The controller for the temperature chamber with Peltier cell

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Abstract: The present work describes the procedures to build a controller for controlling the Peltier cell for achieving the desigred temperature from -5 degree centigrade to 50 degree centigrade. The project is being carried out to fulfill the vision of keeping the potency of the medications while storing them at the makers' recommended temperatures until they are consumed by the patient. The work illustrates the approaches for successfully controlling the Peltier cell by designing a power circuit driver for switching the electric parameters for the Peltier cell, feedback controller using PI algorithm and temperature sensors with a user interface for operating and communication of variables for data logging.

Keywords: Peltier Cell, Temperature Chamber, Controller, Microcontroller, PI, PWM, LCD, Touch display, PCB, MOSFET, driver.

1. Introduction

Peltier module or cell, is a thermoelectric device that uses electricity to generate temperature difference across the ceramic faces, the one face cools while the other face heats up. This phenomenon is reversible, when the direction of electrictrical current is changes the change in temperature produced would be reversed, that means the hot side previously would become cold and the cold side previously would become hot. To control this Peltier cell, a microcontroller is required, and to know the temperature generated a temperature sensor is used to monitor the generated temperature and constantly maintain the temperature a Proportional-Integration algorithm is used to decide the signals of Pulse Width Modulation for controlling the power drivers. A power driving circuit is designed and fabricated with supporting components for obtaining the desired range of temperature inside the insulation box. The user would be interacting with an LCD touch display to set the required temperature, and the real-time data regarding the insulation box would be displaying.

2. Brief overview of Peltier Module

The Peltier module is made of thermoelectric materials, which have the Peltier effect. The Peltier Effect is the phenomenon that results in a temperature differential at the junction of two dissimilar metals when electricity is delivered in a closed loop. These days, semiconductors are utilized to produce thermoelectric materials by doping the material to produce its P- and N-types. Then, these components are linked together in series to create a string of N- and P-type materials that are sequentially but parallelly placed between two ceramic plates[1], [2]. Figure 1[3] shows the dissection of Peltier module where small pellets of P-type and N-type are seen connected to the conducting metals which are fixed to the ceramic plates. The maximum current that can be supplied would be directly proportional to the number and cross-section of pellets used in the module, the rating current and voltage are usually given by the manufacturer of the thermoelectric module.

The theoretical parameters of thermoelectric module is determined by the following equations[1].

$$V = \alpha(T_h - T_L) + IR \quad (1)$$
$$P = \alpha(T_h - T_L) + I^2R \quad (2)$$
$$Q_L = \alpha I T_L - ½ I^2R - K_t(T_h - T_L) \quad (3)$$
$$Q_H = P + Q_L = \alpha I T_h - ½ I^2R - K_t(T_h - T_L) \quad (4)$$
$$COP = Q_L/P \quad (5)$$

R – The total resistance offered by the module (ohm).
K_t - The total thermal conductivity of the module (W°C^{-1}).
α - The Seebeck coefficient of the module (V°C^{-1}).

The performance and efficiency of the Peltier module can be assumed by the dimentionless parameter called as the figure of merit denoted as Z.

$$Z = \alpha^2/K_tR = (\alpha^2\sigma/\lambda)T \quad (6)$$

σ- Electrical conductivity.
λ- Thermal conductivity.

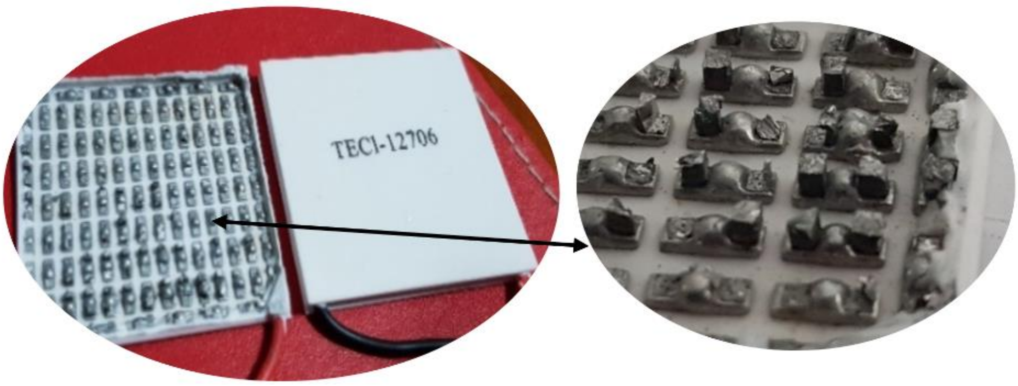


Figure 1: Disection of Peltier Module.

