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EE313 LAB 1 FINAL REPORT

Introduction

In this lab, we were asked to study diodes properties basically. First, we needed to design a method to find reverse saturation current (Is) and n coefficient. The method was used in LTSpice simulation and then experimental work. Second, we designed a temperature-controlled circuit with insight gained from preliminary work. In this lab, we understood temperature reactions of diode and manipulating this we designed a controlling circuit.

PART.A

Preliminary Work:

In this part, we are asked to design a method to find Is and n

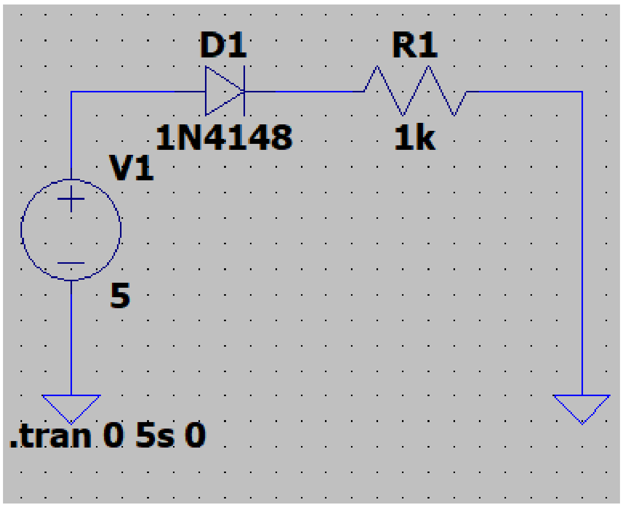

Figure.1: Diode with resistor circuit

$$\ln(I_D) = \ln(I_S) + \frac{V_d}{\eta \cdot V_T}$$

$I_D: Current\ flowing\ through\ the\ diode$

$I_S: Reverse\ saturation\ current$

$V_D: Voltage\ drop\ on\ the\ diode$

$\eta: Emission\ coefficient$

$V_T: Thermal\ Voltage\ (fixed\ in\ room\ temperature)$

Method to find I_S and n

If we apply the same circuit with different voltages, we get different kinds of I_D's and V_D's, so:

$$\ln\left(I_{D_1}\right) = \ln(I_S) + \frac{V_{D_1}}{\eta \cdot V_T}$$

$$\ln\left(I_{D_2}\right) = \ln(I_S) + \frac{V_{D_2}}{\eta \cdot V_T}$$

We have 2 equations, 2 unknowns. This is solvable for η and I_S.

$$\textit{Equation.1:}\ \ln\left(I_{D_1}\right) - \frac{V_{D_1}}{\eta \cdot V_T} = \ln(I_S) \qquad \textit{Equation.2:}\ \ln\left(I_{D_2}\right) - \frac{V_{D_2}}{\eta \cdot V_T} = \ln(I_S)$$

$$\ln\left(I_{D_1}\right) - \frac{V_{D_1}}{\eta \cdot V_T} = \ln\left(I_{D_2}\right) - \frac{V_{D_2}}{\eta \cdot V_T}$$

We know I_{D_1}, I_{D_2}, V_{D_1}, V_{D_2} and V_T. Therefore, we can find η.

Then, we substitute I_{D_1}, V_{D_1}, V_T, η to the Equation-1 and find I_S.

LTspice Simulations

3V Case

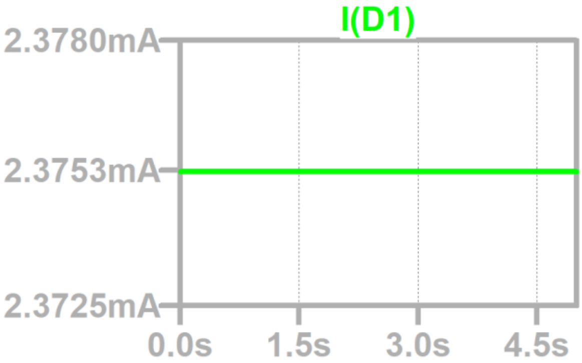

Figure.2: I_{D_1}

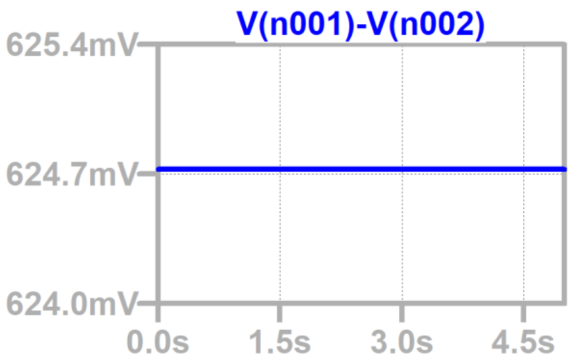

Figure.3: V_{D_1}

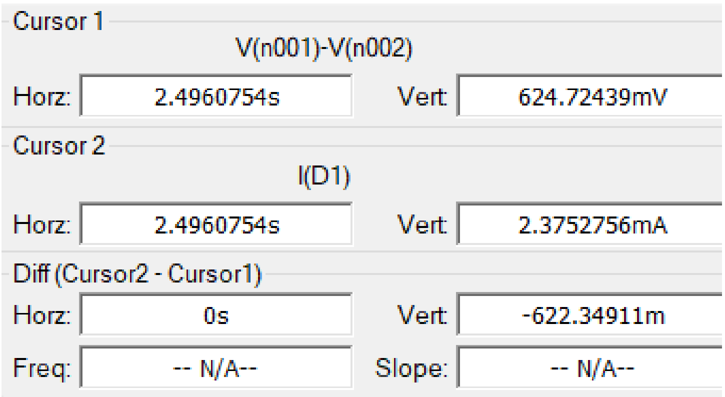

Figure.4: Values of I_{D_1} *and* V_{D_1}

Calculations:

