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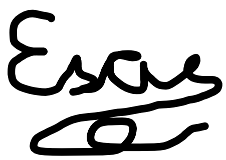
EEE-313-01
Date: 14.12.2024

EEE 313 Project Thermocouple Instrumentation Amplifier Controlled Heater

"I affirm that I have not given or received any unauthorized help on this report and that this work is my own."

Sign:



Introduction

The aim of this semester project is to design a single-supply instrumentation amplifier using an LM324 operational amplifier for temperature control of a resistor (heater), based on a type-K thermocouple. The project seeks to maintain a target temperature, 34°C above room temperature (30+22102764 mod 40 =34), by amplifying low level thermocouple voltage signal (39.2 μV/°C) and employing an ON/OFF control mechanism by using BJT in SAT mode with hysteresis to stabilize operation, ensure accurate thermal regulation, and provide visual feedback using an LED indicator.

The most crucial fact to think about this lab is related to offset voltages and bias currents. Although these deviations are generally negligible they become destructive when the amplification rate is thousands. Since the whole theory behind this circuit detailly explained in the first part I will only talk about th later sections from now on.

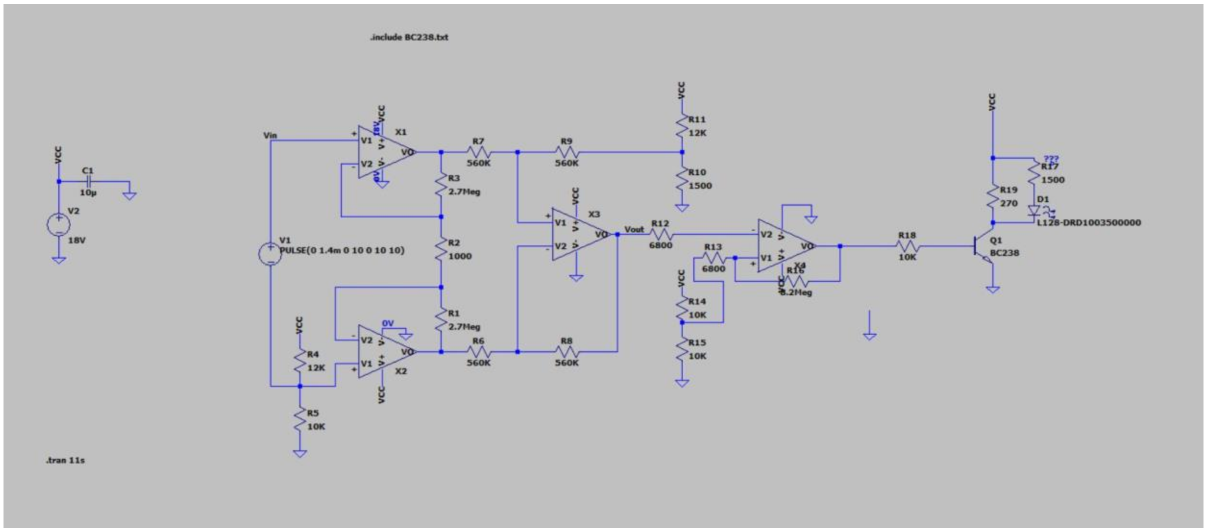


Fig.1: Schematic of the constructed circuit

2) PCB Design

2.1) Updated Schematic

PCB design phase may seem trivial at first glance but, it is actually the most important step of this project since it teaches many things about the design procedures. The first step of creating a solid PCB is creating a schematic on the design program like KiCad, Altium DipTrace etc. In this project DipTrace is used and the schematic can be seen in Fig.2.

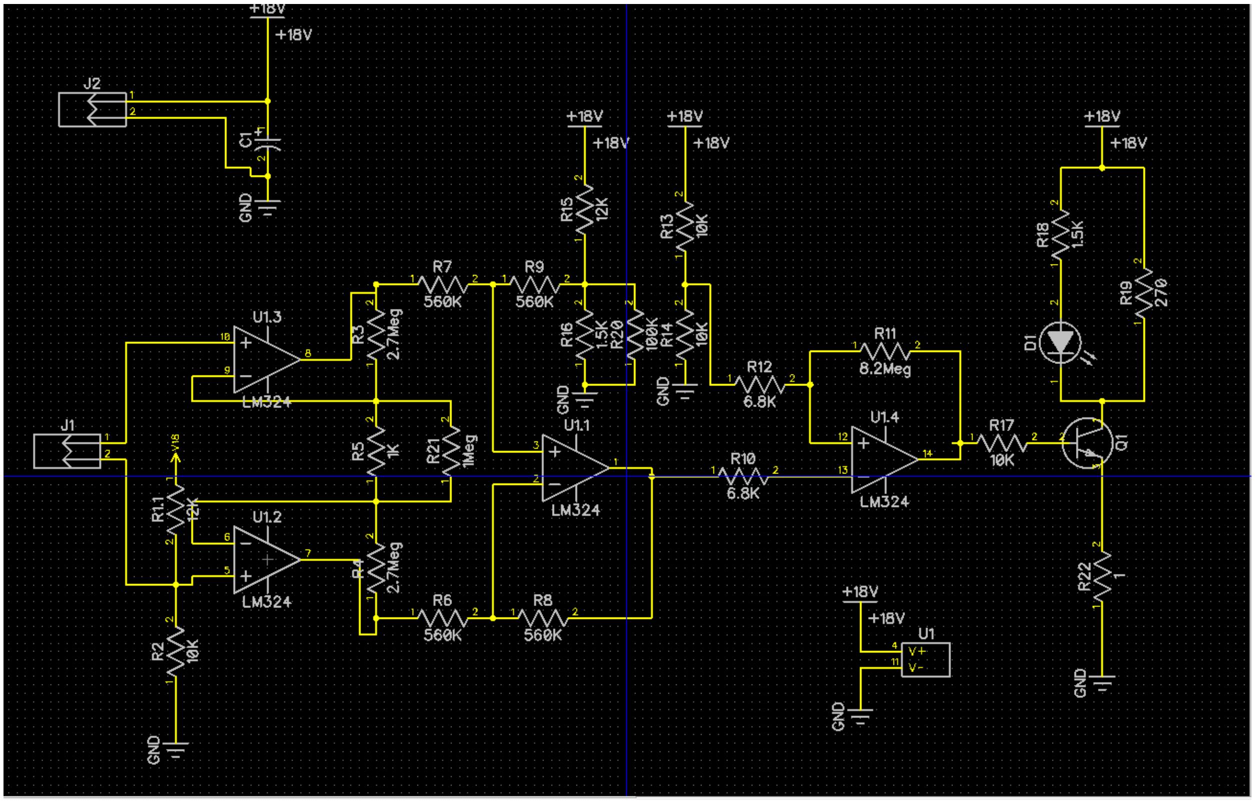


Fig.2: Schematic on DipTrace

As one can see the schematics in Fig.1 and Fig.2 are not exactly the same and the reason behind this is to be able to fine tune the sensitive values like V_R which is supposed to be 2V etc. There are 4 more components in the final schematic. Reason behind adding the resistor R_{21} (parallel to R5) is to be able to adjust the gain value precisely. Having two resistors in parallel gives us the chance to adjust the resistance value as we like. This will be a huge advantage during the hardware part since we are not limited with lab resistance values. The reason behind the resistor R_{20} is exactly the same with R_{21}.

However, R22 has a different task. Since we are not using power resistors and we are exceeding the power limit of axial resistors during the heating process, we have the risk of burning or degrading the heating resistance. To slow down the heating process we experimented with small resistance in the emitter of the BJT, just to be safe. This resistor is short circuited after completing the circuit.

The capacitance at the input is here just to eliminate any oscillations from power source . Also, J2 header is used to connect Vcc and GND. The rest of the circuit is explained in the former report.

2.2) Component Placement

Constraints in PCB design are important to ensure functionality and reliability. Trace width and clearance are defined (20 mil) to handle current without overheating and to prevent electrical shorts. The board dimensions (50 mm x 50 mm) ensure the PCB fits within its enclosure, while proper component placement minimizes routing complexity, reduces noise, and also helps heating. A single-layer design simplifies manufacturing but requires careful planning to minimize jumper wires and optimize trace routing. These constraints are pre-determined by Mr. Atalar to ensure safe soldering and other reasons. Size constraint is also important since these PCB's are integrated in other systems and therefore need to be compact.

