



Module 1, Lesson 5 – Building a linear temperature sensor

Student

45 minutes

Purpose of this lesson

- Combine a thermistor with a potential divider circuit to build a sensor whose output varies linearly and positively with temperature.
- Use a multimeter to measure the output voltages of a circuit.
- Calibrate the temperature sensor.
- Carry out an experiment to empirically evaluate the accuracy of the sensor.

Materials

Copy of the lesson

1 Multimeter

1 9V battery

1 Battery snap

1 Resistor

1 Thermistor

1 Beaker

Ice

Hot water

1 Thermometer

Graph paper (or Excel)

Hook up wire

1 Soldering iron

Solder

Liquid electrical tape

Part 1 - Building a linear temperature sensor

Build the circuit shown in fig. 1. (NOTE: It will be helpful to coat the soldered thermistor/wire union with liquid electrical tape) If you wish to use your sensor to

measure temperatures at different depths in a river, you may want to use long leads (e.g. 15ft) to the thermistor, so that you can lower it into the water to significant depths. You could also mark one foot intervals on these leads with tape, so that you can tell what depth the thermistor is in the water.

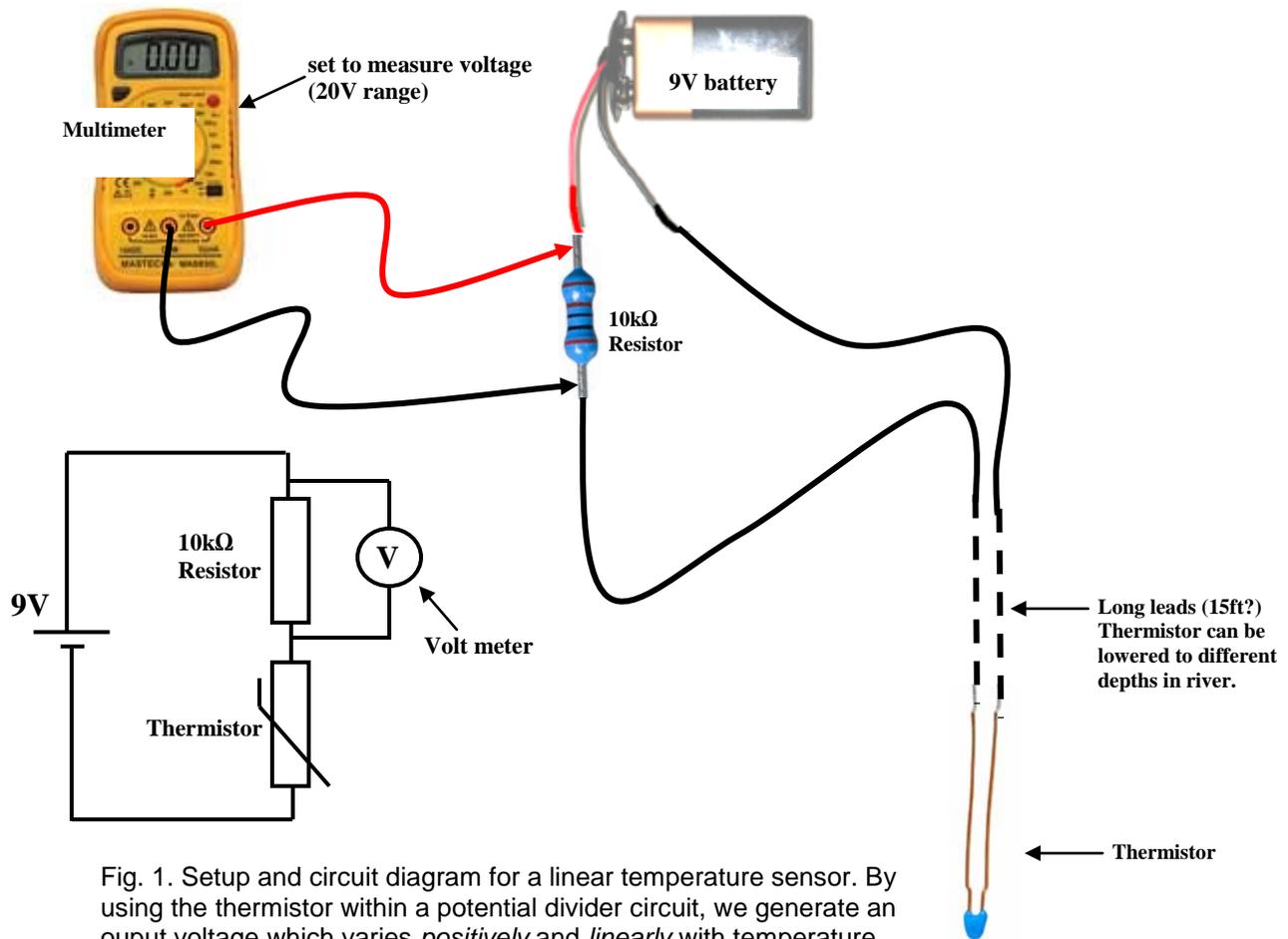


Fig. 1. Setup and circuit diagram for a linear temperature sensor. By using the thermistor within a potential divider circuit, we generate an output voltage which varies *positively* and *linearly* with temperature.

Use the multi-meter to measure the voltage across the 10kΩ resistor (using the multi-meter as a *volt meter* as shown in the circuit diagram). This voltage will be the “output signal” of the sensor. We will convert this output signal into an equivalent temperature.

We could have just used the multi-meter as an Ohm meter, as in lesson 3, to measure the resistance of the thermistor directly. We could then have used a graph or look up table (or perhaps a complicated formula) to convert resistance readings into temperature measurements.

The reason for building this new circuit is that its output varies *linearly* and *positively* with temperature. By understanding the math for an equation of a straight line ($y=mx+b$) a simple formula can be derived that will convert sensor outputs (voltages) into temperature measurements.

Part 2 - Calibrating your linear temperature sensor

