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Section: 1

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EE313- Electronic Circuit Design

Lab1

Diode Characterization and Differential Temperature Sensor

Preliminary Work

Part A

For the very initial part of the preliminary I designed a basic diode circuit with only 3 components to calculate Is (saturation current) of a p-n diode (Figure 1). I observed 798.49mV through the diode which is the forward voltage (Vf) at the room temperature 25◦C. (Figure 2). I also find the current through the diode Id (Figure 3). From the equations below and “n” value given I derive Is with the help of Id and Vd:

$$Id = Is(e^{\frac{V_d}{n\times V_t}} - 1) \quad (\text{eq. } 1)$$

$$V_T = \frac{KT}{q} = 1.752 \qquad (\text{eq. } 2)$$

$$111.362 \times 10^{-3} = Is(e^{\frac{798.71\times10^{-3}}{0.0259\times1.752}} - 1) \quad (\text{eq. } 1.1)$$

$$Is = 2.5258\text{nA}$$

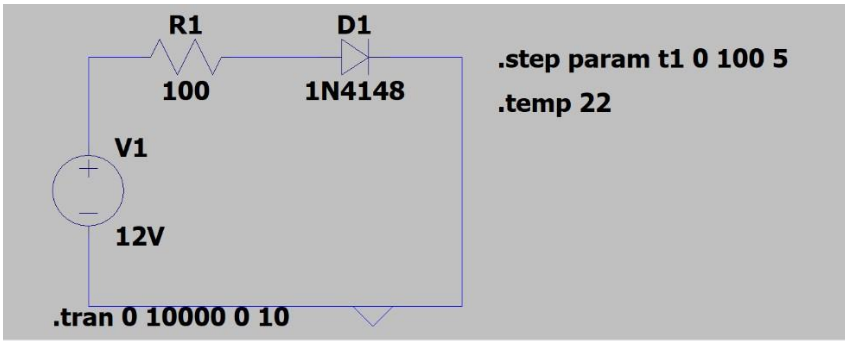

Figure 1: Diode Circuit

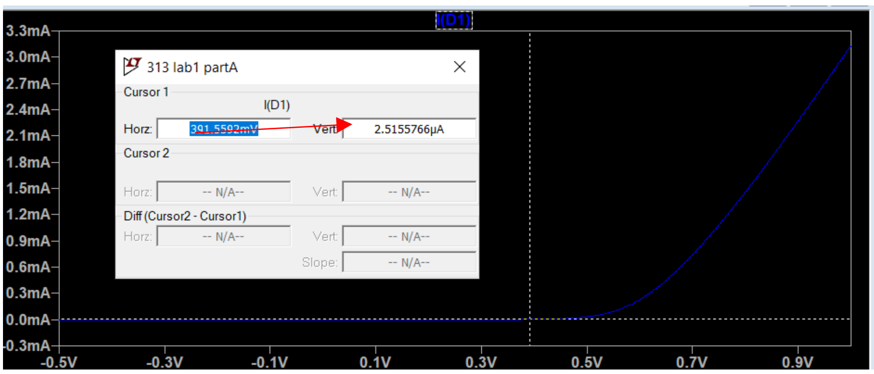

Figure 2: Plot of Is

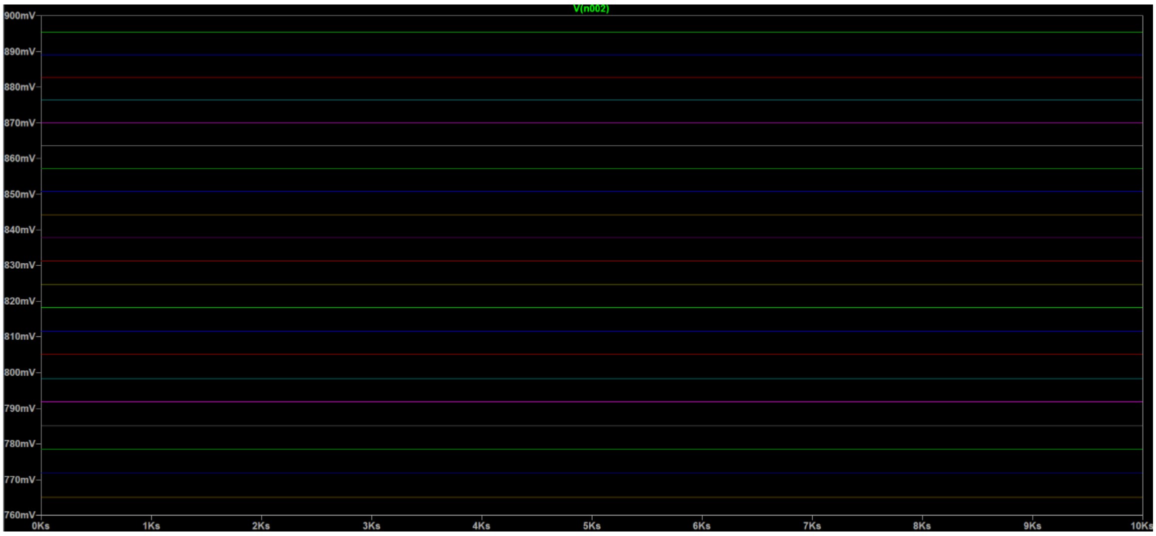

Figure 3: Temperature 0 to 100 with step of 5°C (turquoise after the pink below the plot shows 25°C response of voltage the diode)

