# Thermocouple probe for your digital multimeter

*Do you need a thermocouple probe for your multimeter but cannot afford the commercial models? This probe suits any digital multimeter and can also be used with analog multimeters.*

**by LEO SIMPSON Design by BOB FLYNN**

Anyone who designs and builds amplifiers or power control circuits needs a means of measuring temperatures over a wide range. A thermocouple probe which can be connected to a digital multimeter is an attractive proposition but commercial probes can cost $200 or more. This EA design will cost considerably less than that.

## Temperature range

This design uses an iron-constantan thermocouple which can measure temperatures up to 350°C on a continuous basis or up to 400°C intermittently. The lower temperature limit is about −17°C, as set by the circuit itself.

This large temperature range will allow measurement of body temperatures of all power semiconductors and wirewound resistors. The probe will also have applications in automotive engineering and in many laboratory situations.

At the same time, the minimum temperature limit of −17°C will be suitable for checking freezers and refrigerators.

## Accuracy

Let's immediately put accuracy into perspective. Thermocouples are not particularly linear devices. That is to say, their temperature coefficient is not constant throughout their operating temperate range. An iron-constantan thermocouple is one of the more linear types in this respect but unless a complicated compensation circuit is employed, the best accuracy that can be expected is within about ±3.5% over the whole range.

In other words, just because this thermocouple probe is mainly intended for use with digital multimeters, we make no claim to have achieved typical DVM accuracy. The best you will achieve is within about 2°C over the range from 0°C to 150°C. For most applications that is more than adequate.

## Output voltage

This thermocouple probe is really a temperature to voltage converter. It has an output which is zero at 0°C and varies at the rate 10mV/C°. This makes it suitable for all digital multimeters and analog multimeters with an input impedance of 10MΩ.

The electronic components of the circuit are housed in a small plastic zippy box measuring 83 × 55 × 32mm. This is fitted with two banana jacks on one end to plug directly into any digital multimeter. The unit is powered from a single 9V battery.

Now let's discuss the theory of operation. A thermocouple is made by joining wires of two different metals, as shown in Fig. 1. The output voltage is proportional to the difference in temperature between the measuring junction and the reference junction. The constant of proportionality is known the Seebeck coefficient and ranges from 5μV/C° to over 50μV/C° for commonly used thermocouples.

How do we use this Seebeck effect to directly measure temperatures? One way is to maintain the reference junction at a constant 0°C (in an ice bath). This means that the thermocouple output will be zero when the measuring junction is at 0°C and we will not have to worry about what the ambient temperature is.

Well, ice baths are nice and reproduceable but they are not the most

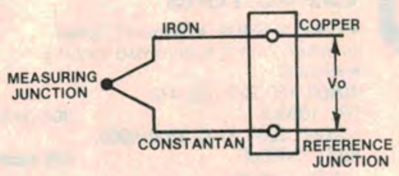


Fig. 1

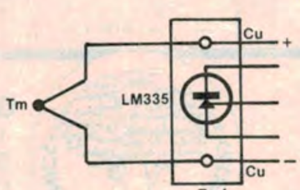


FIG. 2

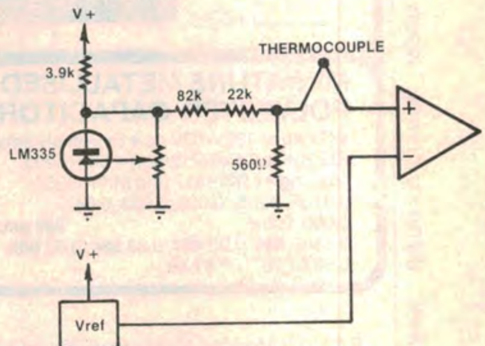


Fig. 3

**Fig. 3: basic thermocouple probe circuit. The LM3535Z provides reference junction compensation.**


convenient way of providing a fixed reference. A more convenient method is to add a compensating voltage to the measuring circuit so that the reference junction appears to be always at 0°C when, in reality, it is floating up and down at the ambient temperature.

