EMBEDDED SYSTEMS WORKSHOP

Team: **Wired and Tired**

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ISOLATION TEST BOX

Project objective:

- EM Shielding and monitoring
- Active Temperature Control
- Optical Isolation and spectral monitoring

Team Objective:

- Components characterization
- Shielded enclosure design and implementation
- PID Implementation
- Web based dashboard integration
- Thermal Insulation

COMPONENTS USED

- TEC (Thermoelectric Cooler – Peltier Module)
- TMP 36 sensor
- H-Bridge Module
- ESP 32
- Aluminum enclosure
- PIR Foam (Polyisocyanurate)
- Silicon sealant
- DHTC sensor
- Power Supply

TEC

- TEC 12706
- Rating of the component:
  - Max Voltage: 12V
  - Max current: 6A
  - Temperature Difference: $65^{\circ}C$
- Why it was used?
  - TEC matches our temperature control requirements
  - Electrical ratings align perfectly
  - Allows polarity reversal for heating + cooling

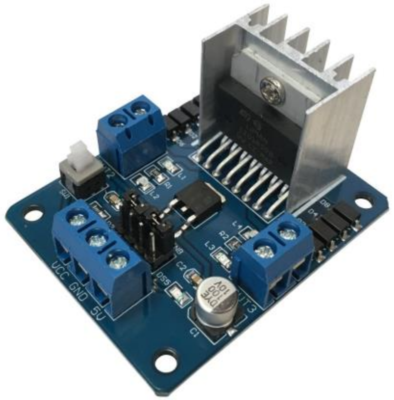
H-BRIDGE MODULE

H-Bridge BTS7960
Rating of the component:

- Operating Voltage: 5V logic
- Peak Current: up to 55A
- Efficiency: ~90%

Why it was used?

- Handles TEC Current Safely
- Enables Heating + Cooling (Polarity Reversal)
- Matched the required ratings for the TEC modules.



TMP 36

- Rating of the component:
  - Operating Voltage: 2.7V – 5.5V
  - Temperature Range: –40°C to +125°C
  - Supply Current: ~50 µA (very low, minimizes self-heating)
  - Response Time: ~1–2 second
- Why it was used?
  - Matches our required temperature measurement range
  - Works at low power with minimal heating
  - Compatible with any microcontroller ADC

DHTC SENSOR

Rating

- Temperature: –40°C to +80°C
- Humidity Ratings

  Range: 0% – 100% RH

  Accuracy: ±2–5% RH
- Supply Voltage: 3.3V – 5.5V
- Average Current: 0.5–1 mA

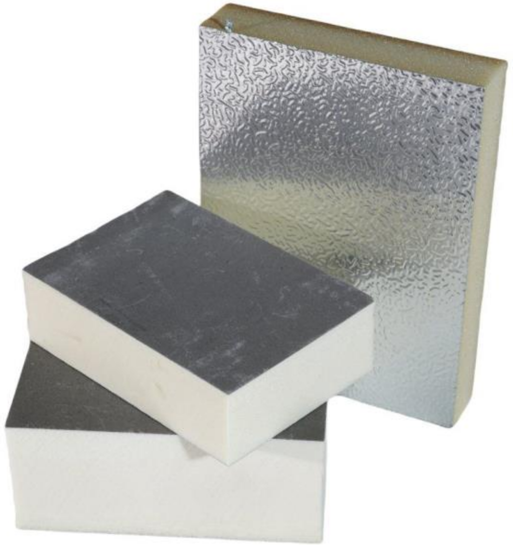
Why it was used?

- Measures Humidity + Temperature Together
- Long-Term Stability Inside Closed Enclosures
- Low Power + No Self-Heating
- Can be used as a backup in case the tmp36 sensor stops working.

PIR FOAM

Why it was used?

- Typical $\lambda \approx 0.023$ W/(m·K) (Thermal coefficient)
- Excellent thermal insulation and cheaper option
- Stable over time & low self-heat leakage
- Chemically Stable and fire-resistant



ESP 32

Why it was used?

- Built-in Wi-Fi + Bluetooth
- Better ADC Resolution + More Sensors
- High-Frequency PWM for TEC Control

AS7341 (SPECTRAL)

Rating of the Component:

- Power Supply: **3.3V – 5V**
- Interface: **I^{2}C**
- Operating Current: **<5 mA** (LED off), **up to 70 mA** (LED on)
- Operating Temperature: **–30°C to +85°C**
- Channels: **11 total** (8 visible, 1 clear, 1 NIR, 1 flicker)
- Wavelength Range: **~350 nm – 1000 nm**
- Resolution: **16-bit ADC**

Why it was used?

- Provides detailed **multi-channel spectral data**
- Covers **visible to near-IR** range
- Built-in **flicker detection**
- Low-power and easy to interface using **I^{2}C**

GUVA S12SD (UV)

Rating of the Component:

- Power Supply: **2.5V – 5V**
- Operating Current: **Microamp range**
- Output Type: **Analog voltage proportional to UV intensity**
- Spectral Range: **240 nm – 370 nm**
- Detection Angle: **130°**
- Diode Type: **Schottky UV photodiode**

Why it was used?

- Simple **analog UV measurement**
- Very low power consumption
- High responsivity around **350 nm**
- Ideal for monitoring **UV radiation inside the chamber**

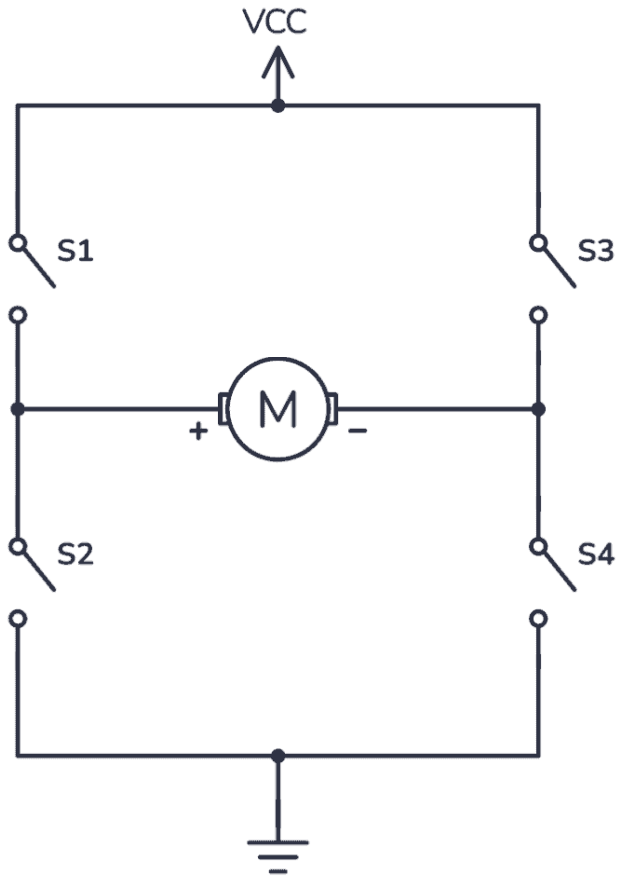
POWER SUPPLY

Why it was used?

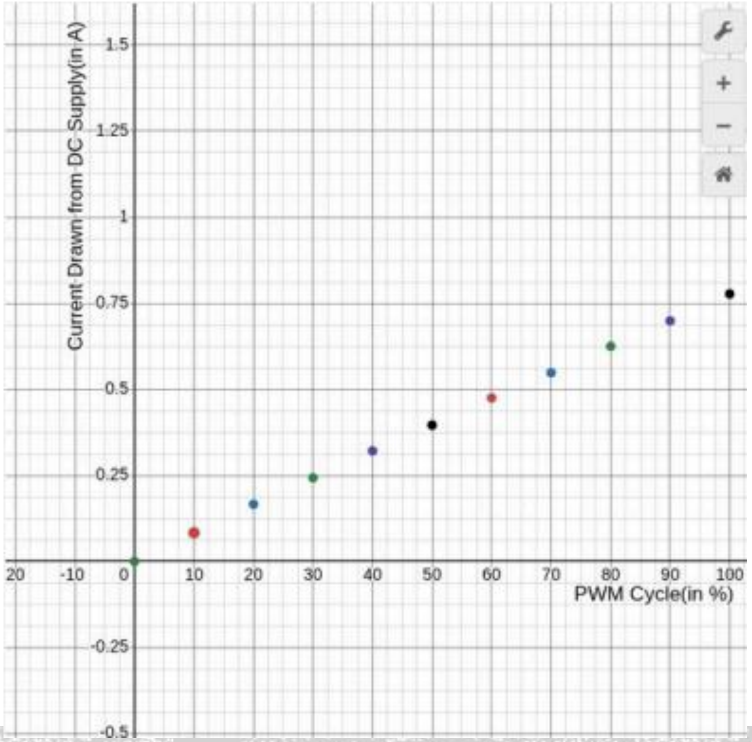
- 12V, 17A power supply
- Must Provide Clean, Stable DC for PID + H-bridge Operation
- It is an AC to DC converter.
- Each TEC requires 2.5A max → 4 TECs in parallel require a combined current of 10A