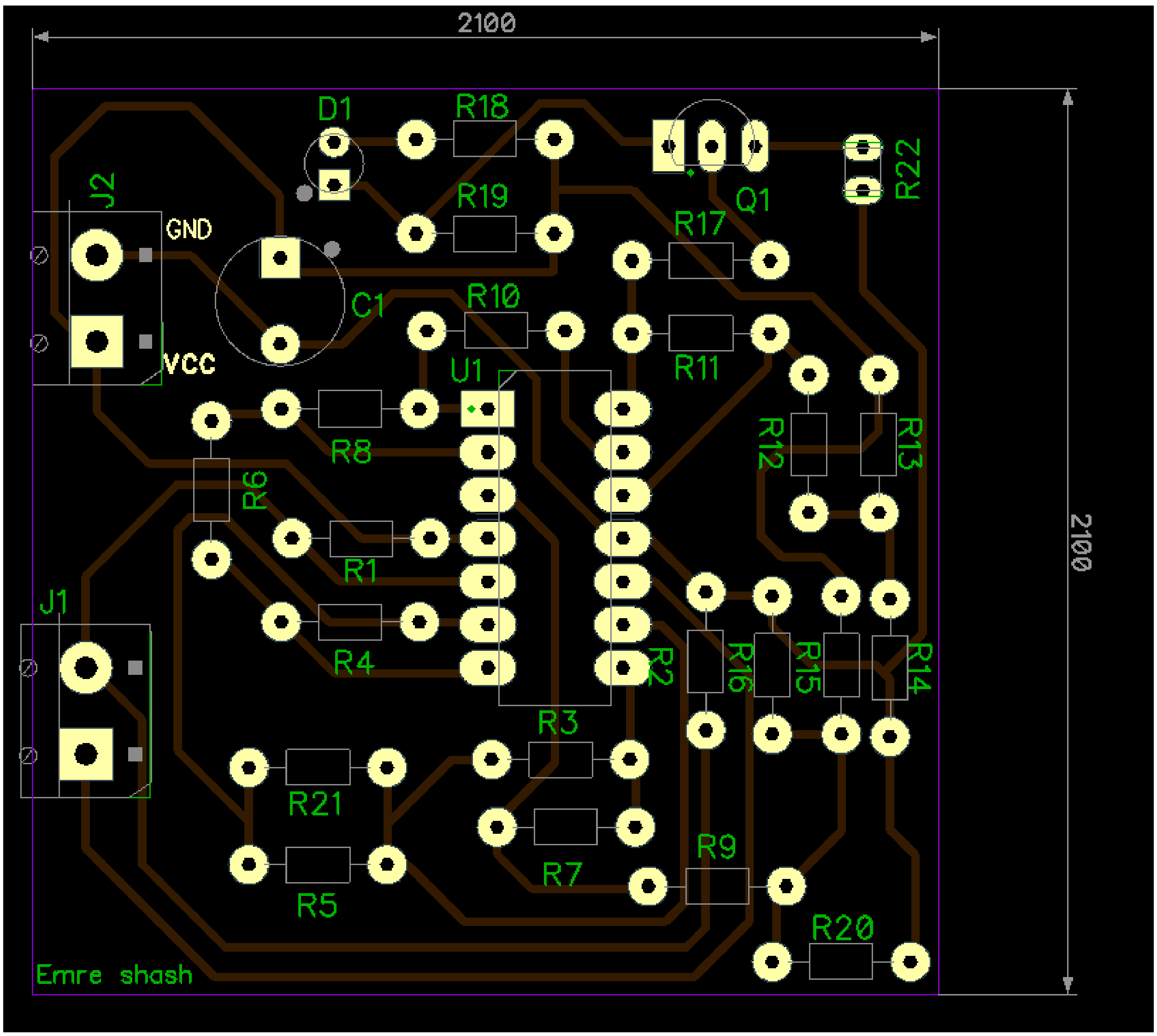


Fig.3: PCB Design

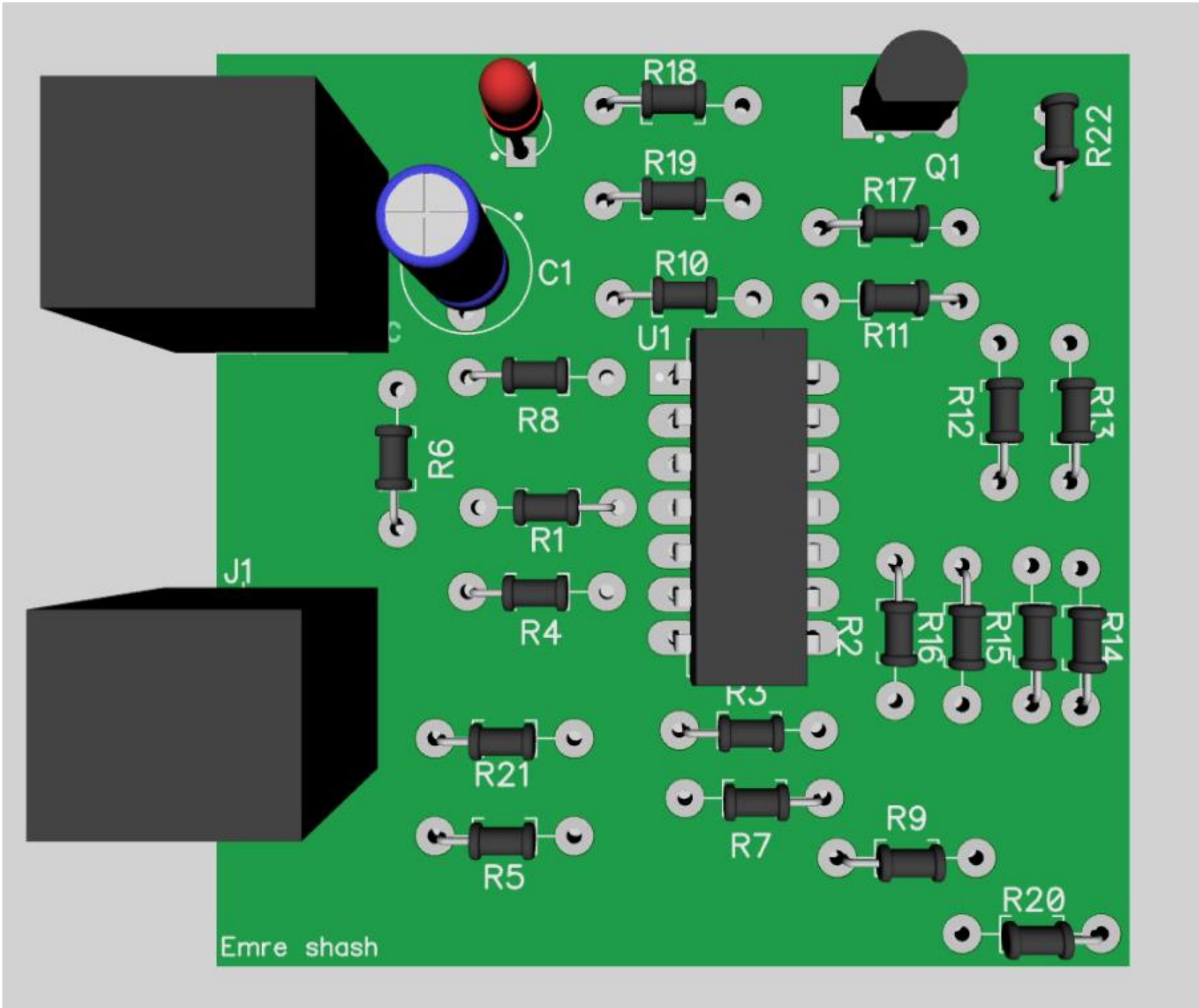


Fig.4: 3D look of PCB design

2.3) Design Check

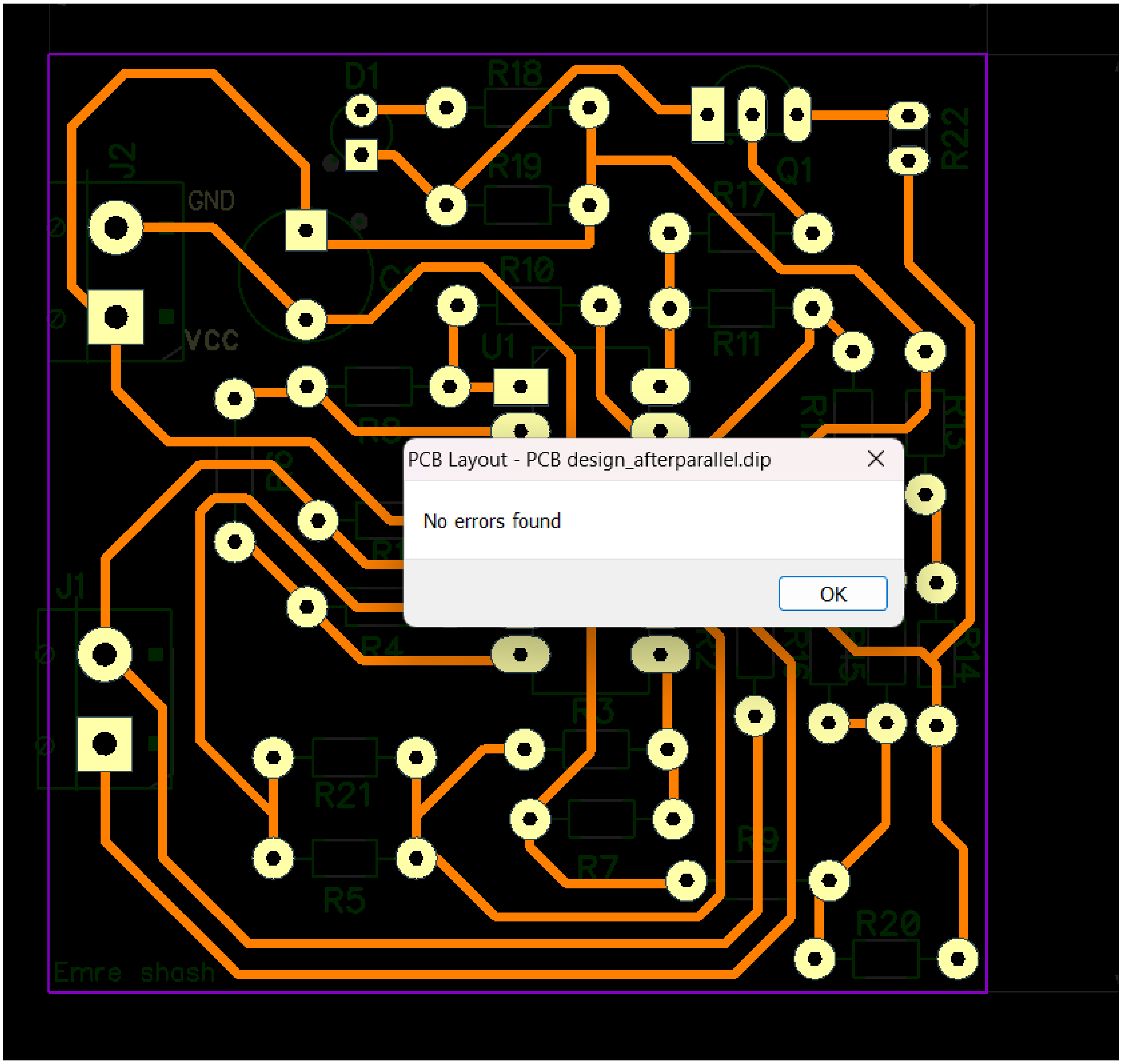


Fig.5: DRC Check is complete (no errors)

To be sure that the design is ok we can get help from a site that previews the Gerber files that we sent to the manufacturer. After checking the Gerber files we can proceed with hardware implementation.

3) Hardware Implementation

3.1) Breadboard Testing

To be sure that simulation values will work in real life I constructed the circuit on breadboard and see if it meets the specifications:

1. The output voltage at 2V±0.5V when the thermocouple is at room temperature (thermocouple output voltage is zero)

2. The output voltage is 9V±1V when the temperature is at the required temperature (thermocouple voltage is 39.2× μV).

3. LED turns ON when the heater resistance is being heated. It should turn OFF when the heater is off.

Although there were some errors these errors are corrected by playing with the sensitive resistances mentioned above. However, I did not spend too much time on getting the exact results on breadboard since it is enough to see that the design is working because PCB and breadboard will respond differently to same circuit. Breadboard testing was extremely useful because it provided us with the possible solutions to the expected problems. These problems will be talked about in detail in later sections.

3.2) PCB Construction

Only thing to be careful about in this section is not to short circuit components during soldering. Other than that this is just a mechanical process that requires no explanation. Final circuit can be seen in Fig.6 and Fig.7. While searching for short circuit in suspicious areas, short circuit mode of multimeter is used.

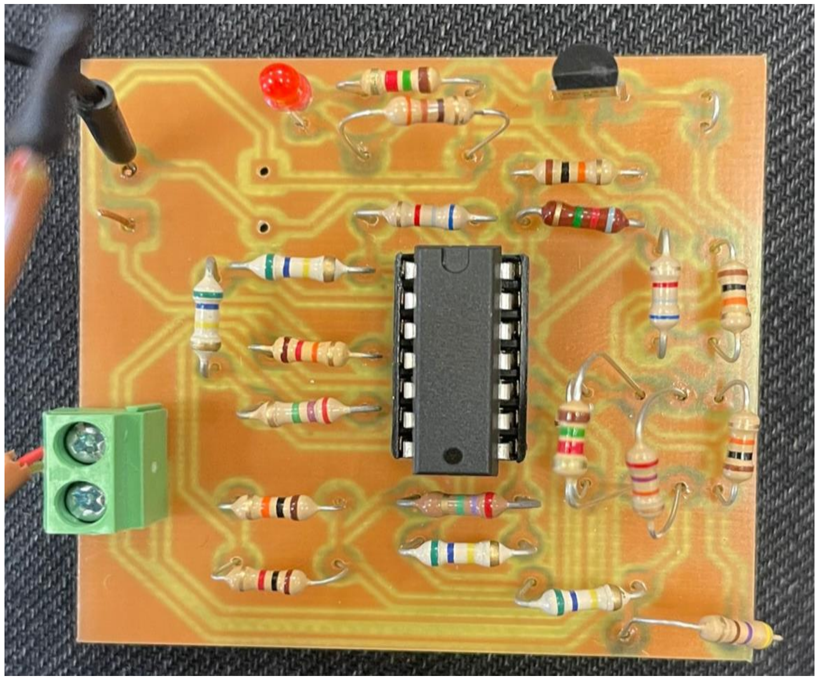


Fig.6: Front look of PCB