Our circuit has this reference junction compensation. It takes the form of a National Semiconductor LM335Z precision temperature sensor. This semiconductor device generates a voltage which is directly proportional to the absolute temperature. Fig. 2 shows

**The Thermocouple Probe plugs directly into your digital multimeter and can measure temperatures from −17°C to +350°C.**


We estimate the current cost of parts for this project to be

**$25-$28**

This includes sales tax but does not include the cost of the thermocouple which will vary according to type.

that the LM355Z is held at the same temperature as the reference junction.

The method of compensation works like this. The output of the LM335Z is adjusted and divided so that it looks like another thermocouple, as far as the circuit is concerned. Its output is connected in series with the measuring thermocouple which is connected to an op amp measuring circuit. At the same time, another reference voltage is used to

**Fig. 5: final circuit for the Thermocouple Probe. Note that the meter is connected to the reference output, pin 1, so that temperatures below 0°C can be measured.**

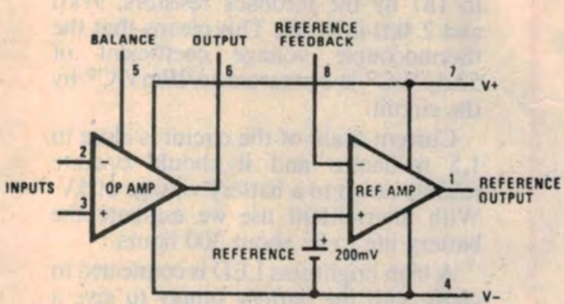
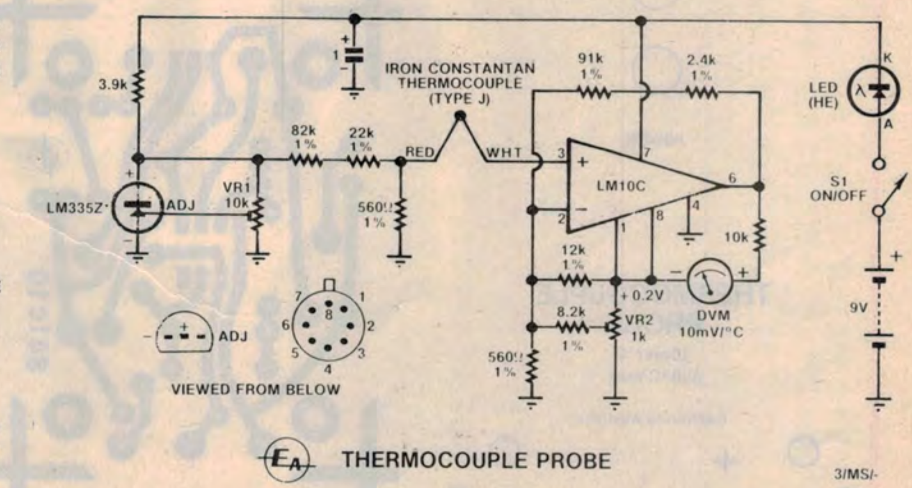



**Fig. 4: the LM10C contains a precision voltage reference, an adjustable buffer, and a high-quality op amp.**



# Thermocouple probe for your digital multimeter

buck out the absolute voltage generated by the LM335Z.

The method of connection is shown in Fig. 3. It works like this. When the thermocouple is at ambient temperature it generates no voltage. But the LM335Z does generate a voltage.

Now the interesting point about the LM335Z is that it can be calibrated to have less than 1°C error over a 100°C temperature range by setting it give 2.932V at 20°C.

If we then feed the LM335Z output voltage through the divider (82kΩ + 22kΩ + 560Ω) the output at 20°C is then 15.7mV and it will change at 53.5μV/C° which is the same as the Seebeck coefficient of the thermocouple.

So now we have two temperature-dependent voltage sources connected in series to the non-inverting input of the op amp in Fig. 3. Thus the output of the op amp will be directly proportional to the temperature at the measuring junction. There will be no need to correct the measured temperature by adding in the ambient temperature; the circuit has done that for us.

One problem remains though. The LM335Z has an output of 14.6mV at 0°C. This means that the op amp will not have a zero output at freezing point which is what we want. We need to cancel out the effect of that 14.6mV "offset" from LM335Z at 0°C. This is accomplished by feeding a fixed 14.6mV to the inverting input of the op amp.

The output of the op amp will now be zero at freezing point and the output voltage will be directly proportional to the temperature in degrees Celsius.

