Introduction

Over the course of this activity, we will construct and calibrate two different temperature-measuring circuits. One uses a silicon diode as the temperature sensor and one uses a thermistor (a resistor that changes its resistance with temperature).

When building the circuits, we will first build a prototype version on a breadboard and then solder a duplicate circuit to a PCB, so we have a more permanent version we will use for our final calibration.

We will go through the assembly and calibration of the diode circuit step by step, and then students will build the thermistor circuit on their own. Your activity kits should have enough parts to build 4 circuits total. A breadboarded diode circuit, a soldered diode circuit, a breadboarded thermistor circuit, and a soldered thermistor circuit. The final schematic for the diode circuit is shown in Figure 1. A completely assembled circuit is shown in Figure 2.

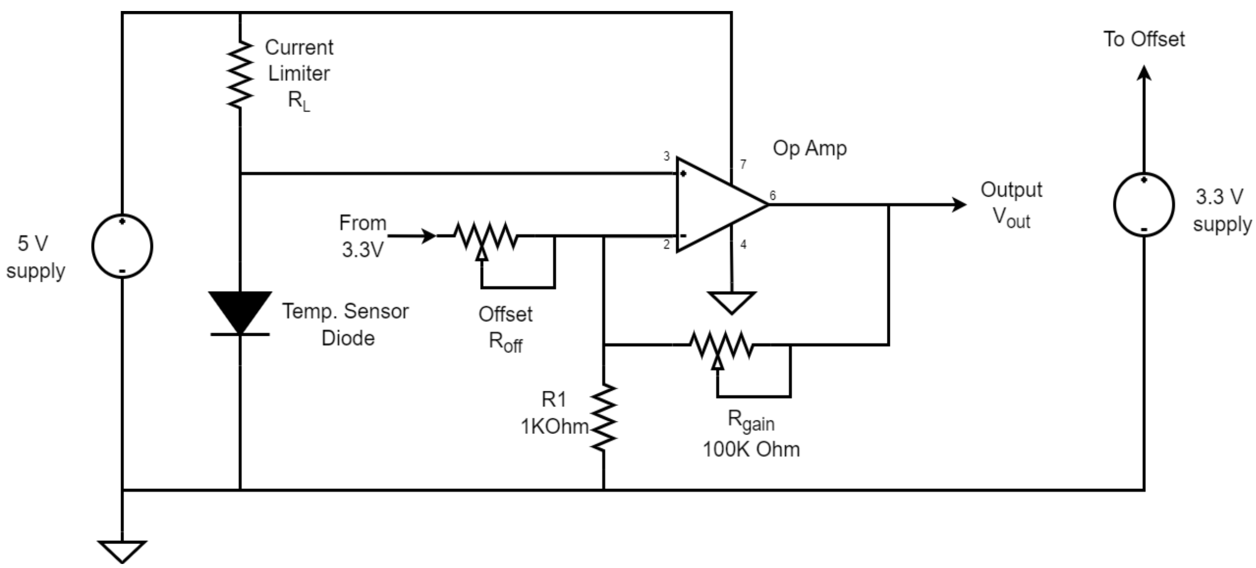


Figure 1: Completed diode temperature sensor. Over the course of this activity, we will prototype this circuit and solder it together.

As you go through the activity, be sure to take thorough notes in your **lab notebook**. Once the calibration is complete, you will need to write a short report to explain how you calibrated the temperature sensor.

It is recommended that you review the Temperature Calibration Report Guidelines before starting the activity to keep in mind what information you will need to include in your report.

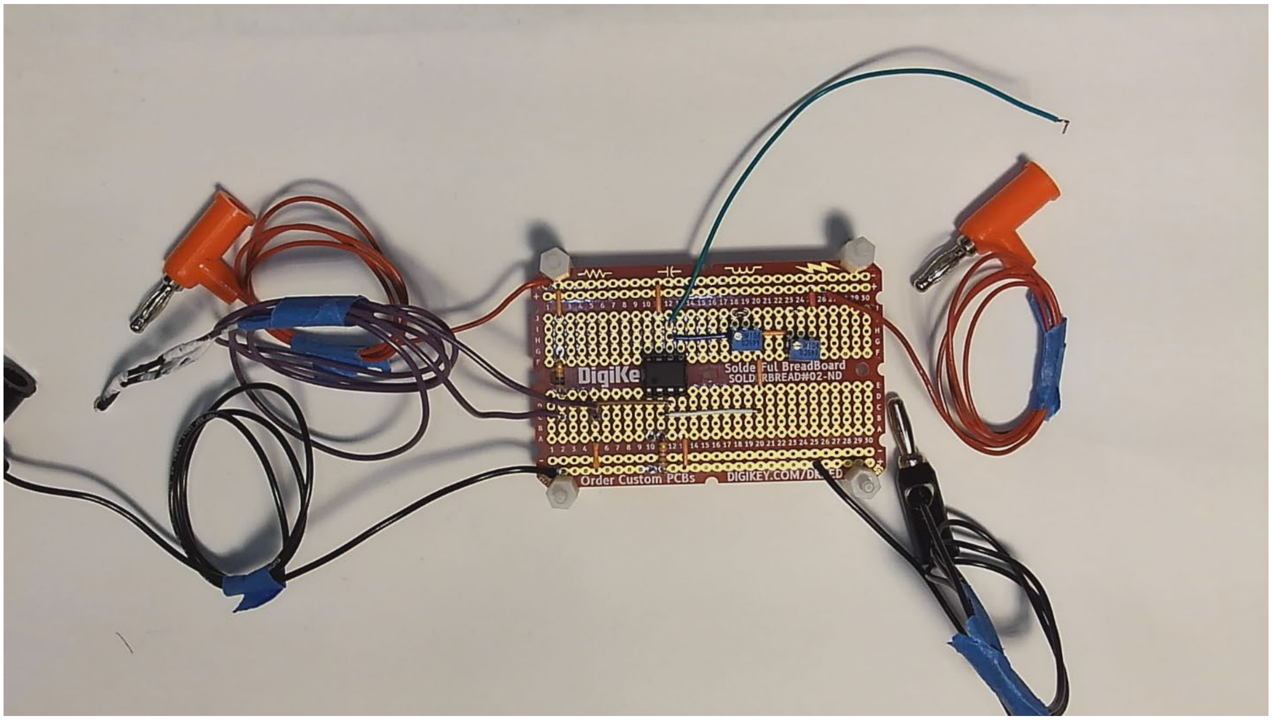


Figure 2: Fully assembled and soldered diode temperature sensor circuit. The two power connections are for 5V main power and 3.3V offset. Two 100kOhm potentiometers allow for adjustment of offset and gain with the green jumper connected to the output for easy measurement.

Materials List

1. From the activity kit
    1. 1N457 Signal Diode (x2)
    2. 100kOhm Thermistor RL0503-55.36K-122MSS (x2)
    3. TLV271 Op. Amp (x4)
    4. 8 Pin IC Socket (x4)
    5. 100 KOhm Potentiometer (x8)
    6. 1000 Ohm Resistor (x4)
    7. 5000 Ohm Resistor (x2_
    8. 56 KOhm Resistor (x2)
    9. Black Power “Banana” Connectors (x6)
    10. Red Power “Banana” Connectors (x6)
    11. Plastic Standoff (x16)
2. Tools and Lab Supplies
    1. Multimeter

2. 2 Power Supplies (One for 5V and one for 3.3V)
3. Thermometer, thermocouple, or other temperature measurement device
4. Hot plate, beakers, ice
5. Heat shrink, liquid electrical tape, or other means of waterproofing.

Preparing Diodes and Thermistors for Sensor Use

We will be using a water bath to calibrate our sensors. Because of that, we want to solder long wires to the leads so we can move the sensors around. It is recommended to use stranded wire and not solid core to minimize the chance of wires breaking. If you do so, use clips to connect the leads to your breadboard since the stranded wire will not push into the connections.