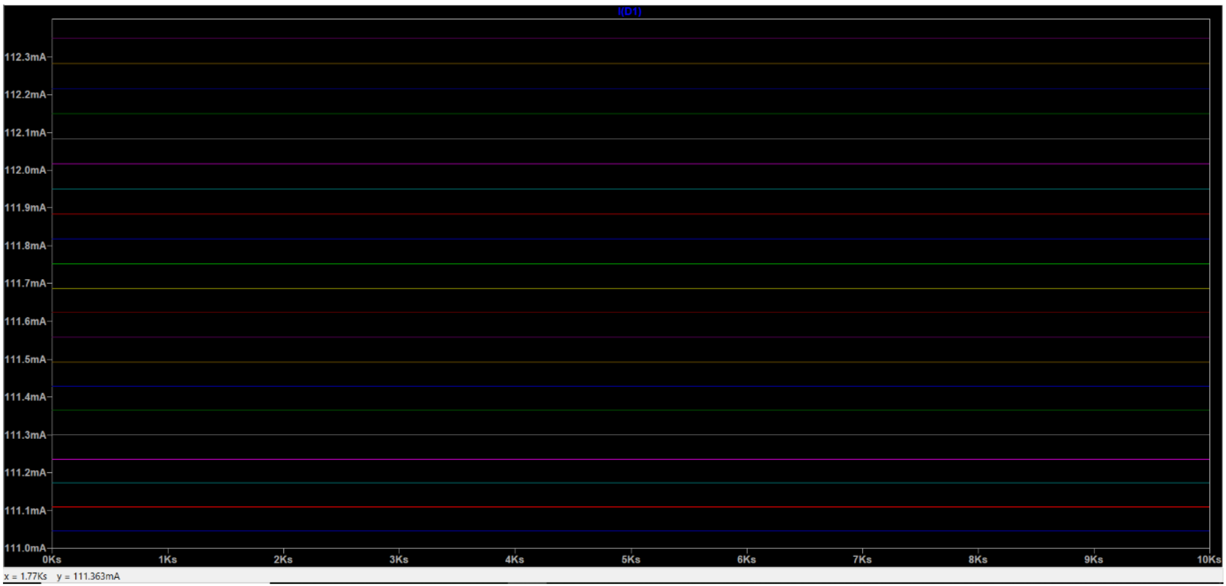

Figure 4: Temperature 0 to 100 with the step of 5°C (gray after the pink below the plot shows the response of the current at 25°C) (cursor shows the exact value left down below)

Part B

For part B, I initially designed the differential opamp (Figure 4) in order to raise the gain after the current goes through the diodes. However, when I grounded the R4 in the figure I got really low voltages like mV. After I connected my supply with my resistor there I observed higher voltages. After that I move on to design my comparator. My overall design shown below (Figure 5). In Figure 6 it is seen that Vout is really close to the value halvet the input voltage at 18℃, also, Vout is shown in Figure 7 at 28℃ still very close to the 6V.