2a) Using the above circuit, measure the output voltage (voltage across the 10kΩ resistor) while exposing the thermistor to a range of different temperatures. Place the thermistor in a cup of hot water. Measure the temperature with a thermometer and at the same time read the output voltage from the multi-meter. Now reduce the temperature by adding a little cold water and stirring/mixing well. Repeat over a range of temperatures, eventually adding ice to get down to 0°C. Record results in the table below (or similar) and then on a graph with temperature on the vertical axis (y-axis) and output voltage on the horizontal axis (x-axis).

| | | | | | | | | | | |
|------------------------|---|----|----|----|----|----|----|----|----|----|
| Temp.°C | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| V_{out} | | | | | | | | | | |

2b) Is your graph exactly the same as the one you predicted in lesson 4? If not, can you suggest some reasons to explain any differences?

2c) Over what range of temperatures is it reasonable to approximate your graph as being a straight line? Is this a useful range if you want to use your sensor to measure the temperature of the Hudson River?

2d) Using a ruler, best fit a straight line to your graph over the range of values that you think can be reasonably approximate by a straight line (probably 0°C up to about 40°C).

2e) Derive the equation of this straight line using the formula $y=mx+b$. In this case your Y axis represents temperature, and X axis represents the sensor output voltage, V_{out}. Hence the equation of the straight line becomes:

$$\text{Temperature} = m \times V_{\text{out}} + b \qquad \text{equation 1}$$

Where m is the gradient and b is the height at which the line crosses the y axis. Note that b may be a negative number, i.e. the straight line may intersect the Y axis at a number below zero, see fig. 2. You can find b graphically by extrapolating the axes and your straight line.

Calculating the values of m and b is really the process of **calibration**. You have now found a simple formula which relates any sensor output, V_{out} , to Temperature (the quantity you want to measure). Now you can use your sensor system and your equation 1 to measure new unknown temperatures in the environment.

2f) How accurate do you think your sensor system is? Design and carry out an experiment to estimate the typical errors that will be associated with your sensor measurements.