

USING THERMISTOR TEMPERATURE SENSORS WITH CAMPBELL SCIENTIFIC DATALOGGERS

In many applications, thermistor probes represent a convenient and reliable method of measuring temperature. The change in electrical resistance of a thermistor with temperature is significant (unlike a PRT) and, when the thermistor is deployed within a suitable bridge, a millivolt output may be obtained in contrast to the microvoltages supplied by a thermocouple.

Unfortunately, the change of resistance with temperature is non-linear for a thermistor, and the characteristic response curve varies with thermistor type. The non-linear response can be compensated for by using an appropriate algorithm or by carefully selecting the value of the bridge resistors to provide linearisation over a limited range, or by a combination of both techniques. Furthermore, most manufacturers produce a range of 'unicurve' thermistors with closely matched characteristics; this allows the user to interchange temperature probes without the need for recalibration.

Virtually any thermistor can be used with Campbell Scientific dataloggers providing sufficient attention is paid to the construction of the probe and the linearisation method. Many users, however, prefer to use a single type of probe which is interchangeable and for which an output in degrees Celsius is easily obtained and recorded. Campbell Scientific's 107 probes fulfil these requirements and are available at a reasonable cost. This Technical Note provides the user with detailed information on the construction, use and limitations of the 107 probe and offers advice on methods of using alternative thermistors with Campbell Scientific equipment.

CAMPBELL SCIENTIFIC'S 107 THERMISTOR PROBE

This probe is based around a precision thermistor and is designed to measure over a wide temperature range. The thermistor has a resistance of 100k Ω at 25°C and has a highly reproducible response curve. The large resistance is useful in minimising the effects of long cable runs and the thermistor is

deployed in a bridge circuit (see 107 Instruction Manual). This has a 1k Ω resistor chosen to reduce the input resistance of the sensor (as seen by the datalogger) and to minimise settling errors which can occur when the cable length is large.

The 107 probe is normally used with Instruction 11, which applies a precise excitation voltage to the bridge before making a single-ended voltage measurement across the 1k resistor. When using Instruction 11, the measured voltage is converted to temperature through a fifth order polynomial conversion. An additional resistor is included in the bridge to optimise the fit of the polynomial over the full temperature range of -40°C to +56°C; the errors introduced are typically $\pm 1.0^\circ\text{C}$ over the range -40°C to +56°C, but reduce to $\pm 0.1^\circ\text{C}$ over the range -23°C to 48°C.

NOTE: The linearisation errors can be reduced in critical applications by using a software correction (see Technical Note 21-95AS).

Good quality polyurethane cable is used with Campbell Scientific's 107 probes and the cable screen is only connected at the datalogger, which provides good interference immunity.

In some applications the physical construction of the 107 probe is not ideal; here the simplest option is to build a probe which mimics the circuit of the 107, and to use Instruction 11 to read the temperature. Points to note for the construction are:

1. The resistors must be either bought or selected to 0.02% tolerance and must also have a low temperature coefficient, i.e. 10 ppm or preferably 5 ppm/ $^\circ\text{C}$.
2. The sensor must be well sealed against the ingress of water; any moisture in the probe will affect the reading because the thermistor has a large resistance, comparable to that of a film of water when it bridges the conductors.

DESIGNING OTHER THERMISTOR PROBES

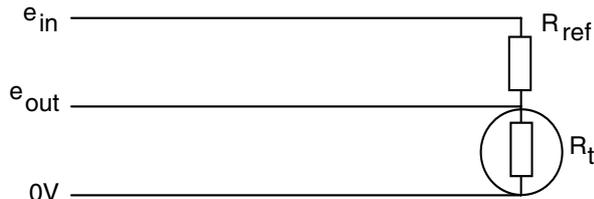
With other thermistors there are two options for calculating the probe temperature.