H-BRIDGE MODULE

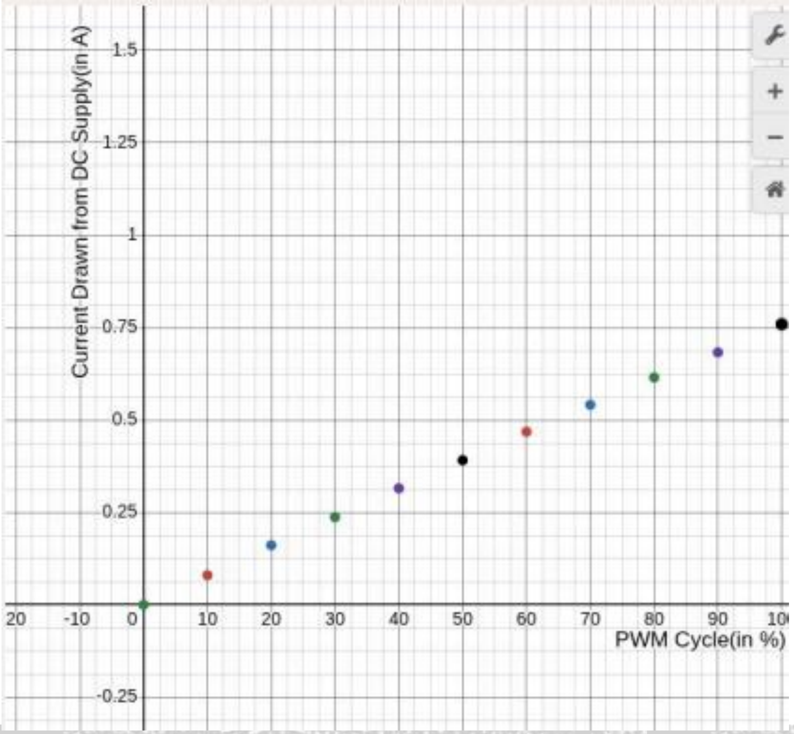
Structure: Four switches (transistors) in an "H" pattern with the motor in the center.
Forward: Two diagonal switches close, letting current flow one way to spin the motor forward.
Reverse: The other two diagonal switches close, reversing the current and the motor's direction.
Brake: Closing both bottom (or top) switches shorts the motor terminals, causing a fast stop.
Speed Control: Pulse Width Modulation (PWM) varies the average voltage by pulsing switches, controlling motor speed.



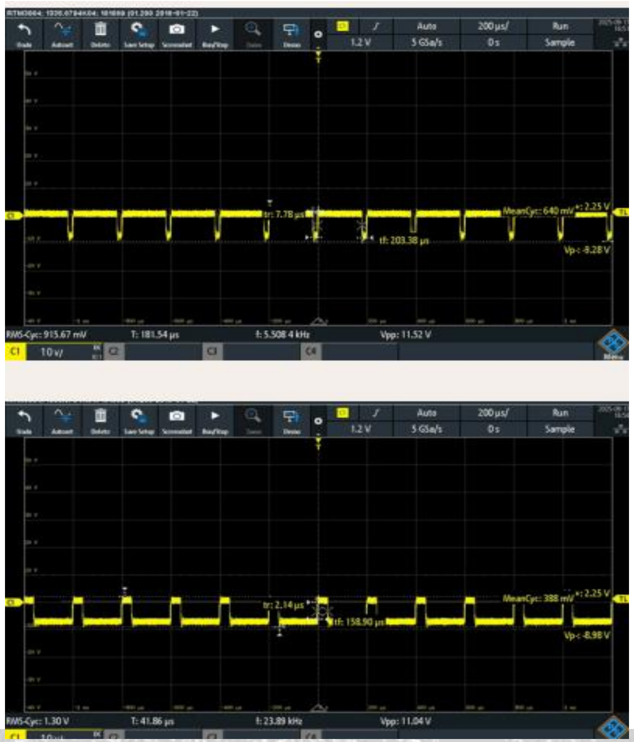
H-BRIDGE CHARACTERIZATION



For RPWM Pin



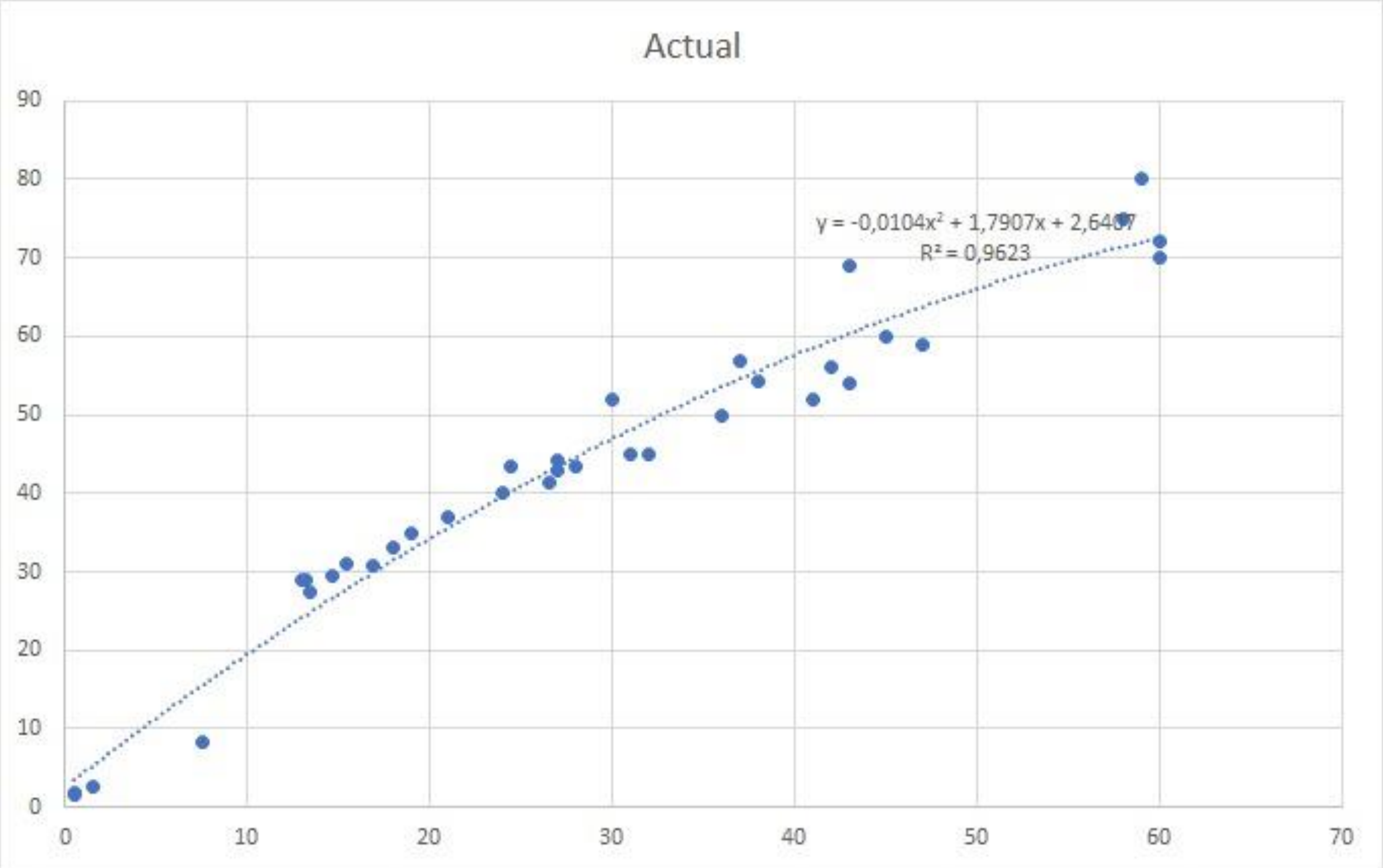
For LPWM Pin



Osclloscope Readings

Measured current vs. PWM duty cycle and confirmed switching signals on the oscilloscope to understand H-bridge behavior.