You should make 2 of each sensor.

For the diode, you should use two different color wires for the cathode and anode, as shown in the figures below.

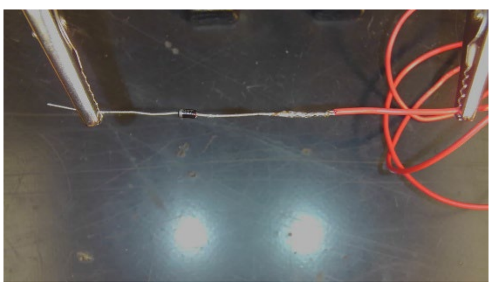


Figure 4: Soldering a red wire to the diode lead. Notice we have soldered this to (+) lead. We will not be able to see the stripe one the diode once we cover it with waterproofing

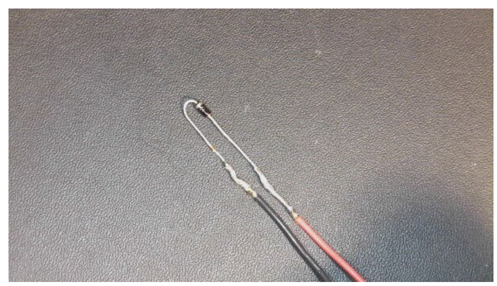


Figure 3: Diode with wires soldered to both leads

The thermistor is not polarized. You can use the same wire for both leads. The thermistor wires are thinner and more prone to breaking once soldered.

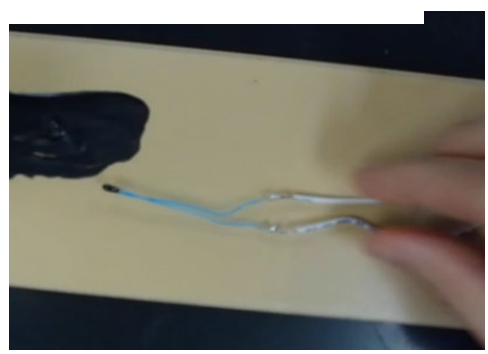


Figure 5: Thermistor with wires soldered to the leads. Note: lead colors may be a different color. The resistor should be about 100 KOhm at room temperature.

After the wires are soldered, you should waterproof the sensor by applying heat shrink. Make sure you cover any bare metal. For the best waterproofing, you should apply liquid electric tape or another sealant.

Liquid electrical tape will take ~24 hours to properly cure. Ensure you wait before putting your sensors in the water. In the worst case, you put your sensors in the Ziploc bag when you place them in the water.

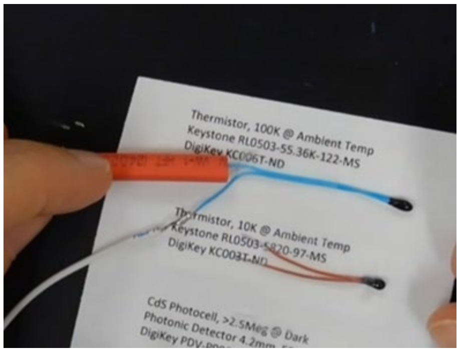


Figure 6: Sliding heat shrink over the solder joint of the thermistor.

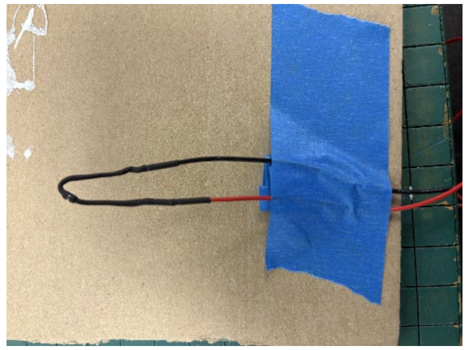


Figure 7: Diode with heat shrink applied

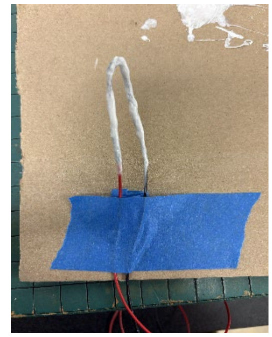


Figure 8: Diode with liquid electrical tape applied

Diode Sensor Theory of Operation

Diodes have a small voltage drop in the forward direction, V_f. This is the vertical line in the plot on the right. We can see that V_f does not change with current.

It does change with temperature. As the temperature increases, electrons are thermally excited and can flow through the diode more easily, causing V_f to decrease.

V_f will be our temperature signal.

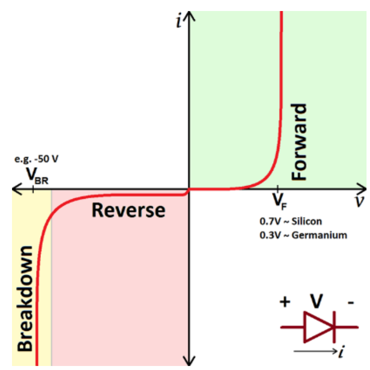


Figure 9: Diode forward voltage Vf depends on temperature.

Building the Diode Sensor Circuit

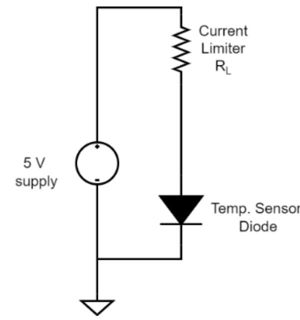
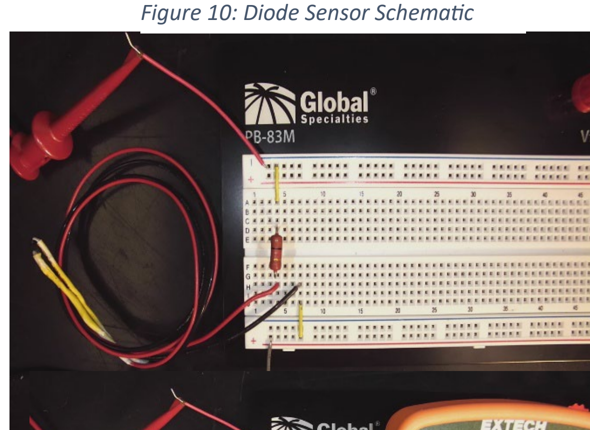


Figure 10: Diode Sensor Schematic

Now we need to assemble the circuit in Figure 10: Diode Sensor Schematic. We connect the diode in series with a resistor to limit the current flow through the diode.

Without the resistor, the current through the diode would be very large and quickly heat and damage the diode. The actual value of the resistor is not critical, so we will use a 1KOhm resistor **for R_L**. We also need to connect our diode to power.

We will use the topmost row for +5V (we will use the second row for +3.3V eventually) and the bottommost row for Ground. So put a jumper in the top row. Add a jumper on the bottom row. We will clip the power supply leads to these leads.



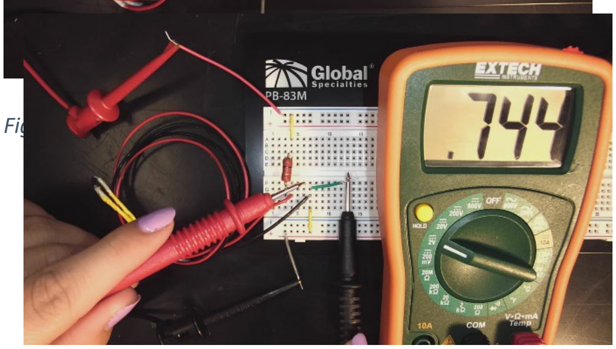


Figure 12: Diode Measuring diode voltage

Now use a jumper to vertically connect the +5V to a column. Then add the 1 KOhm resistor, bridging the gap. Connect the positive lead of your diode in the same column as the resistor. Connect the negative diode lead to the breadboard, three columns to the right. Finally, use a vertical jumper to connect that column to ground.

