper of this trimpot is 0V for 0°C. In other words, the voltage across R4 and the top-end of RV1 is about 0.75V (as discussed before).

When the temperature increases, the voltage across the diode will decrease. The voltage between the wiper and the cathode of the diode will therefore increase proportionally with the temperature decrease.

This voltage difference (between the wiper and the cathode) is amplified about five times. This is done by op-amp IC1a, with its gain determined by R6, R7 and RV2. RV2 should be adjusted so that the voltage between the output of IC1a and the wiper of RV1 is 1V for 100°C.

The voltage at the wiper of RV1 is



Two possibilities for the sensors. The long sensor could be used in an experimental environment. The short sensor is meant for more permanent applications.

Low Cost Temperature Probe

buffered by IC1b. This provides the "zero" reference to which the output is referenced.

Making the sensor

The temperature probe consists of the temperature sensor (the diode) and the electronic circuit as described. There are many ways of constructing the actual sensor, depending on the application. We'll describe two possibilities (see Fig.1).

The first one can be used when a permanent sensor is required. This could be in your wine cellar to watch the temperature, in order to improve the matured taste of your 1972 Château Neuf Du Pape (appelation controlée).

This sensor consists of a 20mm brass spacer (as used in projects) with the sensor diode mounted inside. One end of the diode is soldered to the spacer. The other end is soldered to a length of insulated wire. The junction of the diode and the wire is covered with a piece of heatshrink sleeving.

The second wire is soldered to the spacer itself. The two wires are connected to the temperature probe PCB.

The spacer is quite strong and can be mounted to the wall (or elsewhere) as you would mount a cable or tube.

The second sensor is for more experimental or portable and general-purpose use. If we still assume that wine is your second hobby, then you could use this probe to check the temperature of fermenting wine!

This sensor is made of a long (300mm in our case) aluminium tube. It is 3mm in diameter, which is just enough to hold a normal 1N4148 diode. By the way we bought the aluminium tubing at a shop specialising in model aircraft supplies.

Have a good look at the diagram, which should explain the construction of this probe. We first soldered a length of insulated wire (longer than the main tube) to the diode. The other end of this wire we soldered to the core of a shielded cable. We put heat shrunk sleeves around the solder junctions.

We fed the diode with the wire attached through the tube until the unused lead of the diode appeared at the other side of the tube. For good thermal conduction, we put some thermal grease inside that end of the tube. Using the bench vice we squeezed the end of the tube, with the diode lead still sticking out.

The diode should be as close to the squeezed end as possible. Take care however not to damage the diode, which will happen if it's too close to the squeeze.

With a file we rounded off the squeezed end of the tube. Don't go too far however, otherwise you might get a small gap in the probe head — which would then leak.

The next step is to attach the shielding of the cable to the tube. This is a bit tricky as you can't easily solder to aluminium. Firstly we squeezed this end of the tube a bit, in order to stop it from turning around. Then we fed the shielding along the outside of the tube, and wrapped a piece of tinned copper wire around the tube with the shielding. This wire should be wound as tight as possi-