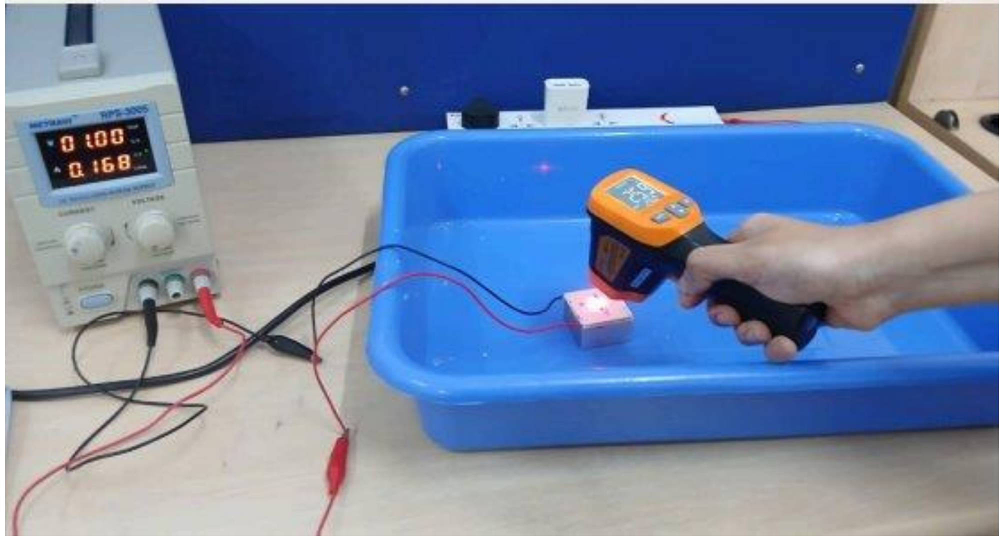
TEMPERATURE SENSOR CHARACTERIZATION AND CALIBRATION



Due to drift in the aging TMP36, we recorded its output at fixed heater setpoints and graphed the results. From this, we obtained the sensor's error function for calibration.

y=-0.0104x^2+1.7907x+2.6407
R^2=0.9623

TEC CHARACTERIZATION

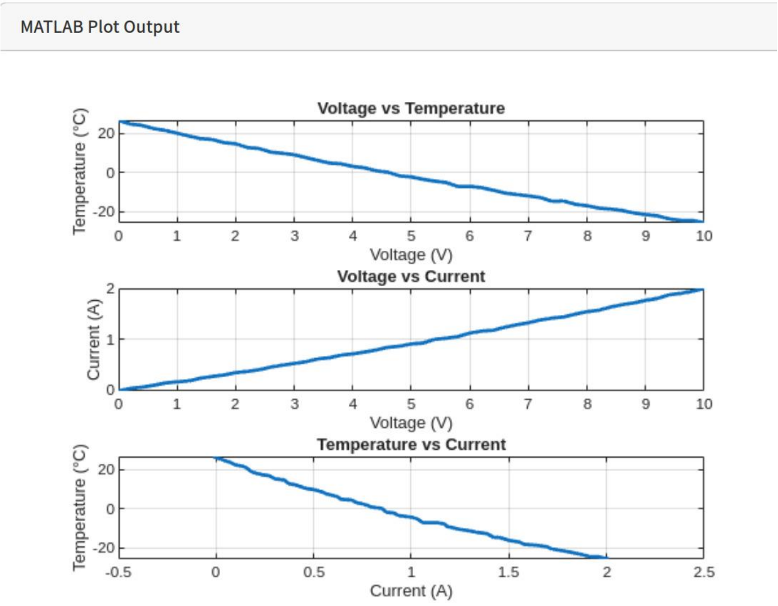


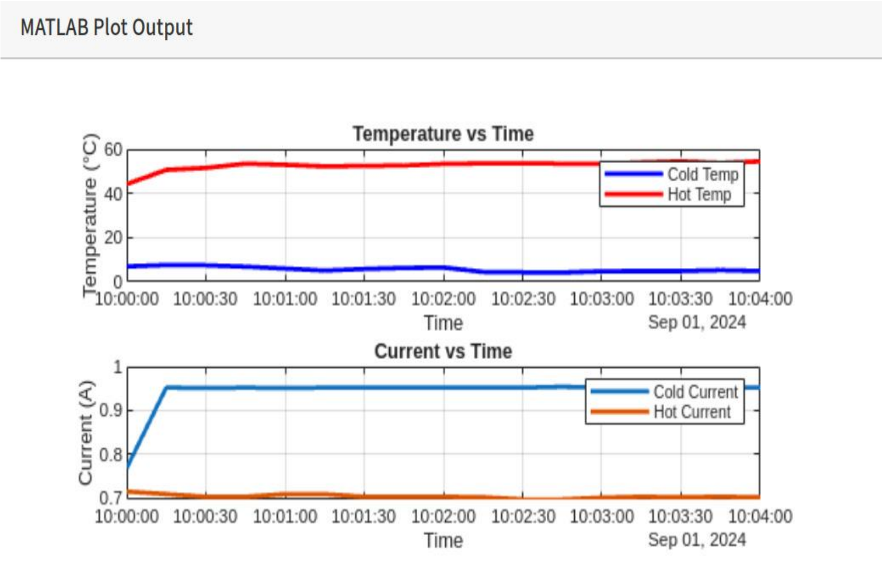
Hardware Setup for TEC Characterization

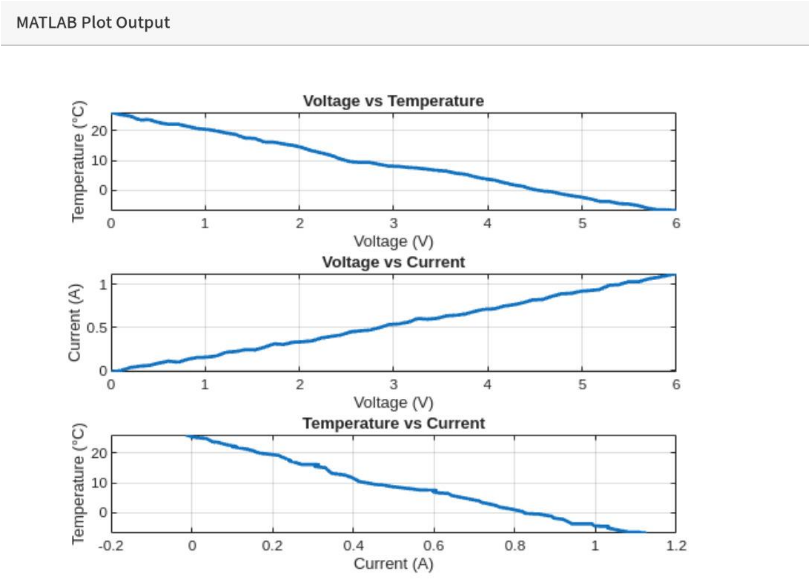
The TEC was tested by driving it with a regulated DC supply and measuring hot- and cold-side temperatures using an IR thermometer. The characterization was done under:

- No Heat Sink
- Heat Sink in Water (incremental voltage steps)
- Full Thermal Cycle (return to room temp each run)

TEC CHARACTERIZATION





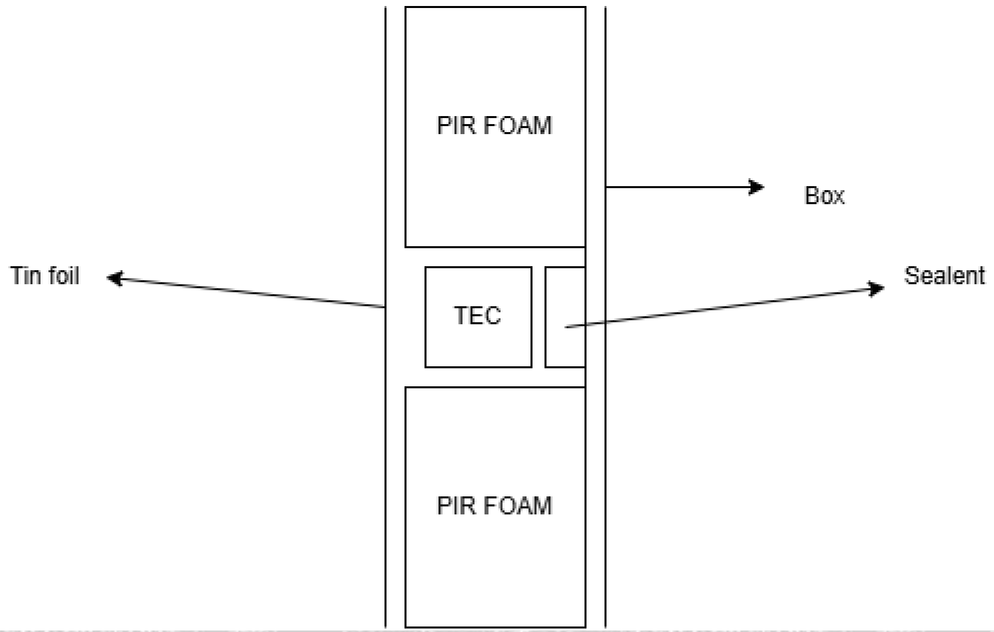


TEC behaviour as the input voltage is gradually increased up to 10 V.

