ENEL361 Lab 2: heat and semiconductors

In this lab, you will use a negative temperature coefficient (NTC) thermistor to measure temperature. Next we will use an opamp-based curve tracer that, using the XY mode of an oscilloscope, will allow us to plot the IV curve of a device under test (DUT). We will use this to measure the IV curve of a Zener diode. Next, we will use a thermoelectric cooler (TEC) that uses the Peltier effect in semiconductors to move heat from one side to another side of a module. Depending on polarity, a TEC can be used to heat or cool. We will observe the effect of temperature on the Zener diode.

A thermister is essentially a semiconductor resistor whose resistance depends on temperature. Review the lecture material to recall how temperature changes carrier concentrations. The relationship between the resistance R and the absolute Kelvin scale temperature T is modeled as an empirical equation, the Steinhart-Hart equation:

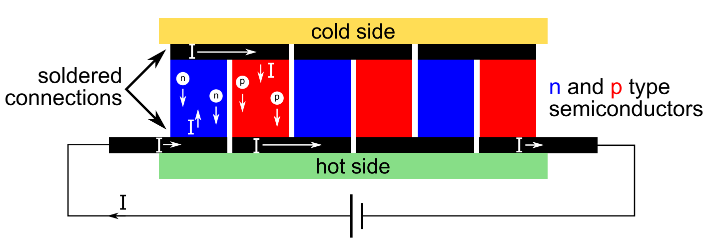
$$\frac{1}{T} = A + B \ln R + C(\ln R)^3 \tag{1}$$

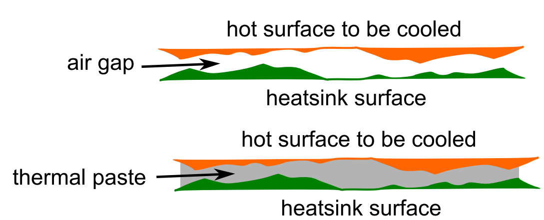
This is often approximated to the B-coefficient equation:

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{B} \ln \left(\frac{R}{R_0} \right) \tag{2}$$

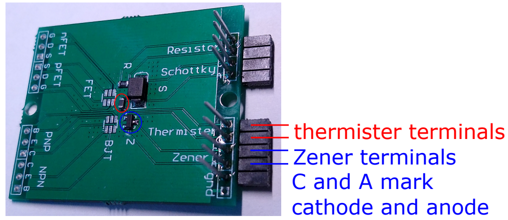
where R_0 is the resistance at $T_0 = 298$ K.

A Peltier device (aka thermoelectric heat pump) moves heat from one side of the device to the other depending on the direction of current flowing through it. Exotic compound semiconductors like silicon-germanium, lead-telluride etc. exhibit strong Peltier effect. The device itself consists of many elements soldered in parallel between ceramic plates. The figure below on the left shows the operation. Carriers (electrons in n material and holes in p material) move in appropriate directions, based on the direction of current flow. They ‘take’ heat with them, cooling one side and heating the other. It is critical to remove or dissipate heat from the hot side, otherwise it gets too hot, melts the solder and the device is rendered useless. Removal of heat is a critical thing in electronics, not just this specific case. Usually, this is done with a metal heatsink that increases the surface area of the hot surface, speeding up the heat dissipation. Sometimes, a fan may blow air on or a pump may circulate water through the heatsink to further speed up the process. As shown in the figure below to the right, the surface to be cooled and the heatsink surfaces may be rough, trapping air in between. Air is a thermal insulator, so this is bad. Thermal paste is usually sandwiched between the two. Thermal paste is a good thermal conductor and may or may not be an electrical conductor. If using the electrically conductive variety, it is important to be careful not to short out any nearby electronics.





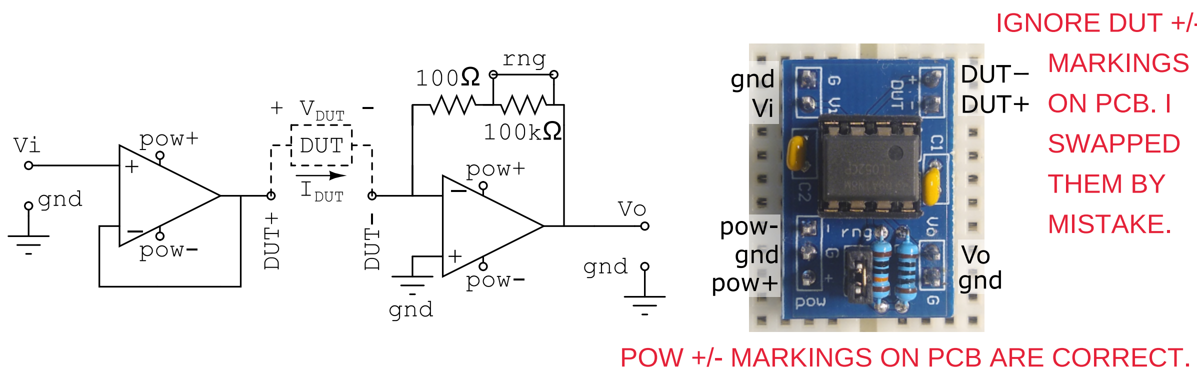
1. We will be using a NCP21XM472J03RA thermistor that is soldered to a printed circuit board (PCB) along with the Zener diode and some other parts as shown below.



   Look up the part on www.murata.com, find R_0 and the B coefficient (use the 25/50 C value) and plot the thermistor resistance from 0 to 100° C.

