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Course Code: EEE313

Section: 02

Experiment Number: 01

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Lab 1 Preliminary Report

Introduction:

This experiment has 2 purposes. First one (Part A) is finding the reverse saturation current of a diode in LTspice, and the second goal (Part B) is to design a differential temperature sensor using the temperature dependence of a diode forward voltage under constant current. The specifications are listed below:

1. When the sensor is at room temperature, the output voltage should be nearly half the supply voltage (Vdd/2 ±0.3V).

2. The output voltage should show the temperature difference between the room temperature and the temperature of the sensor diode in degrees with a 10% tolerance. For example, a +1 degree difference should give us a change of +1±0.1 V in the output voltage.

3. A red LED should turn on when the sensor's temperature exceeds +3±0.5°C the room temperature.

4. The LED should never flicker around the thresholds (it should have a 0.1°C hysteresis).

Methodology:

For Part A, I reverse biased the diode in order to observe the reverse saturation current. The following figure shows the LTspice schematic of the circuit.

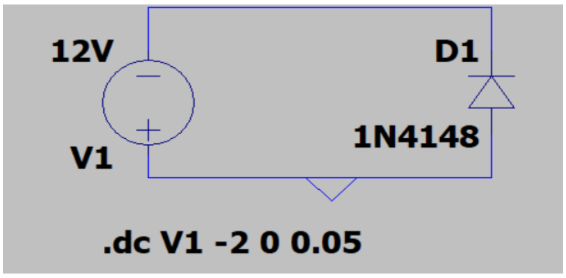

Figure 1: Reverse biased diode circuit

For Part B, in order to design a differential temperature sensor regarding the temperature dependence of a diode, I used two diodes and two OPAMPs. One of the diode is going to be stay at room temperature (between 18°C and 28°C) and the second diode is going to be our sensor diode. The temperature difference will reduce the sensor diodes forward voltage accordingly. Therefore, I used a difference OPAMP to take the difference of the voltages of the two diodes and amplify it to a certain value. Then I used a comparator with hysteresis to determine under which conditions to turn the LED on. The main goal for including a hysteresis is to avoid any possible flickers that may happen on the LED.

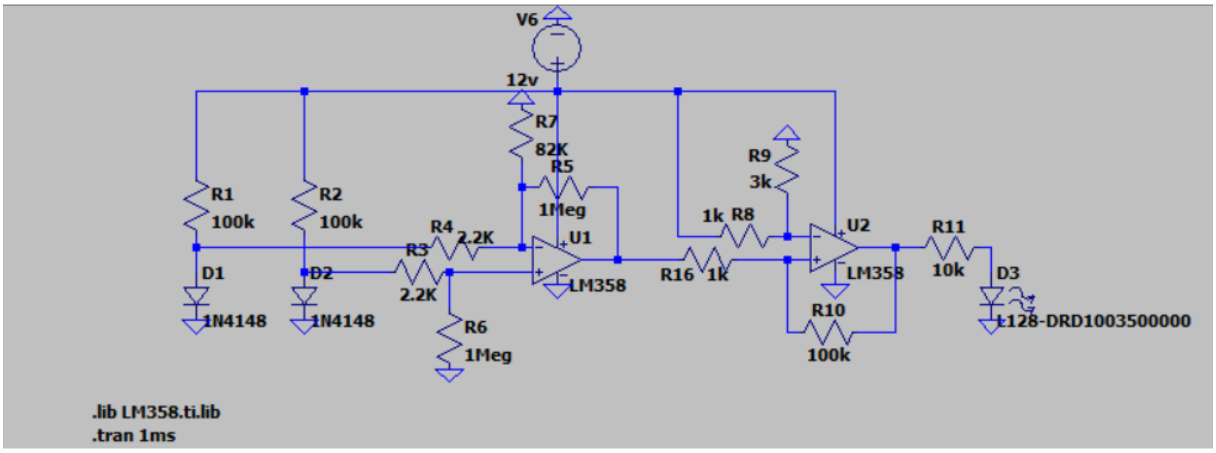

Figure 2: Differential temperatue sensor schematic

Analysis:

Part A

The current equation of a diode is as follows:

$$I_d = I_S\left(e^{\frac{V_d}{(n*V_T)}} - 1\right);\ V_T = \frac{kT}{q}$$

When we reverse bias the diode, exponential value in the equation becomes zero and we obtain the following equation.

$$I_d = -I_S$$

LTspice can measure the I_d of a diode, that is why we obtain negative current values in the simulation. The figure below shows the I_d value for the 1N4148 diode.