Differential Amplifier

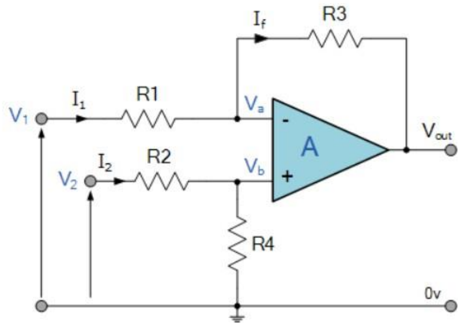

Figure 5: differential opamp design

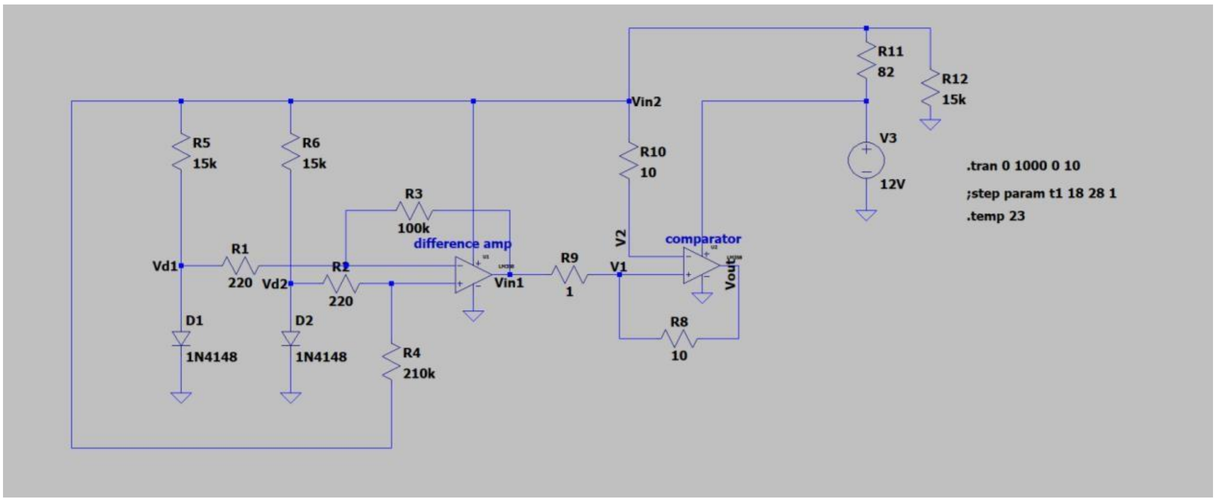

Figure 6: Overall Circuit for Differential Temperature Sensor

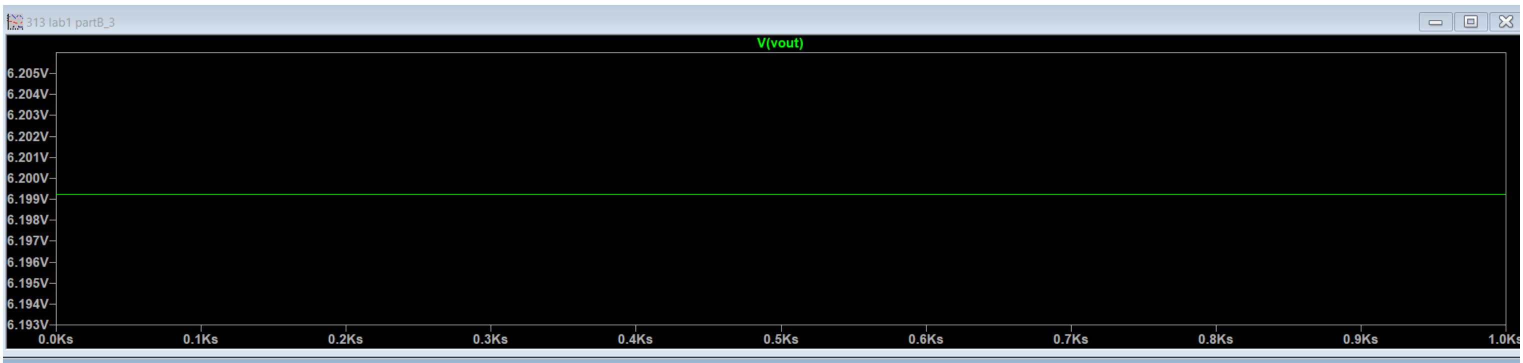

Figure 7: At temperature 18°C Vout is nearly Vdd/2

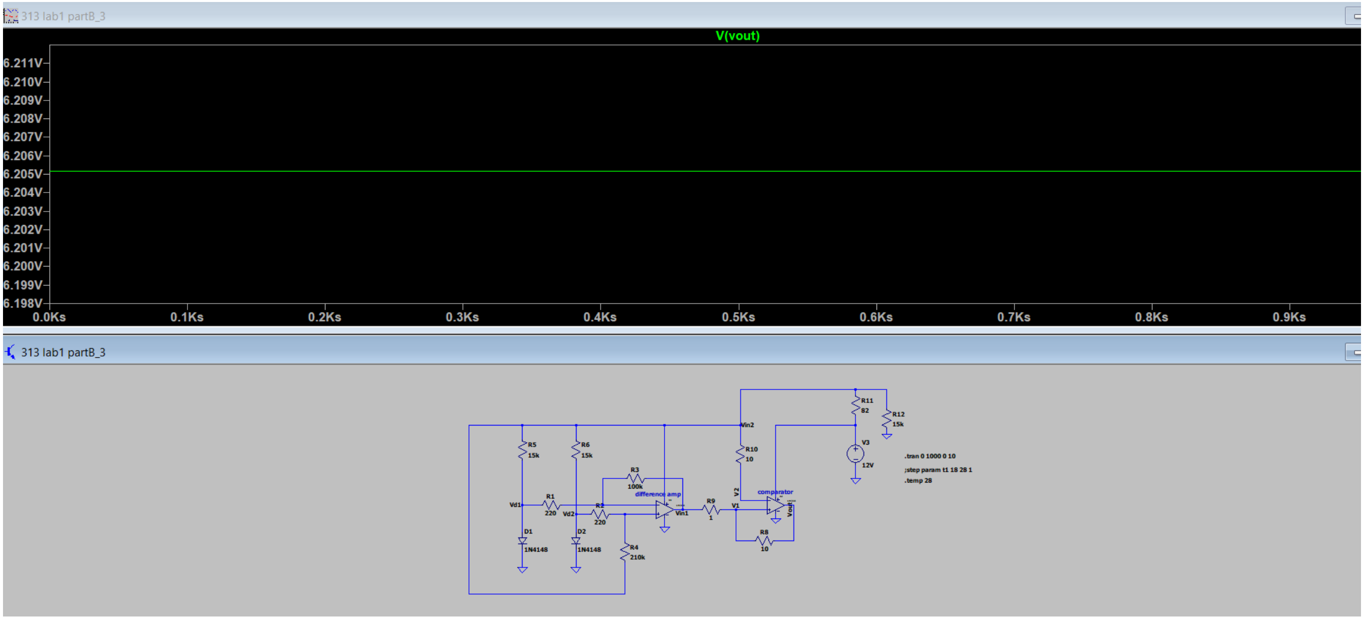

Figure 8: At temperature 28°C Vout is nearly Vdd/2

After checking the room temperature values, now I checked the response with the variety of degree values (18 to 28). Figure 8 shows, that in every 1 *°C* voltage values change with the steps 0.6 to 0.7 which does not satisfy the expectations, however close to 1V.