2. Use the multimeter to measure thermister resistance. See figure in #1 for terminals. Use your plot in #1 to find the ambient temperature. Find the expected thermister resistance at 5° C and 70° C. **Show the plot and ambient temperature to a TA or instructor.**

3. See below for the curve tracer schematic that you soldered earlier. Calculate relations between V_{DUT} and V_i and between I_{DUT} and V_o. The `rng` jumper shorts out the 100 kΩ resistor.

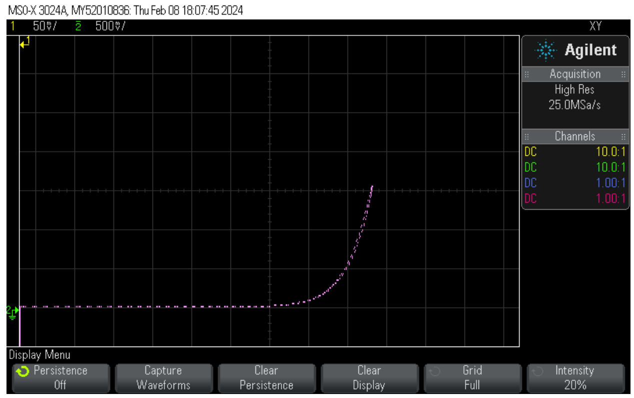


4. Configure the +25 V supply to generate +12 V and current limit it to 120 mA. Configure the -25 V supply to generate -12 V and current limit it to 120 mA. Use these to power the curve tracer PCB plugged into a breadboard. Remember that the ±25 V supplies are referred to the COM terminal, so make sure to connect that to the common ground.

5. Set the function generator to generate a sine wave between -4.8 V to 0.8 V at 100 Hz and apply it to the curve tracer input. Set oscilloscope CH1 to measure V_{DUT+} (please note the markings on the PCB for DUT + and − are swapped, see figure above), CH2 to measure V_o, and the horizontal mode to XY (`https://youtu.be/Q1UUHkyVq0M?t=208` or `https://youtu.be/kwFV6GCQjBQ` if using ADALM). Keep in mind that the bench oscilloscope reference lead is set to ground, so connect those to ground. All grounds on the PCB are connected on the PCB itself. Using the channel menu for CH2, invert CH2 (think about the I_{DUT}-V_o relation from #3 above to understand why). Leave the multimeter connected to measure the thermister resistance.

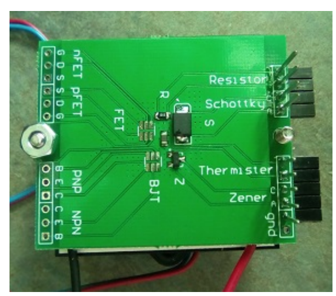
6. Measure the IV curve of the Zener diode. See figure in #1 for terminals, connect `DUT+` to the anode and `DUT-` to the cathode (please note the markings on the PCB for DUT + and − are swapped, see figure above). Adjust oscilloscope X and Y volts/division and offsets to fill the screen with the IV curve. Observe the diode turn on and breakdown. **Show the waveform to a TA or instructor.**

7. Adjust X and Y volts/division to 50 mV and 500 mV respectively, and offsets to focus on the diode turn-on region. See example image on next page.



Save the IV curve (Display→Capture Waveforms). This will save the ambient temperature IV curve on the screen. Don't change the oscilloscope settings after this so we can compare how the IV curve changes with temperature. If using the ADALM, take a screenshot.

8. Power down the supply and see the instructor to apply thermal paste between the PCB and the TEC. Run the bolts through two diagonally opposite holes of the fan and put it bolts facing up on the table. Place the finned side of the heatsink on the fan so the bolts go along the notches. The cold side of the Peltier should now be facing up. Add a bit of thermal paste on the cold side of the Peltier. Then thread the PCB into the bolts such that it is centered on the Peltier. Press the PCB firmly to spread the thermal paste. Some paste might squeeze onto the component side of the PCB, don't worry about that (we're using an electrically insulating paste). Hand tighten the nuts on both bolts. Tighten them alternatively i.e. turn one a bit and then the other before coming back to the first.



9. Power the fan with +12 V (red +, blue COM). Do not use hookup wire, instead use the screw terminals (`https://youtu.be/9dmgBm24BFU?t=74`). Set the 6 V supply on the triple output supply to 6 V, current limited to 2 A. Power the TEC with this (red +, black -). Again, use the screw terminals. Connect the multimeter to measure the thermistor resistance. Connect the Zener diode as the DUT as before. **Before you power up anything, show the circuit to a TA or instructor.**

10. Power up the supplies. If the fan does not run, power down and check connections. You should see the Zener diode IV curve as before. You may have to hold the assembly such that the running fan is not being obstructed.

11. Observe the thermistor resistance as measured by the multimeter and observe any shifts in the Zener IV curve. You can gently touch a portion of the PCB that does not have any components on it to feel it cooling down. When the temperature reaches ∼5° C, save the waveform on screen again (Display→Capture Waveforms).

12. Turn off the power supply and flip the polarity of the TEC (red -, black +). Power up, monitor temperature and the IV curve. Save the IV curve again when the temperature reaches about 70° C. You should now have 3 saved IV curves on the scope display: one at ambient temperature, one at $\sim$5° C and one at $\sim$70° C. How does heat effect diode operation? **Show these waveforms to a TA or instructor.**