EE344: Electronics Design Lab

Final Project Report

Reflow Oven for Soldering SMD Components

TUE- 11

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1. Project Title:
Reflow Oven for Soldering SMD Components

2. Group Number: TUES-11

3. Team members:

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4. Circuit Schematic and Layout: Circuit Schematic Layout
Also added at the end of the document.

5. Project abstract:

Soldering SMD components requires practice, it is time consuming and the quality of soldering depends on the skill.

Aim of this project is to build a reflow oven which follows a configurable reflow profile accurately and covers a large temperature range. We aim to build the system using Nichrome coil mounted on an Copper plate as heating element, a web-interface to add/configure reflow profile, a simple user interface including screen and buttons and an elegant 3D printed PLA enclosure. Proposed system can also be used for de-soldering SMD components.

6. Project Goal:

Goal of the project is build a reflow oven with heating plate size as 100mm x 100mm which covers a large temperature range (up to 300 ^{o}C). Reflow oven should have an option to change reflow profile according the solder paste used. The heating plate should be able to drop temperature after reflow profile peak quickly (about 3^{o}C/second). The heating of surface should be approximately even. Reflow oven should have a screen where relevant data (like current temperature) is displayed and a few buttons to control the oven. Entire project is to be enclosed in a suitable enclosure.

7. Components:

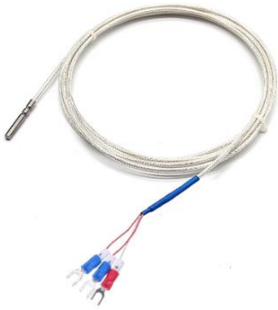
a. Copper plate:
Copper Plate of dimensions 100x100x2mm is used as **heating surface**. Copper is chosen because of high conductivity, it is easily available, requires less energy to heat up than aluminium (for same dimensions), dissipates relatively less energy compared to aluminium.

b. Nichrome Coil:

Nichrome wire will be used as a **heating element**. Resistance of nichrome wire almost remains constant with temperature. Therefore, steady state temperature is entirely dependent on current through the wire.
T directly proportional to I^2 RMS or V^2 RMS.
Ref - http://www.brysonics.com/heating-a-nichrome-wire-with-math/

c. Pt100 temperature sensor:

IT can measure temperature from -200 to 420-degree C. At 0°C, the sensor has a resistance of 100 Ohm and resistance increases as the temperature increases. The sensor has a response time of 1ms. The sensor has an accuracy of around 0.385 Ohm/°C.



d. TFT screen

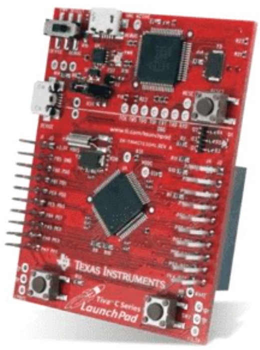
We will use the **1.8 inch TFT LCD to display** the current temperature, time and other important parameters on the screen. 1.8 Inch TFT LCD Module display uses 4-wire SPI to communicate and has its own pixel-addressable frame buffer, it can be used with every kind of microcontroller. We can use it with 3.3V(in our case) or 5V power and logic.

e. ESP01

The ESP01 is a small, low-cost, and easy-to-use microcontroller board that includes built-in WiFi connectivity. We will be using this microcontroller to host a website and control the reflow oven remotely.

f. TM4C123GH6PM TIva C board

We will be using TM4C123GH6PM Tiva C board as a microcontroller. The board includes a range of peripherals, including UART, I2C, SPI, PWM, 12-bit ADC. The board meets all the feature needed for the project. It will be coded with C programming language.



g. Cooling Fan:

We will be using an **8025 5V cooling fan** for cooling mechanism of reflow oven. We are using 80 x 80 x 25 mm casing Frame size of fan which fit comfortably inside the oven.

h. Power supply

We have used SMPS, 12V 10A for supplying power. It provides enough current current to drive our circuit.

i. **LM2596**

We wil be using LM7805 linear **voltage regulator** to convert 12 V (from 12 V adapter) to 5V DC.

j. Push Button:

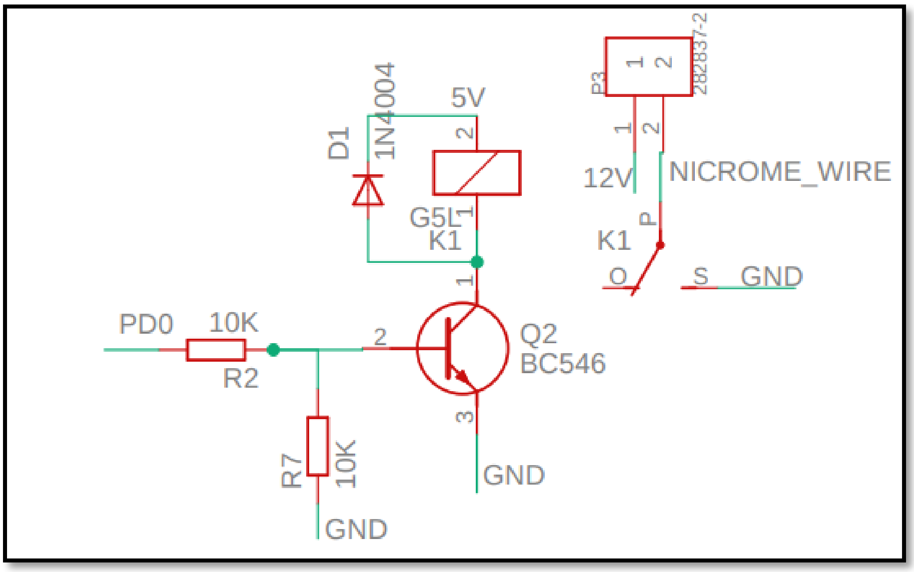
We will be using push button to near LCD mounted on the casing. We will use 4 push button to these 4 features: mode select, resume, pause and reset.

k. Mica sheet

Mica sheet was easily available and suitable for insulating the copper plate and nichrome coil.