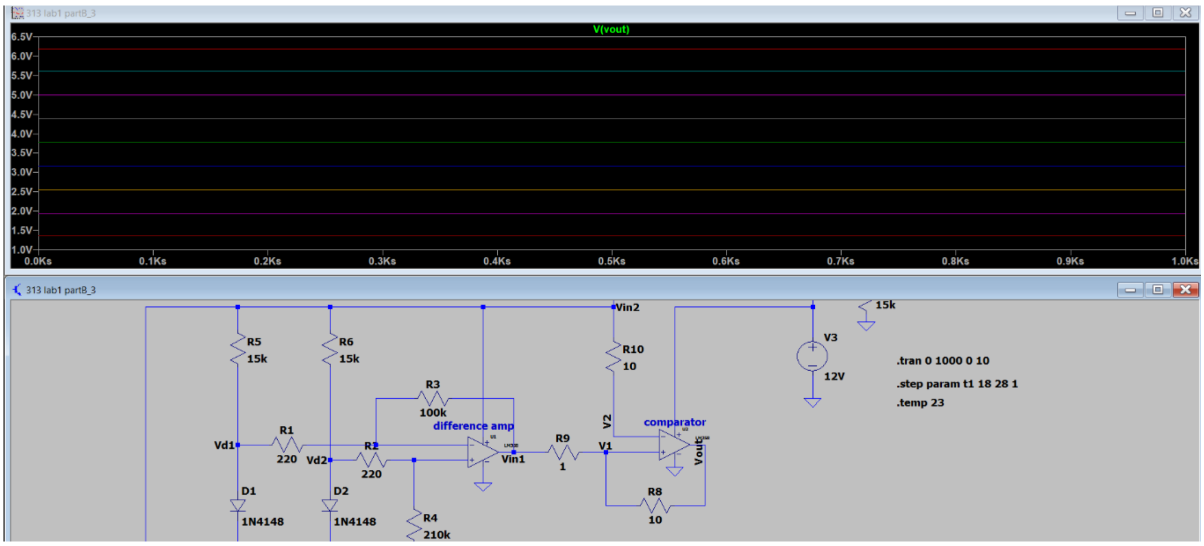

Figure 9: Voltage change based on temperature

In sections B.3 and B.4, the obstacle preventing further progress in my design was the significant alteration of output values upon the addition of an LED and resistor. This change had a ripple effect, impacting preceding steps and necessitating a backtrack to rectify the issue. This phenomenon likely stems from the reintroduction of output voltage feedback, thereby influencing the operational amplifier itself.

Conclusion

Since there are multiple variables affecting the whole circuit and previous steps it was really hard to make some trial and error. However I achieved to reach substeps which are Vin2 and Vin1 shown below with the expected values Figure 9 and the plot I derive with my circuit in Figure 10. However, adding LED was challenging without losing the output voltage so I left at that step.

