

## Lab Exercise 07 Thermal Response

In this lab, we will estimate the lumped-parameter thermal resistance and capacitance of a 3D-printed block of PLA by measuring its temperature time-response to internal heating via a resistor. Temperature measurements will be made with thermistors connected to Wheatstone bridge circuits, the output voltages of which will be measured with a myRIO device. A calibration curve for each thermistor will be generated.

We will be inferring the lumped-parameter thermal resistance  $R$  and thermal capacitance  $C$  of a block of PLA from its time response. Each block has a  $56\ \Omega$  resistor embedded within acting as a heater and three thermistors embedded, but we will use only the one closest to the resistor to measure the temperature response of the block.

### Lab 07.1 Thermistor calibration

We need to “calibrate” the Vishay NTCLE100E3103JB0 thermistors by measuring their resistances at a measured room temperature. We say “calibrate” because we are not fully calibrating the thermistors ourselves, but partially relying on the manufacturer’s datasheet. We will develop a calibration curve and a lookup table for each thermistor.

Thermistors are highly temperature-dependent resistors. The calibration curves of many thermistors, including those we will use, can be described by the [Steinhart-Hart equation](#). The following Vishay datasheet gives the equation’s parameters based on an  $R_{25}$  resistance, which means the measured resistance of the thermistor at a temperature of 25 C:

[ricopic.one/resources/thermistor\\_datasheet.pdf](http://ricopic.one/resources/thermistor_datasheet.pdf)

However, we don’t have a climate-controlled environment at 25 C, so this isn’t helpful. Conveniently, the manufacturer provides the following spreadsheet that can be used to calibrate our thermistors at non-25 C-temperatures:

[ricopic.one/resources/cc6400c1.xls](http://ricopic.one/resources/cc6400c1.xls)

Our thermistors have nominal resistance at 25 C of  $R_{25} = 10\ \text{k}\Omega$ . As the temperature *increases* from there, the resistance *decreases* (this means we have negative temperature coefficient or NTC thermistors).

The spreadsheet gives a temperature-resistance relation, which is the calibration curve. Additionally, it gives an estimated temperature deviation

$\Delta T$  for each point on the curve. It accounts for the tolerance of our temperature measurement.

### Lab 07.2 Calibration measurements

The following procedure will yield the required measurements.

- 1. Locate within the laboratory an accurate temperature measurement device. Be sure to note the model so that you can look up the tolerance/accuracy in its manual.
- 2. Connect the PLA block to a breadboard across the “spine” that runs down the middle. Be sure not to short the thermistors by connecting them to the same circuit node.
- 3. Use a multimeter to measure and record in the table below the resistance of the resistor  $R_L$ .
- 4. Use a multimeter to measure and record in the table below the resistance of the thermistor  $R_{x0}$  adjacent to the resistor  $R_L$ . Note that, when you handled the block to connect the leads to the breadboard, you may have heated it enough to register on the thermistor. If so, the resistance of the thermistor will be climbing as it cools. Once the measurement has reached steady-state, record the resistance in the table below.
- 5. Use the temperature measurement device to measure and record the temperature  $T_\infty$  of the block (or nearby ambient air).

|          | $R_L$ ( $\Omega$ ) | $R_{x0}$ (k $\Omega$ ) | $T_\infty$ (C) |
|----------|--------------------|------------------------|----------------|
| nominal  | 56                 | 10                     | 25             |
| measured |                    |                        |                |

### Lab 07.3 Generate the thermistor calibration curve

The following procedure will yield the required calibration curve.

- 1. Find the manual for your temperature measurement device. Determine and record the accuracy/tolerance of your temperature measurement.
- 2. Using the Vishay spreadsheet, enter (in the `RTCOEF` tab) 0.1 for the temperature step, -10 for the initial temperature, your measured

thermistor temperature  $T_\infty$  for the reference temperature, your measured thermistor resistance  $R_{x0}$  for the resistance at the reference temperature, the accuracy/tolerance  $\Delta T$  of your temperature measurement, 3977 for your B25/85.

- 3. Save a copy of the spreadsheet as a comma-separated-values (CSV) file.
- 4. In MATLAB use the `Import Data` dialog to import the data from the CSV file and select *only the numerical region of the spreadsheet*. Also, give the `Temperature`, `Resistance`, and `DT` columns of each special names—these are the ones we actually care about. Import the data.
- 5. Use the `save` command to save the `Temperature`, `Resistance`, and `DT` ( $\Delta T$ ) variables for each thermistor to a `mat` file. These can then be loaded much easier into a MATLAB script.
- 6. Write a MATLAB script that loads the `mat` file and plots the calibration curve ( $T$  vs  $R$ ). On the same plot, use the `errorbar` command to plot  $\Delta T$  as error bars. Notice how bad this looks. We will do two things to make these plots better.
- 7. Alter the previous plots so that all the data is still plotted, but only 20 error bars appear. (Hint: when using `errorbar`, plot only some of the points.)
- 8. Alter the previous plot with `semilogx` instead of `plot`, which is tantamount to taking `log10` of the resistance data (but MATLAB does some nice labeling for you). This should make the plot look quite sharp. Make sure you do a `hold on` before your `errorbar` plot, which needs to appear at the end.