$$V = 3V \rightarrow \ln(I_D) = \ln(I_s) + \frac{V_d}{\eta V_T}$$

$V_T \rightarrow (0.0259)$

$\eta \rightarrow ?$

$$\frac{2.375}{1000}$$

$I_{D_1} = 0.002375$

$V_{D_1} = 0.6247$

$$\underbrace{\ln(I_{D_1})}_{-6.042} - \frac{0.6247}{\eta \cdot (0.0259)} = \ln(I_s)$$

Figure.5: Calculations for 3V case

4V Case

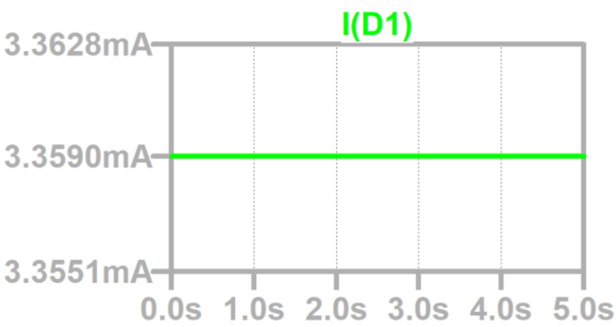

Figure.6: I_{D_2}

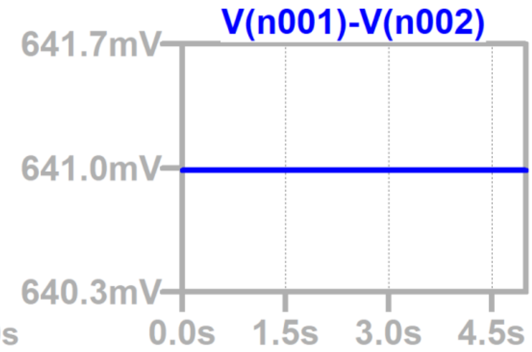

Figure.7: V_{D_2}

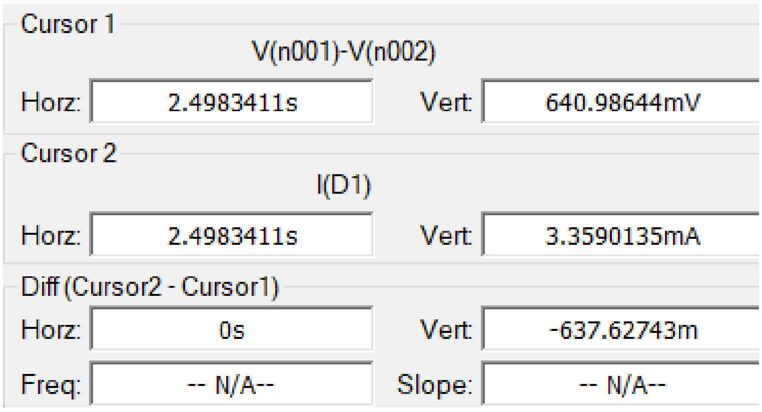

Figure.8: Values of I_{D_2} *and* V_{D_2}

Calculations:

$V = 4V \rightarrow \ln(I_D) = \ln(I_s) + \dfrac{V_d}{\eta \cdot V_T}$

$V_{D_2} = 0.6409$

$I_{D_2} = 0.003359$

$$\underbrace{\ln(I_{D_2})}_{-5.696} - \frac{0.6409}{\eta \cdot (0.0259)} = \ln(I_s)$$

Figure.9: Calculations for 4V case

Finding n:

$$6.042 - 5.696 = \frac{0.6409}{\eta \cdot (0.0259)} - \frac{0.6247}{\eta \cdot (0.0259)}$$

$$0.346 = \frac{0.0162}{\eta \cdot (0.0259)} \rightarrow \eta = \frac{0.0162}{(0.346)(0.0259)} = 1.80$$

Figure.10: Calculations for n

Finding I_s

$$\overbrace{\underbrace{\ln(I_{D_2})}_{-5.696} - \frac{0.6409}{\eta \cdot (0.0259)}}^{-19.443} = \ln(I_s)$$

$$e^{-19.443} = I_s$$

$$0.0000000036$$

$$\boxed{I_s = 3.6 \times 10^{-9} A}$$

Figure.11: Calculations for I_s

As a result, values are:

$$I_S \approx 3.6 \cdot 10^{-9} A$$

$$\eta \approx 1.8$$

There is a slight difference (2.81%) between theoretical n = 1.752 and experimental n.

However, between theoretical Is (2.52nA) and experimental one, there is a 33% deviation. This current is called the reverse saturation current. It is very very small, since we work with 3-significant bits, possibly we have 33% deviation.

Experimental Work:

In the experimental work part, we built a circuit with a resistor (1K theoretical, 0.98 K real) and a diode (1N4148).