OPTION 1: HALF BRIDGE WITH NON-LINEAR OUTPUT

Configure the thermistor in a half bridge with a fixed reference resistor (see Fig. 1). Instruction 4 (Excite, Delay and Measure) can be used to measure the output voltage. Alternatively, Instruction 5 (AC Half Bridge) may be used to measure the ratio (X) of the voltage across the thermistor to the excitation voltage. This may then be converted to the thermistor resistance (Rt) by the simple algorithm:

$$R_t = R_{ref} [X/(1-X)]$$

NOTE: This is a built-in function of the datalogger instruction set (Instruction 59).



$$x = \frac{e_{out}}{e_{in}} = \frac{R_t}{R_{ref} + R_t}$$

FIGURE 1

Individual readings of resistance can be stored by the datalogger and then converted to a temperature at a later stage, e.g. on a computer using a fitted curve. Beware of averaging the measured resistances; a mean resistance will not be easy to convert to mean temperature because the relationship between resistance and temperature is non-linear.

A worked example using the 21X to accurately measure snow and ice temperatures using this technique is given in Appendix A.

OPTION 2: HALF BRIDGE WITH LINEARISED OUTPUT

Configure the thermistor in a half bridge (as above) but select the reference resistor so that the relationship between the voltage output and temperature is 'almost linear' over the desired temperature range. For many applications the non-linearity errors are

small enough to be ignored. For more critical applications the 'almost-linear' voltage output provides a good basis for fitting a non-linear function. Generally a third or fourth order polynomial provides an excellent fit and the function can be used in Instruction 55 (Polynomial) to convert the measured voltage into a temperature.

The method of calculating the optimum value of linearising resistor for a given temperature range was originally published by Burke (*Electronics*, 2nd June 1981). First define the thermistor resistance at the lowest (R_a), middle (R_b) and highest (R_c) temperatures to be measured. R_{ref} is then

$$R_{ref} = \frac{R_b(R_a + R_c) - 2R_a R_c}{R_a + R_c - 2R_b}$$

Generally the value of R_{ref} as calculated is not a 'preferred value' and so the resistor cannot easily be obtained. The closest possible value must therefore be selected. Knowing this value it is possible to predict the output voltage for any bridge excitation voltage. (Refer to Burke's paper or to Campbell Scientific for further details of how to calculate R_{ref} , the output voltage and the errors that would be incurred if this was accepted as a linear response.)

A worked example using this linearisation technique is given in Appendix B.

CHOOSING THE EXCITATION VOLTAGE

Generally, you should choose a voltage so that the highest output voltage, at the lowest temperature, is close to the top of one of the voltage ranges of the datalogger, thereby increasing the sensitivity. For very low bridge resistances the possibility of self-heating of the thermistor should also be considered. In practice the datalogger only powers the sensor for a few milliseconds, which ensures that self-heating is negligible, but for fast, continuous logging it would be safer to reduce the excitation voltage and measure the output on a more sensitive voltage range. This process also reduces power consumption.

THE EFFECTS OF CABLE LENGTH

Long cable runs can cause two sources of error in the measured temperature. Firstly, the cable resistance will add to the thermistor resistance and cause an error in the absolute accuracy of the measurement if not accounted for. The error is generally negligible unless extremely long cables are used and/or the base resistance of the thermistor is low (2k or less).

In such instances the thermistor might either be configured as a 3-wire half bridge (see Instruction 7), which compensates for the lead resistance, or alternatively the cable resistance could be measured once during the sensor construction and this resistance added to the thermistor resistance before calculating the calibration coefficients. The first technique is undoubtedly the most accurate, but it requires an additional input channel.

The second effect of long cables is to increase any settling errors in the voltage measurement (a full discussion of these errors is given in the datalogger manuals). Settling errors can be reduced by using a high quality cable with a low capacitance. Secondly, when using Instruction 4, a delay can be introduced before the measurement is made to allow the reading time to settle. The settling error can also be reduced by dividing R_{ref} into two components (as in the 107 probe). The resistance across the input terminals should be 1000 ohms or less, although the total value of R_{ref} should remain unchanged. The calibration coefficients must, of course, be corrected when using this latter technique.