l. Relay

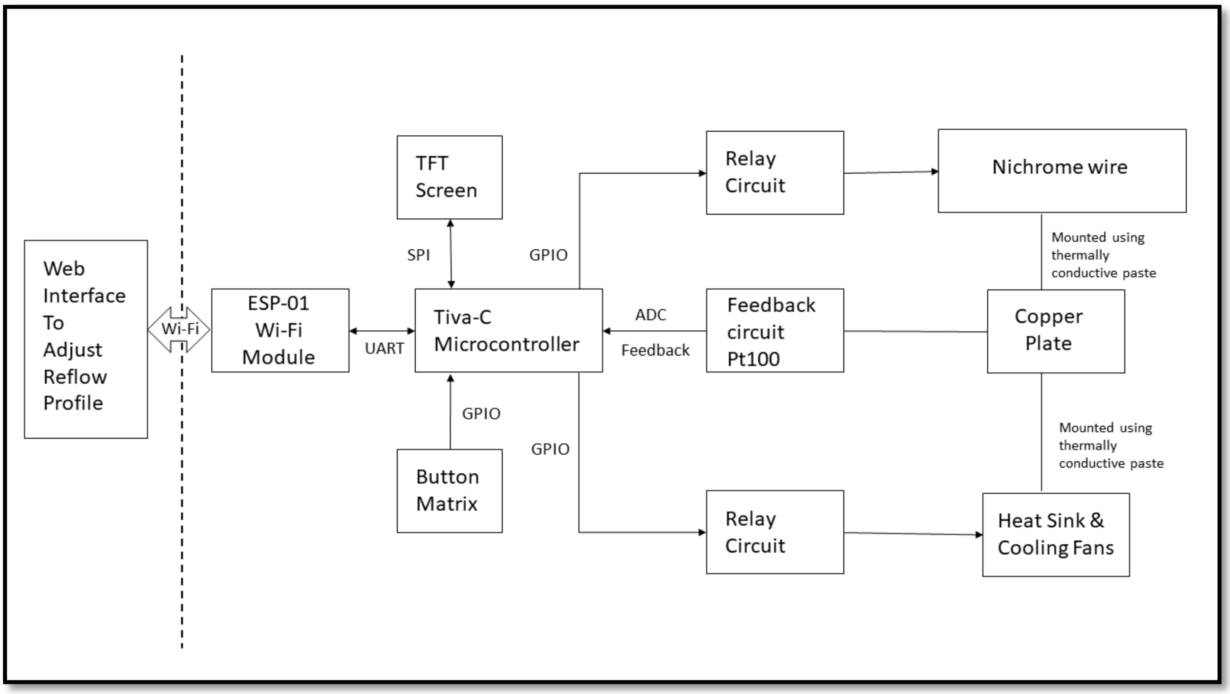
Instead of using IRF3205 power mosfet and 2N2222 for controlling the nichrome coil, relay and related circuits are used which include BC547 NPN BJT and diode 1n4001 (both available in WEL). The circuit diagram is attached. A similar circuit is used for controlling cooling fan.



m. Propeller fan

8520 Magnetic Micro Coreless Motor for Micro Quadcopters along with propeller is used to cool the copper plate. The cooling fan earlier used was not efficient for faster cooling.

8. Principle of operation for each subsystem:



Project consists of following sub-systems:

a. Heating Circuit
b. Cooling Circuit
c. Feedback Circuit
d. Web interface
e. User Interface

a. Heating Circuit:

- Copper Plate of dimensions 100x100x2mm is used as heating surface.
- Nichrome wire will be used as heating element to heat up to desired temperature. It will be power up by the 12 V DC supply.
- Relay circuit is to be used to control power to Nichrome wire using GPIO of microcontroller.

b. Cooling Circuit:

Air Cooling: In order to have an efficient cooling effect 8520 motor is used as cooling fan to transfer heat out of enclosure.

c. Feedback Circuit:

Pt100 temperature sensor along with voltage divider circuit is used as feedback.

d. Web-interface:

We aim to build a web-interface for configuration of reflow profile and to update collected data to user desktop/laptop. To achieve this ESP01 Micro -controller is used.

e. User Interface:

- 1.8’ ST7735 TFT Screen: Screen communicates to Micro-controller using SPI communication and provides user with useful data.
- Button Matrix: Used to take inputs from user to select reflow profile, start/stop process, and other basic utilities.

9. Method - Heating element setup:

Copper plate is being used as heating surface. For heating element 22 AWG Nichrome wire (not insulated) is used. There is need to add an electrically insulating layer between copper plate and nichrome wire. For electrical insulation Mica sheet is used between Nichrome wire and copper plate.

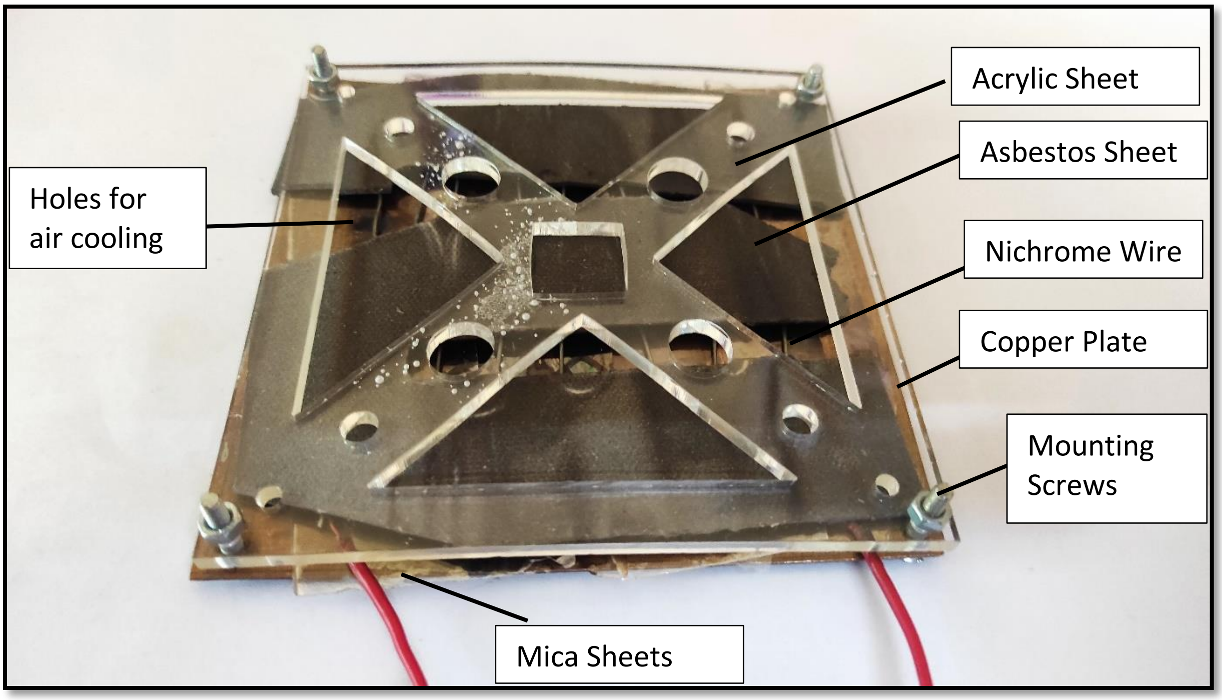
For maximum efficiency, full length of Nichrome wire needs to be in strong contact with Mica sheets. Hence entire assembly is as follows:

a. Copper Plate
b. Mica Sheet
c. Nichrome Wire
d. Asbestos sheet for thermal insulation/buffer
e. Two Wooden plates

In absence of Asbestos sheet wooden plate is burnt by heat from nichrome wire which leads to smoke and burning smell.