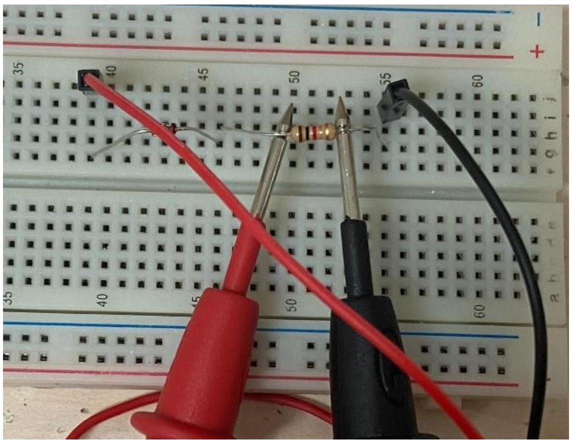

Figure.12: Breadboard setup for the circuit

I first supplied the circuit with 3V, then measured I_{D_1}. Since diode and resistor were connected series, current through resistor also equals to I_{D_1}. Voltage difference between resistor legs divided by the real value of resistance gives us I_{D_1}.

Same method was also used for 4V and 5V case.

	I_D (Experimental)	V_D (Experimental)
3V	2.2 mA	0.659 V
4V	3.2 mA	0.677 V

Table.1: Experimental values for V_D and I_D

Eq-1

$$\ln(I_{D_1}) = \ln(I_s) + \frac{V_d}{\eta \cdot V_T} \rightarrow \underbrace{\ln(2.2\times10^{-3})}_{-6.11} = \ln(I_s) + \frac{0.659}{\eta \cdot 0.0259}$$

$$-6.11 - \frac{25.44}{\eta} = \ln(I_s)$$

Eq2

$$\ln(I_{D_2}) = \ln(I_s) + \frac{V_d}{\eta \cdot V_T} \rightarrow \underbrace{\ln(3.2\times10^{-3})}_{-5.74} = \ln(I_s) + \frac{0.677}{\eta \cdot 0.0259}$$

26.11

$$-5.74 - \frac{26.13}{\eta} = \ln(I_s)$$

$$-5.74 - \frac{26.13}{\eta} = -6.11 - \frac{25.44}{\eta} \rightarrow 6.11 - 5.74 = \frac{26.13}{\eta} - \frac{25.44}{\eta}$$

$$0.37 = \frac{0.69}{\eta}$$

$$\eta = 1.86$$

$I_s \rightarrow$ Eq1

$$-6.11 = \ln(I_s) + 13.67$$

$$-19.78 = \ln(I_s)$$

$$I_s \cong 25\times10^{-9} A$$

Figure.13: Part A experimental calculations.

Since Is is a current power of -9, it is acceptable to see such a deviation. Experimental values and LTSpice simulations were consistent with each other.