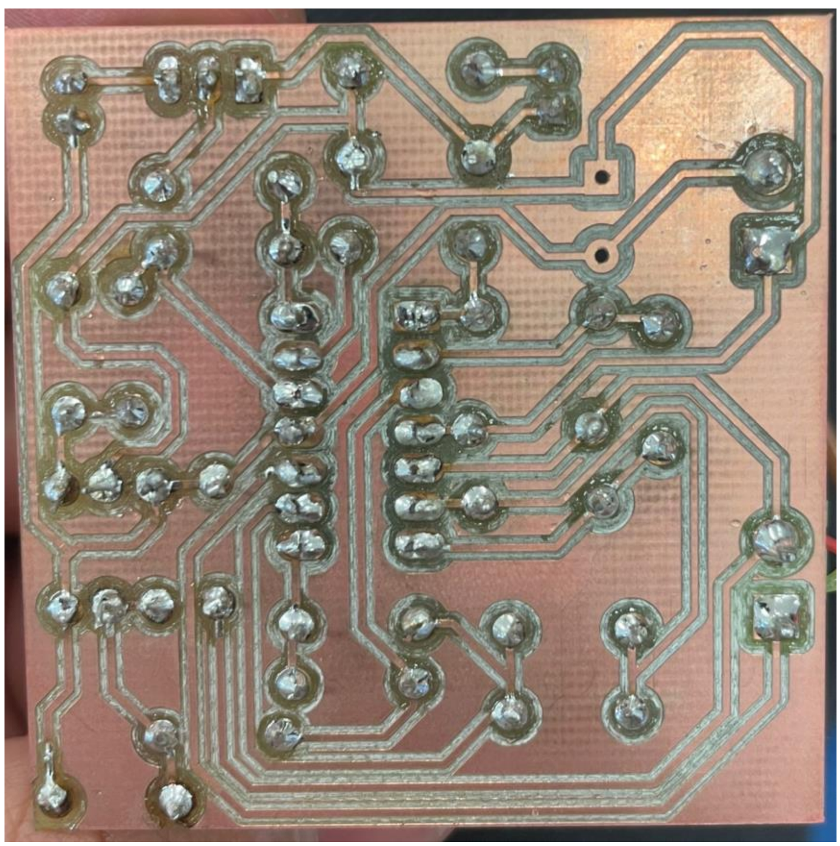


Fig.7: Back look of PCB

3.3) Debugging the Circuit

There are some key factors that can significantly impact the performance of the project including **thermal drift**, where temperature variations alter component parameters like resistor values and op-amp offset voltage, leading to performance instability.

Finally, **low signal levels** from the K type thermocouple (e.g., 39.2 μV/°C) requires precise amplification rate and noise mitigation to get accurate and stable outputs. Addressing these challenges is essential for successful hardware implementation.

In order to compensate these errors I played with the sensitive resistors values.

First Problem: High V_r at room temperature

The first problem was related to V_r . At first V_r was way more than it should be at the room temperature (around 4V). In order to solve this problem I simply inserted a parallel resistor to the resistor R16 and gradually decrease the parallel resistor's value. This results in decrease in total resistance and therefore in voltage.

Second Problem: LED turns off at high temperature

Second problem was related to temperature. There were no problem with the comparator part since the LED closes at 9V but the problem was 9V occurs at 80 degrees which is so high for my circuit. It means that I should check my amplification rate. After some trial and error, I found out that decreasing the overall resistance of the small resistor by 10% solves my problem, so I inserted a 10K resistor.

These two were the most important problems to ensure that the circuit works properly. Other than these there were minor problems like connectivity issues, cold solders etc. But these were mechanical problems that require no explanation.

4) Specification Checks

4.1)First Specification

The output voltage at 2V±0.5V when the thermocouple is at room temperature (thermocouple output voltage is zero).