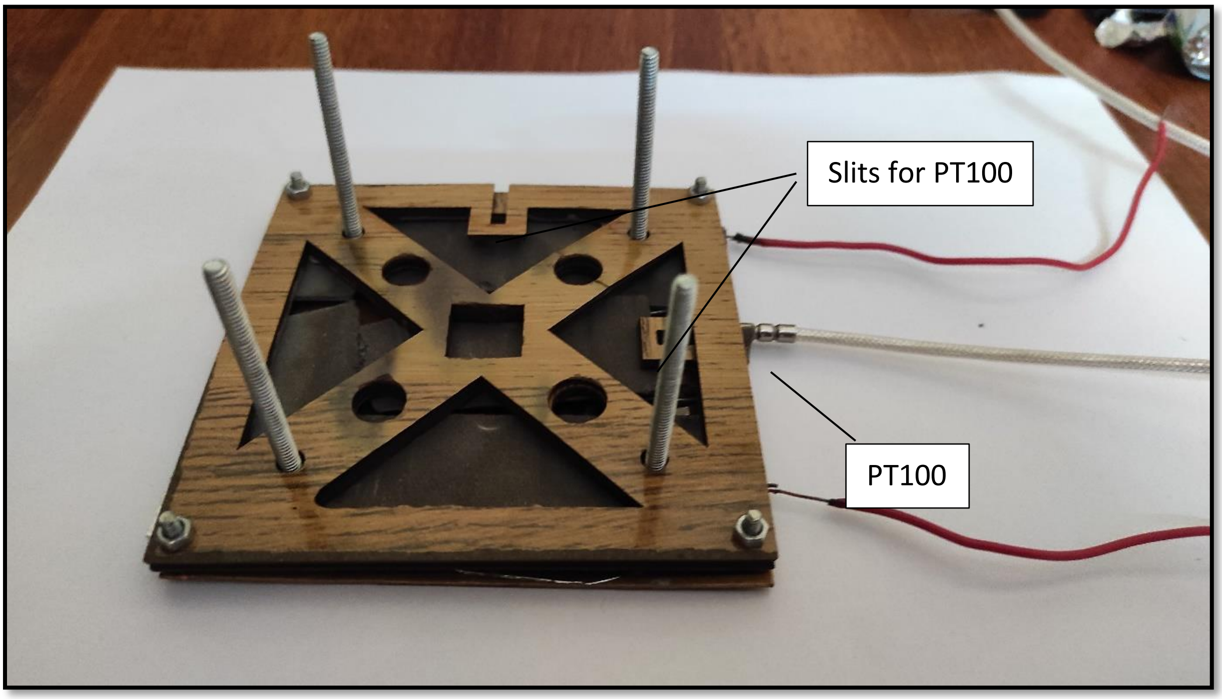
A small slit is made in top wooden sheet to hold PT100(Temperature Sensor) in contact with copper plate.

Four Screw-nuts hold the entire assembly together.



First Version of assembly. All layers as described can be clearly seen.

3mm Acrylic sheet was earlier used as last layer, considering temperature on other side of asbestos sheet does not exceed above 150°C, which is below melting point of acrylic(160°C). However, at much lower temperatures Acrylic sheet begins to lose structural integrity and starts deforming.



Final Assembly with wooden plates

Long Screws are used to attach this heating subsystem to 3D printed PLA enclosure. These also create a temperature gradient such that PLA does not melt where screws are attached.

Technical Specifications of parts:

1mm thick Copper Plate – 105x105 mm.
22 AWG Nichrome wire with 3Ω resistance.
2mm Asbestos sheet.
Two 2mm 105x105mm wood sheets.
5mm Screws to create temperature gradient.

10. Method - ESP-01 Wi-Fi Module Setup:

Wi-Fi Module procured from WEL is ESP-01 module with ESP8266EX micro-controller. It comes with pre-loaded firmware which accepts AT commands through UART.

To create wireless interface to add custom reflow profiles and load in Tiva-C micro-controller.
To achieve this, create a web-server on ESP-01 and host a local website through which user can set custom user profile.

To use this module, it can be interfaced with Tiva-C using UART and AT commands can be used to interact with Wi-Fi module. However, this is inefficient architecture as it creates additional load on Tiva-C micro-controller, takes up storage space of Tiva-C and large amount of data is transferred over UART.

Instead, we can use ESP-01 on-board flash to store program and use computing capabilities of ESP8266EX MCU to share computing load on Tiva-C.

Steps:

1. Download and set-up ESP8266 RTOS SDK with Msys32 from Espressif website. ([Documentation])

2. Run mingw32.exe and run these commands before every use.

```
PATH="${HOME}/xtensa-lx106-elf/bin:${PATH}"
export IDF_PATH=~/esp/ESP8266_RTOS_SDK
```

3. Use template code from (SDK_PATH)/examples/protocols/http_server/simple and modify it according to needs.

4. Create suitable webpage HTML and JavaScript files and add them as EMBED files. For this, save html and JavaScript files in main directory and add following lines in CMakeLists.txt and component.mk.

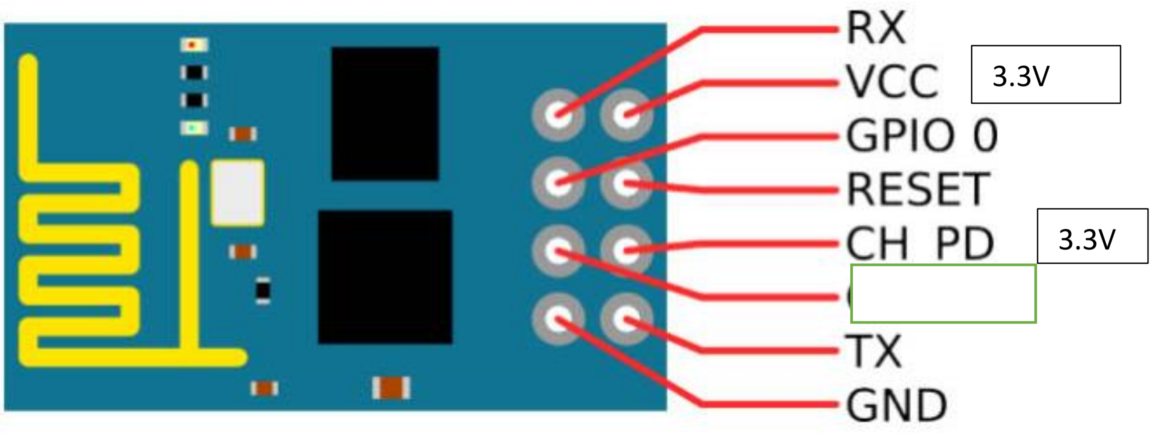
CMakeLists.txt =>

```
register_component(EMBED_FILES
upoad_script.html")
```

component.mk =>

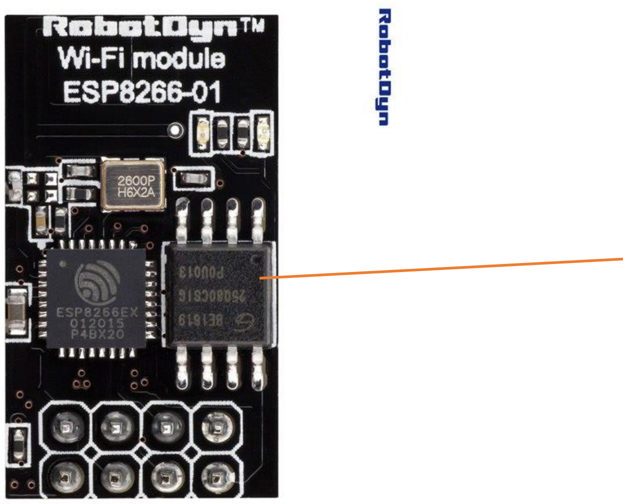
```
COMPONENT_EMBED_FILES += upload_script.html
```

5. Referring to example provided create suitable URI and use HTTP GET to get data from browser.
6. Use a USB-UART converter and use the following schematic.