Before connecting the power, set your power supply to 5V. Then connect the power leads to the +5V and Ground jumpers.

Turn the power on. Your power supply should read ~5mA or .005A. Use your multimeter to measure the voltage across the diode. Your meter should be on the + and – leads of the diode, or their column.

The diode voltage will be ~.7V.

If you are reading 5V, 3 things could be happening. You may have your meter in the wrong location. The diode may be backwards. One of your leads may be broken.

Table 1: Diode Voltage vs. Power Supply voltage

Power Setting	V_f
2V	
3V	
4V	
5V	

Now, let's see how V_f changes with current. Reduce the power supply voltage to 2V and measure V_f. Record these values in your lab notebook. Repeat for 3V, 4V, 5V. You should see V_f increase slightly as the power supply voltage increases.

This is due to small internal resistances inside the diode. To minimize this effect, we want to make sure we perform all of our remaining measurements at the same power supply voltage. Use your meter to measure the power supply voltage and record that number so you can set your supply to that value from now on.

Now, let's verify V_f changes with temperature. Briefly warm up the diode. You can do this with a heat gun, briefly dunking it in a warm water bath, or even holding it in your hands. You should see the voltage drop slightly and then rise as it cools off when you let go.

Now we are ready to start soldering the circuit. The PCBs supplied use the same pattern of connections as the breadboard.

Figure 13: PCB breadboard. Notice this PCB has the same layout as the breadboard. The columns and rows are numbered differently.

Note: The power rails are slightly closer to the vertical columns, so use jumpers that are 1 shorter (orange instead of yellow). All other connections should be the same.

Now, duplicate the breadboard circuit on the PCB. Don't forget to trim the leads to prevent shorts.

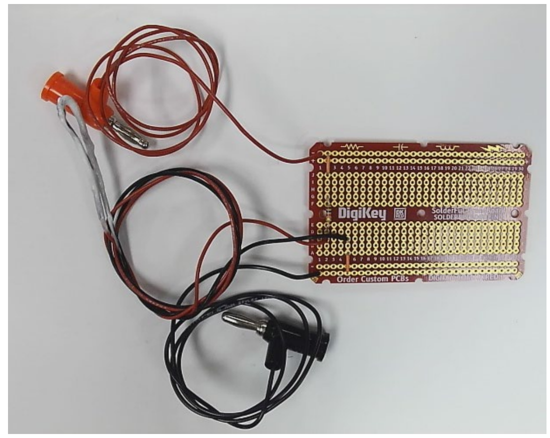


Figure 14: The diode sensor soldered to the PCB.

For the power leads, solder lengths of wire ~2-3 feet long into the top and bottom rows. Your kit includes power plugs that can be attached to the wires using a set screw in the top.

The kit includes plastic standoffs that can bolt onto the notches of the PCB, but it is recommended to wait until the circuit is complete to install them.

When complete, repeat all the checks you just performed on the breadboard with the soldered circuit. If needed, correct any bad solder joints.

Recording Diode Voltage Temperature Data

Using a hot plate, a water bath, and ice, take measurements every 10 degrees from 0C to 50C using the solder temperature sensor.

For each measurement point, record the actual temperature as measured by a thermometer or thermocouple and the diode voltage V_d.

Be sure to allow your diode temperature to stabilize and ensure neither your diode nor your thermometer is touching the walls of your container.

Table 2: Diode Voltage vs Temperature Measurements

Temperature Point	Measured Temperature (C)	V_d(V)
0-10 C		
10-20 C		
20-30 C		
30-40 C		
40-50 C		

Your measurements do not have to be exactly 10 degrees apart, but make sure you take at least 5 roughly, evenly spaced measurements.

Using graphing software such as Excel or Google Sheets, make a scatter plot with Temperature on the X axis and diode voltage on the Y. An example plot is shown in Figure 15.

Next, fit a line to the data. The equation of this line provides the conversion from temperature to diode voltage.

Note: Since this equation goes **from** a physical measurement **to** a sensor signal, we normally would not call it a calibration. For a calibration equation, we want the reverse. A conversion **from** a sensor signal **to** the physical quantity being measured.

We will use this data to set our amplifier gain and offset in our final circuit. Using your fit equation, calculate what the diode voltage should be at 0 °C and 50 °C as V_0 and V_{50}. For example, with the sample date V_0=0.789 V and V_{50}=0.709V

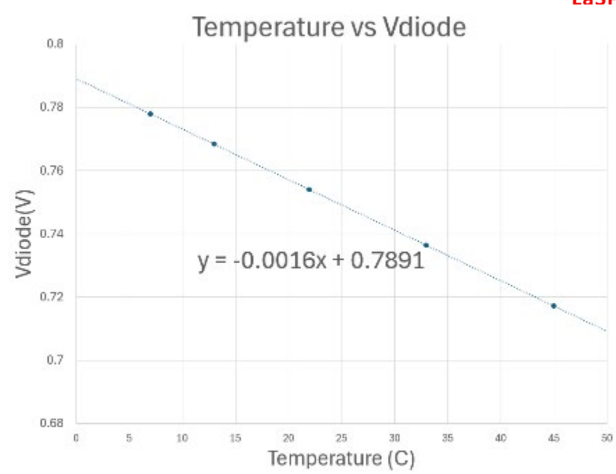


Figure 15: Example diode voltages measured from 0 – 50C.

Adding A Non-Inverting Amplifier

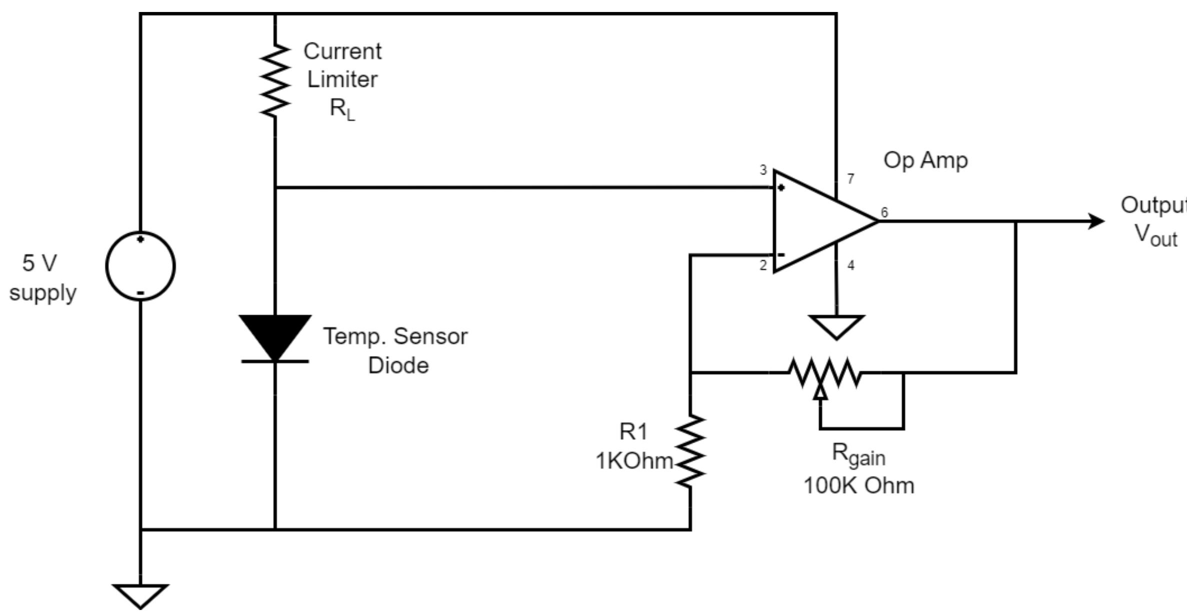


Figure 16: Temperature sensor circuit with a non-inverting amplifier. This circuit will amplify the input voltage from the diode V_d connected to pin 3 to a larger voltage V_{out} at the output on pin 6.