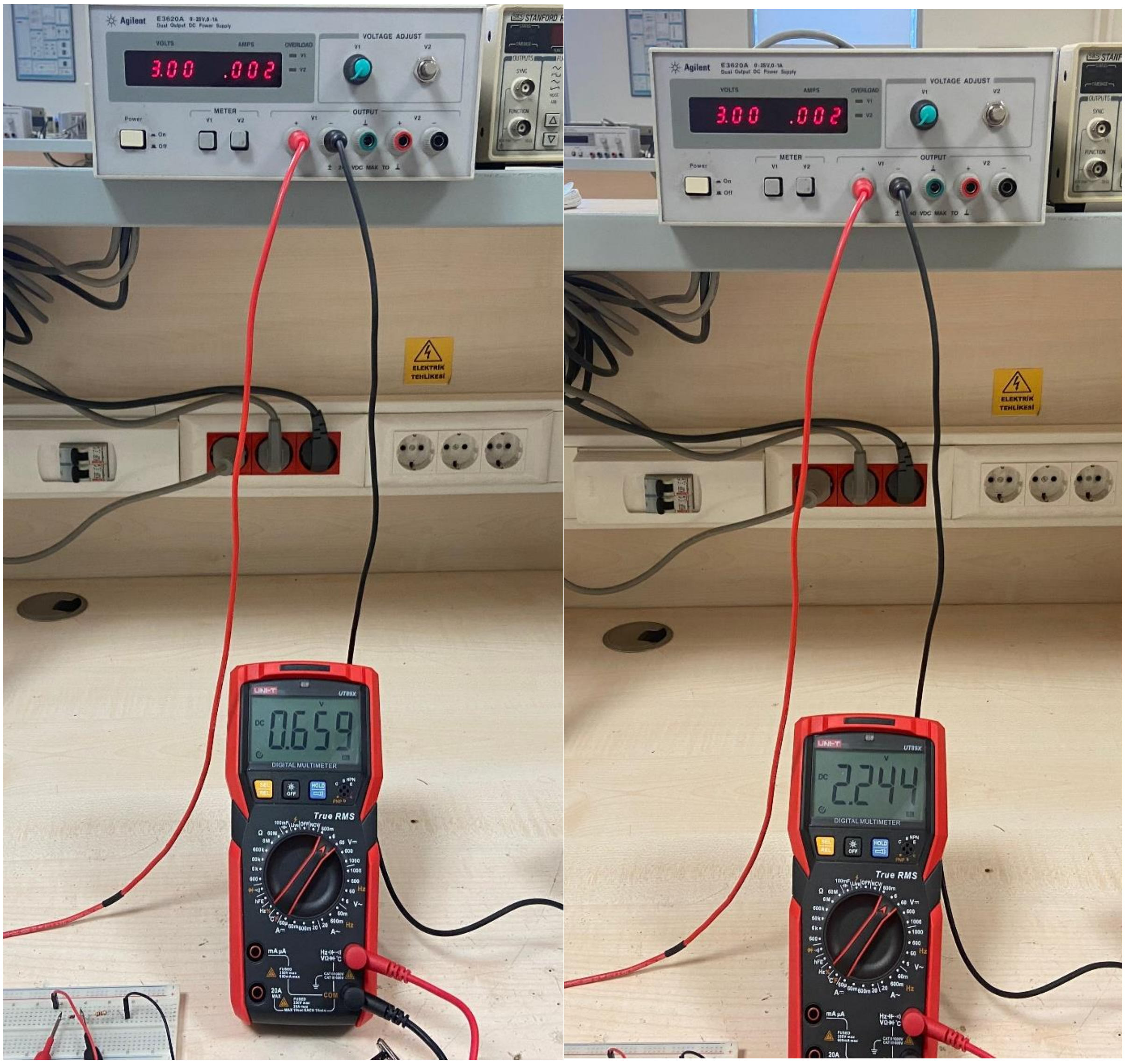

Figure.14: Vd and Vr for 3V case

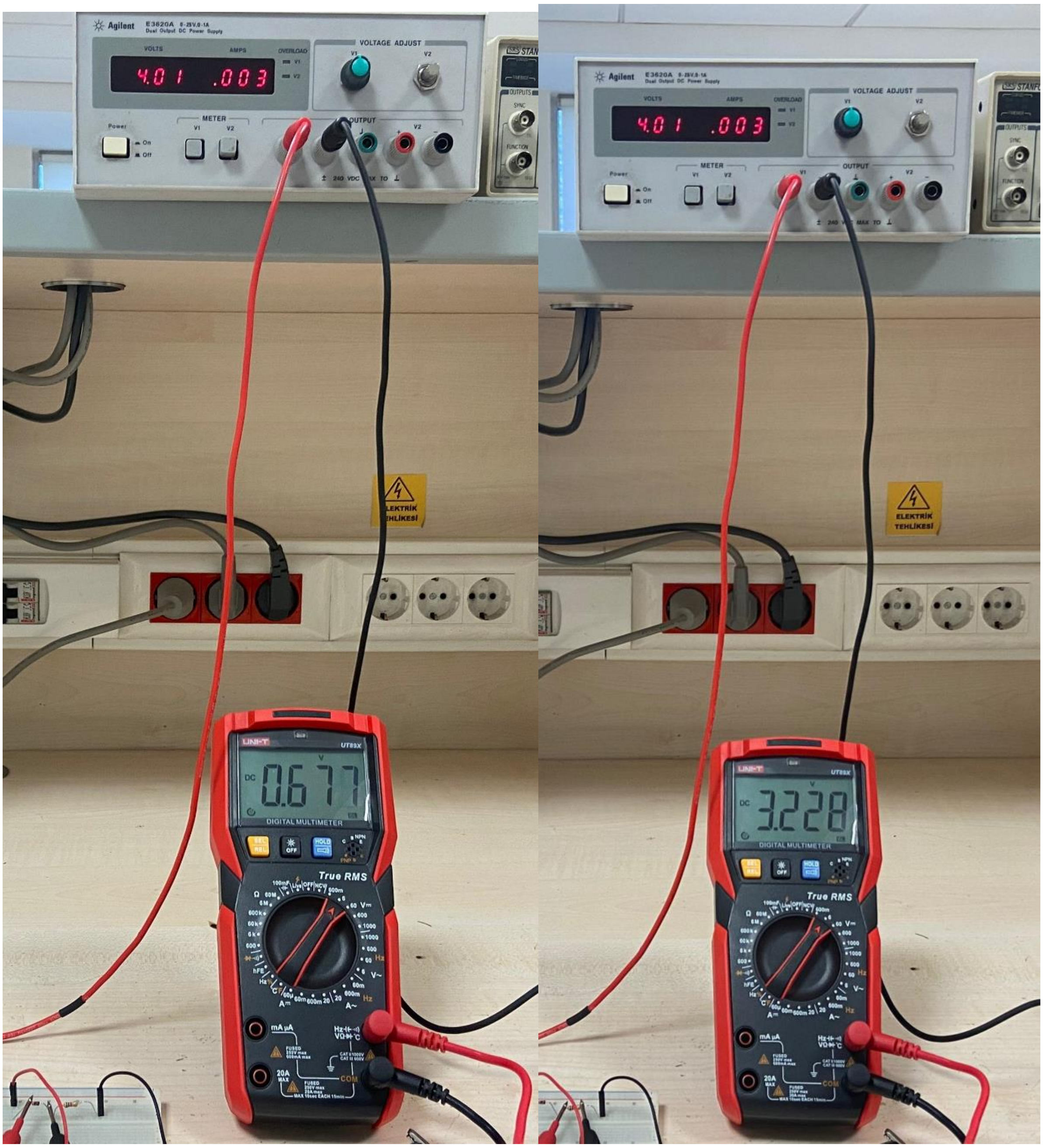

Figure.15: Vd and Vr for 4V case

PART.B

In this part, we are asked to design a very basic temperature sensor. We have two diodes; one detects room temperature and the other detects rising temperature on a diode because of finger.