7. Use menuconfig to set upload port as mentioned in documentation in Step 1 and flash custom firmware.
8. While flashing connect GND to GPIO 0 to put the module in boot mode. Later connect RESET pin to GND for a second and release to activate the normal configuration.
9. Connect the ESP-01 module to Tiva-C through UART and read data as collected through web-interface.

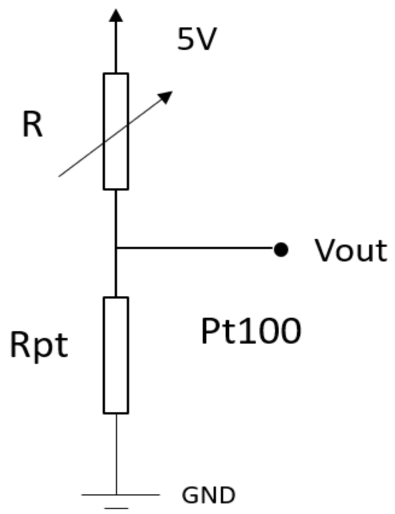
Before executing Step 6, check the flash usage. We have upgraded the default flash of 1 MB in ESP-01 to 4 MB.



Upgrade this flash to 4 MB to store html and JavaScript files.
(Plotly JavaScript Library as described later can also be stored in the flash)

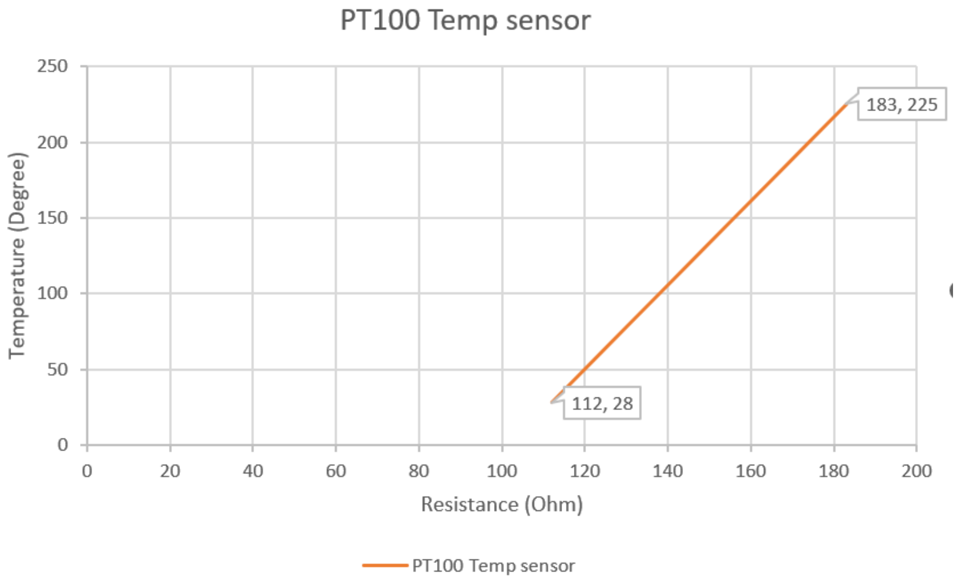
11. Method - Feedback circuit:

Pt100 RTD temperature sensor is used to take temperature reading of the hot copper plate. Pt100 changes its resistance values nearly in linear proportion with the temperature. Temperature reading is used to switch on/off relay circuit which further switched on/off current going through nichrome coil and fan.



$$Vout = \frac{5*Rpt}{R + Rpt}$$

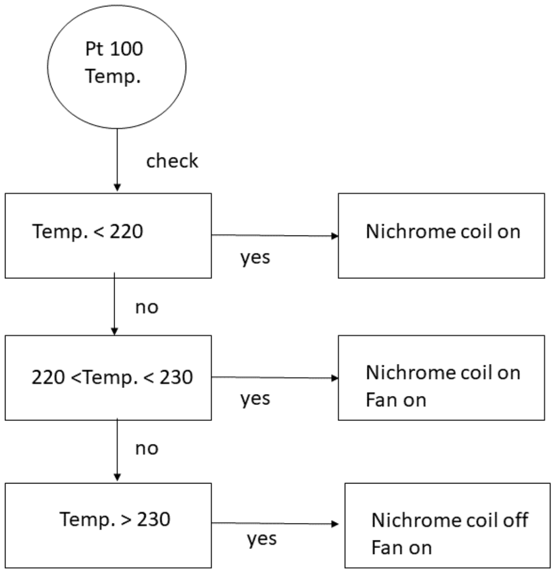
Pt100 temperature sensor is put in a voltage divider circuit with another resistor Rs as shown in the figure. We have used potentiometer in instead of constant Rs, with a value of 120 Ohm. Output of this circuit (V_{out}) is an input to Micro-controller through an in-built 12-bit Analog-to-Digital converter (ADC). Resistance of the Pt100 is calculated from the V_{out} with the formula shown in figure. We found that temperature of the Pt100 varies linearly with its resistance value as shown:



(Note: Feedback circuit in the prototype is not on PCB because the routes had lot of noise as it was incorrectly placed near 6A routes.)

12. Method - Cooling Circuit:

8520 Magnetic Micro Coreless Motor for Micro Quadcopters along with propeller is used as a cooling mechanism. Both nichrome coil and fan is controlled with relay circuit. If the temperature is below 220 degree C, we keep the fan switched off and nichrome coil is switched on. If the temperature is between 220-2330 degree C, we start the cooling fan with nichrome coil switched on. If the temperature is above 2330 degree C, fan is switched on and nichrome coil is switched off.