While V_d does change with temperature, it is a relatively small change <1V over 50 C. To make that change easier to measure, we now want to amplify it.

To accomplish this, we will use an Op Amp. In this case, the TLV271 made by Texas Instruments. To determine the pin layout, we should look up its data sheet [1] and find the diagram of our specific part and package.

Be careful when looking up pin layouts because often a datasheet will include the information for a family of components (ex., Single, dual, and quad Op Amps) and a single part may come in multiple packages.

The correct pinout from [1] is shown in Figure 17. Looking at the chip, we can see a circular dimple indicating pin 1.

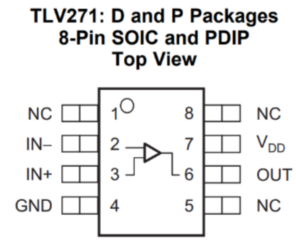


Figure 17: Pin out for Op Amp TLV271. V_{DD} is the another common symbol for +V Power,

Install the chip in the breadboard to the right of the sensor diode with pin 1 to the left. This orientation will set up the +V supply pin on top and the -V supply (ground on the bottom.

When inserting the chip into the breadboard, take care to line up the pins with the holes

We want to leave some space for any future connections, so install the chip so pin 1 is five columns to the right of the diode ground column (7 and 12 in the image to the right).

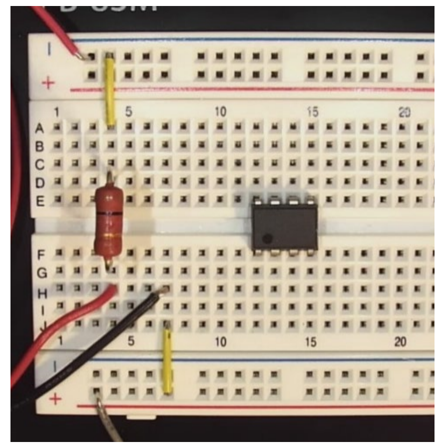


Figure 18: Proper orientation of the Op Amp in the breadboard.

Now add the power connections to pin 7 and pin 4. We want to try and leave as much room as possible for the amplifier resistors.

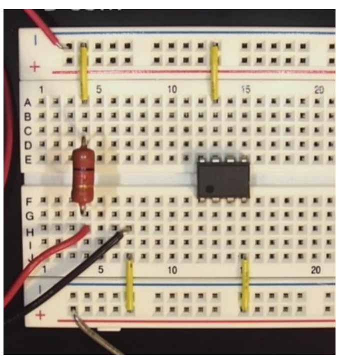


Figure 19: Connecting the Op Amp to Power and Ground.

Next, we need to connect the diode voltage to the non-inverting input V+ on pin 3. Looking at the schematic, we see that the positive side of the diode, R_L, and pin 3 of the op amp should all be connected to each other, so run a jumper from pin 3 to where the resistor and diode connect.

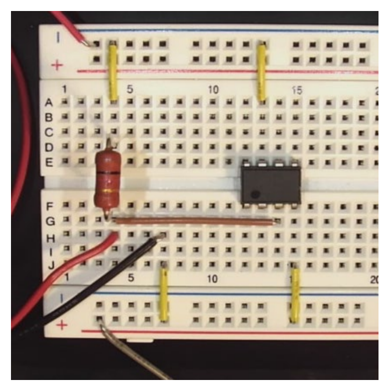


Figure 21: Connecting the diode V_{in} to the Op Amp. Note that the red wire, the resistor lead, and the brown jumper are connected to the same column.

Next is R_1. Since it connects pin 2 directly to ground, it has an obvious location. We just need to make sure we leave room to connect pin 2 to pin 6 via the gain resistor.

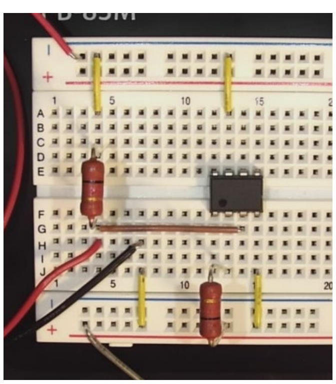


Figure 20: Connecting the diode V_{in} to the Op Amp.

Now it gets a bit trickier. Our gain potentiometer needs 3 columns since it must be placed horizontally. Also, the pins are staggered across two rows. Finally, we also need to connect two of its pins together.

It is best to move this part of the circuit away from the chip rather than trying to squeeze everything together. Figure 22 shows one way of accomplishing this.

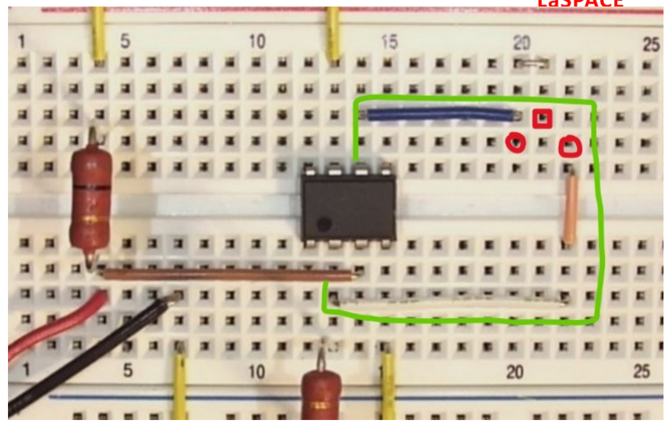


Figure 22: Connecting pin 2 (V-) to pin 6 (Vout). The green line roughly shows the path formed by the jumper connections. The red circles indicate where the potentiometer will be installed. Note the white jumper connecting columns 13 to 22 and the bare jumper at the top connecting columns 21 and 22.

Finally, we just need to install the potentiometer in the designated location and our amplifying circuit is complete.

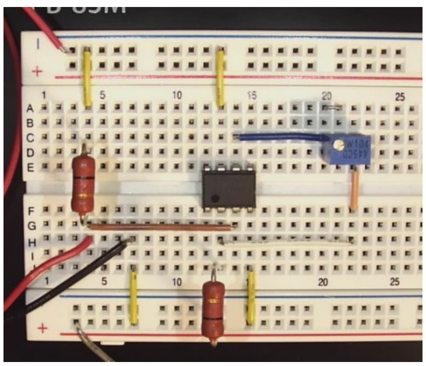


Figure 23: Installing the gain potentiometer completing the feedback path.

Testing the amplifier

Recall that the equation for a non-inverting amplifier (using our resistor symbols) is:

$$V_{out} = \left(1 + \frac{R_{gain}}{R1}\right) V_{in} \text{ , } Gain = \left(1 + \frac{R_{gain}}{R1}\right)$$

With R_1=1000 and R_g 0 – 100K

Since V_{in} ~0.7V let us first set our gain to ~5. Which should set V_{out} to ~3.5V. So we need to set R_g to 4000

Note: Make sure the circuit is unpowered when measuring resistance. Some power supplies have very low resistance between + and – V when off, so it is best to disconnect one of the leads when setting resistors in order to prevent erroneous readings.

To set $R_{g,}$ place your multimeter leads on pin 6 and pin 2. Then use a screwdriver to turn the screw on the potentiometer until the desired value is reached.

Do not worry about getting the resistance exactly to 4000; just get it close and record the setting.

Table 3: Gain Measurements

Target Gain	Target R_g (Ohm)	Actual R_g (Ohm)	V_{out} (V)	V_{in} (V)	Actual Gain
5	4000				
4	3000				
3	2000				
2	1000				

Reconnect power and measure V_{in} on pin 3 and V_{out} on pin 6. Calculate the actual gain by dividing V_{out} by V_{in}. Record these values in your lab notebook.

Repeat this for gains of 4, 3, and 2, as shown in Table 3.