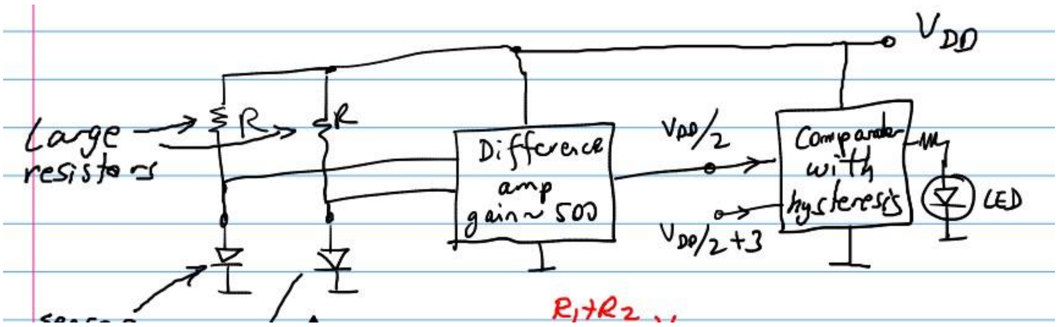

Figure 10: Vin1= Vdd/2 and Vin2=Vdd/2 +3

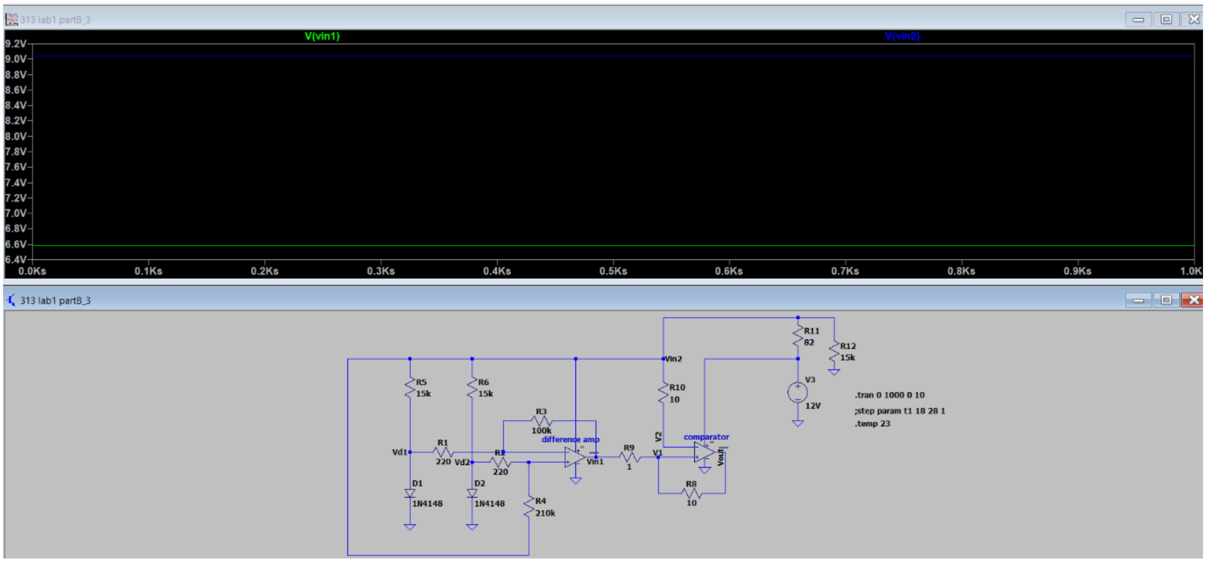

Figure 11: Vin= 6.58V and Vin2= 9.04V

Experimental Work

Part A

In this part, the reason why I burned my resistor I picked a bigger value resistor and increased the voltage.The new schematic and the plot seen below:

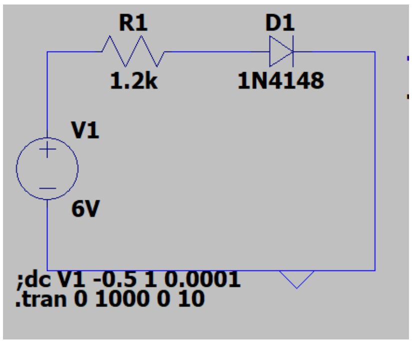

Figure 12: Circuit to calculate Is

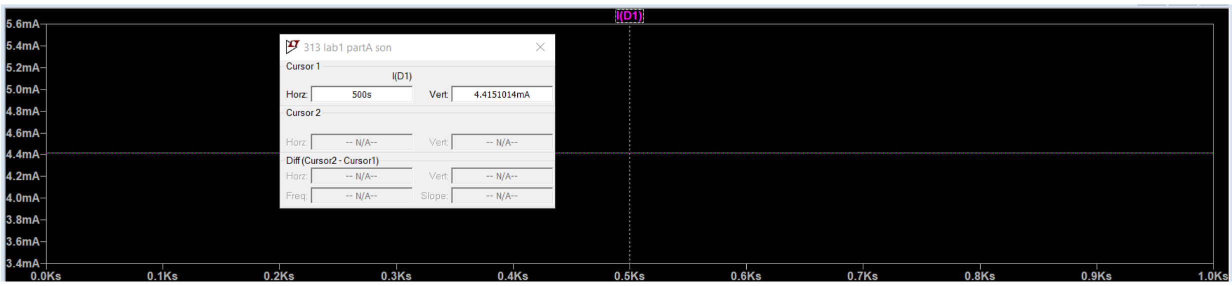

Figure 13: Id current of Figure 12

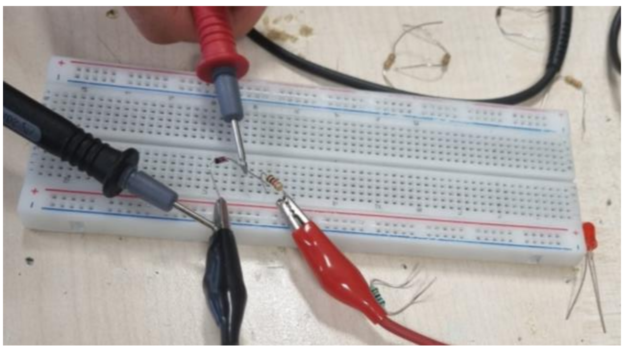

Figure 14: Implementation of Figure 12 on breadboard

Note: To lower the error I encountered I haven't used any jumpers in this design (Figure14).

Figure 15: Observation of 0.654V for Vd for Figure14.