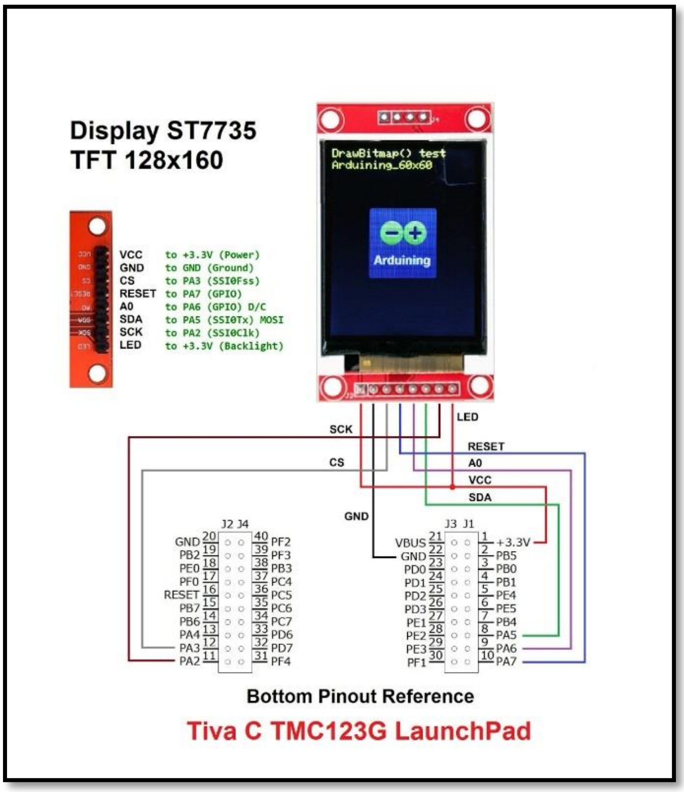


13. Method - User Interface

1.8’ ST7735 TFT Screen is used to show useful data such as current temperature, time elapsed, resistance value of pt100, current status of nichrome coil, percentage of completion of reflow process. TFT screen communicates to micro-controller using SPI communication.

Test setup and method:

1. TFT screen is interfaced using SPI communication as shown.



- MOSI(Master Output Slave Input): (PIN SDA) Used by Tiva C to send the data TFT screen.
- SCK(Serial Clock): (PIN SCK) Used to synchronous the transfer of data between the Tiva C and screen. The clock is generated by the Tiva C.
- SS(Slave select): (PIN CS) Used to select the slave device with which Tiva C wants to communicate.
- RESET: Used to reset the TFT screen.
- LED: This is the backlight pin, which is used to control the brightness of the screen backlight.
- A0(D/C): This is the data/command pin, which is used to differentiate between data and command signals.

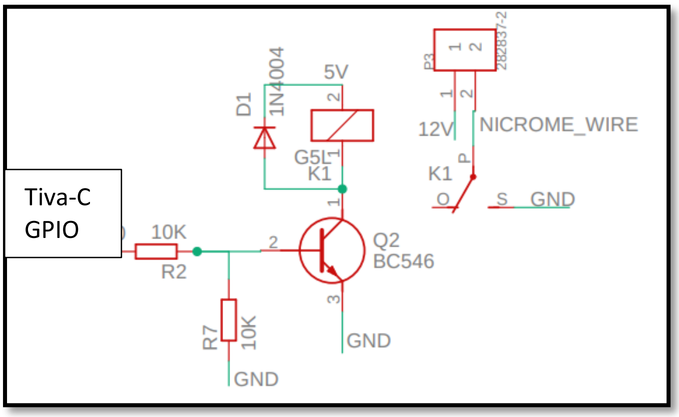
14. Method - Integrated Setup:

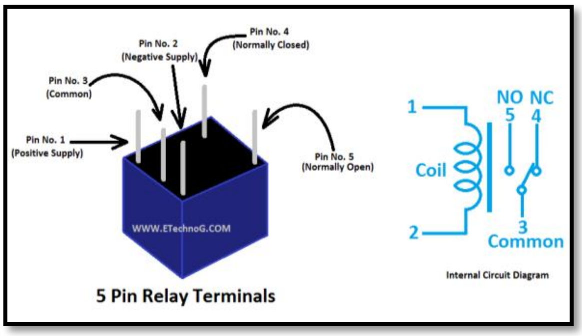
In this part, we integrated all subsystems.

Tiva-C MCU was programmed accordingly and it was controlling the temperature of Copper plate while displaying technical details on screen.

a. Heating element:

Connected using relay circuit as mentioned. Circuit was designed using NPN transistor (BC547), diode(1N4001) and a (5V, 5 pin) relay.





b. Feedback Circuit:

In the assembly of heating element Pt100 was placed which acted as feedback to micro-controller through a resistor voltage divider circuit.

A potentiometer was connected in series with PT100 to have control over the sensitivity of the voltage. Default value of potentiometer =120 Ω.

(Rest structure and figures are not specified as it is same as described in respective experiment section.)

c. User Interface:

Display was used to show relevant data on screen.

(Rest structure and figures are not specified as it is same as described in respective experiment section.)

d. ESP-01 Wi-Fi Module:

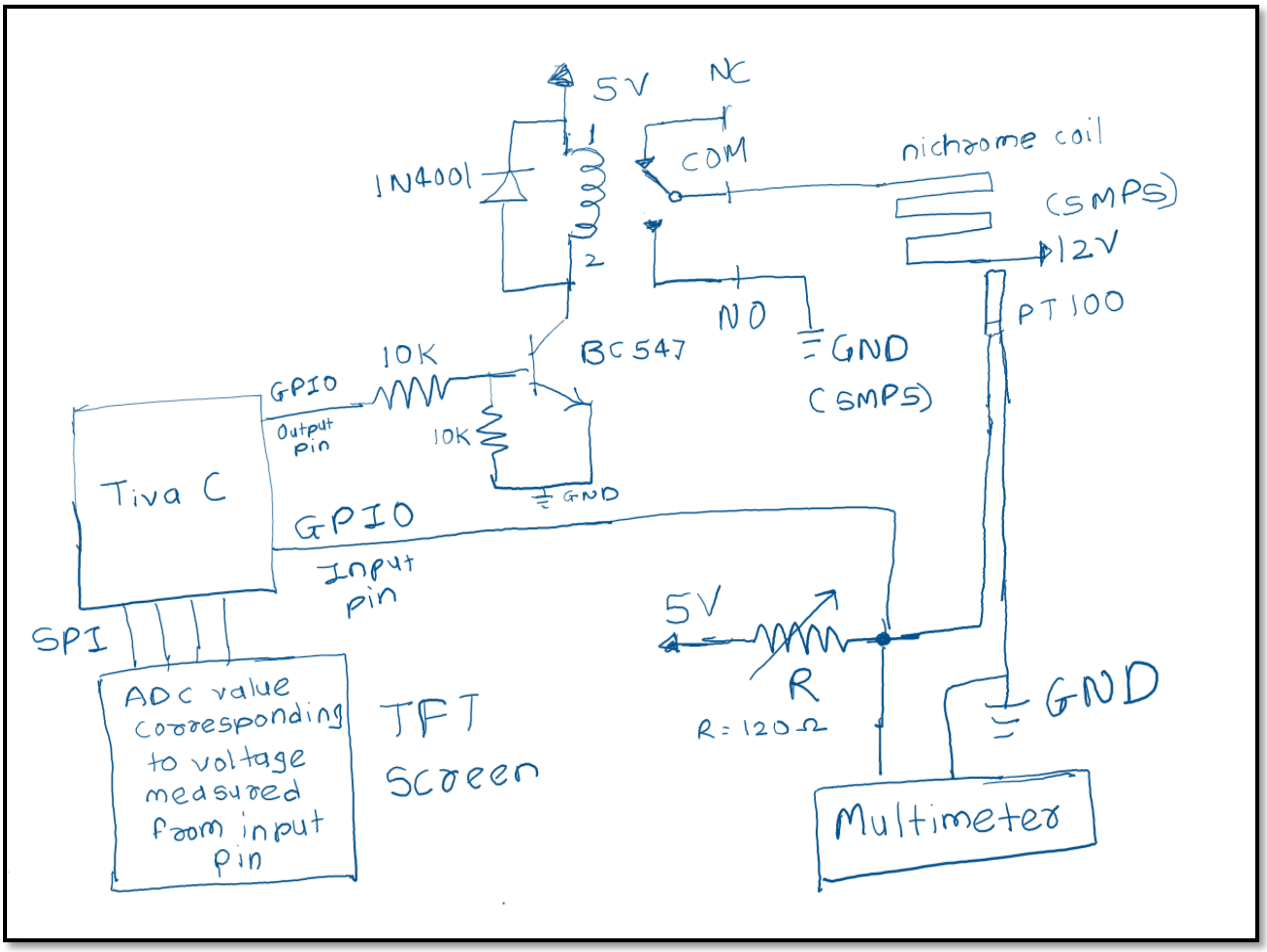
Wi-Fi Module was set up as described earlier.