Now reset the gain to ~5. While measuring V_{out}, slowly reduce the voltage of the power supply to 2V. What happens when the supply voltage drops below the original output voltage? Now slowly raise the supply voltage to 7V. What happens to V_{out}? When done, reset the power supply to the value of 5V you have written in your lab notebook.

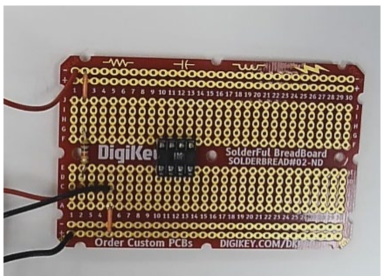


Figure 24: Soldering Op Amp socket in the PCB

Now we will add the amplifier to our PCB circuit. To allow easy chip replacement and protect the IC from heat, we will use an IC socket. Solder the socket into the board in the same spot as the breadboard (5 to the right of the diode ground again).

Now, one at a time, add the 1000 Ohm resistor R1 and the jumpers to match the breadboard. Take your time and ensure the components are in the correct place before soldering them in place. If you try and do several components at once, they are more likely to fall out or be misplaced when you flip the board to the backside for soldering.

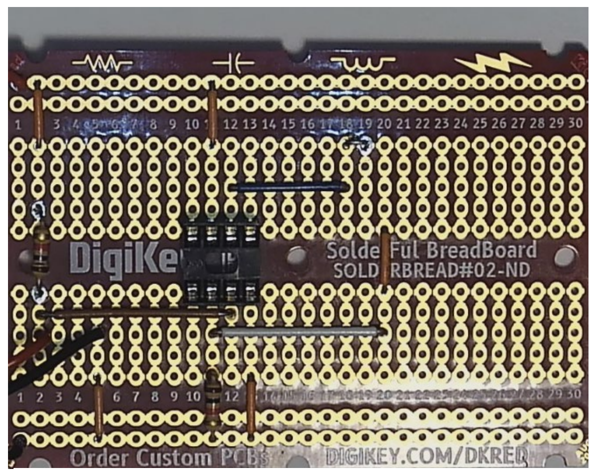


Figure 25: Adding the jumpers to the PCB.

We will wait to install the potentiometer and IC until we have all jumpers installed for the final circuit.

Adding An Offset to the Amplifier

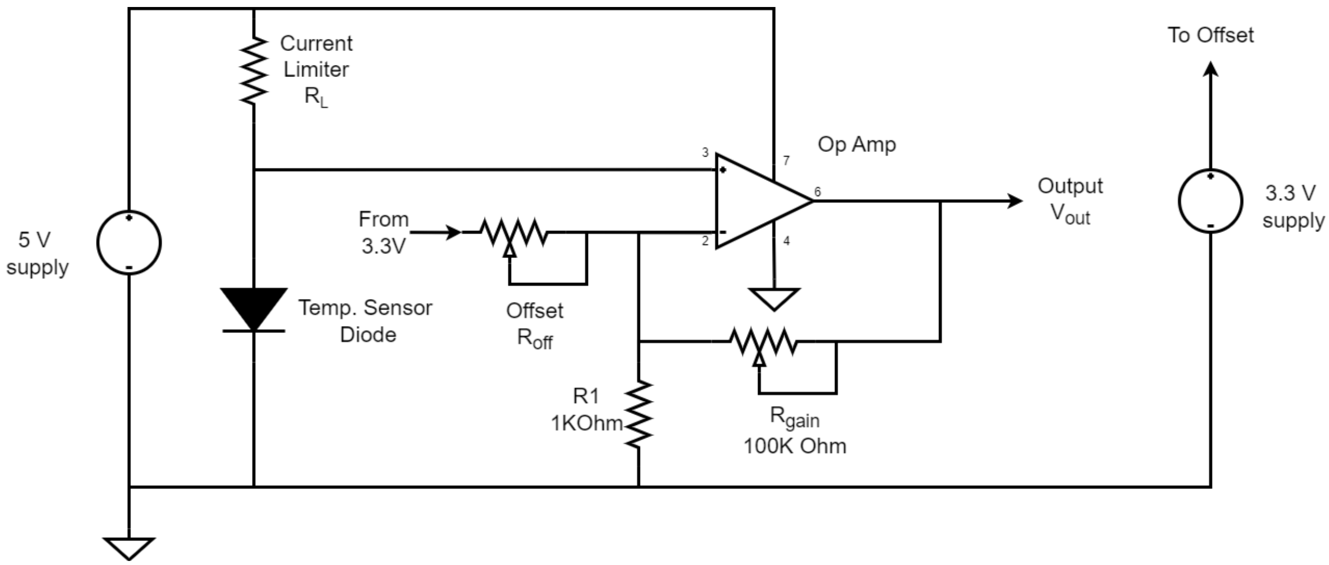


Figure 26: Adding the offset to the amplifying circuit. Notice the arrows showing that the potentiometer R_{off} is connected to the 3.3V supply. This is often done on schematics to prevent having an excessive number of confused crossovers in the schematic.

We next want to add an offset to our amplifying circuit. This will allow us to shift our amplification line up and down. To do so, we need to add a second power supply and another potentiometer R_{off}. The equation for the new amplifying circuit can be determined using KCL, KVL, and the Op Amp Golden rules. Doing so gives us:

$$V_{out} = V_{in}\left(1 + R_{gain}(\frac{1}{R_1} + \frac{1}{R_{off}})\right) - V_{off}\frac{R_{gain}}{R_{off}}$$

Where V_{off}=3.3V, R_1=1000 Ohms, and R_{gain} and R_{off} are 0-100KOhm.

We could also supply the offset from the 5V supply, but that would mean our amplifier output would vary with supply voltage, which is usually undesirable (consider if using batteries, the voltage would drop as the batteries drain).

We will use the 2nd Power Rail at the top for our +3.3V supply. The negative lead will connect to the bottom row (our ground). Then each supply will be relative to the same 0V point.

When connecting multiple devices, it is important to ensure they have the same 0V reference point. This is usually accomplished by connecting their V- or Ground connections together.

First, let's remove R_{gain} to keep it out of the way while we build the circuit. Looking at the schematic, we need to connect 3.3V to pin 2 through the second potentiometer R_{off}.

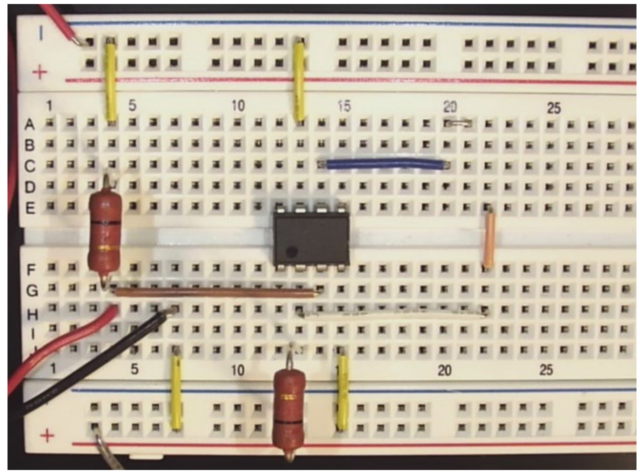


Figure 27: Amplifier with potentiometer removed. If we connect our offset resistor to the orange jumper on column 23, it will be connect to pin 2 through the orange and white jumpers.

If we have plenty of space to the right of R_{gain} and that will allow easy connection to the 3.3V supply on the second power rail at the top of the circuit.

First, add a set of jumpers to the 2nd and bottom power rows for the 3.3V supply.

Ensure the +5V and +3.3V supplies are on different rows.