3. Ideology and Approaches

The following sections cover the fundamental ideas behind putting the components into action.

- **a.** Design of power circuit and fabrication.
- **b.** Interfacing microcontroller with sensors and control algorithm.
- **c.** Designing a prototype insulated closed box and testing.

3.1 Design of power circuit and fabrication.

The heat rejected or heat applied was found to be 65 W inside the closed insulated box considering to store insulin. By checking the performance curves of the Peltier module as per the manufacturer's datasheet, the working voltage is decided to be of 14 V and the current to be 3A. These parameters are for reaching the desired temperatures, while the PCB power circuit should be capable of working more in higher current and voltages for increasing the capacity further to use to drive more powerful Peltier modules. Figure 2 would show the schematics of the circuit layout plotted for driving the power. The following schematic layout is designed in Altium Designer software.

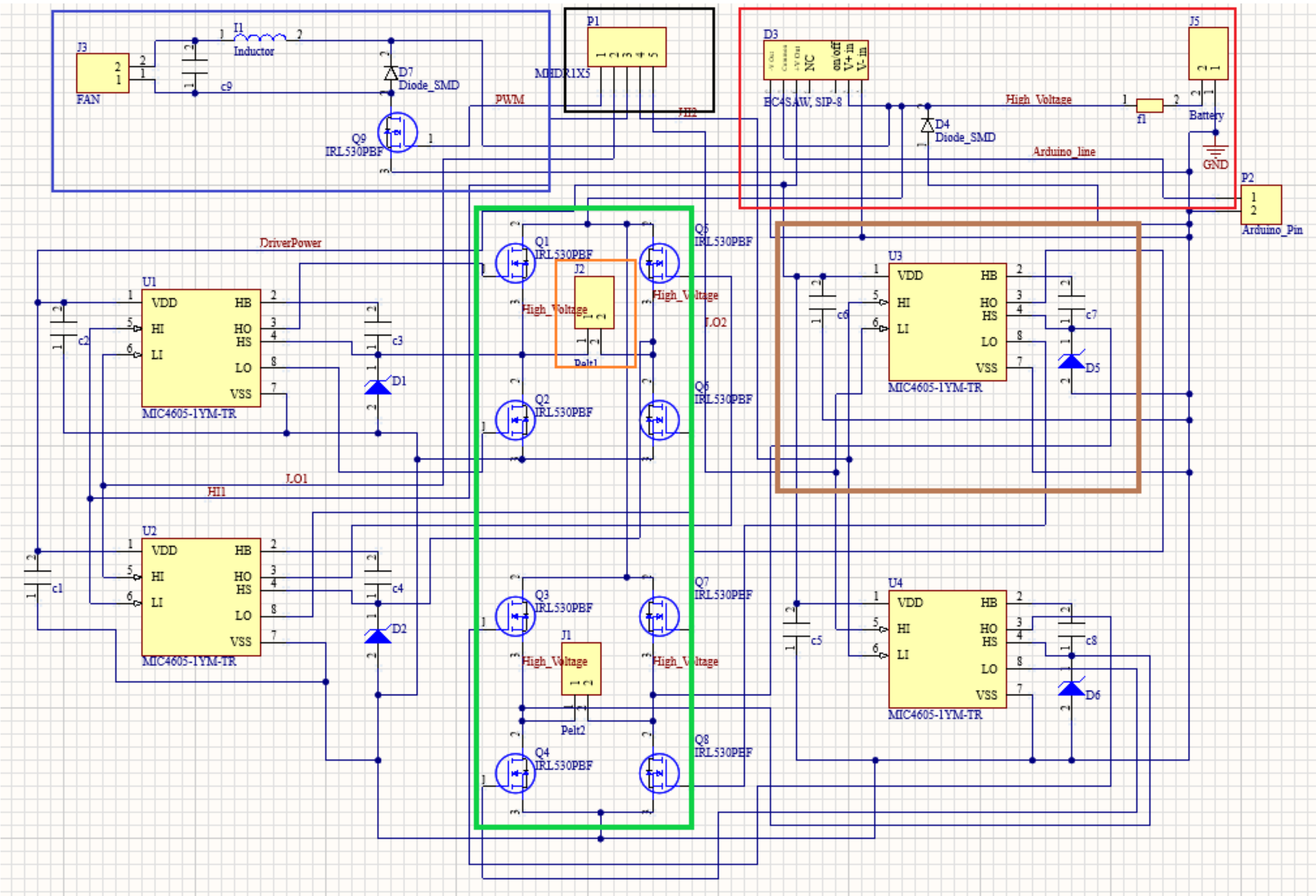
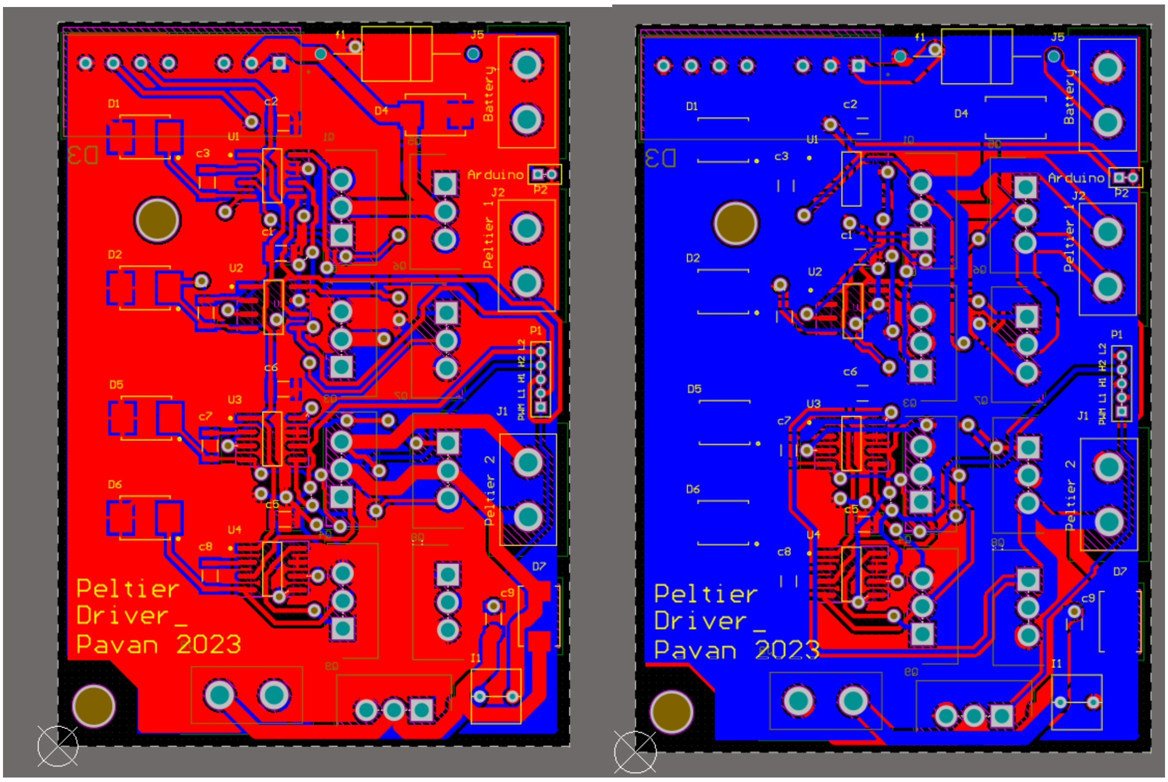


Figure 2 : Schematic layout of the Circuit

The schematic layout consists of two H-bridge circuits (inside green box) which are responsible for changing the current direction in the connectors Pelt1 and Pelt2 and these H-bridge circuits are connected in parallel to each other, a power circuit (inside the red box) to divide the voltage to a microcontroller and the H-bridge is obtained by using suitable DC/DC converter. The simple chopper circuit is also connected to the power circuit for powering the fan necessary for dissipating the generated heat from Peltier to the surrounding air. Molex connectors (inside the black box) are used to drive with the MOSFET drivers where signals are transferred from the microcontroller. The connection for the MOSFET driver is shown inside the brown box in Fig 2.