## Op amp requirements

The op amp we require is rather special. Ideally it should operate from a single low voltage supply, have a low current drain to conserve the battery and have an especially low drift. In addition, we also have the requirement of a fixed voltage reference which is needed to cancel out the LM335 offset.

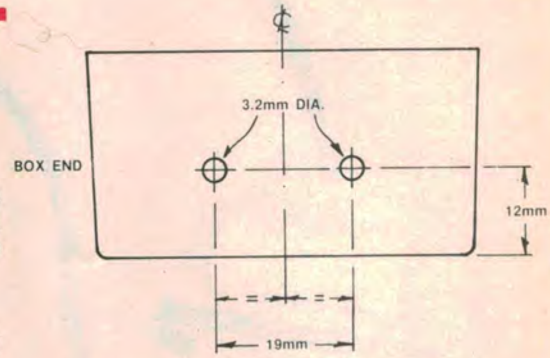
It so happens that there is one op amp which meets all these requirements neatly, including having an inbuilt voltage reference. It is the National Semiconductor LM10C. This is described by the manufacturer as a monolithic IC consisting of a precision voltage reference, an adjustable reference buffer and an independent high quality op amp.

The LM10C will operate from a single supply voltage ranging from a low of 1.1V up to 40V, with a current drain of only 300μA (typical). Its complementary output stage will swing to within 15mV of the supply terminals.

The inbuilt voltage reference is 200mV and this may be amplified by the buffer if necessary.

## The circuit

Now lets have a look at the final




**Above: mounting details for the banana jack plugs. At right is the wiring diagram. Take care with the orientation of polarised parts.**

circuit which uses the LM10C. The components associated with the LM335Z have already been discussed but the way in which the internal voltage reference is used needs explanation.

The reference output of the LM10C is set at 200mV by operating the internal buffer stage as a unity gain amplifier. This is accomplished by connecting pin 1 to pin 8 (see the function diagram of the LM10C, Fig. 4.) VR2 sets the input voltage to pin 2 to balance out the 14.6mV from the LM335Z (at 0°C).

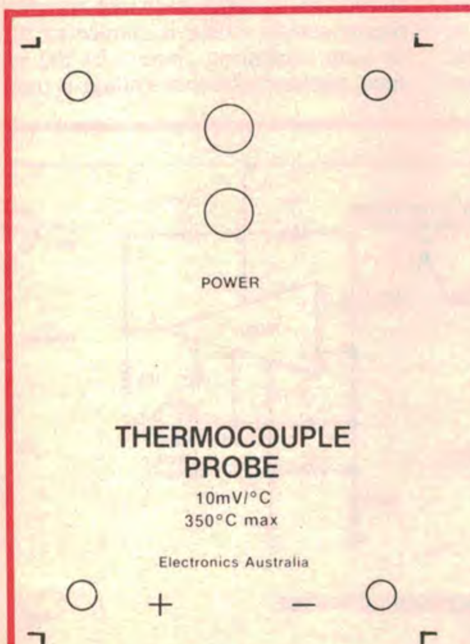
There is another wrinkle in the way in which the meter is connected. Note that it is not connected to the 0V rail but to the reference output, pin 1. This means that the negative side of the meter is jacked up by 200mV above the 0V rail. This means that pin 6 of the LM10C should also be at +200mV when the thermocouple is at an ambient temperature of 0°C. In fact VR2 accomplishes this.

The reason for tying the negative side of the meter to +200mV is so that temperatures below 0°C can be measured. If the meter was tied to 0V it would not be able to register temperatures down to 0°C because the LM10C cannot swing its all the way down to 0V.

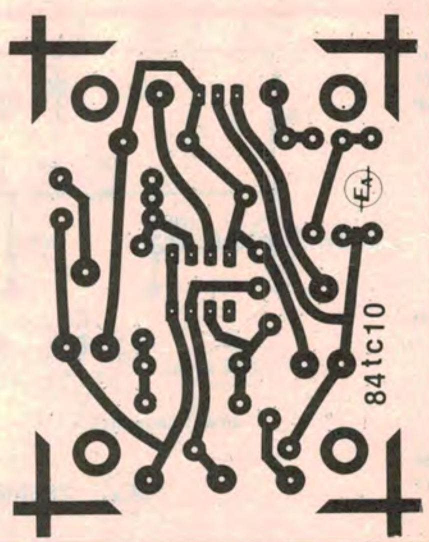
The voltage gain of the op amp is set to 187 by the feedback resistors, 91kΩ and 2.4kΩ in series. This means that the thermocouple voltage coefficient of 53.5μV/C° is converted to 10mV/C° by the circuit.