Note that R4 resistor (6.8K -> 8.2K) and R9 resistor (150K -> 100K) had changed after preliminary work was submitted. Therefore, the preliminary report results were changed a bit.

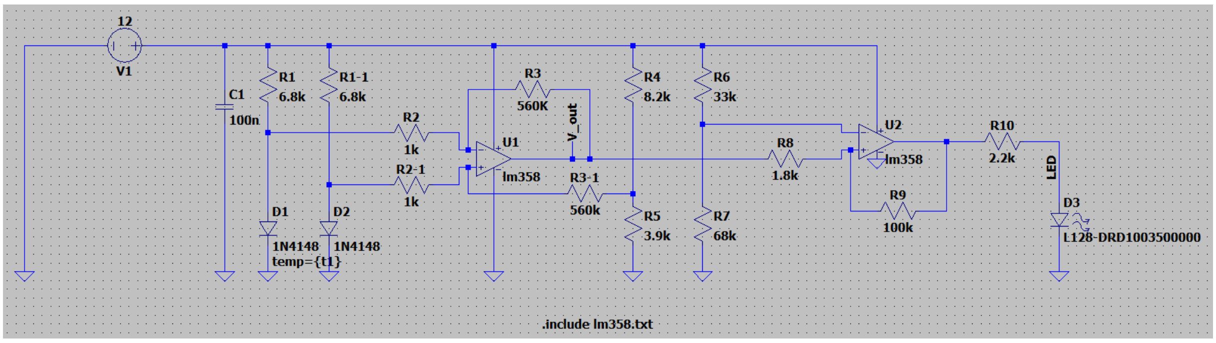

Figure.16: Temperature sensor circuit

Figure.17 shows the basic principle of a sensor. Brown line is below 30 degrees, LED doesn't work. Blue is above 30 degrees and LED works.

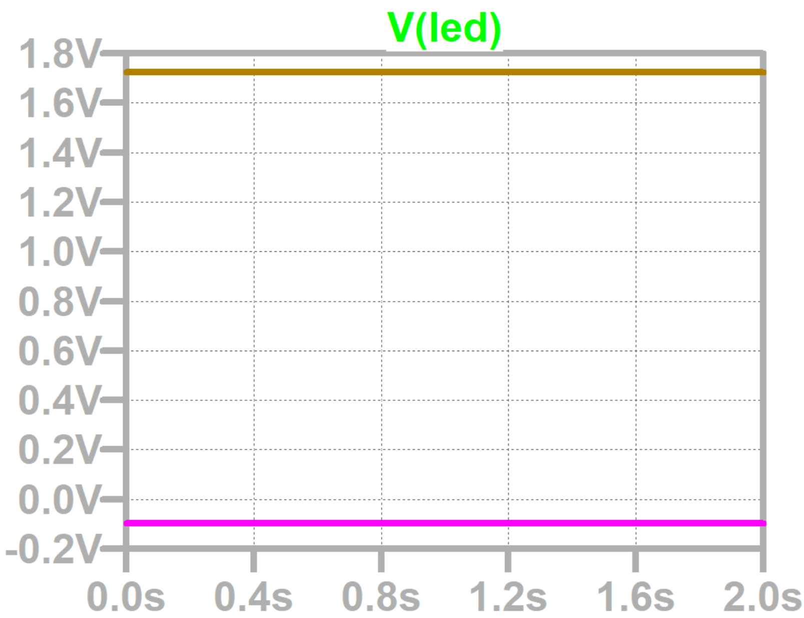

Figure.17: Graph of LED with temperature sensor

Figure.18 shows LED voltages for different temperatures. The key here is after 30 degrees, LED has around 1.7 voltage difference.

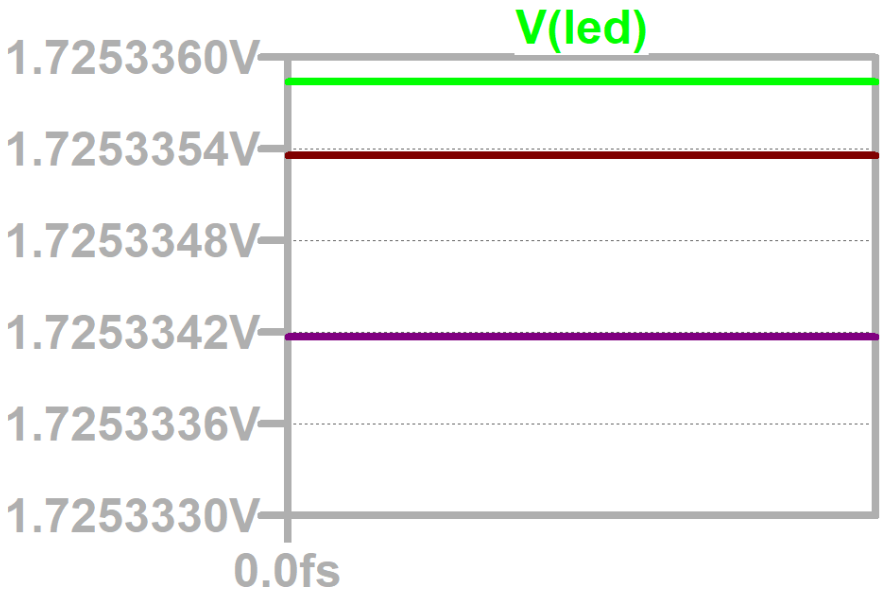

Figure.18: Voltages of LED with temperature 30 to 33

In Figure.19, we have 9 graphs. Each graph shows that LED doesn't work below 30 degrees.