THERMISTOR BRIDGES

Burke (1981) describes how to construct multi-thermistor bridges which have errors in non-linearity which are an order of magnitude better than for a single thermistor. However, apart from the cost of using two or more thermistors and precision resistors, similar accuracy can be achieved by fitting a polynomial to the output of a single thermistor bridge. It follows that the construction of multi-thermistor bridges is rarely justified, especially as ready made, linearised, multi-thermistor probes and bridges have recently become available from manufacturers such as Fenwall. These sensors may be used directly with a Campbell datalogger, but note that settling errors and cable length must be considered as with any other high resistance sensor.

ABSOLUTE ACCURACY OF THERMISTOR PROBES

Whichever linearisation technique is used, the absolute accuracy (as opposed to the linearisation accuracy) is dependent on the quality of the thermistor used. Most thermistors are only guaranteed to be within $\pm 0.2^\circ\text{C}$ absolute accuracy over a limited temperature range. For improved tolerance, the thermistors must either be selected carefully from batches, or else each probe must be calibrated individually and corrections made when calculating the linearisation coefficients.

In the case of the 107 probe, individual calibrations can usually be catered for by a linear correction whereby the multiplier and offset are changed from one and zero to give the corrected reading.

RESISTOR SELECTION

Finding a supplier for resistors with non-standard values and a low temperature coefficient can be difficult, and often these components are available only in large quantities. One compromise is to buy resistors with a low tolerance and select to the specification required. It is often the case that one fifth of resistors sold with a 1% tolerance are actually within 0.1% of the marked value.

In many applications, the use of resistors with a temperature coefficient of 50 ppm will be quite acceptable as the error introduced over a 50°C range of temperature rarely exceeds 0.1°C .

Several suppliers offer resistors with less common values, and Campbell Scientific Ltd. are willing to supply the resistors used in the 107 probe.

APPENDIX A. WORKED EXAMPLE USING HALF BRIDGE WITH NON-LINEAR OUTPUT

An accurate measurement of ice temperature is required using a precision thermistor. Power dissipation in the thermistor must not exceed $1\mu\text{W}$. Lead wire resistance is to be measured separately. A 21X will be used.

Required measurement range	9k Ω -40k Ω
Max. power dissipation in the thermistor	$1 \times 10^{-6}\text{W}$
Resolution required	0.05% of the reading
Accuracy required (thermistor measurements)	0.25% of the reading

As lead wire resistance is measured separately and used in the subsequent calculations to obtain ice temperature, a standard 2-wire half-bridge configuration is considered adequate. This produces one single-ended output per thermistor allowing up to 16 thermistors to be connected to a 21X datalogger.

Max. power dissipated, $I^2R_t = 1 \times 10^{-6}\text{W}$

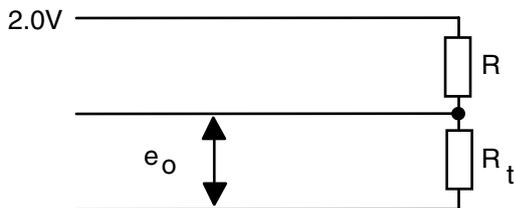
if $R_t = 40\text{ kohms}$,

$$I = \sqrt{0.25 \times 10^{-10}} = 5 \times 10^{-6}\text{ A}$$

Therefore current through a thermistor must not exceed $5\mu\text{A}$. Assume an excitation voltage (for the bridge) of 2.0V.

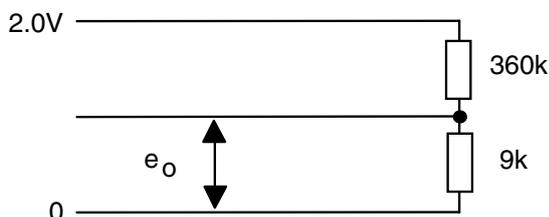
if: $R_t = 40\text{ k}\Omega$
 $i = 5\mu\text{A}$

then $(R + R_t) = 400\text{ k}\Omega$

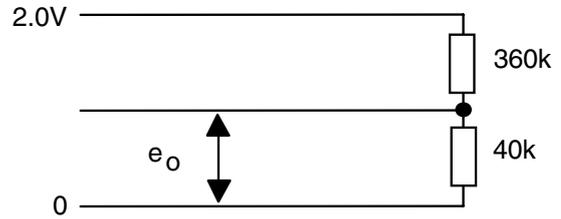


Thus $R = 360\text{ k}\Omega$

Now consider the extreme cases:



$$e_o = 2. \frac{9}{9 + 360} = 48.78\text{mV}$$



$$e_o = 2. \frac{40}{40 + 360} = 200\text{mV}$$

Unfortunately, the ranges on the 21X do not match well with these outputs, and some adjustment is required to get the best resolution for the measurements. We select the 50mV range on the 21X and reduce the bridge excitation voltage to 0.5V. The bridge output voltages are now 12.19mV (9k Ω) and 50.0mV (40k Ω) which makes the fullest use of the 50mV range.

RESOLUTION

On the 50mV range, the resolution is $6.66\mu\text{V}$ (for a single-ended measurement).

When $R_t = 9\text{ k}\Omega$, resolution is

$$\frac{0.006}{12.19} \times 100 = 0.05\%\text{rdg}$$

When $R_t = 40\text{ k}\Omega$, resolution is

$$\frac{0.006}{50.0} \times 100 = 0.01\%\text{rdg}$$

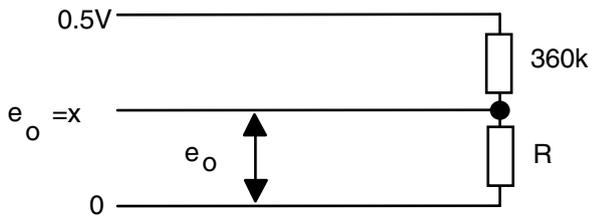
Thus the required resolution is achieved over the full working range.

ACCURACY

The accuracy of voltage measurement on the 21X is 0.1% FSR which exceeds the required specification. Note, however, that accuracy depends on the characteristics of the 360k resistor. A precision wirewound resistor would be ideal (a few ppm temperature coefficient and $\pm 0.1\%$ accuracy).

CONVERTING BRIDGE OUTPUT TO RESISTANCE

A multiplier in the measuring instruction is used to scale the bridge output initially and a Bridge Transform instruction is subsequently used to calculate resistance for each thermistor.



$$x = \frac{R}{(360k + R)} \times 0.5$$

$$R = \frac{\left(\frac{x}{0.5}\right)}{1 - \left(\frac{x}{0.5}\right)} \times 360k$$

The following program illustrates the use of Instructions 4 and 59 to calculate the resistance of a single thermistor.

*1 Enter Table 1
10 Execution interval is 10 seconds

P4 Excite, delay and measure
1 Repts
3 Range = 50mV
1 Input Channel
1 Excitation Channel
10 Delay by 0.1 sec
500 Excitation is 500mV

1 Location to store
0.002 Multiplier (to give X/0.5)
0.0 Offset

P59 Bridge Transform X/(X-1)
1 Repts
1 Location of X
360 Multiplier

Output (in kohms) is stored in location 1.

APPENDIX B. WORKED EXAMPLE USING HALF BRIDGE WITH LINEARISED OUTPUT

Consider the Fenwall Unicurve UUA4IJ1 thermistor. This has a resistance of 10k ohms at 25°C. For the temperature range of -10 to +30°C the optimum bridge resistance is calculated at 15677 ohms. The closest value commercially available from a standard range is 15800 ohms. Using this value and 2.5V excitation, the maximum error in assuming a linear relationship between temperature and output ($\text{Temp} = 36.35 * V - 30.2$) is $\pm 0.6^\circ\text{C}$.

By fitting a polynomial to the output:

$$\text{Temp} = -38.79 + 65.1V - 28.55V^2 + 8.65V^3$$

the error can be reduced to $\pm 0.03^\circ\text{C}$.

In practice it is better to select a temperature range for the linearisation which is slightly less than that actually required. This procedure reduces errors slightly; in the example above, choosing a range of -5 to +25°C reduces the linear error to $\pm 0.2^\circ\text{C}$ within that range, yet the errors at the extremes of the span are increased only slightly.