#### Lab 07.4 Build the circuit

The Wheatstone bridge circuit we are building can be represented by the diagram of [Figure 07.1](#).

- 1. Select three resistors with nominal resistance  $R_1 = R_2 = R_3 = 15 \text{ k}\Omega$ .
- 2. Measure and record the actual resistances  $\tilde{R}_1$ ,  $\tilde{R}_2$ , and  $\tilde{R}_3$  with a multimeter.
- 3. Build a bridge circuit on a breadboard. Connect the source voltage terminals to a 9 V battery (the DC power supplies are too noisy).
- 4. Set up, but do not yet connect, a DC power supply. Set it to 5 V and connect the  $-$  lead to one side of the block resistor.

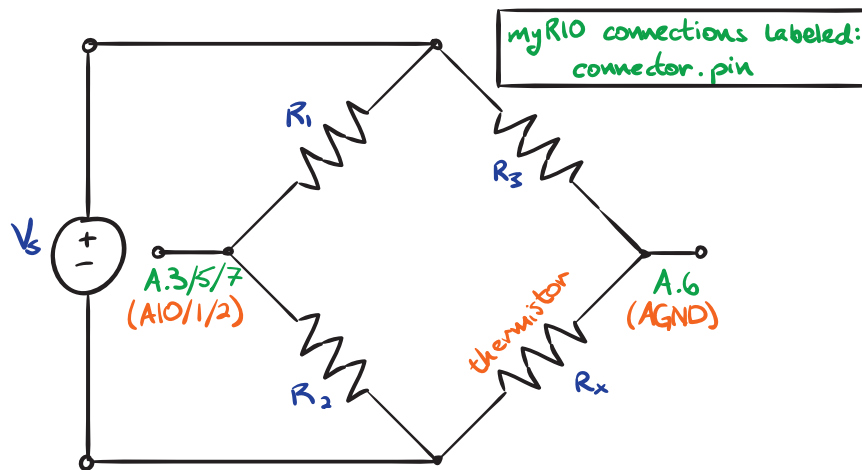


Figure 07.1: the Wheatstone bridge circuit and pinout diagram.

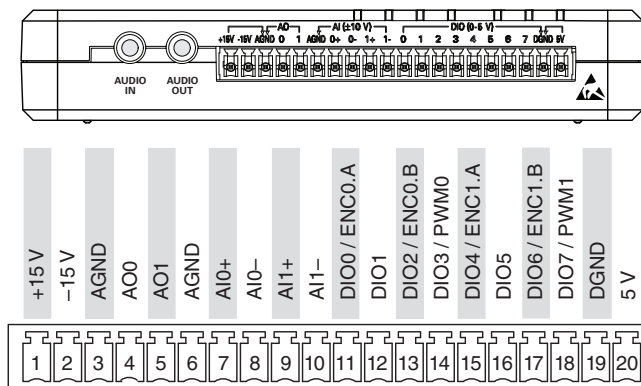


Figure 07.2: myRIO Connector C (from Instruments (2013)).

### Lab 07.5 Connect the myRIO to the circuit

We are using the myRIO to measure the bridge's output voltage.

We will be using the MSP connector named C for the bridge output voltage measurement. It is shown in Figure 07.2.

Connect the myRIO to the breadboard as described in the circuit diagram of Figure 07.1. You can use any analog input. The C connector differential inputs are slightly better for this application, but any will do. Use the pin numbers shown in the connector diagrams above (or equivalent).

### Lab 07.6 LabVIEW program to control the myRIO

Write a LabVIEW program to control the myRIO and save captured data. You will want to be able to measure the bridge output voltage time response with an analog input, plot, and save the data (and associated time array). Previous Lab Exercises' programs may be easily adopted.

### Lab 07.7 Measure the temperature response

- 1. Let the thermal system come to equilibrium with its (room temperature) environment.
- 2. Begin to capture data and connect the heater power supply. The bridge output voltage (which you should be plotting in your program) should increase. Be careful not to use too high of a sample rate in order to avoid excessive data (1/2 Hz is probably sufficient for this slow system).
- 3. Once the response has reached something close to steady-state, disconnect the power supply.
- 4. Observe the slow decay of the temperature to equilibrium.
- 5. Once the temperature has settled back to room temperature (the bridge voltage will return to its original value), terminate the data capture (and save the data).
- 6. Copy the `.lvm` data file from the myRIO to a convenient PC location.

### Lab 07.8 Report requirements

Write a detailed report of your experimental results, as outlined in the report template. Pay special attention to the following.

- 1. Include your calibration curve plots (with error bars) that allow you to convert from thermistor resistance  $R_x$  to temperature  $T_C(t)$ .
- 2. Include a theoretical derivation of the bridge output voltage as a function of the thermistor resistance  $R_x$ .
- 3. Compute and include a plot of  $T_C(t)$ , your temperature measurement.
- 4. Include all measured values of resistance.
- 5. Review the following for guidance before continuing:

[ricopic.one/resources/thermal\\_lab\\_handout.pdf](http://ricopic.one/resources/thermal_lab_handout.pdf).

- 6. Plot the Region II linear plot that has slope  $-1/\tau$ .
- 7. Plot the Region I constant plot that has constant value  $R$ .
- 8. Give final estimates for  $\tau$ ,  $R$ , and  $C$ .