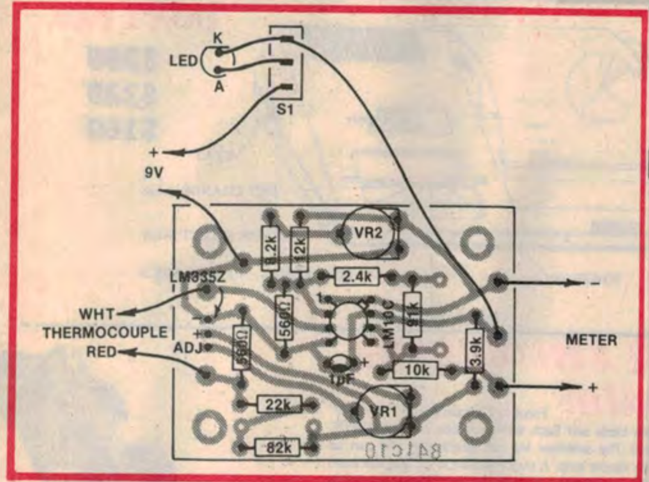
Current drain of the circuit is close to 1.5 milliamps and it should operate reliably down to a battery voltage of 5V. With intermittent use we estimate the battery life to be about 300 hours.

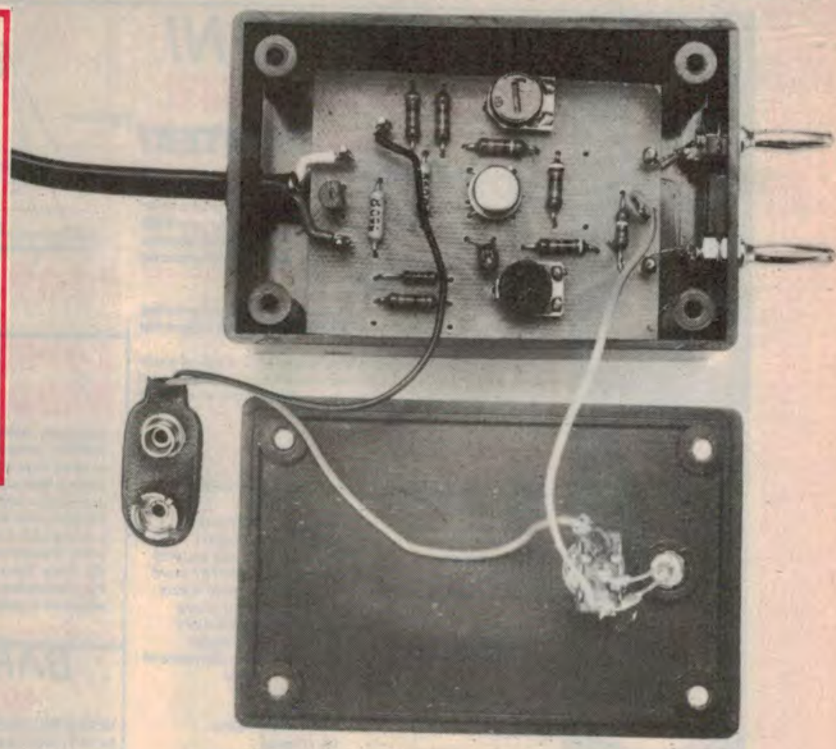
A high brightness LED is connected in series with the battery supply to give a pilot light. This scheme is more economical than separately powering the LED from the battery supply, yet provides sufficient LED brightness.