It is connected using UART to Tiva-C. ESP-01 sends corner points of reflow curve. Arrays are generated in Tiva-C after data is received from ESP-01.

Currently ESP-01 connects to Wi-Fi with SSID: hhhhh, password: mypassword. Fing application(Android) can be used to find the local IP address where the webpage is hosted.

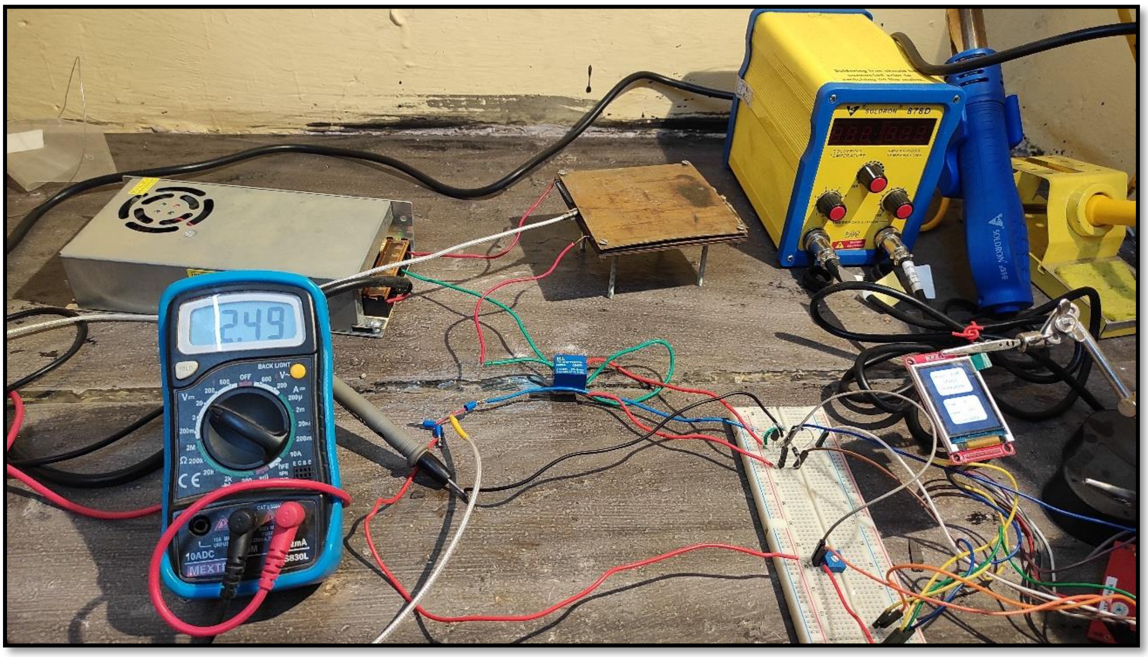
e. Cooling Circuit:

Small drone propeller motor was mounted below Heating element and controlled in similar way as nichrome coil.



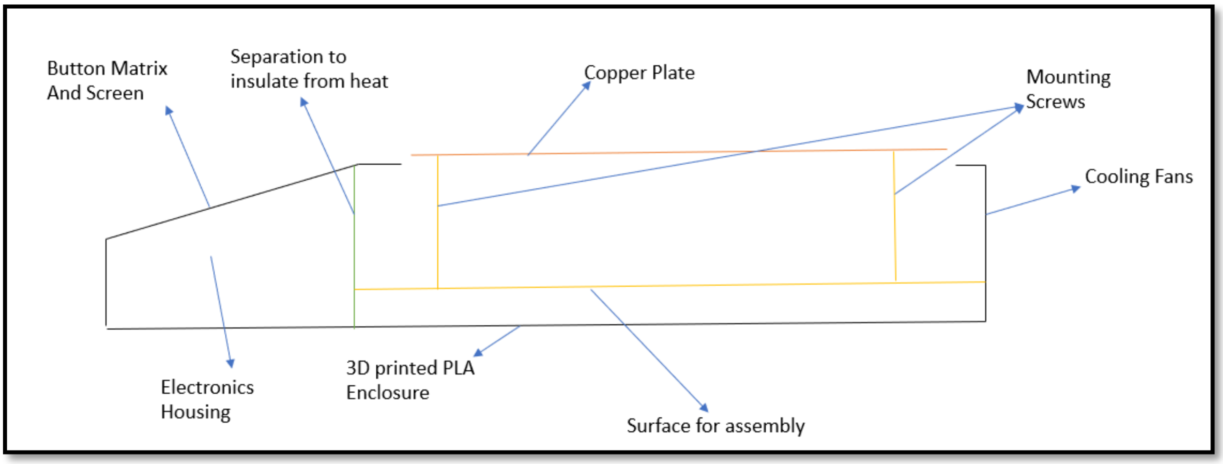
Integrated test setup figure

Integrated testing;