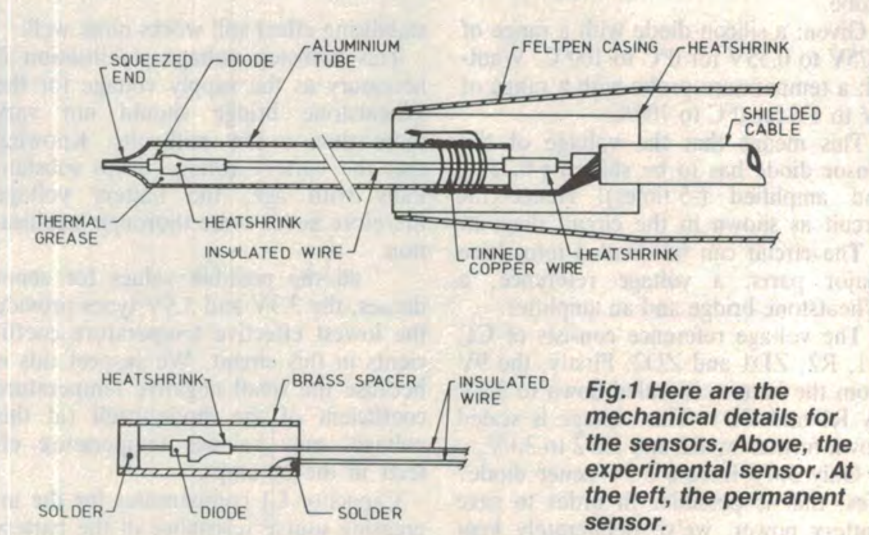
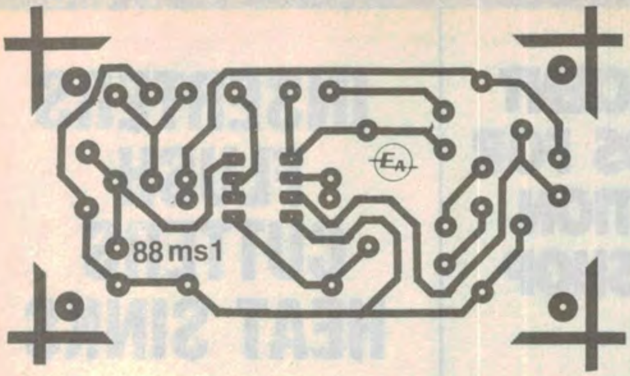
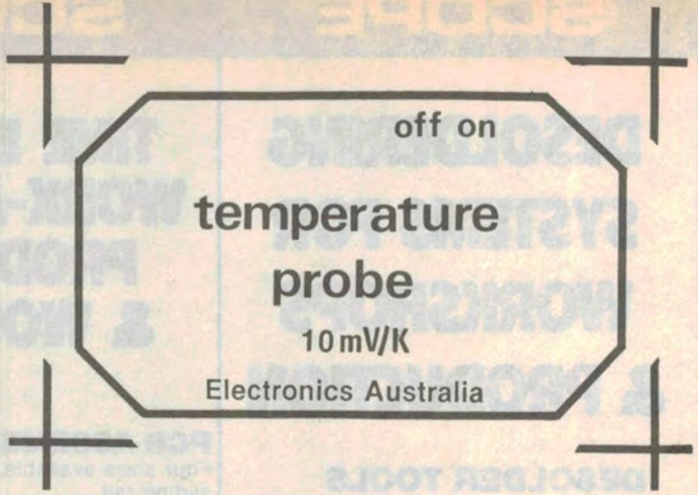
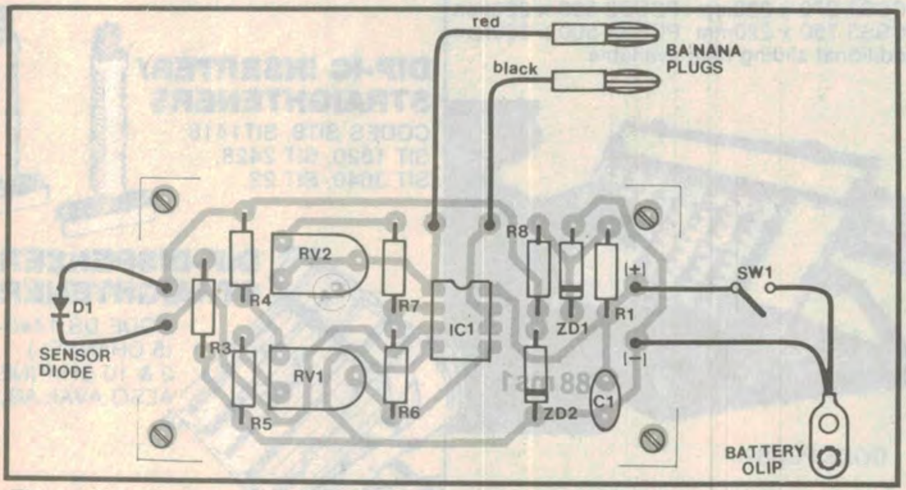


Fig.1 Here are the mechanical details for the sensors. Above, the experimental sensor. At the left, the permanent sensor.