The power circuit consists of an isolated DC/DC convertor EC4SAW-24D05N, through hole with input range 9-36 VDC input, ±5 VDC output with ±600mA current. The main reason to use this convertor is to divide the voltage of +5V to microcontroller and +10V to the

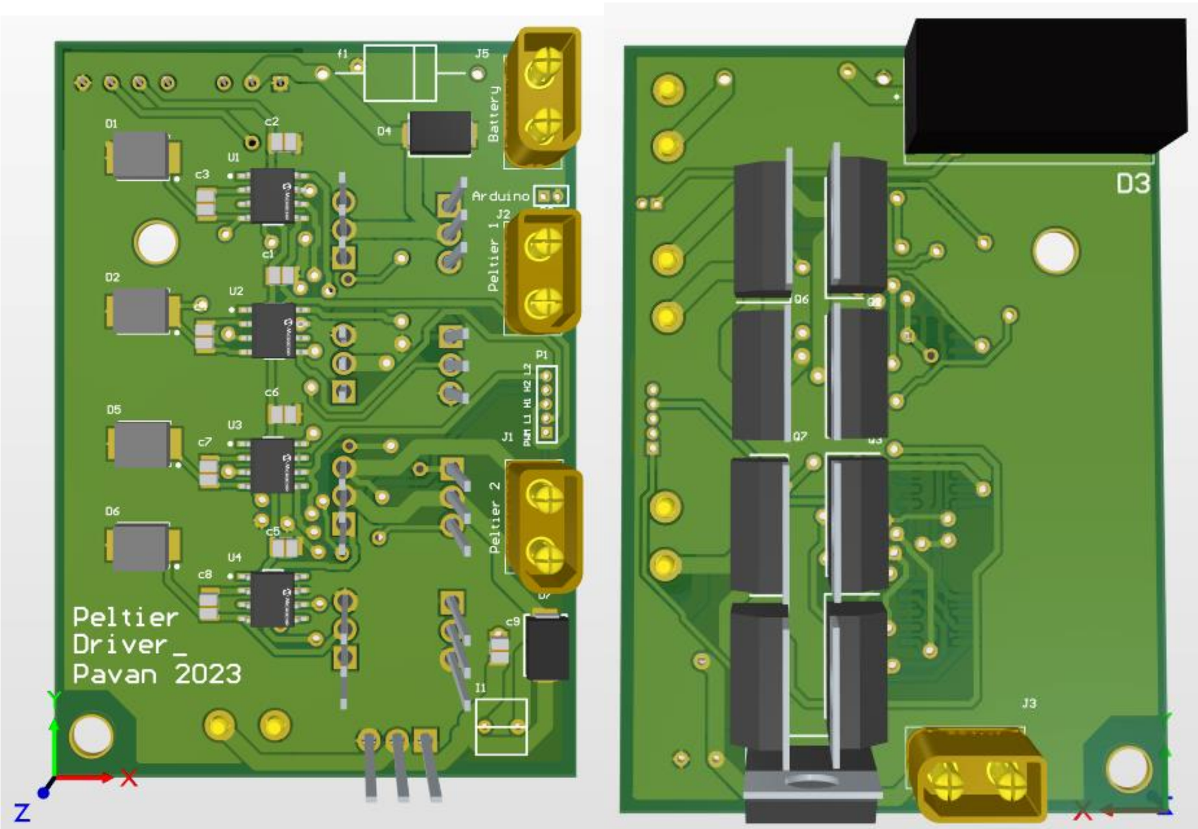
MOSFET driver, while the total supplied voltage would be passed to the Peltier module. The H-bridge circuit consists of N-MOSFET IRLUO24NPBF from Infineon technologies which are capable of working at maximum 55 V continuously (V_{DSS}) and 17 A (I_D) current, resistance offered is 0.056 Ω ($R_{DS(on)}$), these MOSFETS can be operational till 200° C where the heat sink for cooling MOSFETS is not required for this application. To drive these MOSFETS, a half bridge MOSFET driver MIC4605-1YM of 8-pin SOIC package is used. These drivers are capable of supplying 5.5 V to 16 V to the gate with operating junction temperature of -40° C to +125° C which is suitable for many motor driving applications. To activate the proper gates of MOSFET it is recommended to check timing diagram of the MOSFET driver from manufacturer's datasheet to signal LI and HI pins from microcontroller for changing the direction to the Peltier module through HO and LO pins. There is an inbuilt undervoltage lockout (UVLO) with the driver which led to use bootstrap capacitor, in the circuit the capacitors of 0.2 µF is used for both bootstrap and to reduce fluctuations from the supply. The power circuit consists of fuse holder connected to the battery supply and DC/DC convertor, and a diode is connected in blocking direction to the ground to the battery supply for reduce power surge for the circuit. The chopper circuit consists of a MOSFET to open the voltage for the external fans placed on both sides to the Peltier module by PWM from microcontroller, to keep the current continuous a capacitor is connected parallelly and an inductor in series to reduce the fluctuation of the voltage across the fan, this circuit is used basically to control the fan speed as desired and also to overcome the different voltage level of the fan compared to the voltage supply from the convertor. After validating the schematic layout, the Printed Circuit Board is designed. Figure 3 illustrates the arrangement of the components to keep the PCB compact and the dimensions are 4.7 by 6.6 cm.