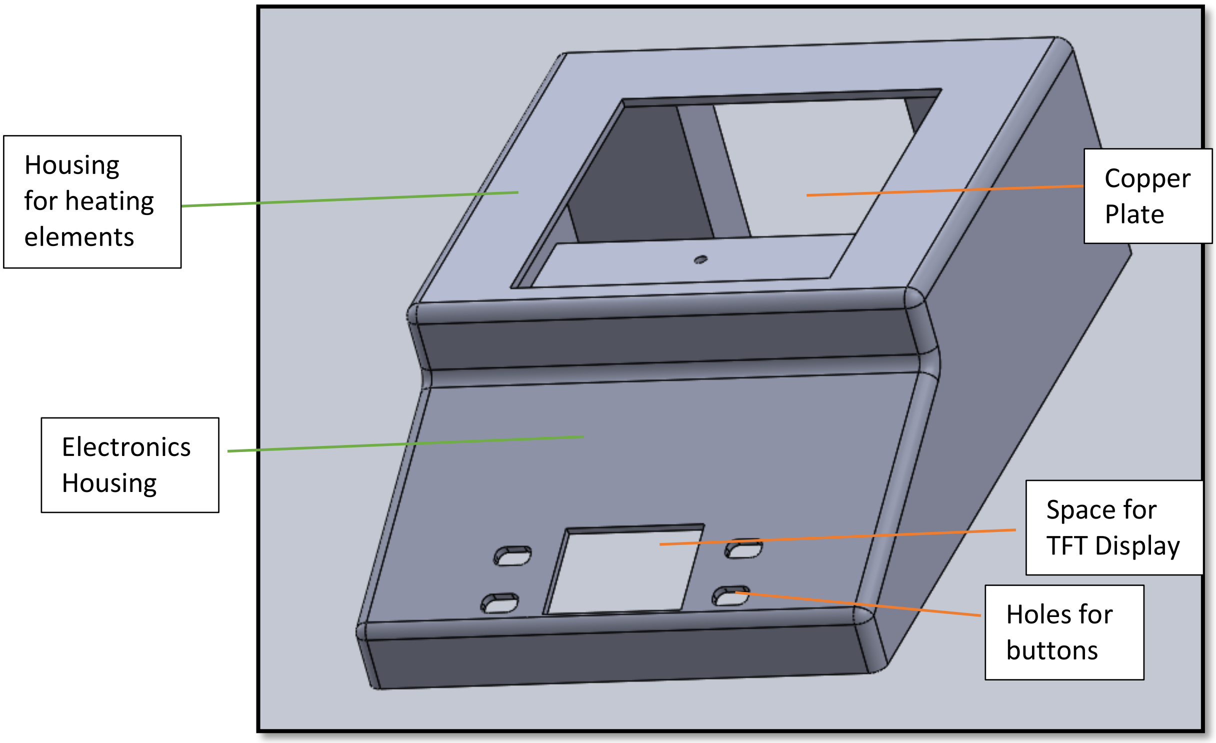
15. 3D model for enclosure:

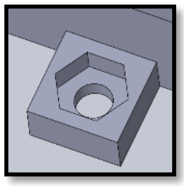
Enclosure will be 3D printed using PLA material.
No hot surfaces will be in contact with PLA according to following design. Separate.
As confirmed from previous experiments temperature at end points of mounting screws is sufficiently lower such that it won't melt PLA.