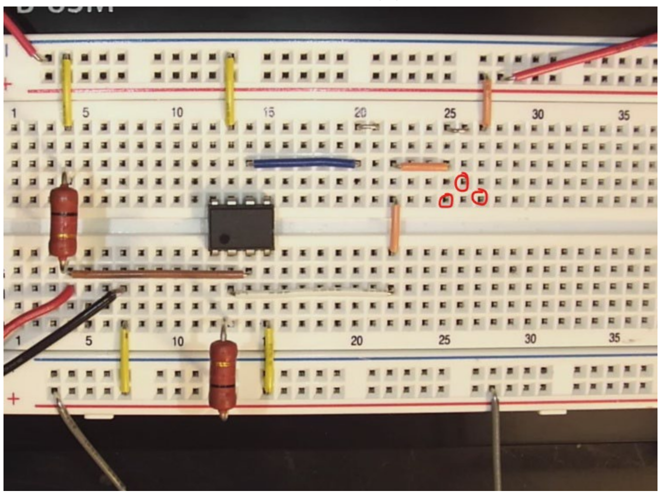


Figure 28: Adding the jumpers for the offset potentiometer. Make sure you notice the bare wire jumper connected column 25 to 26; this connects two of the potentiometer leads together. The red circles show where R_{off} will be installed.

Then use a horizontal jumper to connect from the rightmost column where R_{gain} would sit. This should be where you have a jumper across the gap connecting to pin 2. Install a 1-space bypass jumper. And finally, add a vertical jumper from the 3.3V rail to the right of the bypass jumper. When done, it should look like Figure 28.

Now we just need to install R_{gain} and R_{off}, and our breadboard circuit will be complete.

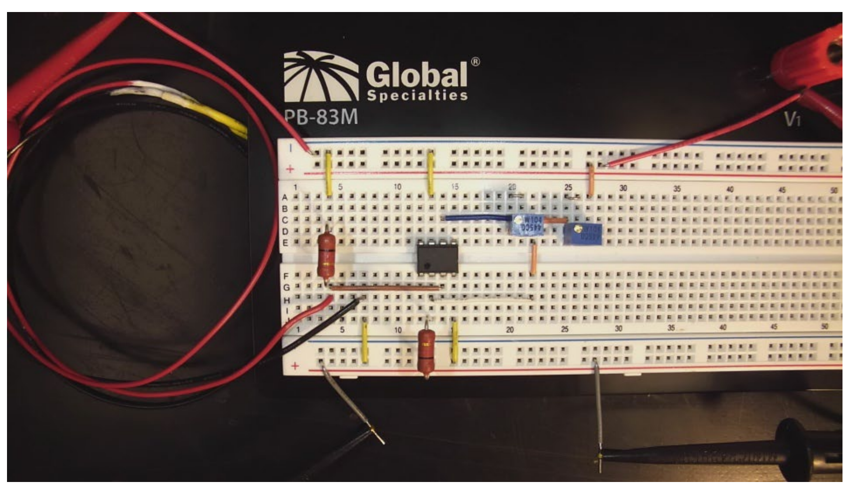


Figure 29: Complete breadboard diode temperature sensor circuit.

Finally, before we proceed further, let's record our settings for the 3.3V supply. With the power supply disconnected, set it close to 3.3V. Measure the exact voltage with your multimeter and write it down in your lab notebook.

Determining Desired Transfer Equation

Now we want to determine how to set R_{gain} and R_{off}. To do that, we need to decide what we want our transfer function to be. For this exercise, we want the circuit to measure 0 °C to 50 °C and have an output range of 0-5V.

We already calculated what the V_{in} should be at 0 °C and 50 °C, V_0 and V_{50}. Notice V_0 is larger than V_{50}. If we plot a line through (V_{50}, 0V) and (V_0, 5V), the equation of the line will be our desired transfer equation. The slope of the line is our Gain, and the y-intercept is the offset.

The line for our sample data is shown in Figure 30.

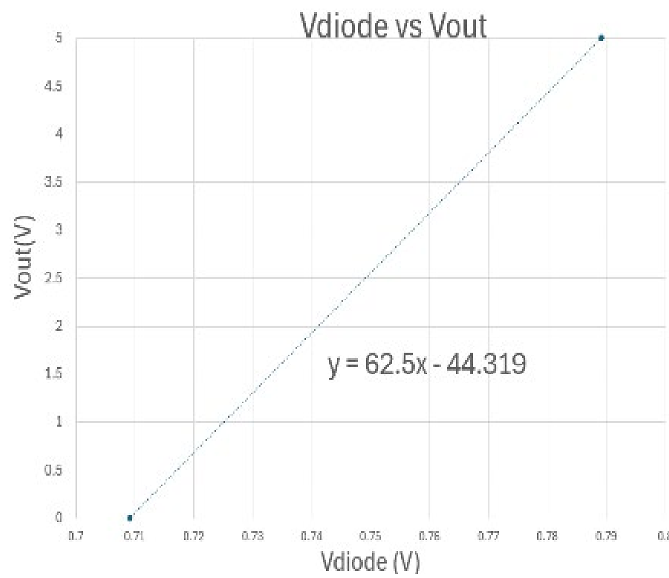


Figure 30: Plot of V_{in} vs desired V_{out}(0 to 5V)

Now we can calculate the settings for R_{gain} and R_{off}. If we set the amplifier equation

$$V_{out} = V_{in}\left(1 + R_{gain}(\frac{1}{R_1} + \frac{1}{R_{off}})\right) - V_{off}\frac{R_{gain}}{R_{off}}$$

Equal to the Transfer function

$$V_{out} = Gain * V_{in} + Offset$$

We will get two equations:

$Gain = \left(1 + R_{gain}(\frac{1}{R_1} + \frac{1}{R_{off}})\right)$ and $Offset = -V_{off}\frac{R_{gain}}{R_{off}}$

Plugging in the values (be sure to use your values for Gain, Offset, and V_{off} not the sample values shown here) yields

$$62.5 = 1 + R_{gain}\left(\frac{1}{1000} + \frac{1}{R_{off}}\right), \qquad -44.319 = -\frac{3.3R_{gain}}{R_{off}}$$

Now we have 2 equations and 2 unknowns. We will need to solve for R_{gain} and R_{off} numerically using software like Wolfram Alpha or Matlab. Or we can make plots, replace R_{gain} with X, R_{off} with y, and plot the 2 equations on a graphing program like https://www.desmos.com/calculator. The point where the lines intersect is the desired values for R_{gain} and R_{off}. For our sample data, R_{gain}=48.2KOhm and R_{off}=3.6KOhm. Record your values calculated values in your lab notebook as target R_{gain} and R_{off}.

Note: if you get a number less than 0 or greater than 100,000, you cannot achieve the needed gain and offset with existing components. Possible solutions would be changing the values of R_1 or the 3.3V supply, getting a different sensor, or getting bigger potentiometers.

Setting Amplifier Gain and Offset

Now you want to set the potentiometers. Be sure the power supplies are disconnected from the circuit. To set $R_{gain,}$ place your multimeter on pins 2 and pin 6 of the Op Amp while turning the screw on R_{gain}. For $R_{off,}$ put your meter on pin 2 and the 3.3V power connector.

You likely will not be able to set the potentiometer exactly to your calculated values. Set them as close as you can and record the set values in your lab notebook as actual R_{gain} and R_{off}.

Once the resistors are set, reconnect both 5V and 3.3V supplies and turn them on. You may want to check that both are set to the correct values, matching what you have recorded.

You should now measure V_{in} and V_{out}. V_{in} should be ~0.7, and Vout should be between 2 and 3 V. If not, check your circuit for proper connections and double-check your potentiometer settings. You should also be able to heat your diode and see both V_{in} and V_{out}. Once you are satisfied your circuit is working, measure V_{in} and V_{out} at two different temperatures (one may be room temperature). Plot the line between those two points with V_{in} on the X axis. Compare that line to your target transfer function. If it is significantly different, the potentiometers may not be correctly set.

Table 4: Amplifier Verification Measurement

V_{in}	V_{out}

Completing the PCB Circuit

Once you have properly set up and are working with a breadboard circuit, you are ready to finish the breadboard circuit.