(a) (b)

Figure 3: PCB(a) Top layer, (b) Bottom Layer.

The width of the routing traces is calculated using the following formulae and an interactive routing is made. The considered widths are 50 mil, 28 mil and 15 mil. The power circuit and H- bridge are composed of track width of 50 mil while MOSFET driver circuit is composed of 28 mil and 15 mil track width. On the top layer the high voltage net and on bottom layer ground net pour is generated for harvesting voltage difference for other devices if required.
The 3D image is the circuit is shown in the Figure 4 for visualization of PCB board with components. The Surface Mount Devices (SMD) are placed on one side mostly while the through hole components are placed on other side.



(a) (b)

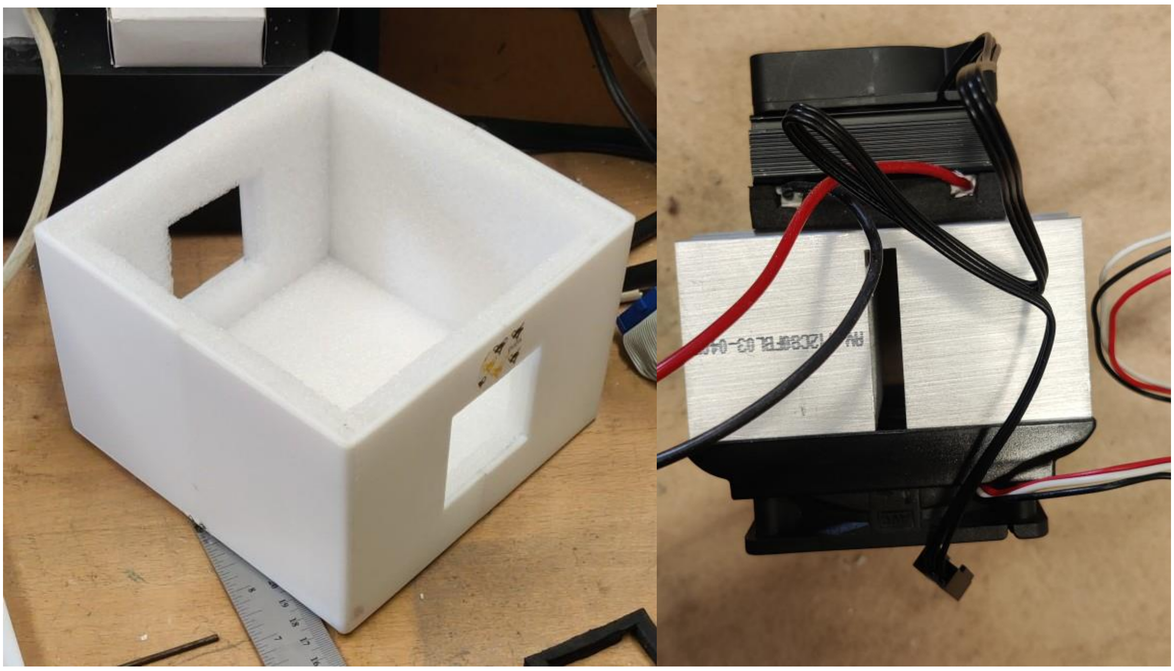
Figure 4: (a) Front side of the board, (b)Back side of the board.