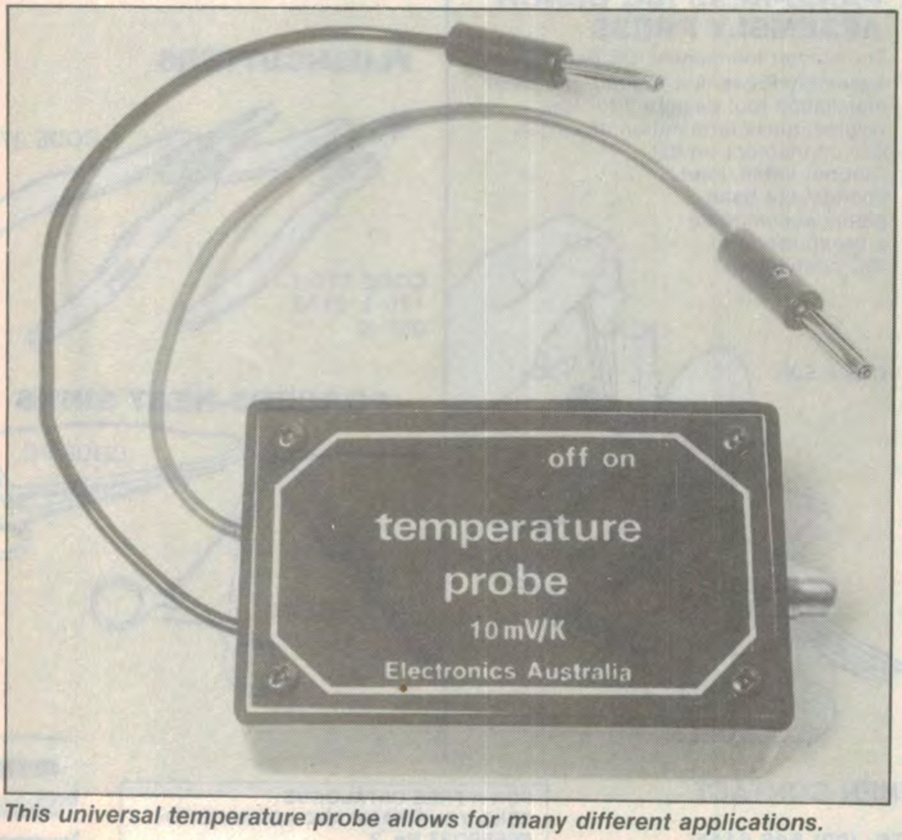




Full size reproduction of the PCB artwork (above) and the panel artwork (right).



The wiring diagram gives details of the assembly. Pay special attention to the orientation of the sensor diode.



This universal temperature probe allows for many different applications.

ble. The two ends were twisted together and soldered, to make the assembly as secure as possible.

The junction of the tube and the shielded cable was covered with heat shrink sleeving, as before.

Finally we rescued an old feltpen from the bin and used its casing to create a rigid sleeve around the cable/tube junction. At the other end of the cable we mounted an RCA plug.

Construction

The electronics of the probe is built on a printed circuit board (PCB) coded 88ms1 and measuring 38 x 72mm. We mounted the PCB in a small project case as we wanted to use it as an add-on temperature probe for our multimeter. As said before however, the probe has many other applications. If you intend to use it as part of a system, then you might be able to incorporate the PCB in another instrument case.

Start the construction of the probe by assembling the PCB. First mount the resistors, the zener diodes, the trimpots, the IC, and finally the capacitor. Make sure you watch the orientation of the IC, the electrolytic capacitor and the zener diodes.