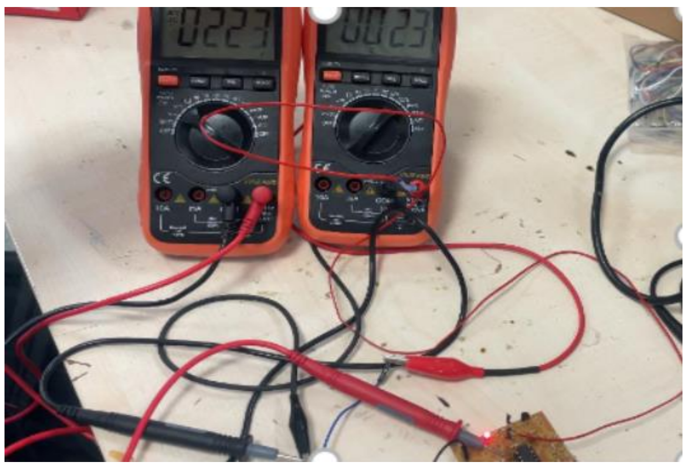


Fig.8: Output Voltage is in the desired interval at room temperature (23C°)

Therefore, we met the first criteria.

4.2) Second and Third Specification:

2. The output voltage is 9V±1V when the temperature is at the required temperature.

3. LED turns ON when the heater resistance is being heated. It should turn OFF when the heater is OFF.

Since the two specification is highly correlated it is more convenient to show them together.

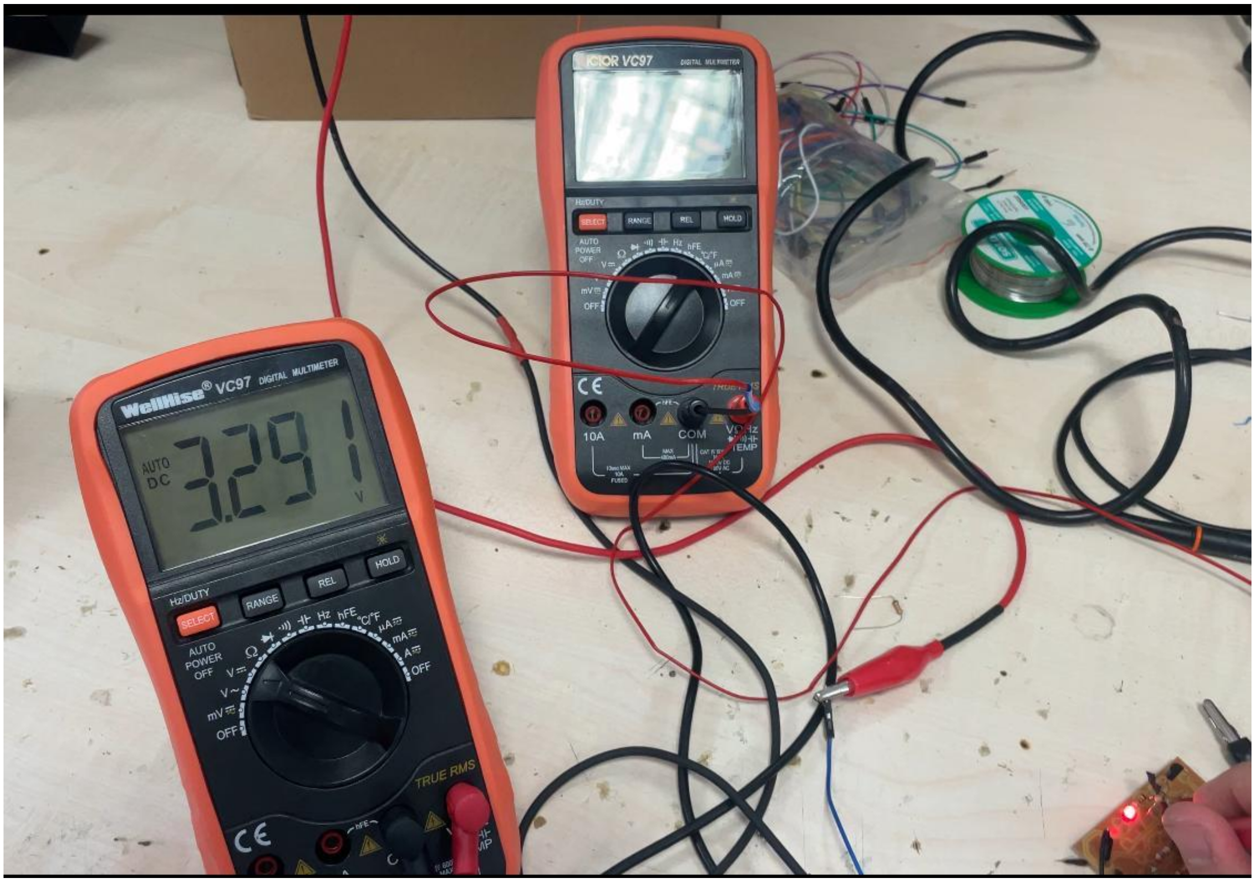


Fig.9: Voltage at 27 C ° (LED on)

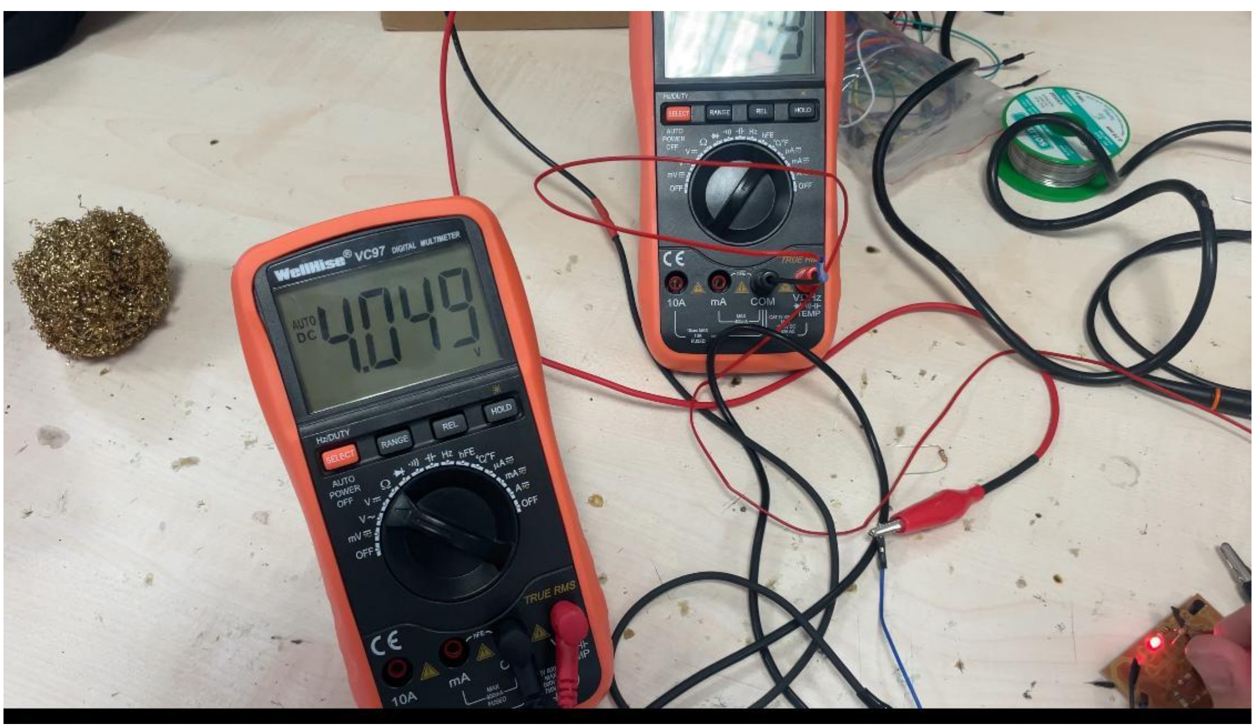


Fig.10: Voltage at 31 C ° (LED on)