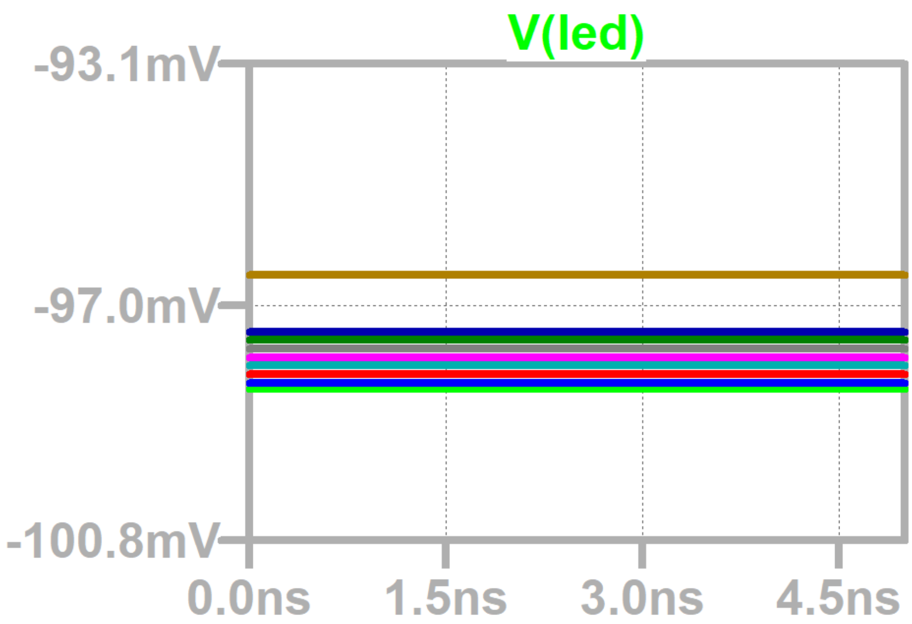

Figure.19: Voltages of LED with temperature 23 to 30

These graphs show temperature sensor works. However, the sensor should require some specific conditions. We must check them.

Requirements

1. ***When the sensor is at room temperature, the output voltage, v_{out}, should be nearly a third of the supply voltage ($V_{dd}/3 \pm 0.5V$).***

   Vdd is chosen as 12 V, so Vout should be between 3.5V and 4.5V.
   As shown in Figure.20, sensors require this condition.

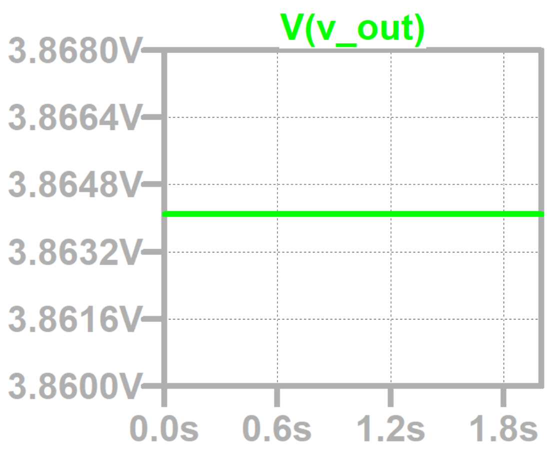

Figure.20: Vout voltage at 27 degrees

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 +1degree difference should give us a change of +1±0.2 V in the output voltage.***

   Figure.21 shows Vout is 5.4 at 28 degrees, so this requirement is satisfied.

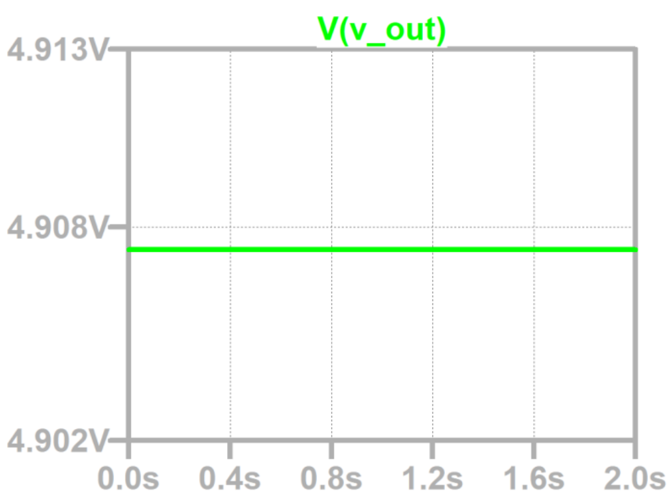

Figure.21: Vout voltage at 28 degrees

3. ***A red LED should turn on when the sensor's temperature exceeds +3±1°C the room temperature.***

For detailed observation I changed the parameter “as .step param t1 29 31 1”

Figure.22 shows that LED is turning on between 30 and 31 which is safe interval.