Very often it is difficult to read the value of zener diodes. It is therefore advisable to keep the two zeners separated from the start, or perhaps even mark them yourself. It would be all too easy to mix them up.

The project case we used measured 28 x 54 x 83mm. The PCB is a bit larger than the four plastic uprights of the case to allow it to fit in easily. To make the PCB fit, we filed its corners in the shape of the uprights (round), after which the PCB fitted nicely in the case. No screws are required.

The 9V battery clip is connected to the PCB with the on/off switch in the "+" lead. The battery lays loose in the case, on top of the PCB. The battery should be isolated from the PCB by either a piece of foam, or otherwise a piece of cardboard.

The sensor is connected to the PCB via an RCA plug and socket. The socket is mounted to the project case, close to the actual connections on the PCB. Take care that you wire the socket up correctly; the diode in the sensor head should be conducting when operating.

The voltage output from the PCB is put out via two test leads. These leads are fed through two holes in the case and are directly soldered to the board.

Finally we made front panel artwork out of aluminium Scotchcal. The temperature probe should now be ready for testing and calibration.

Calibration

Connect the battery to the clip and switch the unit on. With a voltmeter you should measure the voltages across the two zener diodes. They should be 5.1V and 3.0V respectively. If this is not the case, then you should switch the unit off and check for solder faults, polarised components connected in the wrong way around, or cracks in PCB tracks.

Parts list

1 PCB coded 88ms1, 37 x 71mm
1 project case 25 x 54 x 83mm
1 Scotchcal panel artwork
1 RCA socket
1 pair of banana plugs
1 SPST switch
1 9V battery and clip

Semiconductors

1 LM1458 dual op-amp
1 1N4148 silicon diode
1 5.1V zener diode
1 3.9V zener diode

Capacitors

1 220uF 25VW electrolytic, vertical mount

Resistors (0.25W, 5%)

2 x 270Ω, 1 x 1k, 1 x 4.7k, 1 x 6.8k, 1 x 47k, 1 x 180k
1 x 1k, trimpot horizontal mount
1 x 100k, trimpot horizontal mount

Sensor

1 x aluminium tube 3 x 300mm (see text)
1m shielded cable
1 x RCA plug
heat shrink sleeving

Now connect the sensor to the unit and connect the voltmeter to the appropriate leads (red to the voltage input and black to the common input). The voltmeter will read something between +2V and –2V. When you warm up the sensor with your hands, you should see the reading of the meter change. If you haven't encountered any problems yet, you can move on to the calibration of the unit.

For the calibration operation itself you'll first need a bowl of water with plenty of melting ice cubes. Put the sensor into the bowl and stir vigorously for a few minutes. This bath should have a temperature of exactly 0°C. Now adjust the 'zero' trimpot (RV1) for 0V reading on the voltmeter.

The next step is to boil some water and insert the sensor in the boiling water. The water should have a temperature of 100°C, provided that the air pressure is at 1 atmosphere (as it will be if you're at roughly sea level). So unless you're on the top of the Blue Mountains or somewhere, it won't be far from 100°C, and you can adjust the "100°C" trimpot (RV2) for 1.00V reading on the voltmeter.

You could repeat the 0°C calibration, but this shouldn't have changed.

For an exact calibration you should use distilled water for both calibrations, but this is probably gilding the lily for most purposes.

You can easily check whether the temperature probe works alright for other temperatures. For instance the room temperature. At the time of writing, the probe read 21.4°C, which should be about right. You could also check your own body temperature. If the probe reads less than 35.5°C or more than 40.0°C, then you should consider either recalibrating the probe or more dramatically, seeing your doctor . . .

By the way, if you're really planning on using the probe to check whether your kids are running a fever, we suggest that you don't put it in their mouth. Get them to hold it under their armpit for a couple of minutes — it'll be more hygenic, unless you make up a special probe that can be dunked in germicide to kill the germs. Otherwise they might develop a fever after you check their temperature, even if they didn't have one before!