Add the three jumpers for R_{off} to the right side of the circuit.

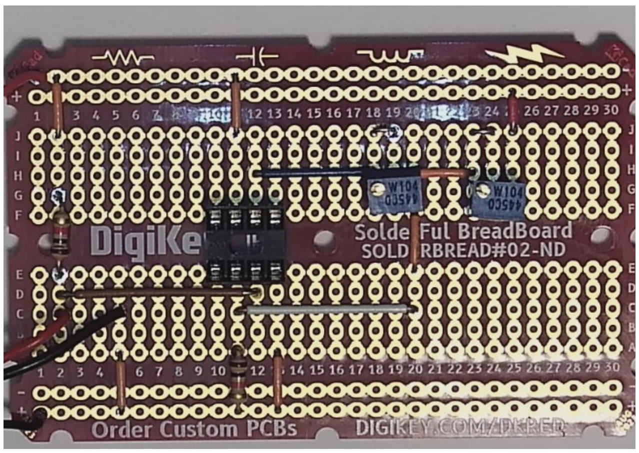


Figure 32: Soldering in R_{gain} and R_{off}

You can set the potentiometers before installing the Op Amp. You should use the same settings as you used on the breadboard.

To set R_{gain}, install your meter on pins 2 and 6. For R_{off} use pin 6 and the 3.3V supply rail.

Install a long lead to the output on Pin 6. This does not affect the circuit but will make taking our final measurements easier.

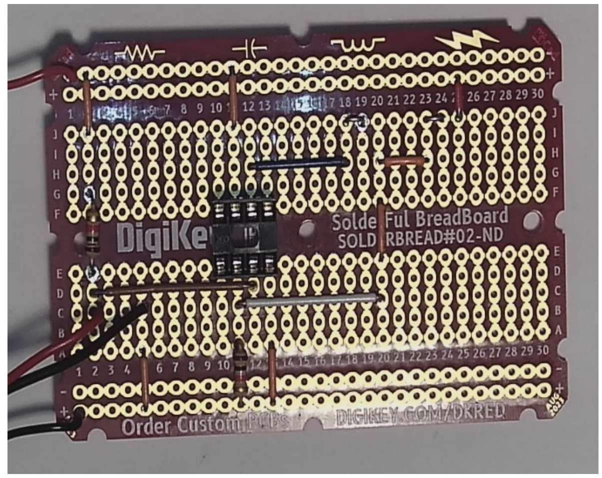


Figure 31: Jumpers for offset connection.

Solder the two potentiometers in place.

Finally, solder two long power leads to the second power and bottom power rails for the 3.3V supply.

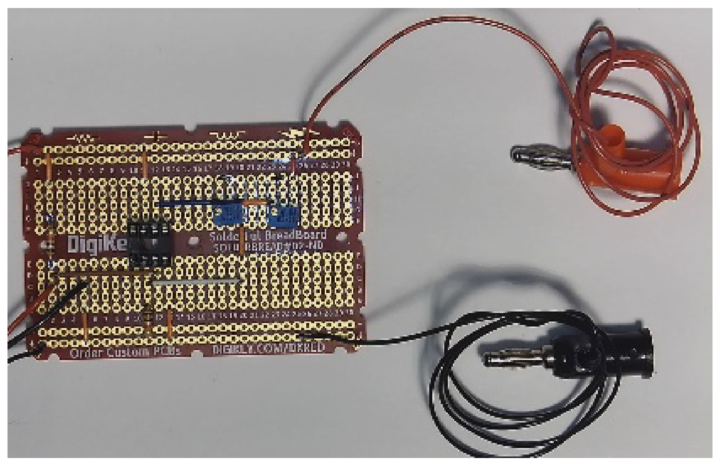


Figure 33: Connections for 3.3V Power Supply. Notice the +3.3V is on a different row from the +5V supply.

Finally, install the Op Amp in the socket, making sure the orientation is correct.

You should not have a complete circuit as shown in Figure 34. You connect power and verify the circuit is operating correctly by repeating the measurements of V_{in} and V_{out} like you just did on the breadboard circuit.

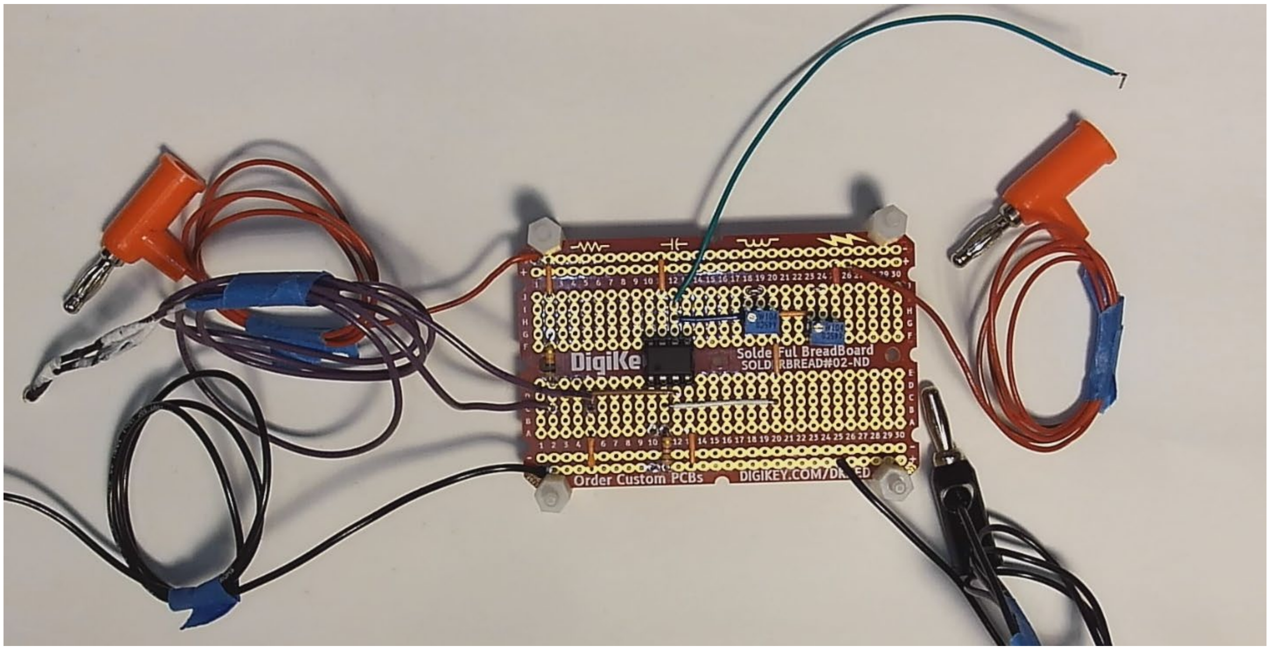


Figure 34: Complete Diode Temperature sensor circuit.

Final Calibration of the Diode Circuit

We are now ready to take final calibration measurements of our diode temperature circuit.

At a minimum of 5 temperatures between 0 and 50 °C, measure Temperature, V_{in} and V_{out}. Be sure to record photos of your water bath calibration setup for your report.

Table 5: Diode Sensor Final Calibration Points

Temperature Point	Measured Temperature (C)	V_{in}(V)	V_{out}(V)
0-10 C			
10-20 C			
20-30 C			
30-40 C			
40-50 C			

Make a plot of V_{in} (x) vs V_{out}(y) and fit a line to your data. This is the actual amplifier performance.

Next plot V_{out} (x) vs Temperature(y). Again, fit a line to this data. This is your calibration equation, it allows you to convert a voltage reading from the sensor to a Temperature in Celsius.