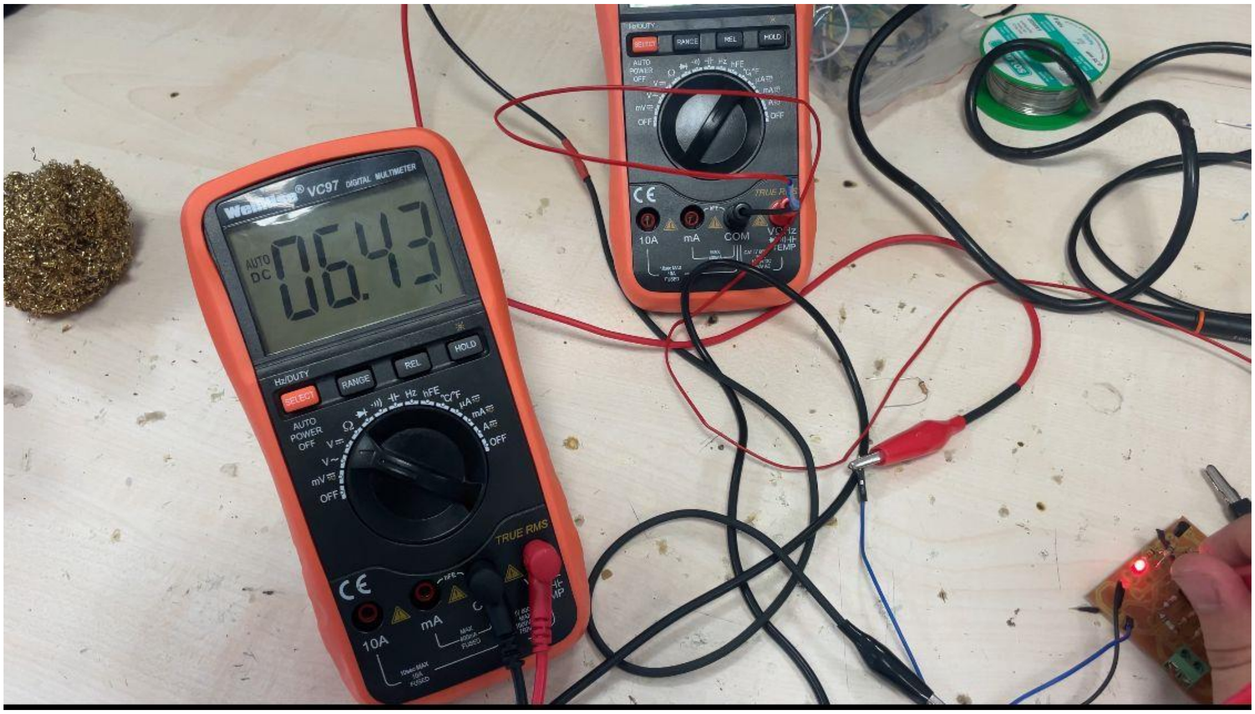


Fig.11: Voltage at 42 C ° (LED on)

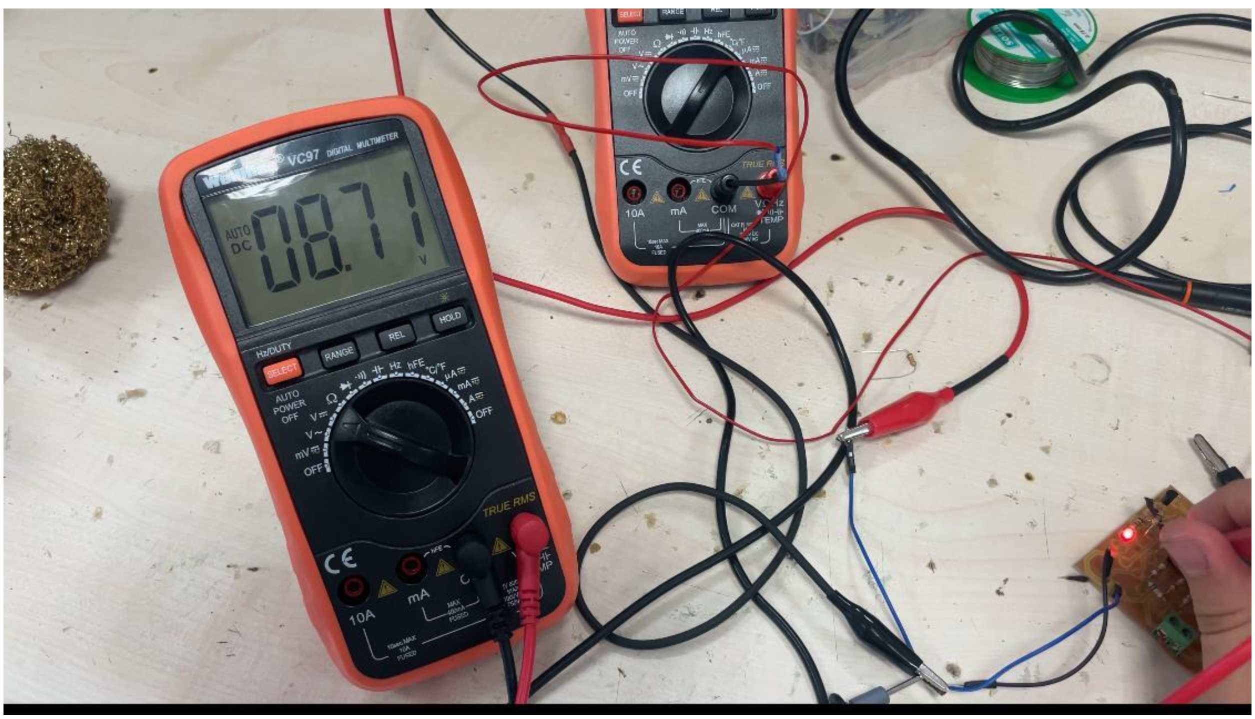


Fig.12: Voltage at 52 C ° (LED on)

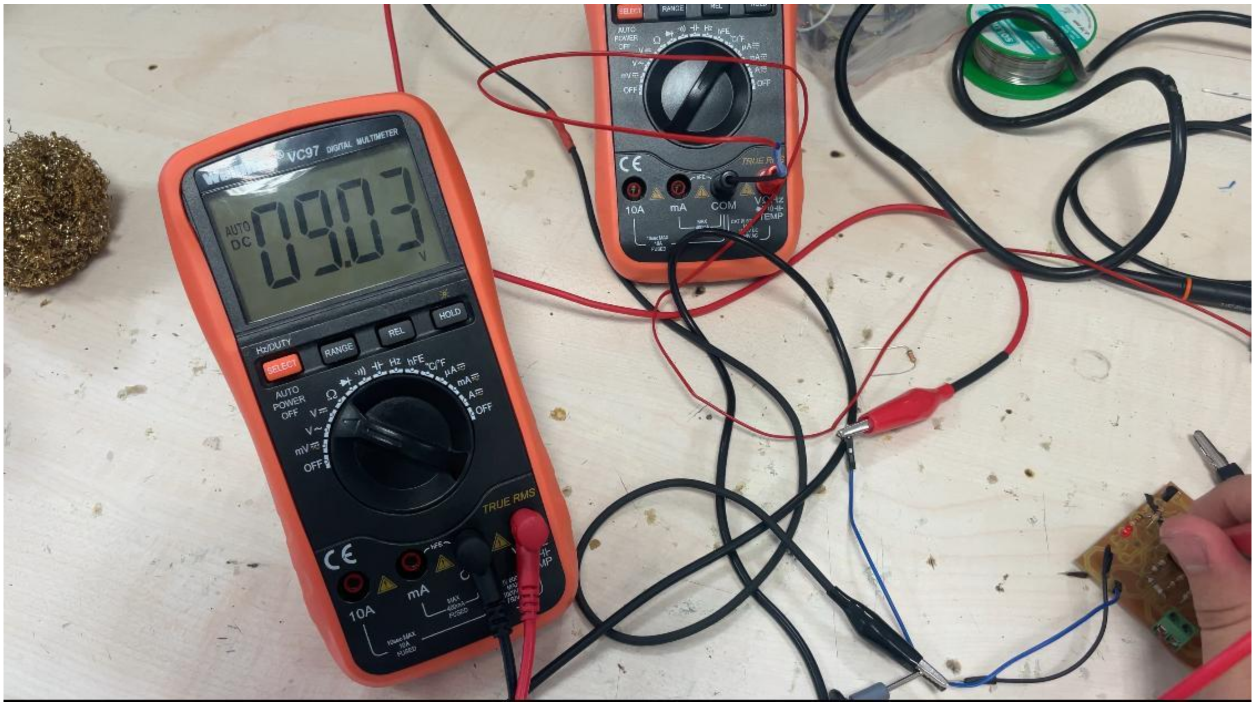


Fig.13: Voltage at 57 C ° (LED off)

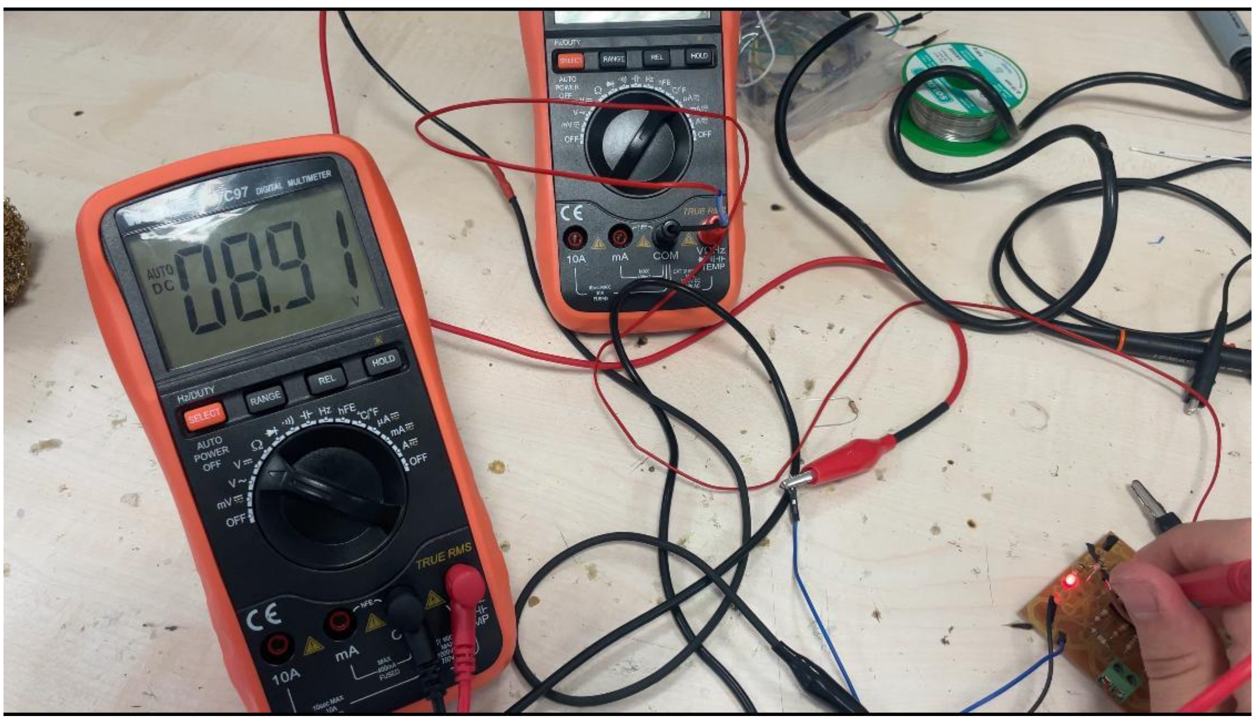


Fig.14: Voltage at 54 C ° (LED on)