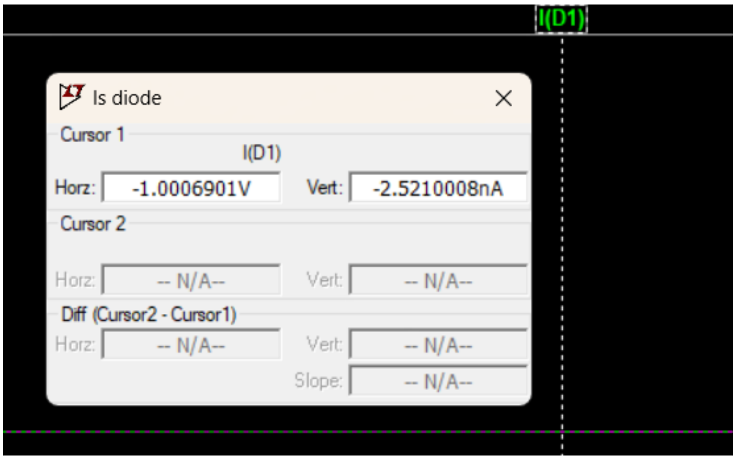

Figure 3: I_S value of the 1N4148 diode

Also looking at the LTspice library, it is seen that the real reverse saturation current for the 1N4148 diode is 2.52nA. (Figure 3)

Figure 4: I_S value

Part B

As I learnt in the class, forward voltage of a diode decreases by 2mV/°C. To meet the second requirement, I need to amplify this 2mV difference to 1V. (Figure 5 shows the voltages of two diodes. The green lined voltage belongs to a diode with 27°C and the blue lined voltage belongs to a diode with 28°C.) Therefore I used a difference OPAMP which takes the difference of inputs and outputs an amplified voltage. To do it, I choose my resistor that will make 500 gain due to the ratio of 1V/2mV. Regarding that, I choose the resistor values as follows: 2.2KΩ and 1MΩ.

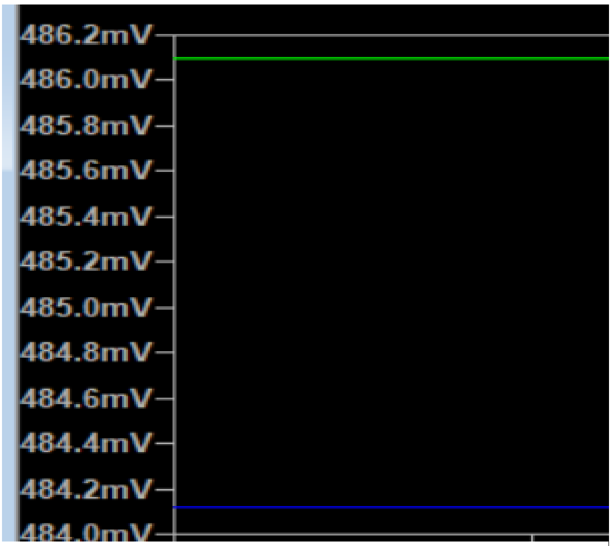

Figure 5: 2mV difference per °C

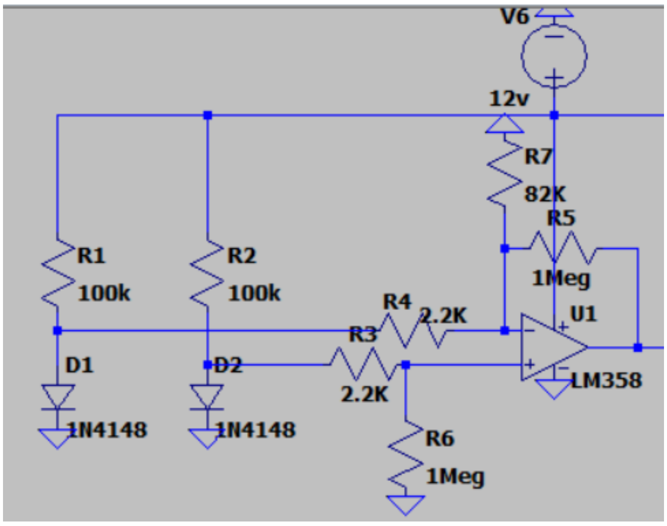

Figure 6: Difference OPAMP part of the circuit

For the first requirement, which is when both diodes are in room temperature, output voltage should be $V_{DD}/2 \pm 0.3V$, I connected an additional 82 KΩ parallel to the inverting input of the difference OPAMP. This resistor's job is to amplify the output voltage to $V_{DD}/2 \pm 0.3V$, and because my $V_{DD} = 12V$, I get an output voltage slightly close to 6V which can be seen in the figure below. (Figure 7)