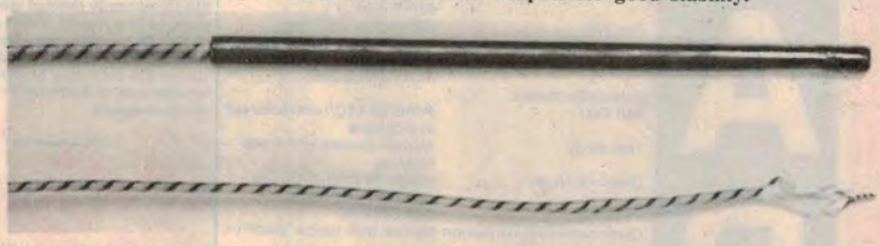

**Here are actual size artworks for the front panel and the PC board.**





View inside the prototype. Use enclosed cermet trimpots for good stability.



Depending on your application, you can use either a probe-type thermocouple or a simple welded junction thermocouple (eg, for monitoring heatsink temperature).

## PARTS LIST

- 1 zippy box, 83 × 55 × 32mm, with plastic lid
- 1 label to suit
- 1 PC board, 60 × 45mm, code 84tc10
- 1 216 9V battery plus clip connector
- 1 SPDT miniature toggle switch
- 1 thermocouple probe (see text)
- 1 LM10CN op amp
- 1 LM335Z temperature sensor IC
- 1 high brightness red LED plus bezel
- 1 1µF/35V tantalum capacitor
- 6 PC pins
- 2 banana jack pins

***Resistors*** (¼W, 1% unless specified)
1 × 91kΩ, 1 × 82kΩ, 1 × 22kΩ, 1 × 12kΩ 1 × 10kΩ/5%, 1 × 8.2kΩ, 1 × 3.9kΩ/5%, 1 × 2.4kΩ, 1 × 560Ω, 1 × 10kΩ cermet trimpot, 1 × 1kΩ cermet trimpot

## Construction

All the circuit components with the exception of the LED are mounted on a small PC board measuring 60 × 45mm and coded 84tc10. Assembly is a simple matter as only a few parts are involved.

Two versions of the LM10C are suitable for this circuit. They are the LM10CH, the metal package, or the LM10CN, the dual in-line plastic package. If the metal package is used its leads should be bent to suit the in-line lead configuration and pushed down onto the board as far as possible.

Note that most of the resistors are specified with 1% tolerance and so will have five colour code bands instead of the usual four. Read them carefully before installing the resistors.

Both trimpots should be the enclosed "cermet" variety for good stability.

Note that the PC board should be installed in the zippy box and the thermocouple connected before any checks can be made. Make sure the thermocouple leads are well-tinned before attempting to solder them to the PC pins on the board.

Output connections are made to banana jack pins (fitted with nuts) which are fitted to the zippy box at ¾-inch centres (19mm) to suit most digital multimeters.

We fitted the high brightness LED into a red bezel to make an effective pilot light for the unit. The LED is wired across the SPDT switch as shown in the diagram.

By the way, all the parts for this project may be obtained from Geoff Wood Electronics, 656a Darling St, Rozelle NSW 2039. Phone (02) 810 6845.

## Calibration

This is a simple procedure. Ideally you need a laboratory grade thermometer plus your digital multimeter. First step is to note the ambient temperature in the vicinity of the thermocouple junction. Then VR1 should be set so that the voltage across the LM335Z is equal to 2.732V plus 10mV multiplied by the ambient temperature.

For example, if the ambient temperature is 15°C the voltage across the LM335Z should be 2.732V plus 150mV which equals 2.882V.

Now plug the unit into your digital multimeter which should be switched to the 2V range. Adjust VR1 to give a reading on the DMM which is the product of the ambient temperature multiplied by 10mV/C°. For example, if the temperature is 21°C the voltage reading should be 210mV.

And that's it. If you wish you can now check the thermocouple at reference temperatures of 0°C and 100°C using ice and boiling water respectively but it should only confirm that the system is accurate to within about 2° or better

*Continued on page 117*

# Thermocouple probe . . . from p55

over the whole range.

Final assembly consists of shoehorning the PC board and battery into the case. The battery should be insulated from the circuit board components with a thin layer of foam rubber.

A number of thermocouples are pictured in this article. If you require a probe type thermometer it can be quite expensive, depending on its construction. For many temperature applications a simple welded junction with fibreglass leads is all that is required and it is inexpensive. Such a cheap thermocouple can be readily attached to a semiconductor case or heatsink and good thermal contact is assured with a dab of heatsink compound.