TEC's temperature and current change when operated without any heat sinking.

TEC's temperature and current response when cooled using a water-immersed heat sink.

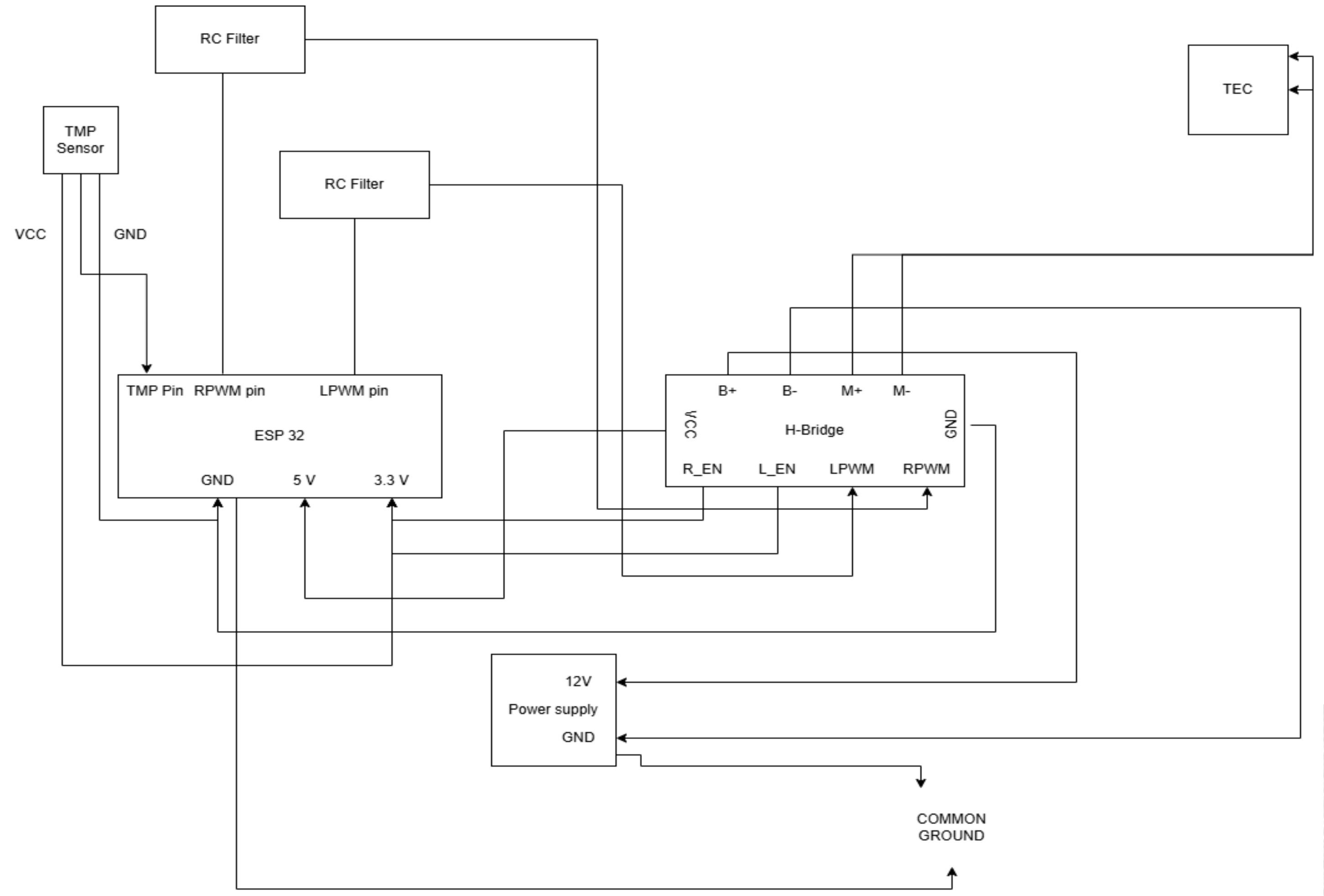
SET UP



The TECs are placed on all the walls, all four covering the four vertical sides of the box so that the entire area can be covered

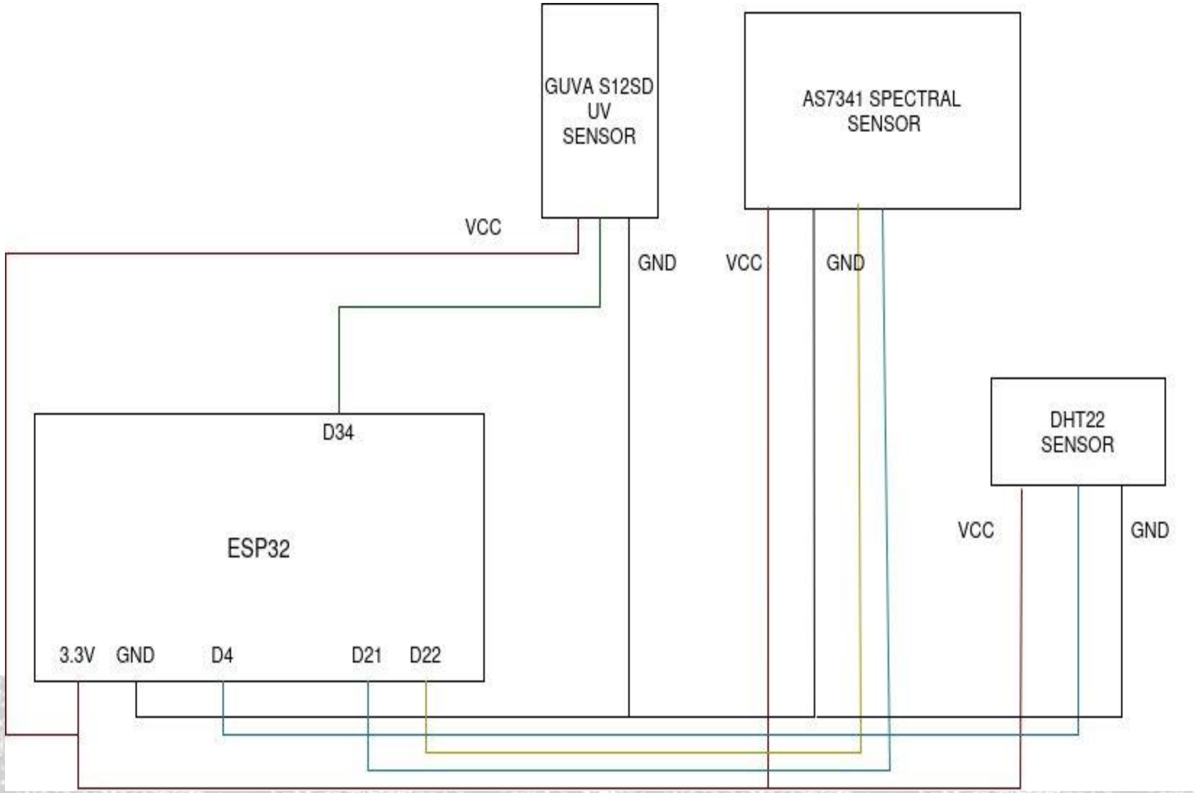
Sealants are used to stick the TEC's and to allow effective heat dissipation. This prevents the TECs from overheating at extreme temperatures.

CIRCUIT DIAGRAM 1



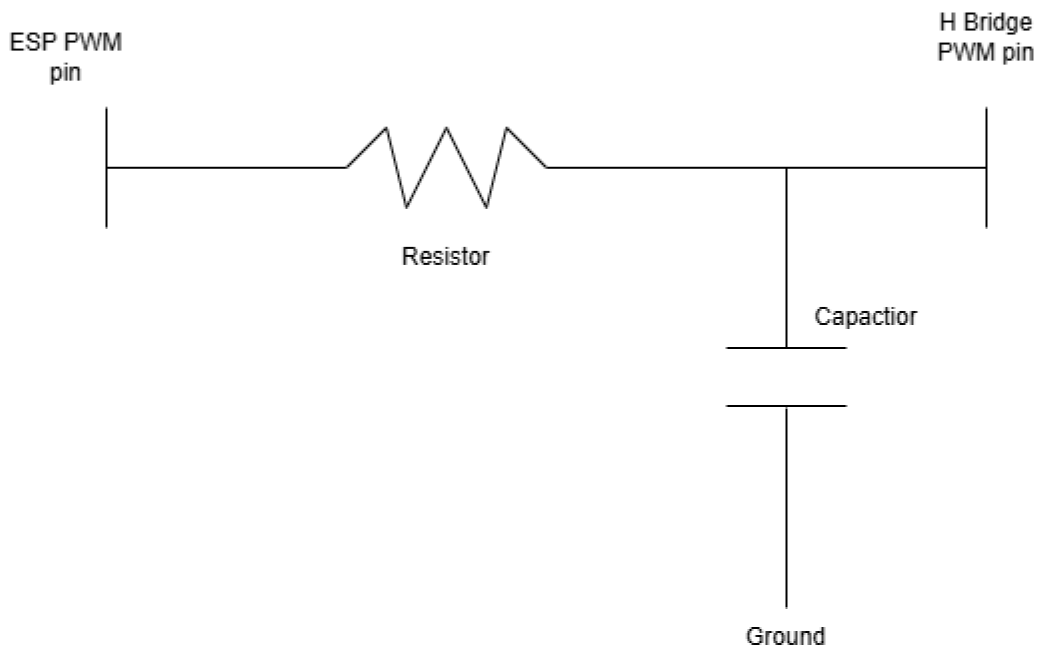
This circuit shows the TEC control system where the ESP32 reads temperature from the TMP36 sensor, filters the PWM signals through RC networks, and drives the TEC using the BTS7960 H-bridge powered by a 12 V supply.