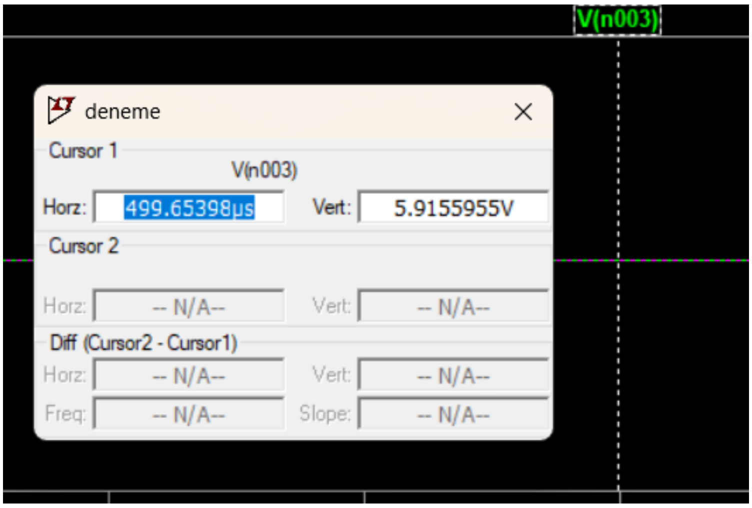

Figure 7: Amplifed output voltage at room temperature

When I increase the degree of the sensor diode 1°C, output voltage should be in the range $\frac{V_{DD}}{2} \pm 0.3V + 1V \pm 0.1V$. As seen in the figure below, when I increase 1°C, the output voltage is equal to 6.8V.

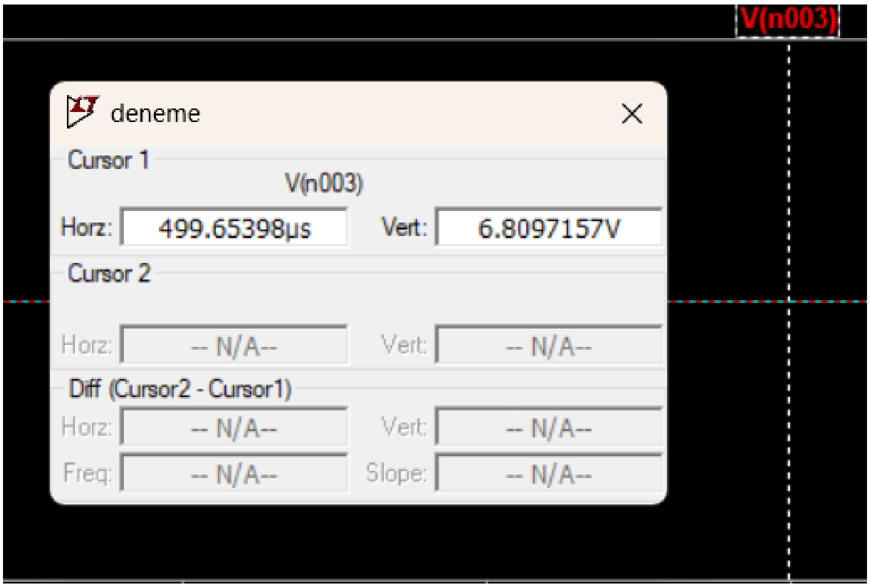

Figure 8: Output voltage when 1°C increase

For LED to turn on when sensor diode exceeds the temperature of the reference diode by +3±0.5°C, I used a comparator OPAMP. Comparator OPAMP basically compares the inverting and non-inverting inputs and gives an output regarding these. If the inverting output is bigger than the non-inverting input, then the output will very close to 0V. Otherwise, output will be equal to $V_{DD} - 2$ because LM358 OPAMP attenuates 2V of the given V_{DD}. Figure 9 shows the comparator OPAMP schematic.