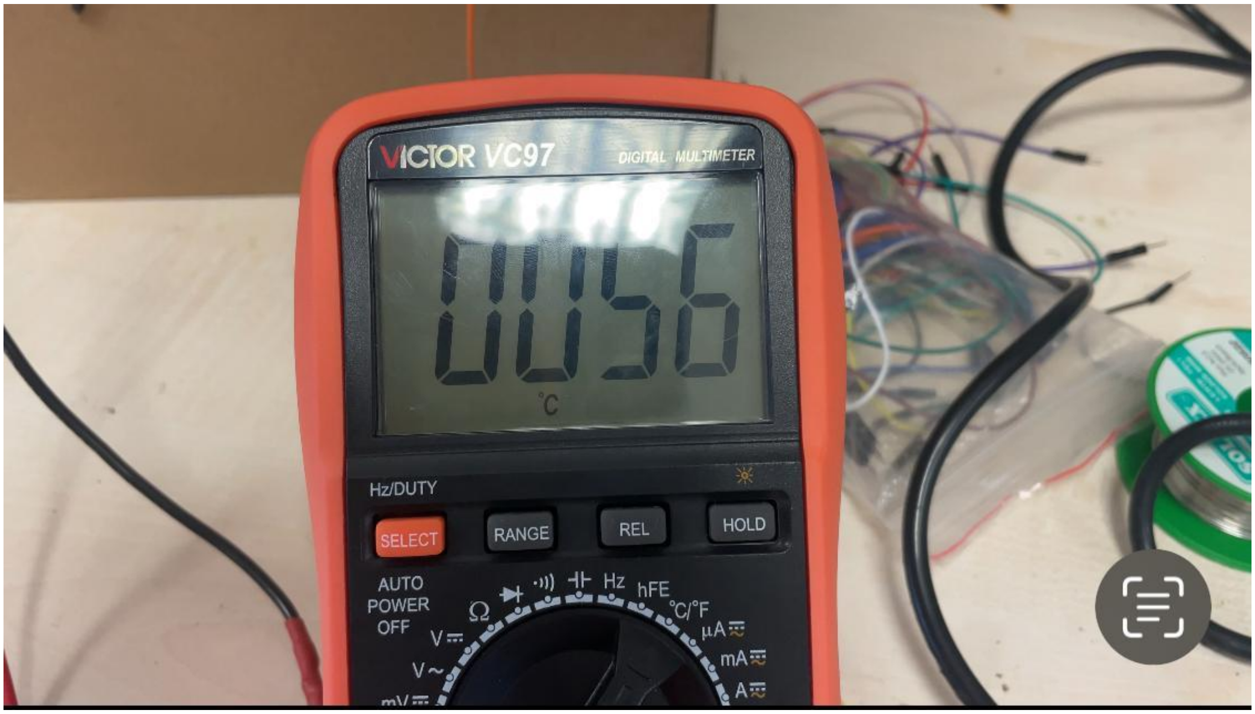


Fig.15: Temperature oscillates between 56 and 57 C °.

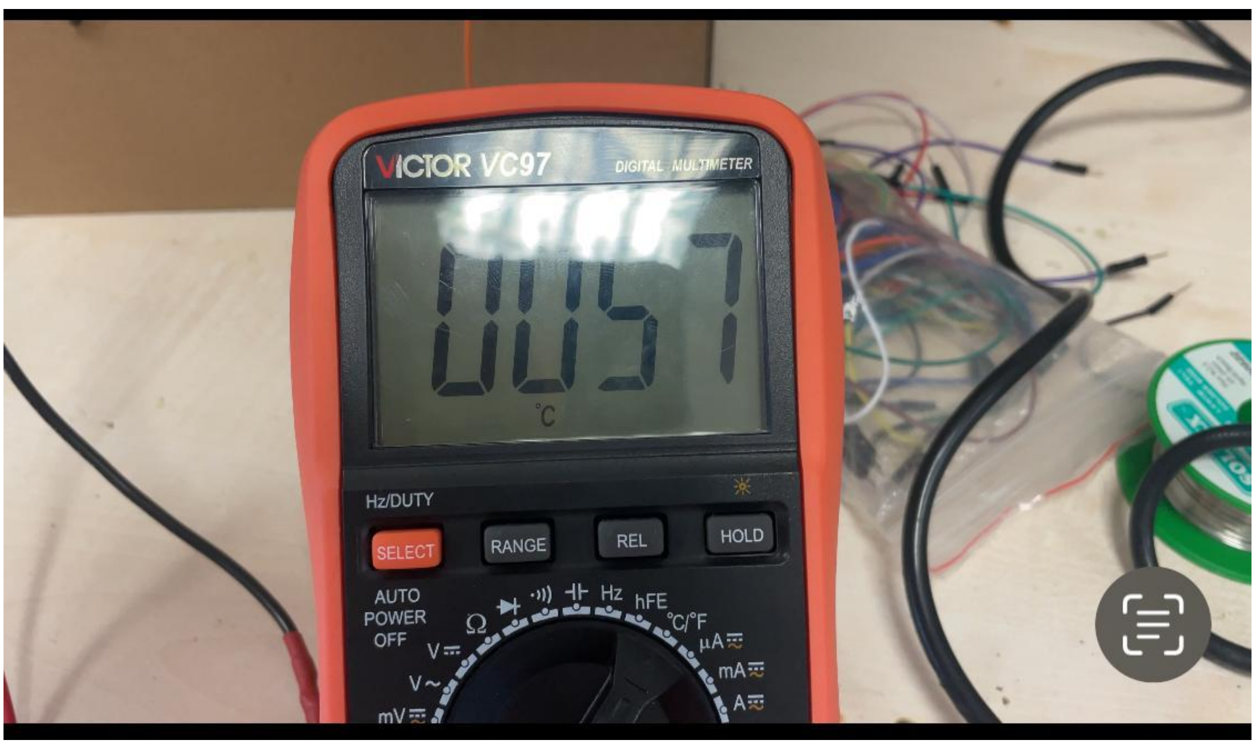


Fig.16: Temperature oscillates between 56 and 57 C °.

It is much easier and convincing to show the results on the oscilloscope since we can see the voltage levels in continuous graph.