As seen in Figure 13 we observe Id= 4.41mA. From again Eq. 1 we can calculate Is as below with a little error with the voltage value we observe:

$$\frac{4.41 \cdot 10^{-3}}{e^{\frac{0.654}{0.0259 \cdot 1.752}} - 1} \longrightarrow = 2.42719046 \times 10^{-9}$$

Figure 16: Calculation of Is based on values I measured

Software (nA)	2.52
Experimental (nA)	2.43
Error (%)	3.57

Table 1: Error of Is compared to preliminary part

Part B

We used LM358 and 1N4148 in our implementation. Due to the errors, I got in implementation I changed some of my resistor values. For example, I increased my R3 and R8 values to change Vin1 and Vout. Here is my new schematic and plot (Figures 17, 18, and 19). I couldn't use an oscilloscope because it was really hard to catch the opamp's linear region and make a basic opamp circuit and control whether my opamp was working or giving a gain. Also, the oscilloscope's inner resistance will mess up all of my calculations. So instead I used a multimeter to check if I was getting a gain or if Vout was right.

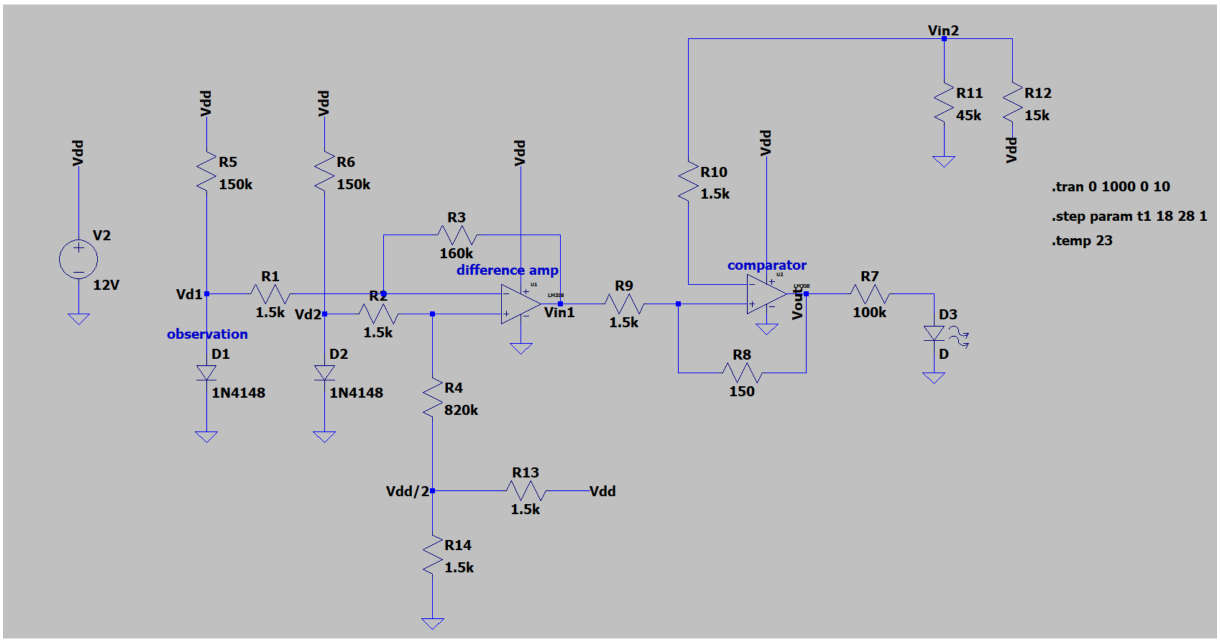

Figure 17: New Circuit for Differential Temperature Sensor at room temperature

I again chose a 12V supply, and to hinder using extra power supplies I designed voltage dividers to feed my opamps and also for inverting and non-inverting inputs. Also, we are asked to have a 500 gain in the first differential opamp. R1 and R3 ratios gave me the gain, however, the reason we have a voltage divider at the non-inverting input of the opamp rather than GND, the ratio was not exactly 500 here. The second opamp doesn't give us amplifying but we used it as a hysteresis comparator. So we were expecting our LED not to flicker around unless we had a sufficient voltage (temperature) difference. As seen in Figure 18, the Vin2 value is Vdd/2 +3 as indicated in the lab document and also we can observe with the cursor, in the left below side Vout is 10.26V. This value is normal because after some temperature difference which is 3℃, the LED should turn on and stay at that specific value which is Vdd-2 (in our case 10V), showing that, our comparator works just as desired. Other than that, if we don't have 3V potential difference Led wouldn't turn on under 1V because our LED doesn't emits light if we don't apply 1V or above.

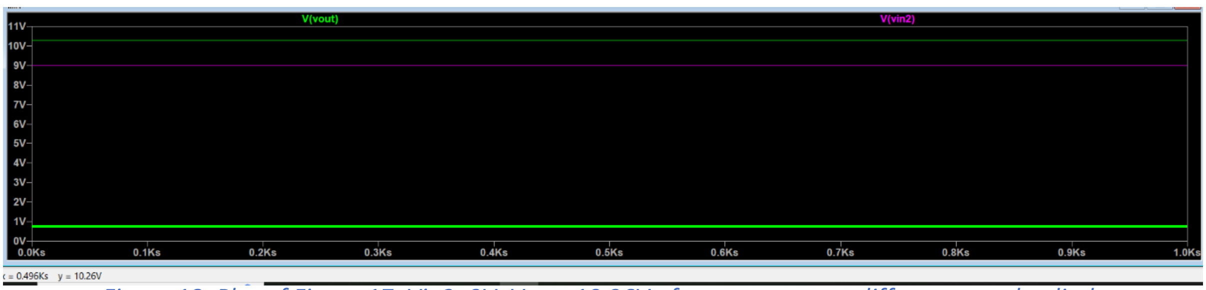

Figure 18: Plot of Figure 17, Vin2=9V, Vout=10.26V after temperature difference on the diodes