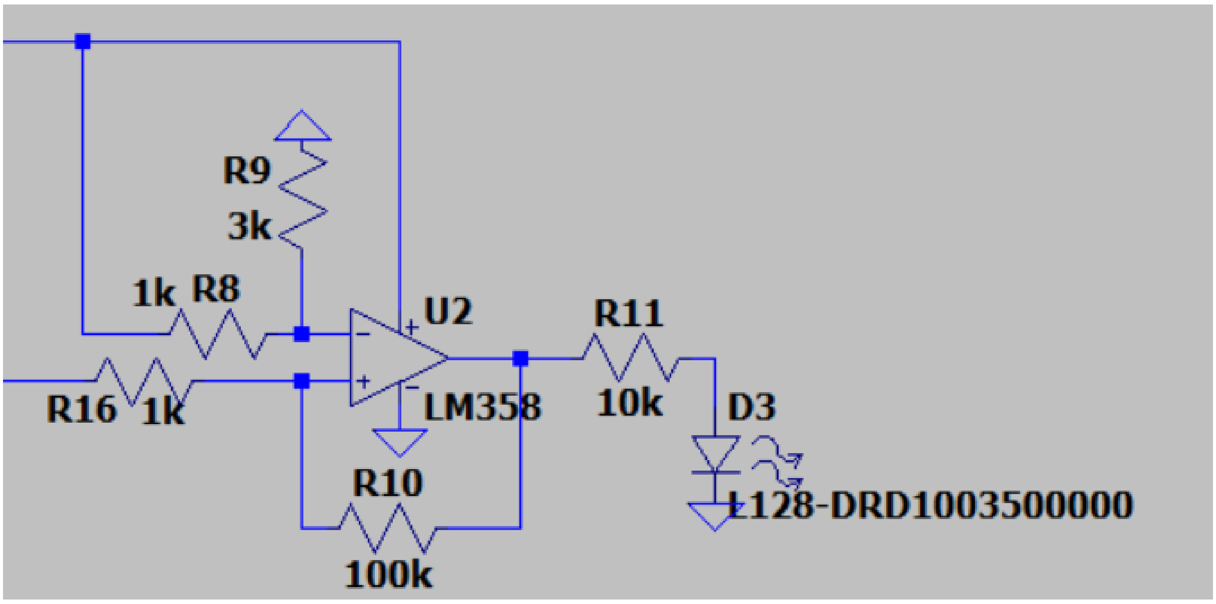

Figure 9: Comparator OPAMP schematic

Instruction says that whenever the difference of diodes' temperature exceeds +3±0.5°C, LED should turn on. As I mentioned above, every 1°C increase gives us 1V increase in the output voltage. Starting from this point, I need nearly $\frac{V_{DD}}{2} + 3V$ to turn LED on. Therefore I get 9V to the inverting input of the OPAMP by a simple voltage divider, and directly connected the difference OPAMP output to the non-inverting input of the comparator OPAMP because this is the value we are considering whether temperature difference is +3±0.5°C.

Also, to obtain a 0.1°C hysteresis, I connected a 100KΩ from non-inverting input to the output of the comparator OPAMP. I choose the resistor values for hysteresis using the equation below.