3.2 Interfacing microcontroller with sensors and control algorithm.

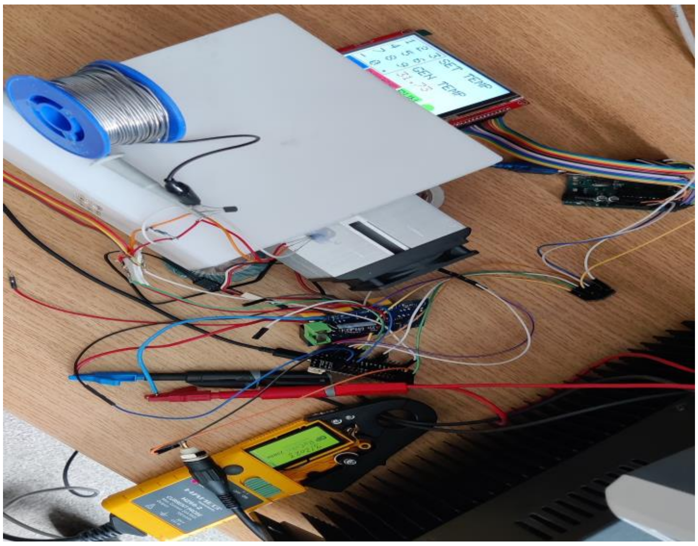
For this control task, Wemos Lolin 32 was choosed, as is capable of handling the control algorithm and communication with its dual core Xtensa dual-core 32-bit LX6 microprocessor, operating at 160 or 240 MHz obtain performance up to 600 DMIPS. Available memory is upto 520 Kb SRAM and wireless connectivity. The DS18B20+ sensor is used for feedback from the closed box. The temperature can be known by calling the unique 64- bit serial number or by index. The reason for choosing this sensor is its easily affordable, easy to connect use and with the accuracy of ± 0.6 °C. In this application, four temperature sensors are placed for monitoring the temperatures, like on inside heatsink, outside heatsink, one for ambient temperature and other for inside induced temperature. The control algorithm used is Proportional and Integral (PI) controller**[4], [5]**, where the logical operator is used for changing the direction**[6]** of the current is based on set and generated temperature, while the temperature difference is less than ± 5 °C then PI controller algorithm is then activated. This blocking of the regulator at a greater distance from the setpoint accelerates the achievement of the set value and at the same time suppresses the parasitic wind-up effect of the PI regulator. The driving of respective MOSFETS is by MCPWM (Motor Control Pulse Width Modulation), the duty cycle of this PWM signals is decided by the PI algorithm when the difference temperature is ± 5 ° C, else the duty cycle would be full. For user interface, the touch LCD connected to Arduino Uno is used to take the set temperature and display the generated temperature. The set temperature and generated temperature are interchanged between Arduino uno and Lolin 32 by UART communication.

3.3 Designing a prototype insulated closed box and testing

The prototype box is designed to hold 2 Peltier modules but for experimenting the controller, only one Peltier module is used. The designed box is 3-d printed and inside is lined with an insulation foam to trap the temperature as shown in the Figure 5(a). The Peltier module is then fitted with fans on both the sides and tightened with nylon bolts to reduce the thermal short circuiting, it is shown in Figure 5(b). The electronics are then connected to the box and powered for testing as shown in Figure5(c).