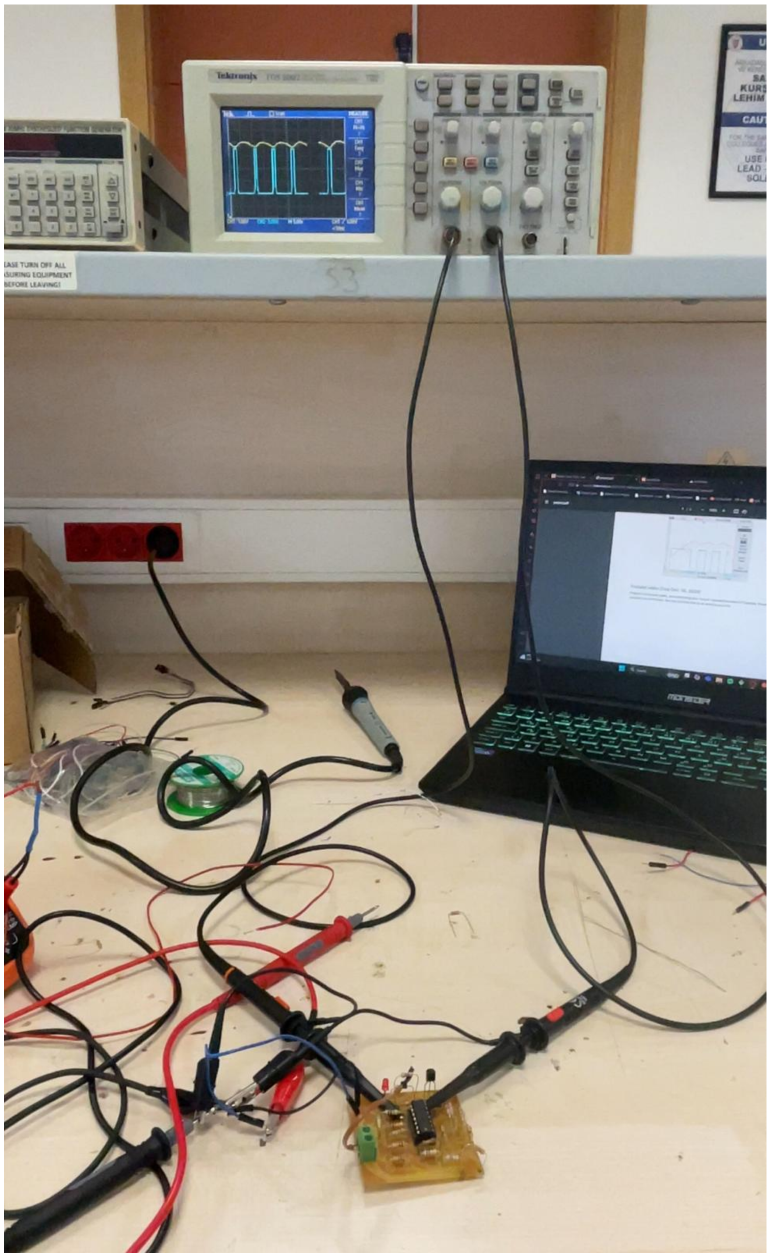


Fig.17: Comparator output is 0 when temperature is high (LED OFF)

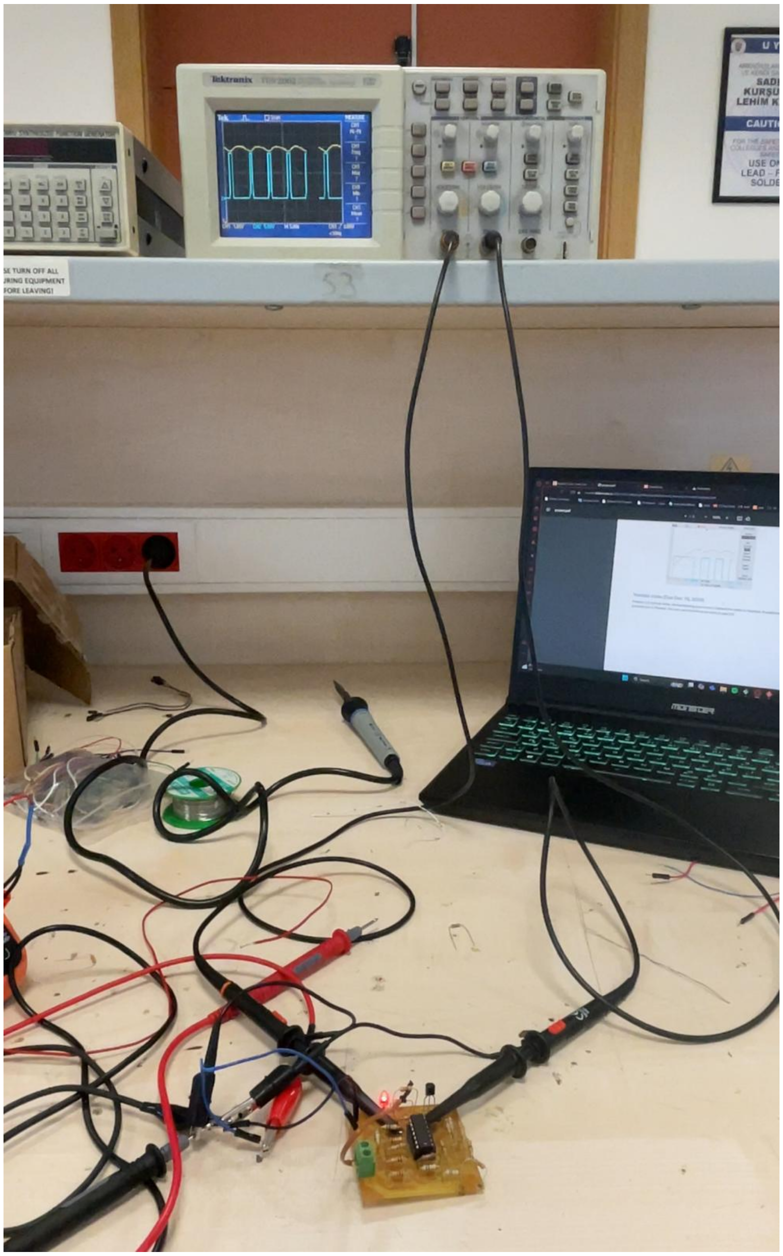


Fig.18: Comparator output is 9.2V when temperature is low (LED ON)

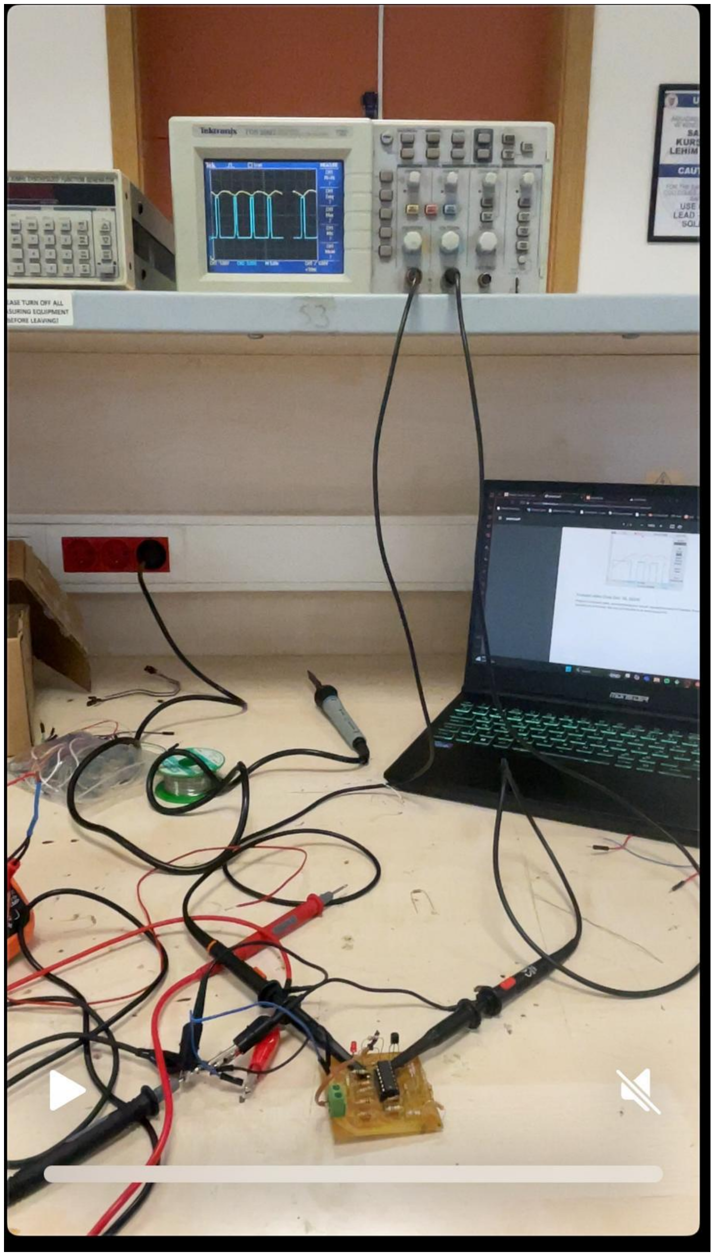


Fig.19: Comparator output is 0V when temperature is high (LED OFF)