CIRCUIT DIAGRAM 2



This circuit integrates the UV sensor, spectral sensor, and DHT22 temperature–humidity sensor with the ESP32 to monitor environmental conditions inside the chamber.

SWITCHED TO AN RC FILTER



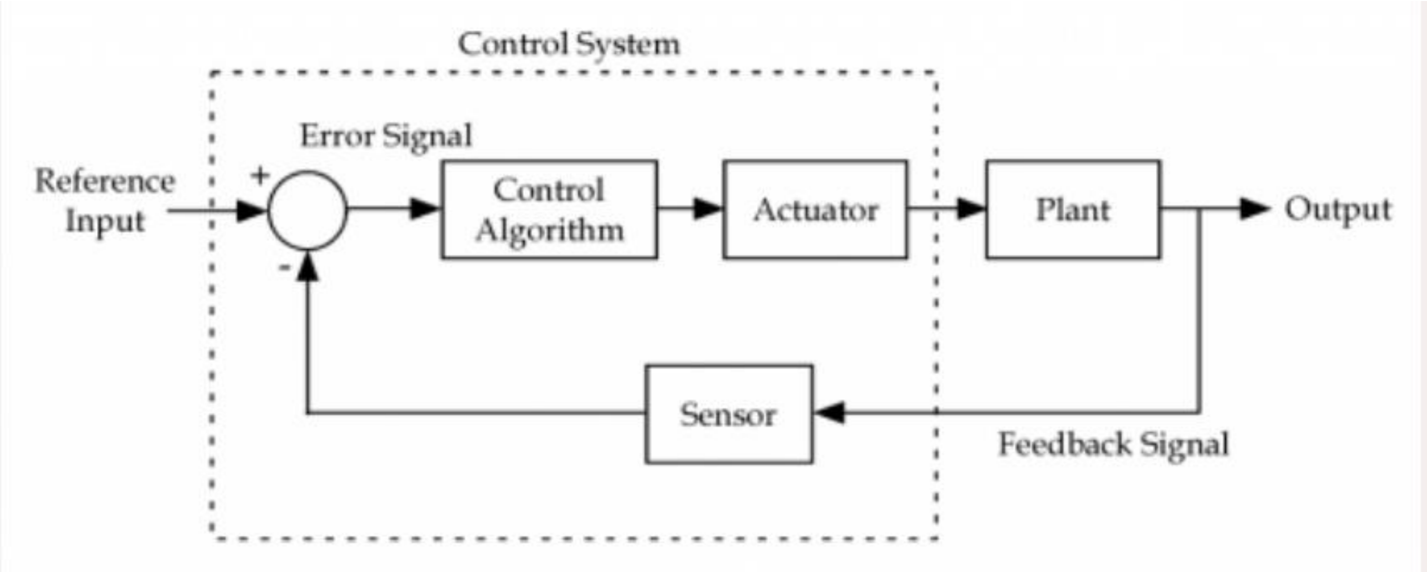
- Direct PWM control from the ESP32 switches too fast for the TEC.
- This causes current spikes at every PWM edge.
- Leads to overheating risk, even at low power levels.
- The RC filter smooths the PWM signal and provides a stable control input.
- This results in smoother temperature regulation.
- The RC filter also increases the lifespan of the TECs.

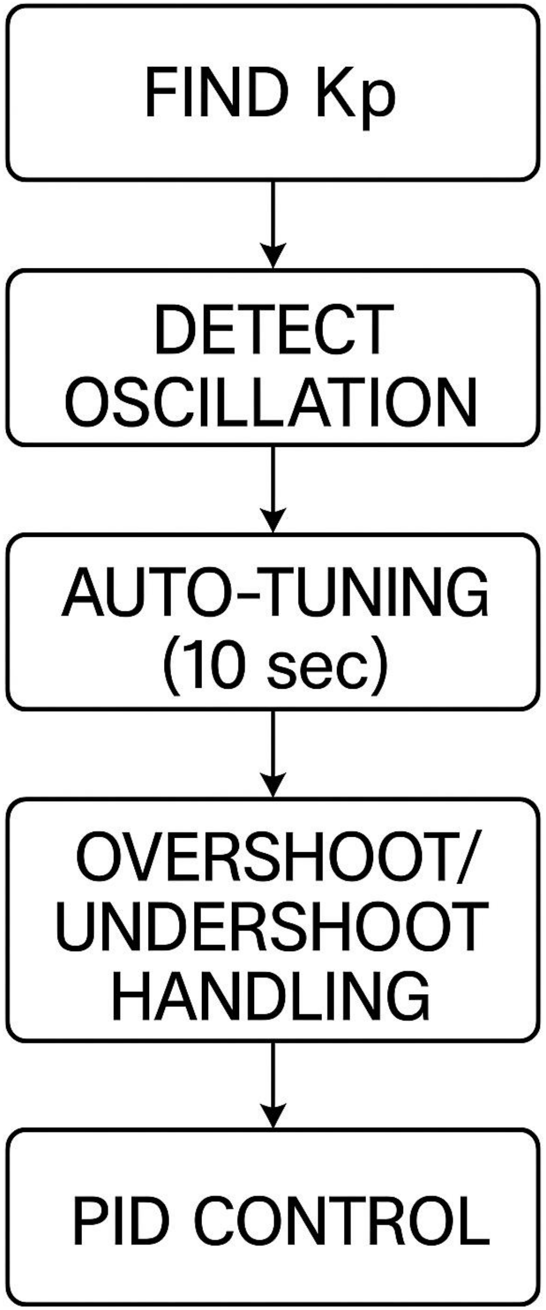
RC filter for smoothing the PWM signal to the H-bridge.

PID CONTROL

- Feedback mechanism that adjusts system to remain close to the desired set point.
- Mechanism on the basis of the error detected.
- Error signal: e(t) = Tsetpoint - Tmeasured
- Controler output: $u(t) = Kp*e(t) + Ki*\int e(t)dt + Kd*de(t)/dt$