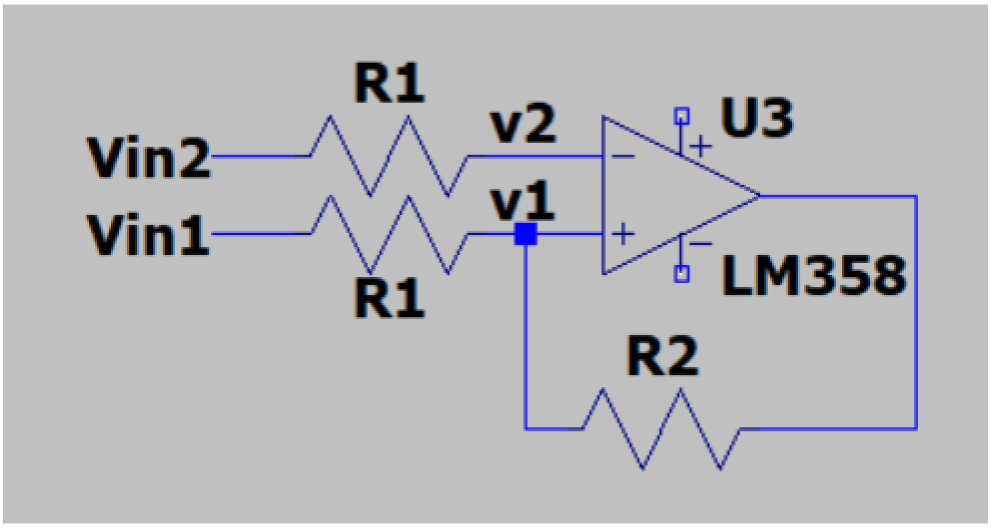

Figure 10: Basic comparator OPAMP with hsyteresis

$$V_{out} = \begin{cases} V_{DD} - 2 & if\ V_{+} > V_{-} \\ 0 & if\ V_{+} < V_{-} \end{cases}$$

$$Hysteresis\ Value = \frac{R_1}{R_2}(V_{DD} - 2); \qquad V_{DD} = 12$$

0.1°C difference is equal to 0.1V. Therefore I made calculations according to that and choose R2 = 100K Ω and R1 = 1K Ω.

Figure 11 shows the output voltage level when room temperature is 23°C and sensor diode's temperature is 26.5°C.

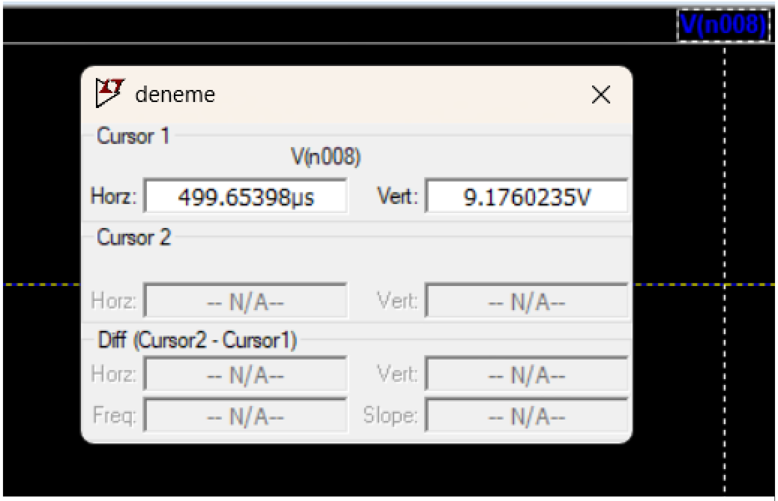

Figure 11: 3.5°C difference output level

As expected, the output voltage is around $\frac{V_{DD}}{2} + 3 * (1 \pm 0.1)$. Which is between $8.7 \leq V_{out} \leq 9.3$

My sensor diode's turn on point is 26.5°C when the reference diode's temperature is 23°C. Figure 12 shows the voltage level of the LED at 26.5°C. Also as assumed, LED voltage is slightly similar to 1.7V