Thermistor Circuit

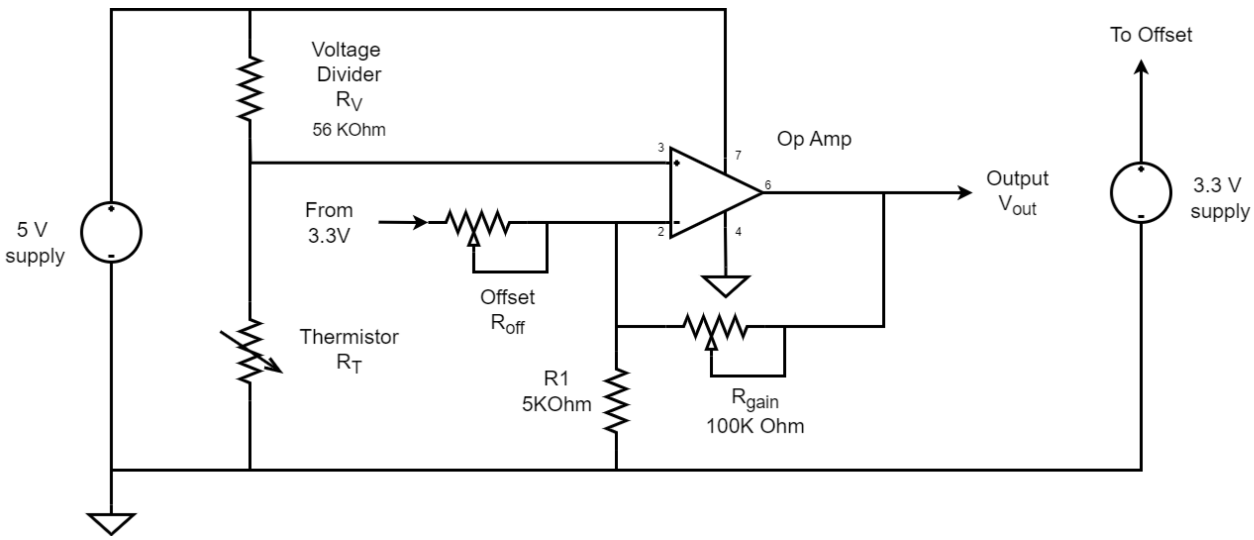


Figure 35: Completed thermistor temperature sensor circuit.

Now, on your own, construct and calibrate the circuit above to build a second temperature sensor. Construct the prototype circuit on the breadboard and build a soldered PCB circuit just as we did with the diode.

Repeat all the necessary measurements to set the gain and offset for the amplifier. But this time set the amplifier so that it outputs **0V at 50 °C and 5V at 20 °C.**

Notice that the circuit is the same as the diode circuit with the following changes. R_L is replaced with a 56 KOhm Resistor R_v, the diode is replaced with a thermistor, and R1 has been changed to a 5000 Ohm resistor.

Thermistor Theory of Operation

The Thermistor is a variable resistor that changes its value depending on its temperature. If we combine it with a fixed resistor, we can get a voltage signal V_{in} given by:

$$V_{in} = \frac{R_T}{R_T + R_v}$$

To figure out what R_T will be, look at the datasheet [2], there we see a table that has the resistance at 25C and a material type.

Epoxy-coated thermistor

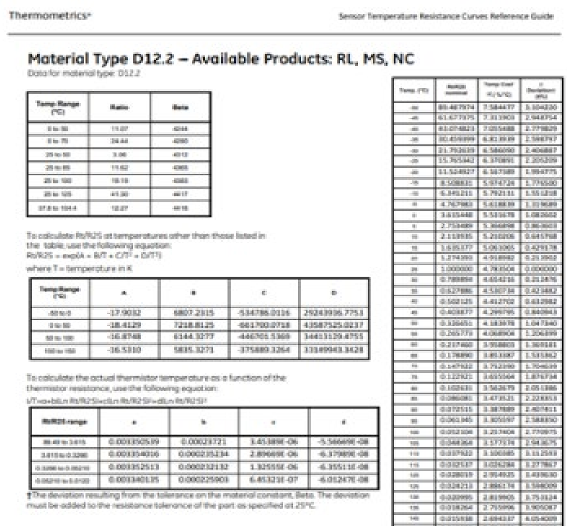
Type Number	Ro@ 77 °F (25 °C) (Ω)	Material System	A in	mm
RL0703-624-73-MS	1K	D7.3	0.120	3.05
RL0503-1248-73-MS	2K	D7.3	0.095	2.41
RL0703-1445-95-MS	2.5K	D9.5	0.120	3.05
RL0503-2890-95-MS	5K	D9.5	0.095	2.41
RL0703-2910-97-MS	5K	D9.7A	0.120	3.05
RL0703-3720-84-MS	6K	D8.4	0.120	3.05
RL0503-5820-97-MS	10K	D9.7A	0.095	2.41
RL0703-5744-103-MS	10K	D10.3	0.120	3.05
RL0503-7440-84-MS	12K	D8.4	0.095	2.41
RL0703-8780-96-MS	15K	F9.61	0.120	3.05
RL0503-11.49K-103-MS	20K	D10.3	0.095	2.41
RL0703-13.77K-120-MS	25K	D12.0	0.120	3.05
RL0503-17.56K-96-MS	30K	F9.61	0.095	2.41
RL0503-27.53K-120-MS	50K	D12.0	0.095	2.41
RL0703-27.68K-122-MS	50K	D12.2	0.120	3.05
RL0503-55.36K-122-MS	100K	D12.2	0.095	2.41

Figure 36: Thermistor material table from thermistor datasheet.

To determine the resistance values, we need to look up an additional document [3] from the manufacturer, the Temperature Resistance Curve Reference Guide.

This 80-page document has tables for many different types of thermistors. Looking up the correct material listed on the datasheet, we see the thermistor resistance in 5-degree increments from -50 to 150.

One thing to note is that the resistance is given as a ratio in terms of resistance at 25 °C, so we need to multiply the number from the table times R_{25} (100KOhm in this case) to find R_T.



Thermometrics

Sensor Temperature Resistance Curves Reference Guide

Material Type D12.2 – Available Products: RL, MS, NC

Temp Range (°C)	A	B	C	D
-50 to 0	-17.9032	6807.2315	-534786.0116	29243936.7753
0 to 50	-18.4129	7218.8125	-661700.0718	43587525.0237
50 to 100	-16.8748	6144.3277	-446701.5369	34413129.4755
100 to 150	-16.5310	5835.3271	-375889.3264	33149943.3428

Figure 37: Thermistor Resistance table for 100KOhm resistor.

Temperature Calibration Report Guidelines

After you have built and calibrated both the diode and thermistor circuits, you will write a report. The report should contain the following sections and elements. You should include both the diode and thermistor, with different plots or data where they differ.

Introduction

Briefly(1 to 2 paragraphs each) explain how the temperature sensors work, including diagrams of the circuit and photos of your completed circuit.

Amplifier Setting

Explain how you set the amplification. This should include(for both sensors):

- Plot of V_{in} vs Temperature
- The plot used to determine your target transfer function (and the values)
- Target and Actual settings for potentiometers R_{gain} and R_{off}

Calibration Procedure

Briefly(again 1 to 2 paragraphs) explain how you took your final calibration data for each circuit. Be sure to include how you controlled the temperature of the water, how you measured the temperature, photos of your calibration setup, and any additional equipment used.

Calibration Results

Include your final V_{in} vs V_{out} and V_{out} vs Temperature. Be sure to include both calibration equations. Compare the actual amplifier performance with your target values.

References

[1] T. Instruments, "TLV271 Datasheet," [Online]. Available: https://www.ti.com/product/TLV271.

[2] Amphenol, "NTC Type Thermistor Datasheet," [Online]. Available: https://laspace.lsu.edu/laaces/wp-content/uploads/2020/09/R05.05_NTC_Type_Thermistor_Datasheet.pdf.

[3] Amphenol, "Sensor Temperature Resistance Curve," [Online]. Available: https://laspace.lsu.edu/laaces/wp-content/uploads/2020/09/R05.06_Thermistor_TvsR_curves.pdf.