SYSTEM INTEGRATION

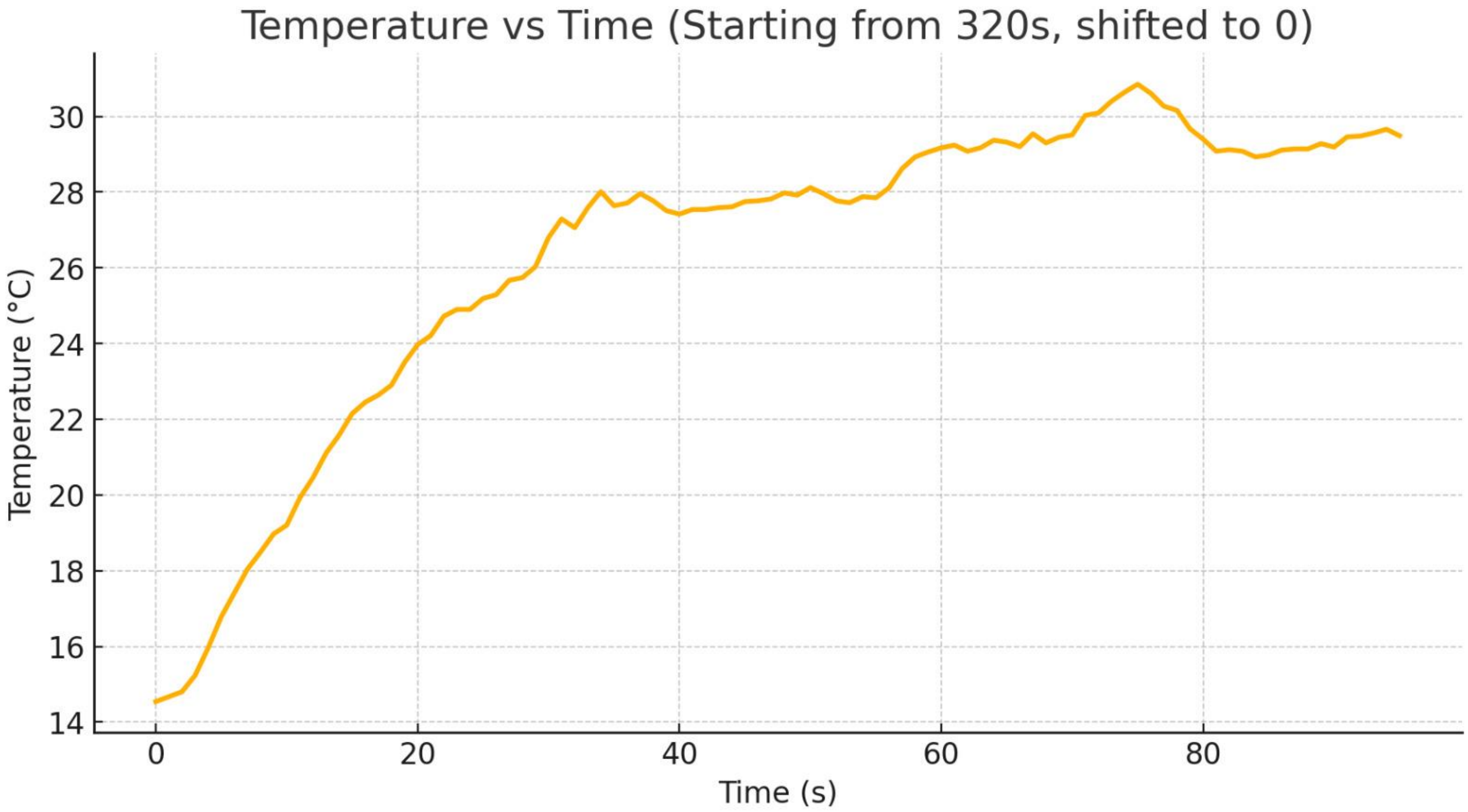




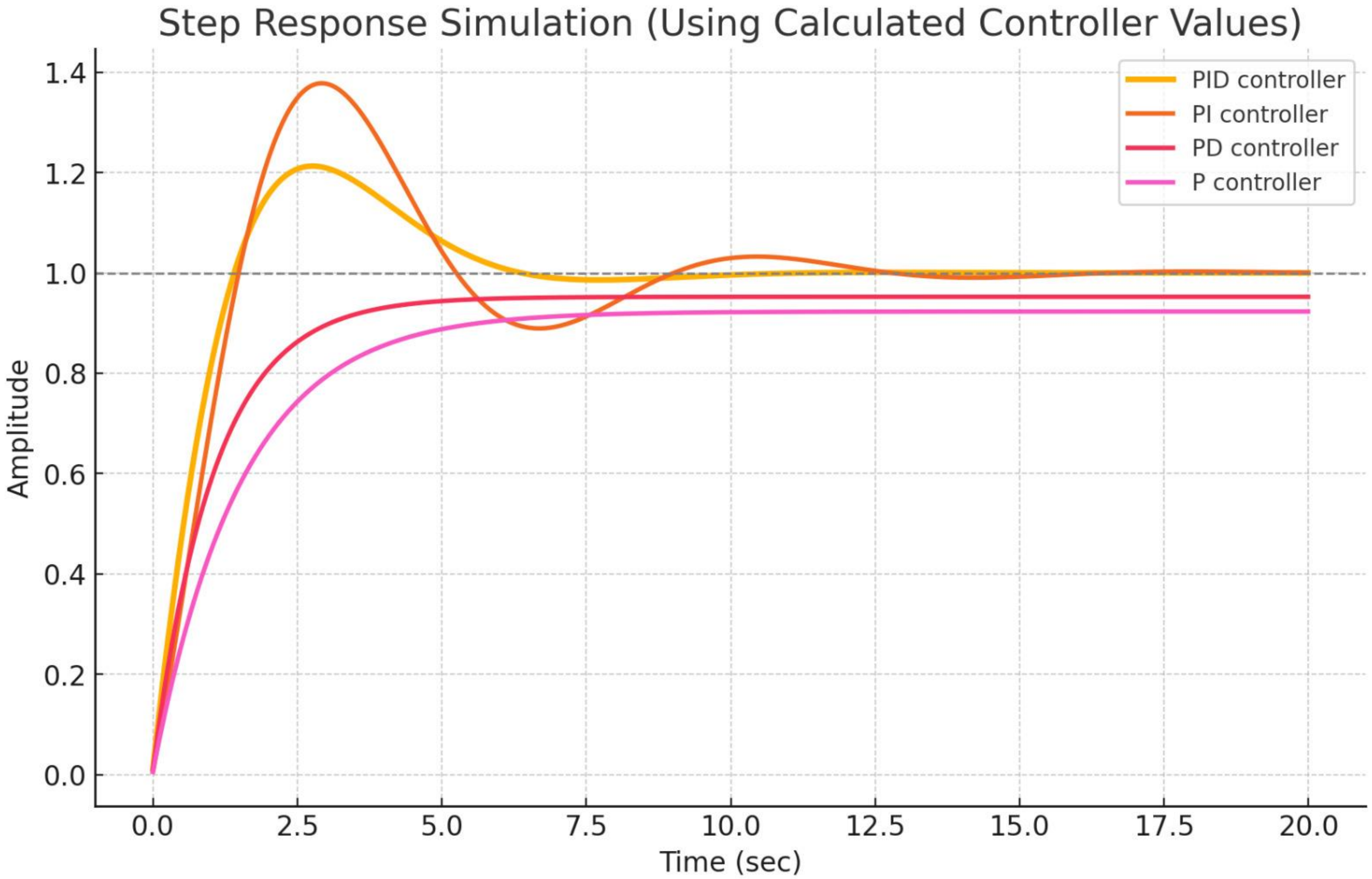
ZIEGLER NICHOLAS METHOD

- Identify how the system responds to the initial control input.
- Start with **Ki = 0** and **Kd = 0**, and gradually increase **Kp** until the system reaches the setpoint.
- Automatically adjust control parameters based on the observed behavior, determining suitable PID constants.
- Minimize overshoot and undershoot during the tuning process.
- Converge to a stable PID loop for accurate and reliable temperature regulation.