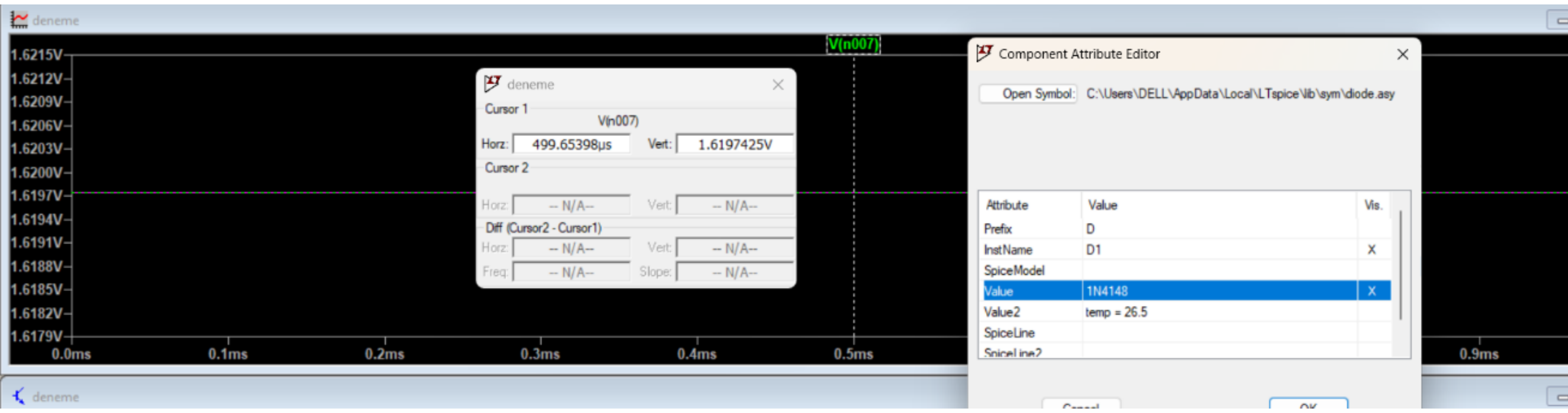

Figure 12: LED voltage at 26.5°C

When I decrease voltage by 0.1°C, LED voltage goes low as seen in figure below.