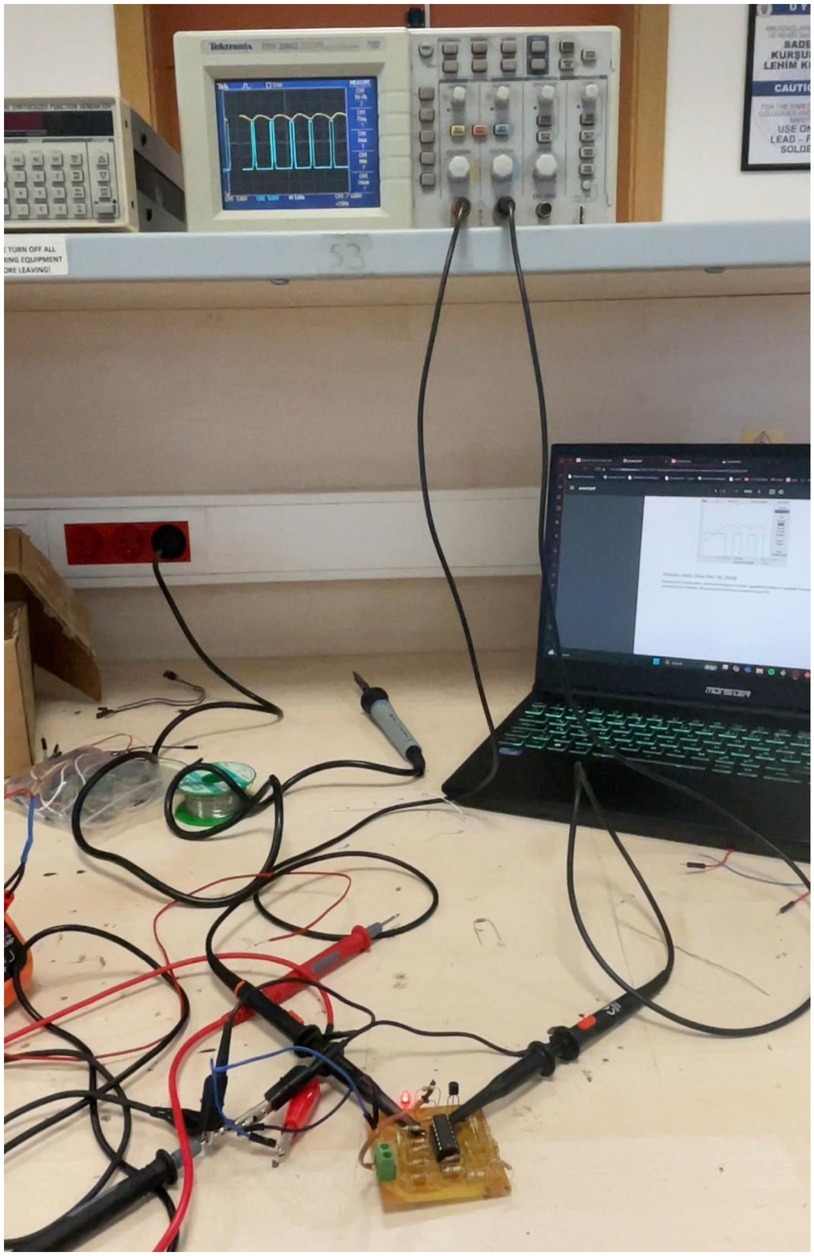


Fig.20: Comparator output is 9.3V when temperature is low (LED ON)

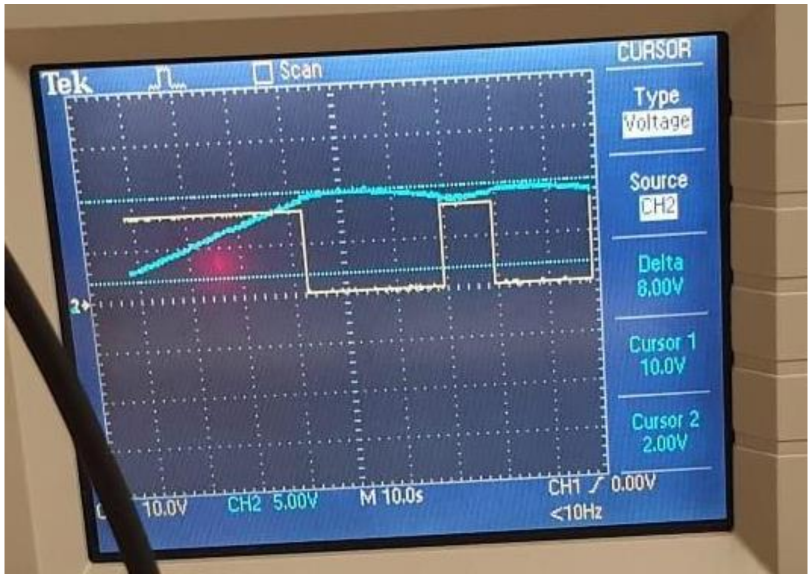


Fig.21: Voltage levels during heating

As it is seen in Fig.21 the output voltage starts from 2 V(Cursor 2) and goes up to 10V (Cursor 1) and oscillates around 9V.

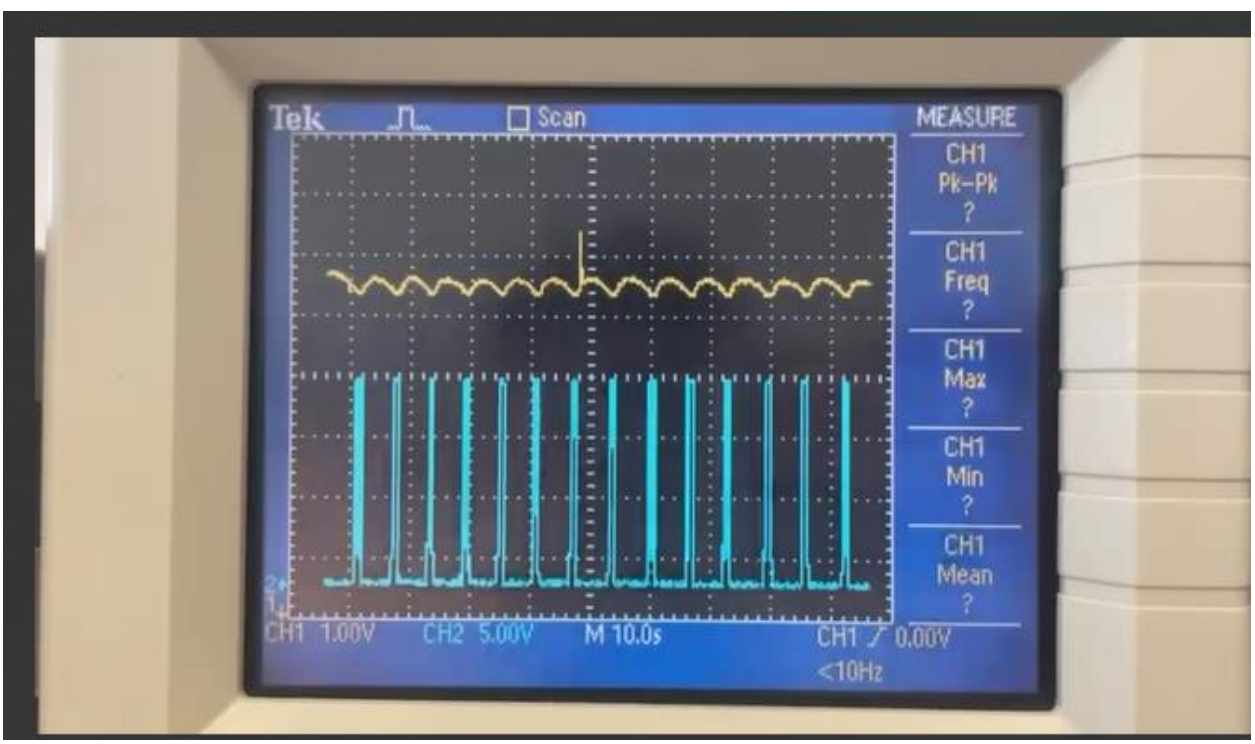


Fig.22

As it can be seen in above figures after we get close to the intended temperature circuit stabilizes and oscillates between 54C° and 57C °. In Fig.22 I tested the circuit for a long time to ensure that the resistor wont burn even if we leave the circuit working for a long time and the results were promising. Circuit acts very stable even if we work with it for a long time. Therefore, we can say that the circuit meets all the requirements and is safe tp use.

5) Conclusion

In this project I successfully designed, simulated, and implemented a single-supply K-type thermocouple instrumentation amplifier for temperature control of a heater using an LM324 OPAMP. Aim was to achieve stable thermal regulation by amplifying the small voltage generated by a type-K thermocouple (39.2 μV/°C) and implementing an BJT switching mechanism with hysteresis to ensure smooth operation. The project includes several phases, including schematic design, PCB layout, hardware implementation, and debugging.

The **schematic design** focused on amplifying the thermocouple's low voltage changes while managing offset voltages and input bias currents, which becomes important when the amplification is great. The design also included a comparator circuit with hysteresis to prevent flickering around the desired temperature (room temperature + 34C) and a BJT in saturation mode to control the heater with LED feedback for visual monitoring.

The **PCB layout** adhered to strict constraints, including 50mm x 50mm board size, 20mil trace width, and appropriate trace clearances to handle current and avoid shorts. Additional components, such as parallel resistors and capacitors, were added to fine-tune the gain value and provide flexibility. Careful component placement was performed to optimize routing, minimize noise, and ensure the circuit's thermal stability. The design was verified using Design Rule Checks (DRC) and Gerber file previews to eliminate errors before fabrication.

During **hardware implementation**, the circuit was first tested on a breadboard, where key issues such as high Vr at room temperature and incorrect LED switching thresholds were identified and resolved by fine-tuning resistor values. Debugging revealed that thermal drift, voltage offsets, and noise could significantly impact performance, particularly for the amplified thermocouple signal. By utilizing the theory I managed to achieve the desired values

The final system was rigorously tested against project specifications. At room temperature, the output voltage stabilized at 2V ± 0.5V, and at the target temperature (34°C above room temperature), the output reached 9V ± 1V. The LED indicator successfully turned ON when the heater was active and OFF when the temperature exceeded the setpoint. Long-term testing demonstrated the circuit's stability, with the temperature oscillating smoothly between 54°C and 57°C, ensuring the heater's safety and reliable operation.