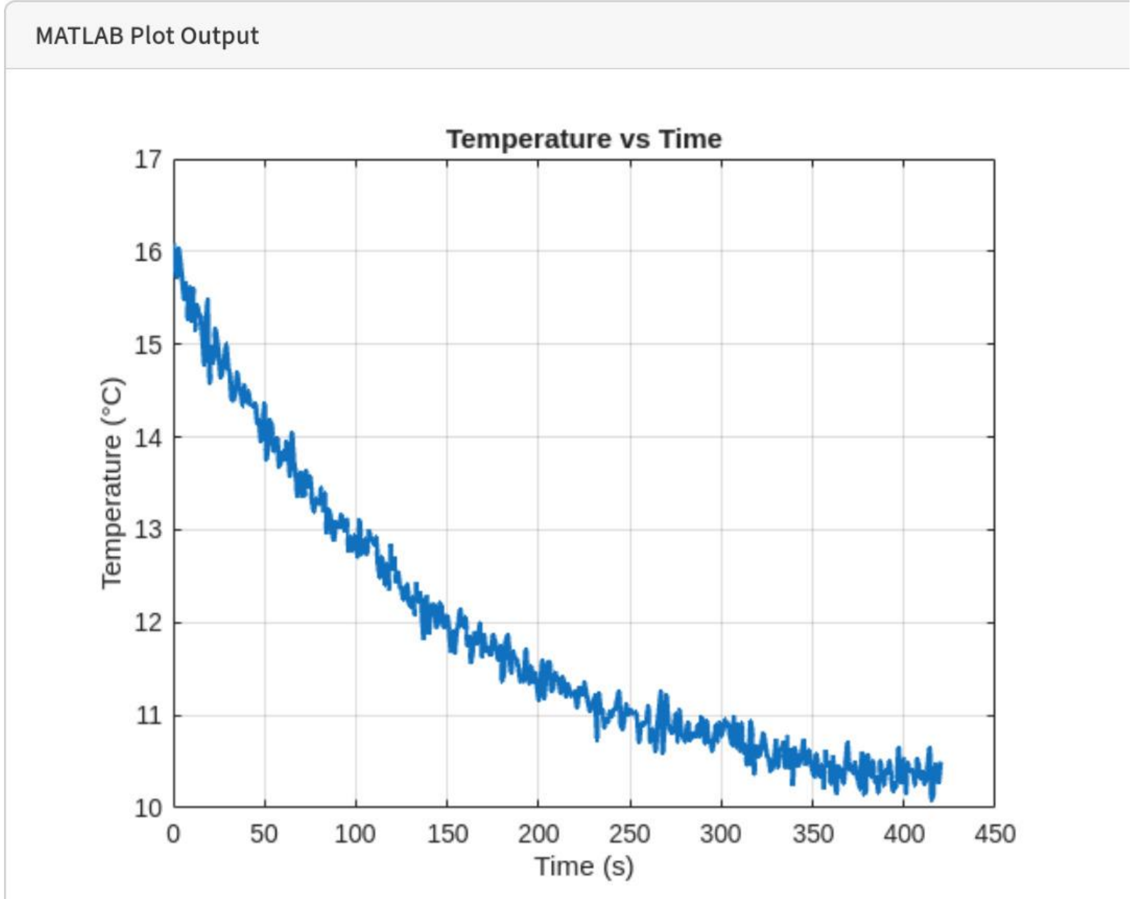
GRAPH ON THE 1ST THREE STAGES OF OUR PID CONTROL SYSTEM



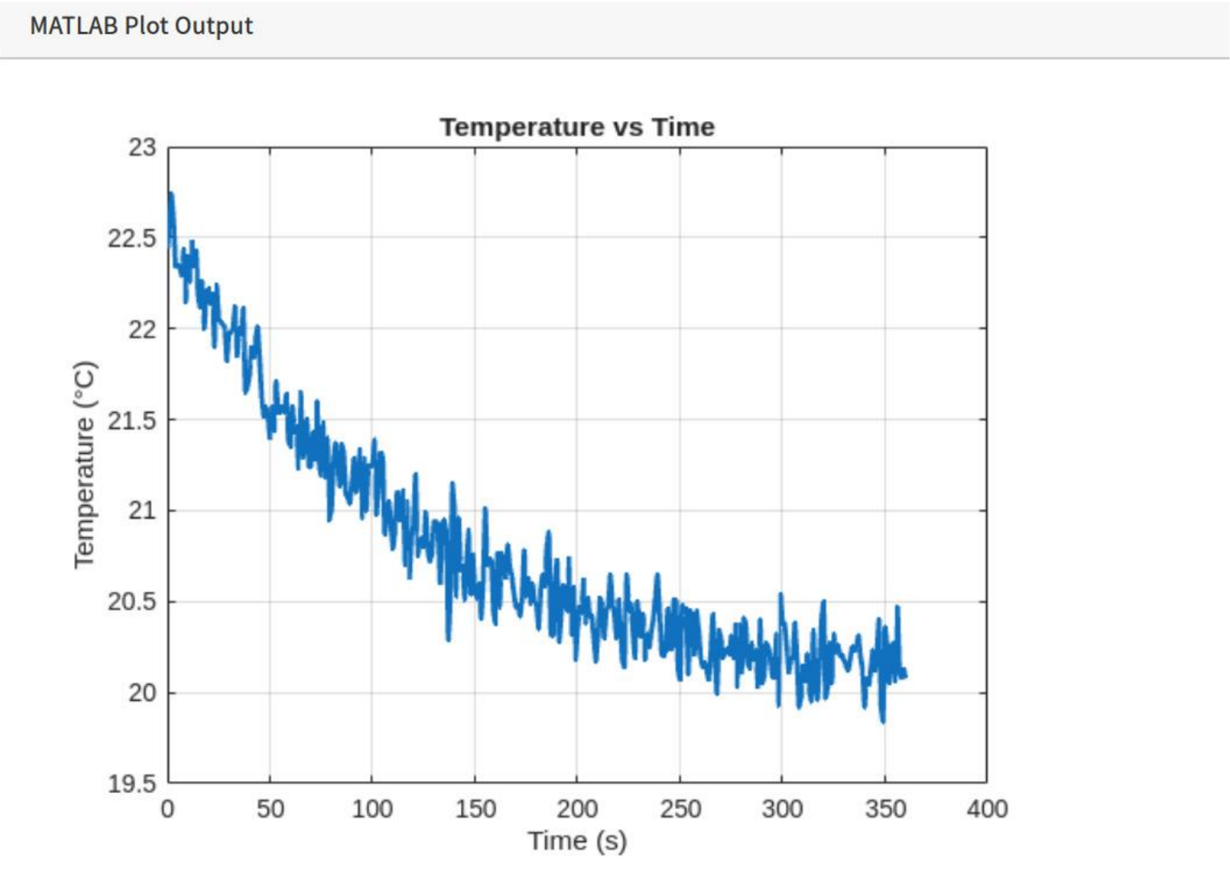
SIMULATED GRAPH BASED ON THE VALUES OBTAINED