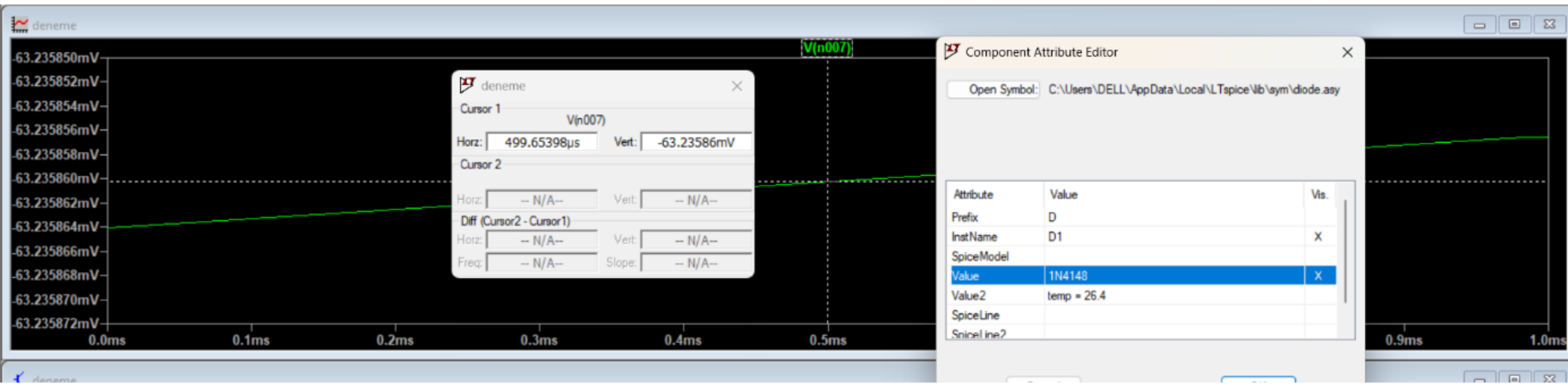

Figure 13: LED voltage at 26.4°C

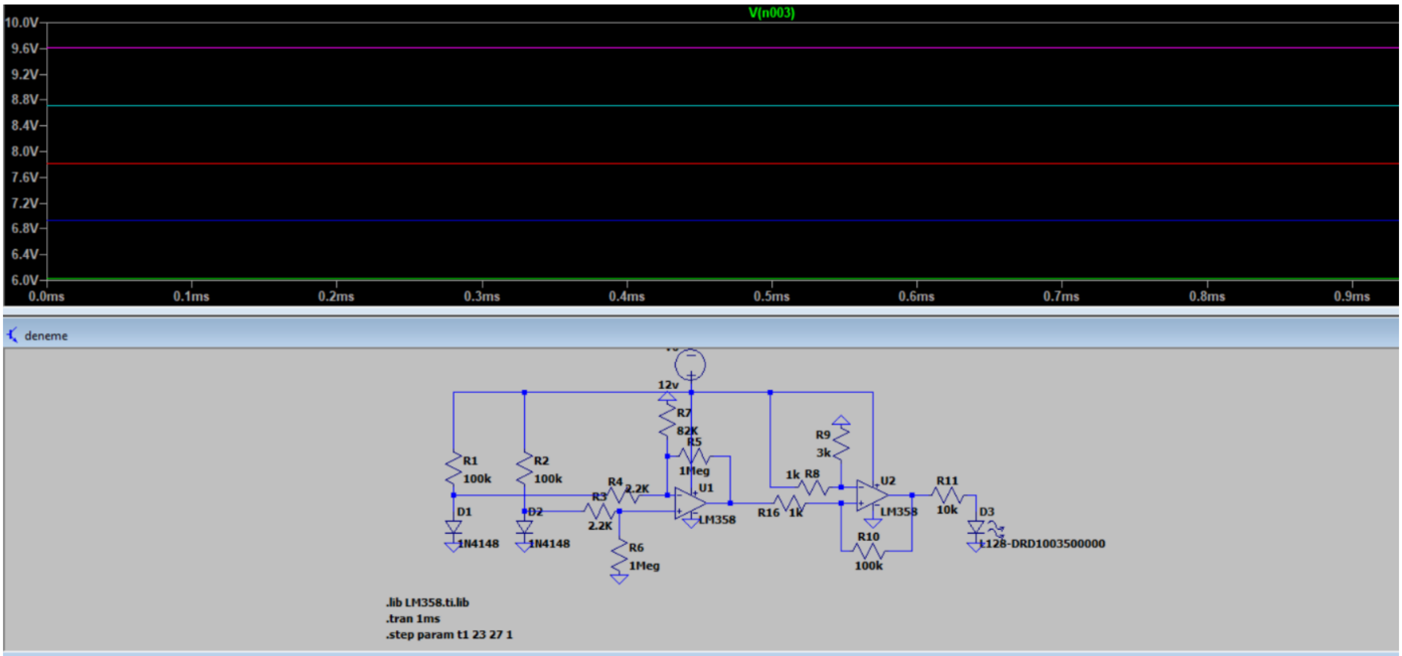

Figure 14: Output voltage for different temperatures

In the figure above, output voltage of the difference OPAMP is shown with temperature values from 23°C to 27°C incrementing by one. As expected, when both diodes are at 23°C, output voltage is around 6V, and for every 1°C increase, we get around 1V increase in the output voltage.

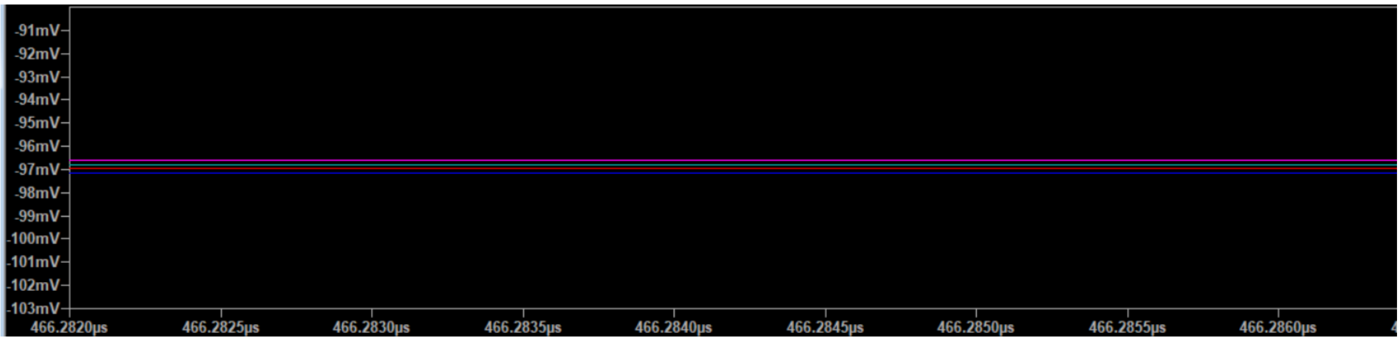

Figure 15: LED voltage for 23°C, 24°C, 25°C, and 26°C when reference diode's temperature is 23°C

Looking at Figure 15, we get approximately 0V at LED voltage for temperature values: 23°C, 24°C, 25°C, and 26°C. (As I mentioned above, my LED turns on when the temperature of the sensor diode exceeds 3.5°C of the reference diode.) However, as expected, Figure 16 shows that when the temperature of the sensor diode is 27°C, LED voltage increased to approximately 1.6V (Figure 16).