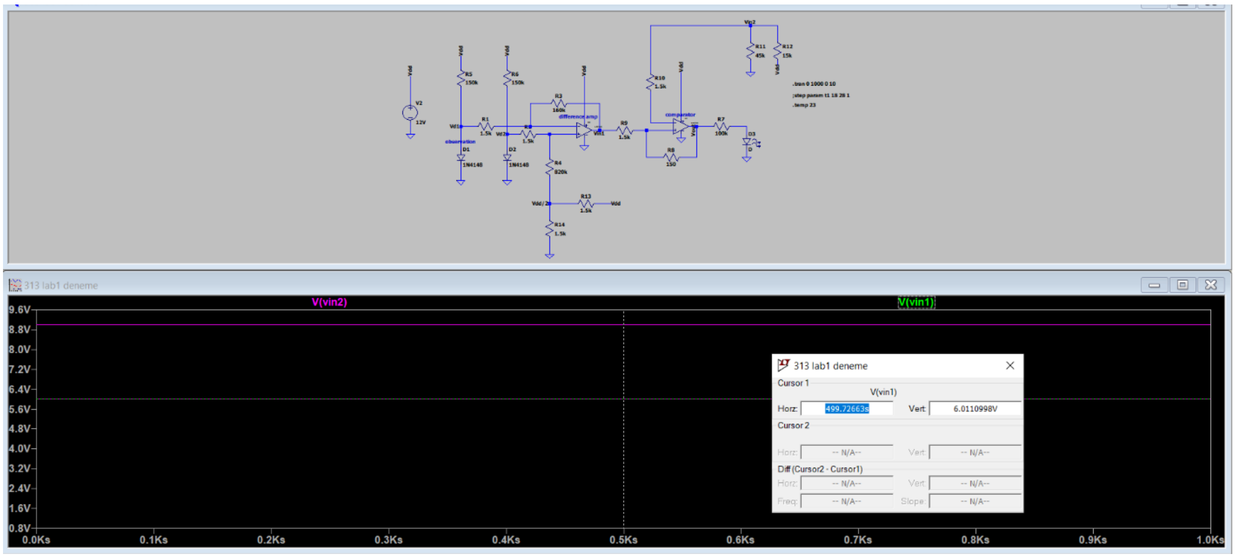

Figure 19: Vin1=6.011V

In the experimental part, I implemented my circuit using minimum equipment and jumper which I got lower error based on my experience (Figure 20).

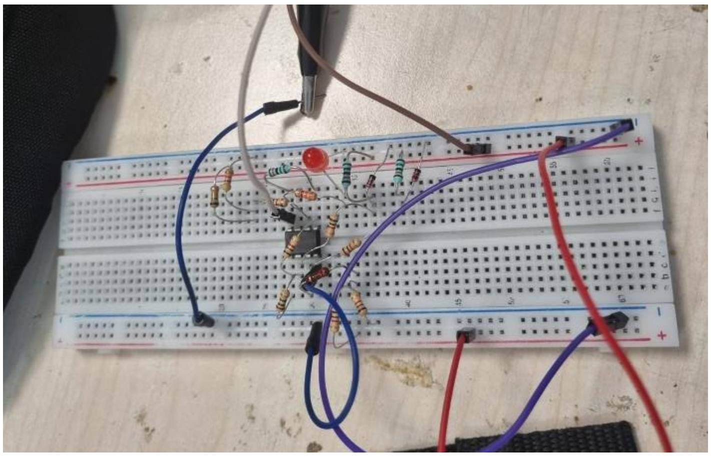
Figure 20: Implemented Circuit

Without touching the diodes, there is almost no voltage difference (temperature difference between diodes) (Figure 21).

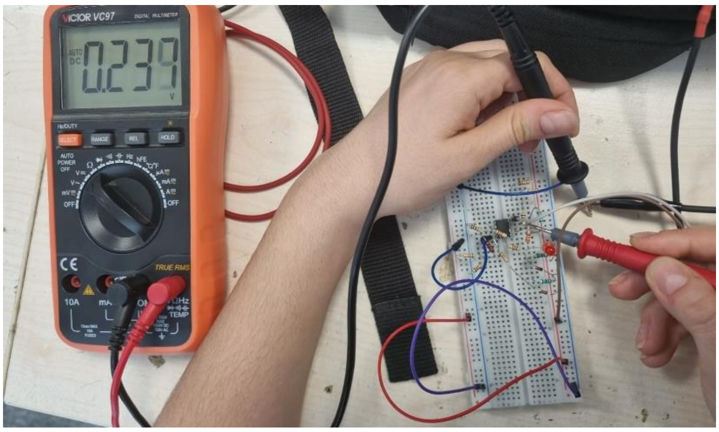

Figure 21: Implemented Circuit, without temp difference 0.237V measured

Vin1 (output of the differential opamp) measured 6.28V which is really close to Vdd/2 (Figure 22).