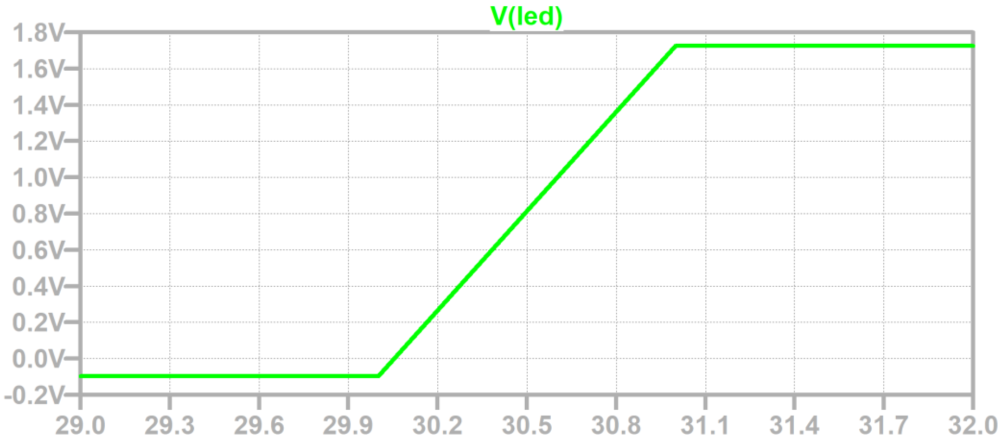

Figure.22: LED voltage at different temperatures

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

Figure.23 shows that there is no flicker at threshold temperature 30.

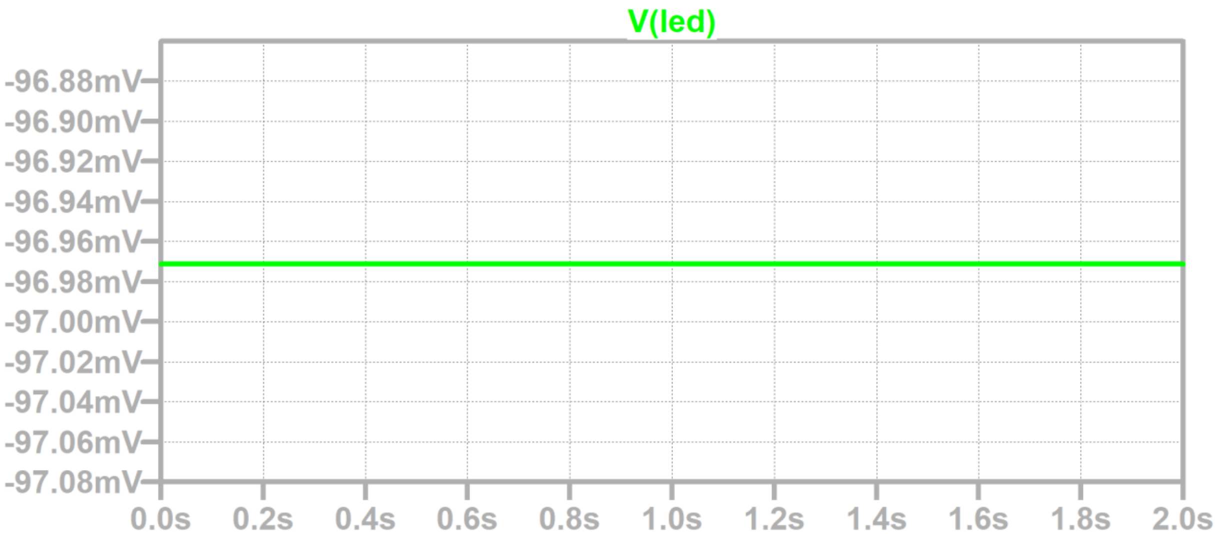

Figure.23: Threshold Voltage

Experimental Work:

We have 2 diodes, one of them detects room temperature and the other is controlling to LED. When I touch controlling diode for a while, its inner current changed compared to another diode. Using this difference, we designed a temperature sensor to control LED. The circuit worked well, and we could control the LED. Overall, the lab work was completed successfully. Around 7V at Vout, LED worked.

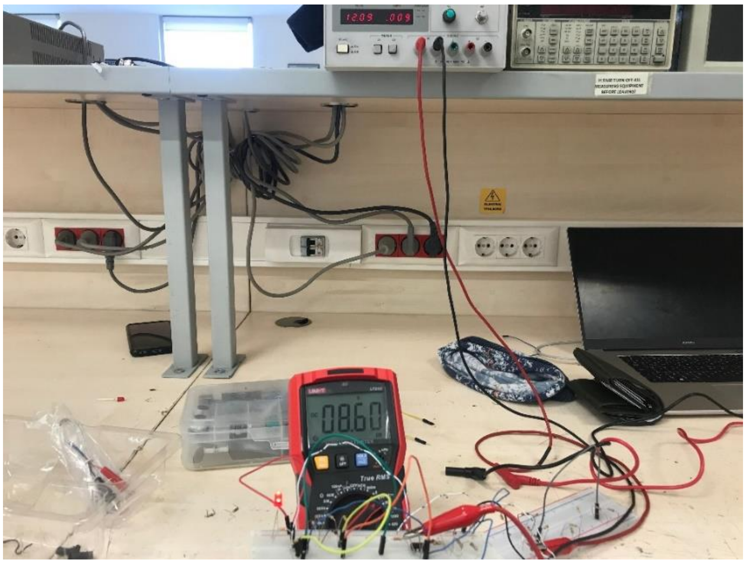

Figure.24: Implementation of Lab Work

Requirements

1. ***When the sensor is at room temperature, the output voltage, v_{out}, should be nearly a third of the supply voltage ($V_{dd}/3$ ±0.5V).***
   In Figure.25, I observed V_{out} as a 3.79 V when the sensor was at room temperature.
   Since input voltage is 12V, V_{out} should be between 3.5 V and 4.5 V our result was nearly consistent with preliminary value which is 3.85 V.