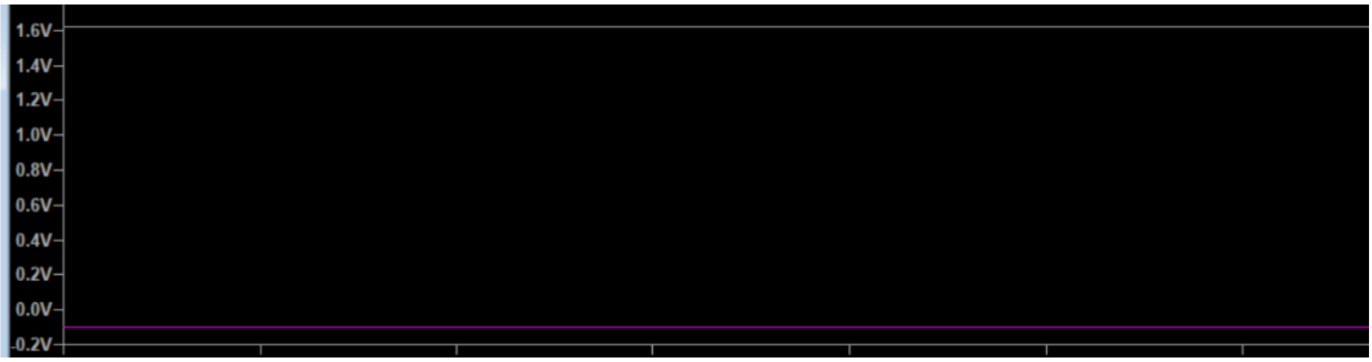

Figure 16: LED voltage for 27°C, when reference diode's temperature is 23°C

Figure below shows the DipTrace schematic of the differential temperature sensor.

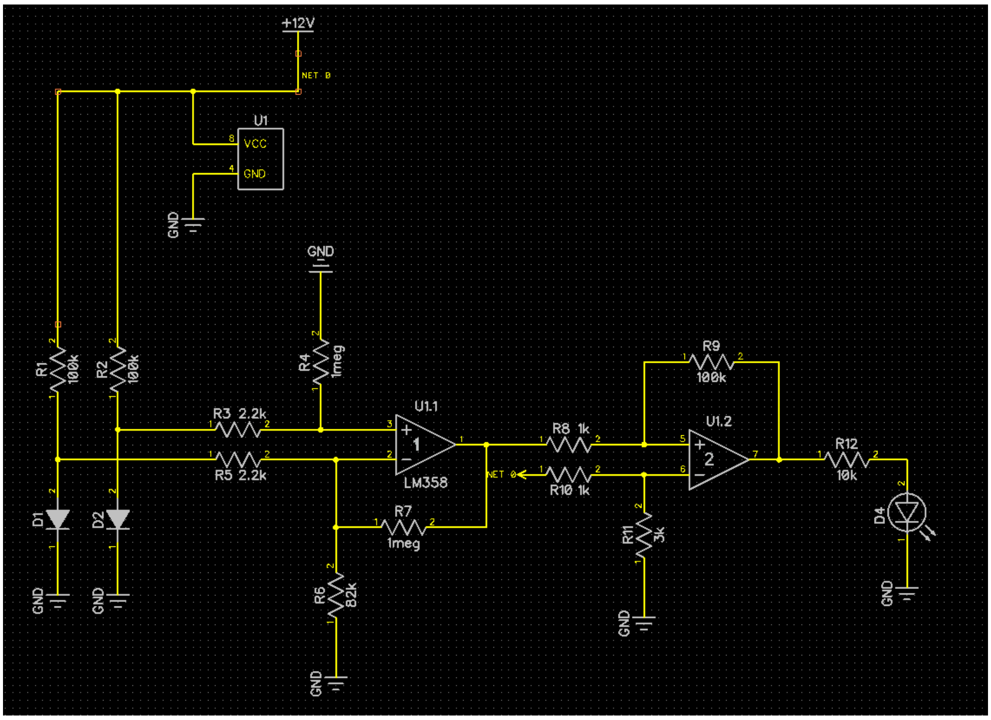

Figure 17: DipTrace Schematic

Component table can also be observed in Figure 18.

#	RefDes	Value	Name	Quantity
1	D1, D2		1N4148,113	2
2	D4		LED	1
3	R1, R2, R9	100k	CFR-12JB-52-100K	3
4	R3, R5	2.2k	CFR-25JB-52-1K	2
5	R4, R7	1meg	CFR-25JR-52-10K	2
6	R6	82k	CFR25SJR-52-100K	1
7	R8, R10	1k	CFR-12JB-52-10K	2
8	R11	3k	CFR-50JB-52-120R	1
9	R12	10k	CFR200JR-73-10K	1
10	U1	LM358	LM358N	1

Figure 18: Component Table