EXPERIMENTAL GRAPHS 1

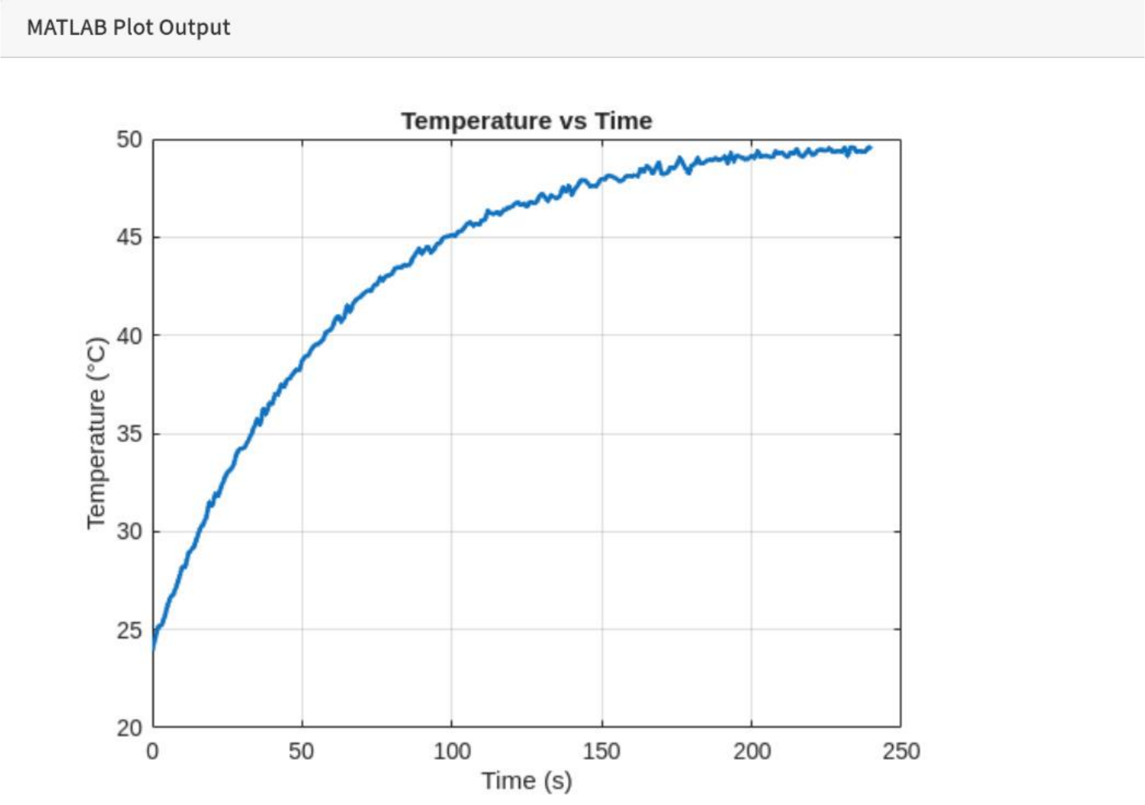


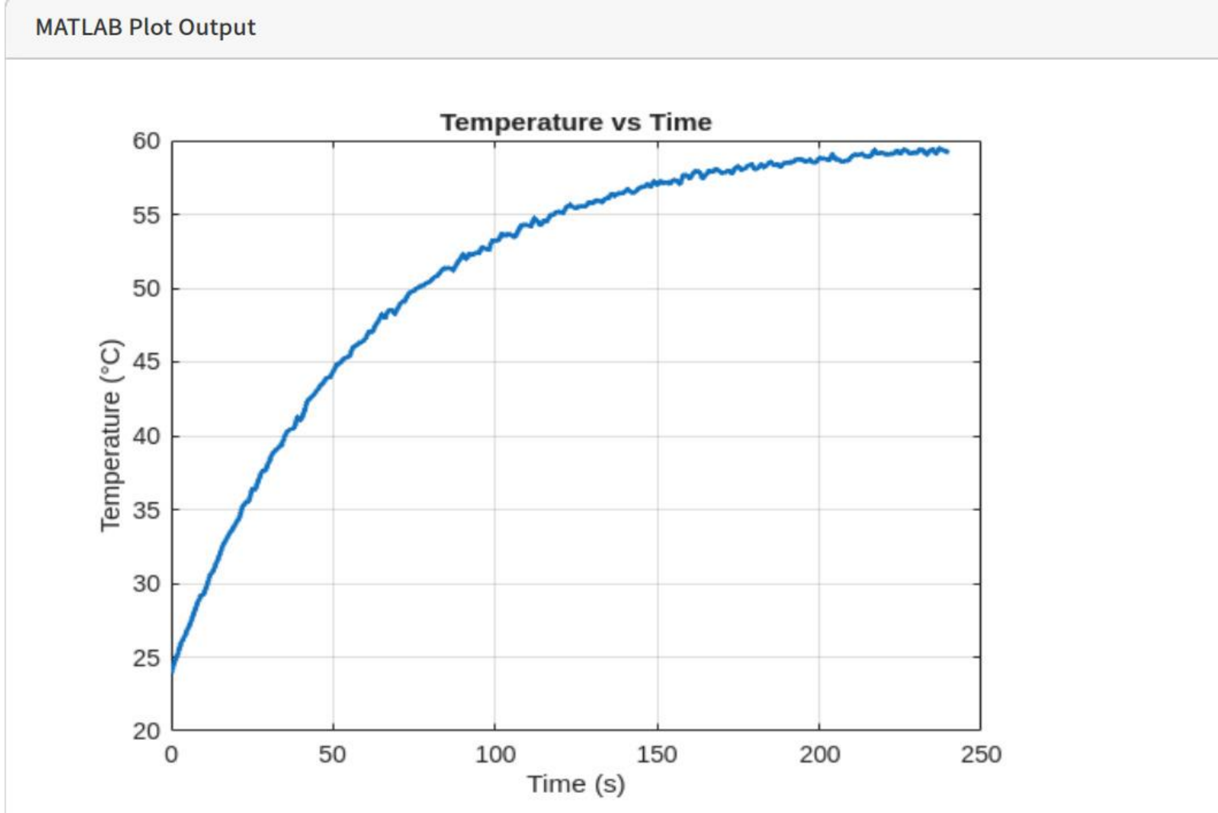
Setpoint=10 degree celsius



Setpoint=20 degree celsius

EXPERIMENTAL GRAPHS 2





Setpoint=50 degree celsius
Time taken =230s

Setpoint= 60 degree celsius
Time taken=250s

WHY THE PID CONSTANTS KEEP CHANGING

- Ziegler–Nichols tuning depends on Ku & Pu, which are NOT constant.
- Both Ku and Pu depend on the system's behavior near the setpoint.
- Newton's Law of Cooling → More Heat Loss at Higher Temperatures

  According to Newton's Law of Cooling:

$$\text{Heat } loss \propto \left(T_{object} - T_{ambient}\right)$$

- Higher setpoint = more heat escaping = system heats slower and behaves differently.
- TEC Internal Resistance Increases With Temperature
- Higher setpoint = TEC becomes weaker = system responds slower.

OPTICAL SPECTRUM MONITORING

How we monitored the spectrum

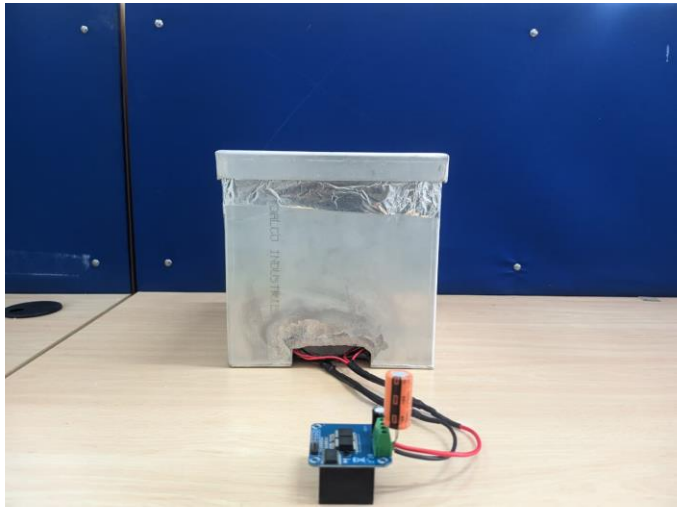
- We used the **AS7341 multi-channel spectral sensor**, which measures light from the visible spectrum to near-IR (410 nm to ~1000 nm).
- It includes 11 channels:
  - 8 visible-light channels (color bands)
  - 1 CLEAR channel (total intensity)
  - 1 NIR channel (near-infrared)
  - 1 FLICKER channel (detects 50/60 Hz flicker)
- For UV detection, we used the **GUVA S12SD UV** sensor, which outputs an analog voltage proportional to UV intensity through a UV-sensitive photodiode.

OPTICAL SPECTRUM MONITORING

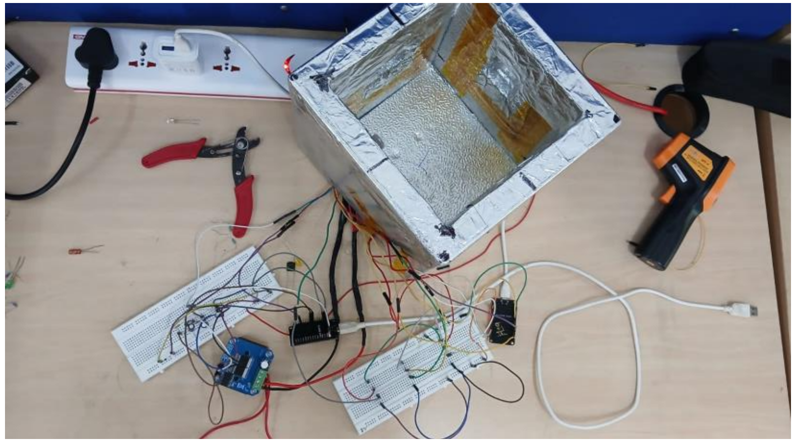
- A goal of the project was to check how much stray light is present inside the Faraday Cage.
- We used the **AS7341 spectral sensor** to measure light from the visible range up to near-IR, and tested it with different known light sources to confirm that it was giving correct readings.
- The readings were shown in our GUI as a bar graph with **8 visible channels** and **1 near-IR channel** (Violet, Blue, Cyan, Green, Yellow-Green, Yellow, Orange-Red, Deep Red).
- When we tested different colored lights, the bar for the main color always rose higher than the others, showing that the sensor was detecting the correct wavelength and that our monitoring setup was working as expected.

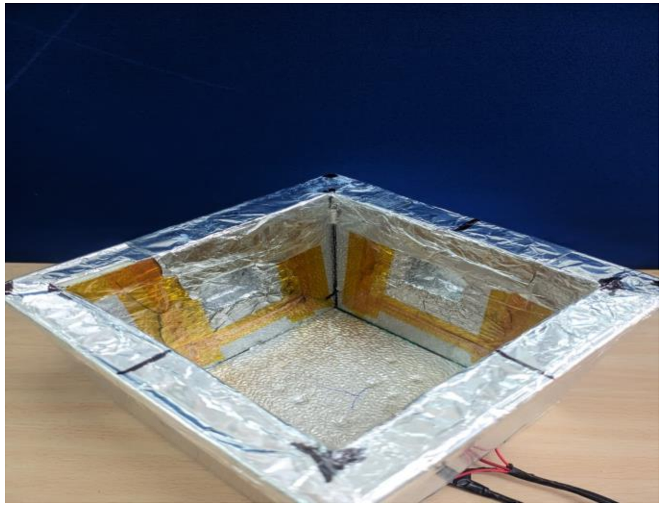
RF SHIELDING

- The box originally had small holes and gaps at the lid where electromagnetic waves could leak in.
- To improve shielding, these openings were covered with **aluminum foil**, ensuring proper conductivity and grounding across the entire enclosure.
- To check whether the Faraday Cage was actually blocking RF signals, we used an **RF transmitter–receiver setup**.
- The receiver was placed inside the box, while an external transmitter sent signals toward it to test for leakage.
- A properly shielded cage should show **no detectable RF signal** inside, confirming good isolation.



PROJECT IMAGES





PROBLEMS FACED

- Started with 1st-order and 2nd-order thermal models. Math was complicated and hard to apply practically- Switched to the Ziegler Nicholas method.
- Drilling holes individually for each tec module required sealing all of the excess part of the holes- switched to a common port from where wires were taken out.
- Routing the wires through the PIR foam- used straws to make holes through the foam.
- Temperature sensor calibration- couldn't get a fixed offset, so we had to find a function wrt the offset.
- TEC's were overheating, so to protect them, we switched to an RC circuit implementation.
- The polarity switching was too fast which could damage the TEC's- had to put delay when changing polarity.
- The lab lacked a power supply capable of meeting the required rating -procured an appropriate 12V, 10A regulated power supply.
- Unsure whether to use multiple H-bridges (one per TEC) or a single one .Finalized on one H-bridge since the 12V/10A supply supports the total TEC current (each TEC ≈ 2.5A), meeting project requirements.

THANK YOU