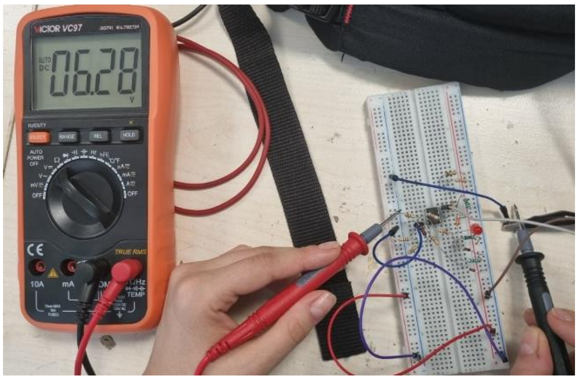

Figure 22: Vin1 was measured as 6.28V

Vout is measured 10.83V after touching one of the diodes (Figure 24).

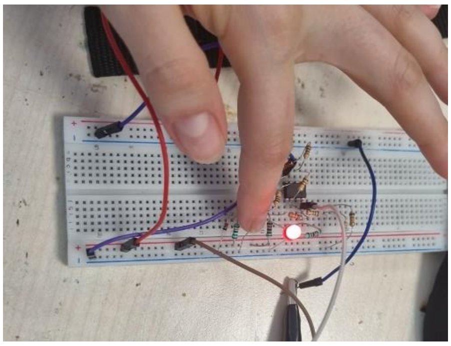
Figure 23: Voltage difference causes to Led turn on

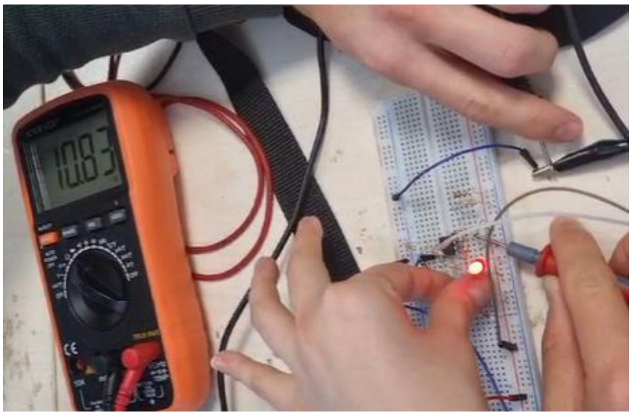

Figure 24: Led is turned on, Vout = 10.83V

Software (V)	6.011
Experimental (V)	6.28
Error (%)	4.48

Table 2: Error Table for Vin1

Software (V)	10.26
Experimental (V)	10.83
Error (%)	5.55

Table 3: Error Table for Vout

Conclusion

Firstly, I learned how to use and implement LM358 and1N4148 and also do research on components. Subsequent adjustments to resistor values and circuit design led to the successful implementation of a functional circuit. Voltage dividers were utilized to supply voltage to op-amps and input terminals, while hysteresis was introduced to stabilize LED behavior in response to temperature changes. Experimental measurements confirmed the circuit's effectiveness, with Vin1 and Vout demonstrating expected behavior. Also, errors were lower than 10%. Despite challenges, the study highlights the importance of iterative design and careful consideration of circuit parameters for successful implementation.

#	Name	RefDes	Value
1	1N4148	D1, D3	
2	LED	D2	
3	CFR25SJR-52-100K	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14	150k
4	LM358N	U1	LM358

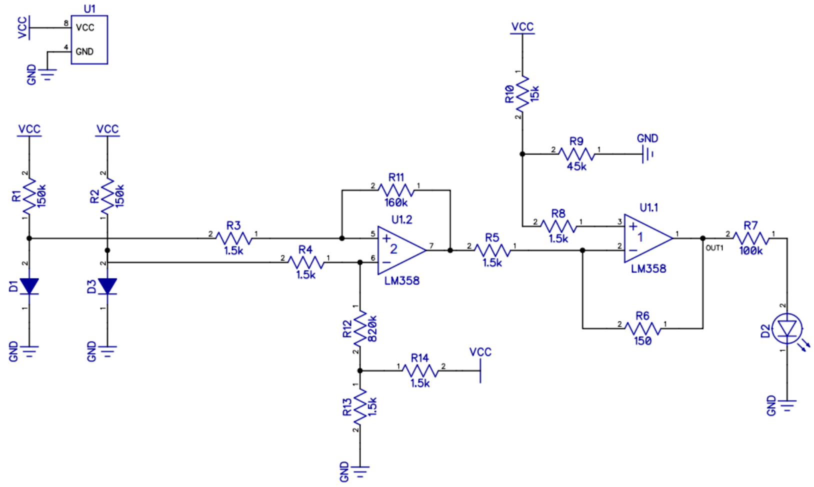

Figure 25: Diptrace Schematic and Component List

REFERENCES:

https://www.electronics-tutorials.ws/opamp/opamp_5.html

https://www.desmos.com/scientific

https://moodle.bilkent.edu.tr/2023-2024-spring/pluginfile.php/68686/mod_resource/content/2/Lab1Hints.pdf