(a) (b)

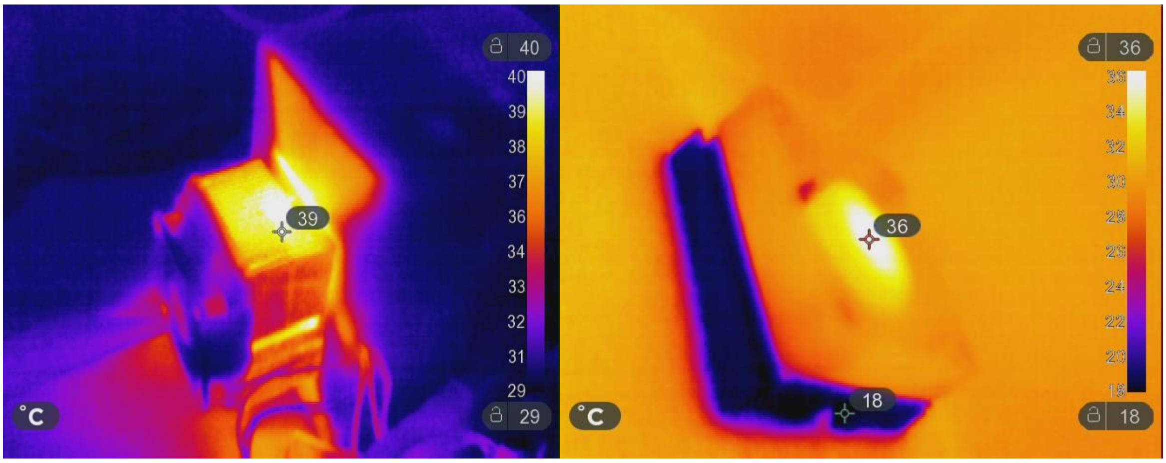


(C)

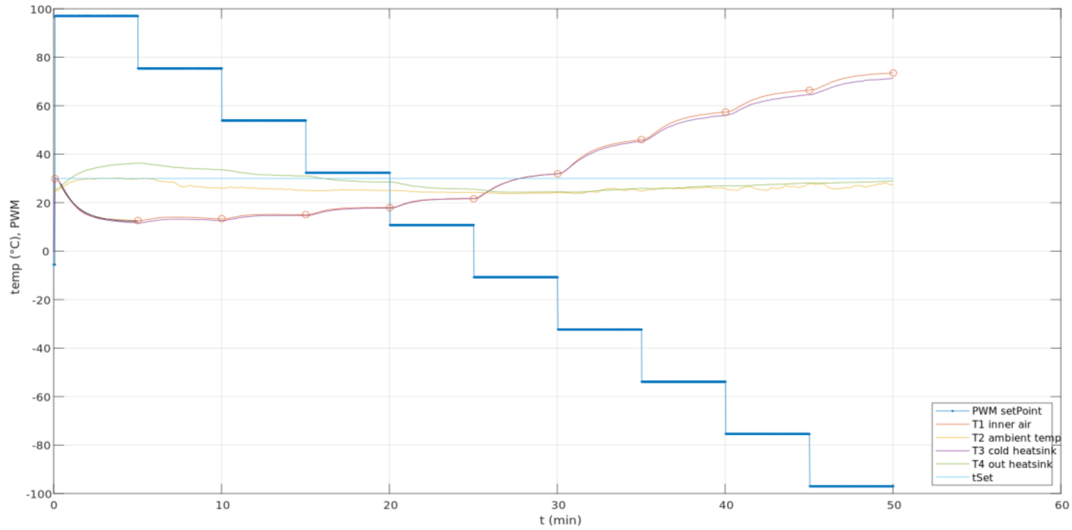
Figure 5: (a) 3D printed box, (b) Peltier Module, (c) Test setup.

4 Results

The results are promising while there are some drawbacks for the first approach, it is observed that the insulation is not proper to trap the temperature Figure6 (a) (b) would show the spread of temperature when set to 15°C inside, and interference of temperature from outside heatsink to inside heatsink, and further the study of change in temperature is done by changing the change in PWM for every 5 minutes from +98 % to -98 % duty cycle. Figure 6(c) shows the changes and the reading of the temperature from the sensors while the set temperature is not considered.



(a) (b)



(c)

Figure 6: (a) Outside heatsink (b) Inside heatsink, (c) Temperature/PWM vs Time.

5 Conclusion

It is observed that the temperature controller is working with a over shoot of ± 4 ° C as the system is bit slow and the insulation should be further processed to make air tight. While the second Peltier module can be also implemented to further increase the speed of the system. Further the box can also be implemented with a Battery Management system (BMS) and can be operated by Li-Po batteries. Lastly, proper insulation should be achieved to avoid the thermal interference from external to the inside of the insulation box.

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