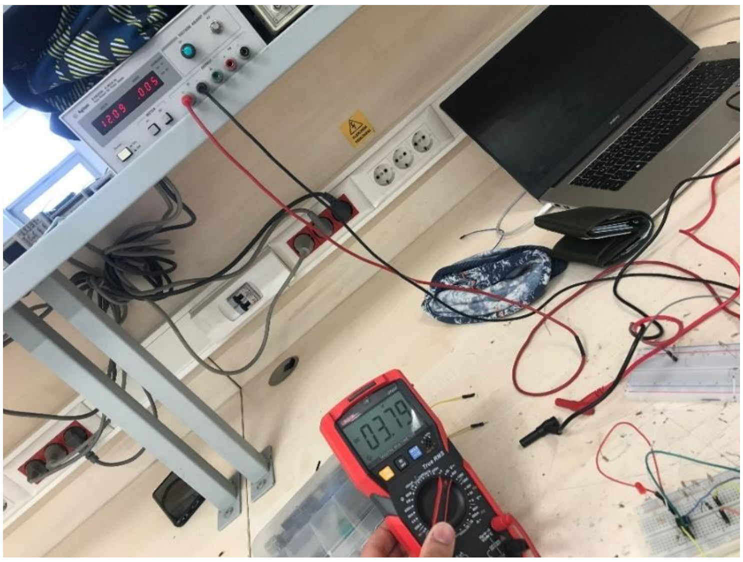

Figure.25: Vout at room temperature

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 +1degree difference should give us a change of +1±0.2 V in the output voltage.***

In Figure.23, I wanted to show that requirement 4 was satisfied. I touched the sensor and rapidly removed my finger to make a slight difference. Although it was impossible to make sensor diode 1 degree higher than another diode, the Figure.26 shows Vout = 4.86V. In preliminary work, Vout was 4.90 V, so this experimental result was highly consistent with preliminary work.

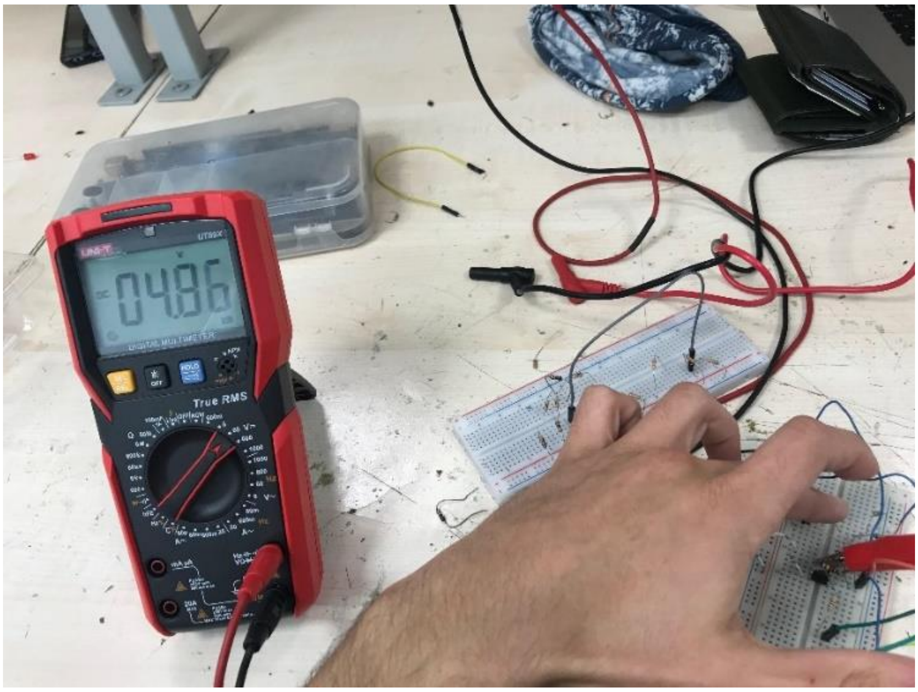

Figure.26: Higher voltage on controlling diode

It is not that possible to show those 2 requirements were satisfied in the report, but TA's got the check for those.

3. ***A red LED should turn on when the sensor's temperature exceeds +3±1°C the room temperature.***

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

Conclusion

In preliminary work, some properties of diodes were studied. The method was developed to determine saturation current and n coefficient, then LTSpice simulation was done to test the method. For Part B, I designed a temperature sensor circuit. We used LM-358 which has two OPAMP's in it. Temperature sensor was based on the voltage/current difference due to temperature of diodes. In preliminary, I gained some insight to do experimental work.

In experimental work for part A, we again tested our method in real life. N coefficient was near to our simulation value. For Is saturation current, there was a bit high deviation because its value is significantly small. That's why deviations is not that much.

For the sensor part, circuit implementation was done successfully. Requirements were also satisfied with acceptable deviations.
However, there were some problems. We had so many components and sometimes it was a bit hard to build such a circuit. My major problem was about Vout value, and it was a bit hard to debug. I changed R4 and R9 then the circuit worked. At the end of the day, we successfully designed our temperature sensor.

In lab 1, we learned some insights about diode. We specifically focused on the temperature properties of it. Manipulating this property, we designed temperature-controlled LED circuit.