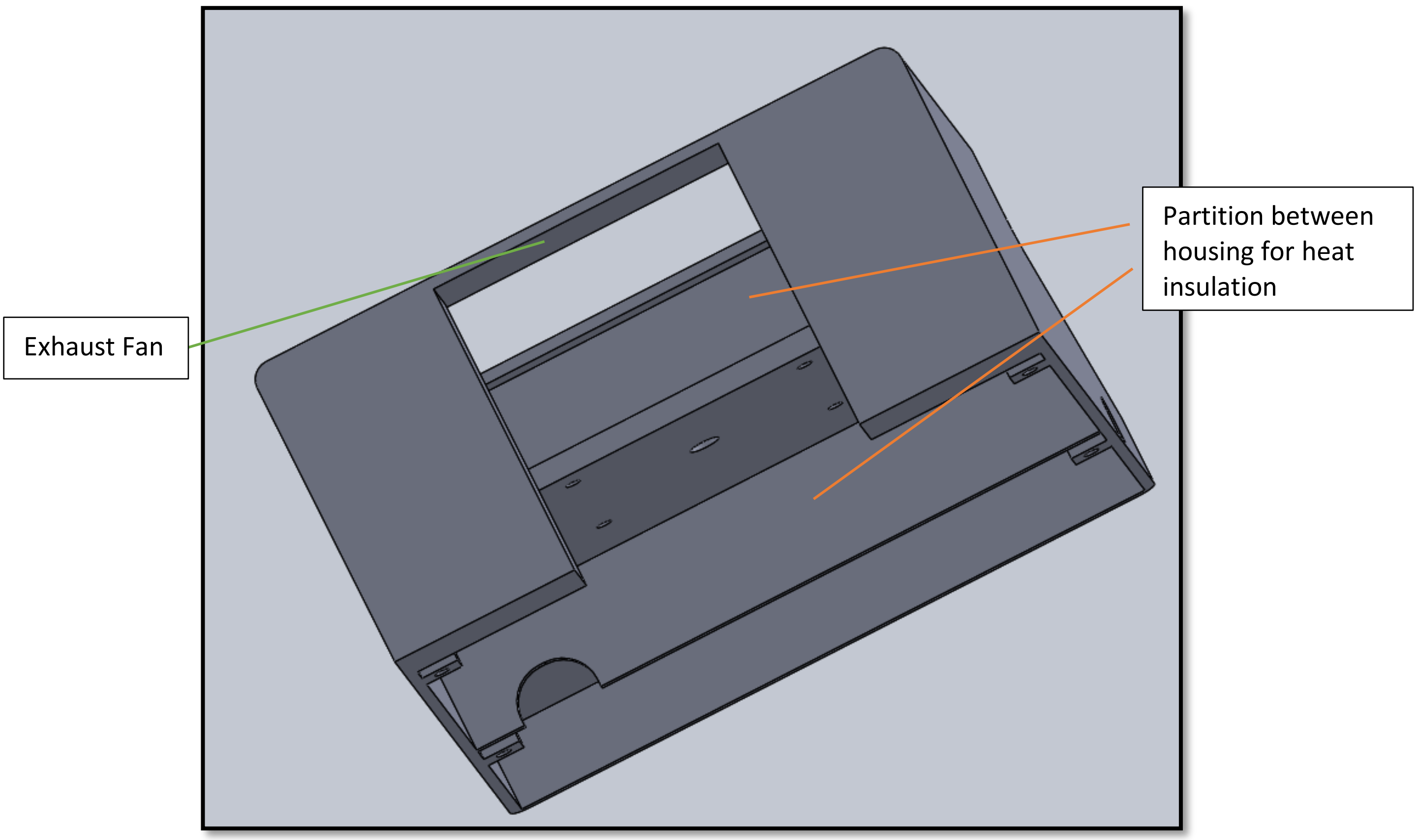


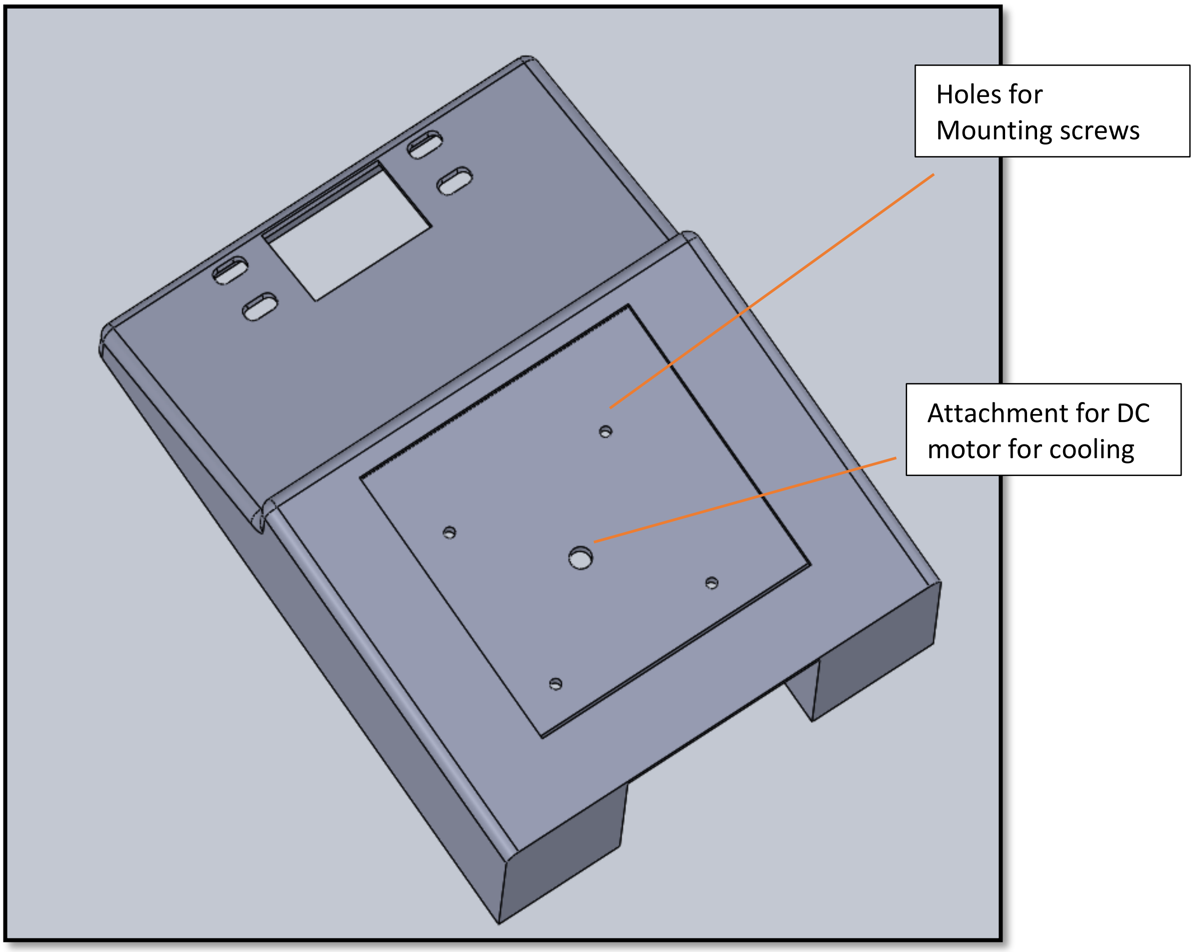
3D model designed in Solid works is as follows:

CAD:


Housing
for heating
elements
Copper
Plate
Electronics
Housing
Space for
TFT Display
Holes for
buttons

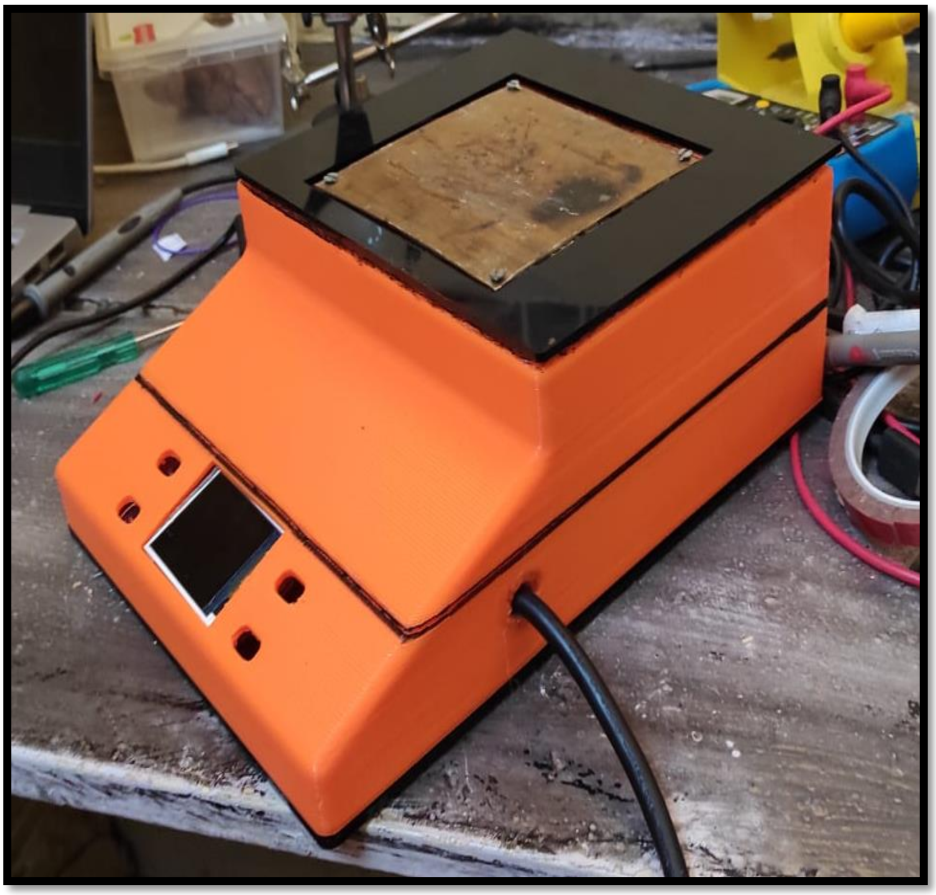



Exhaust Fan
Partition between
housing for heat
insulation

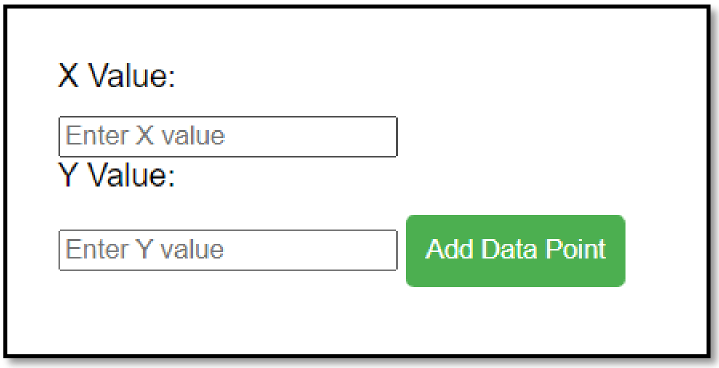

Holes for
Mounting screws
Attachment for DC
motor for cooling

16. Result and Observation

Final Prototype:



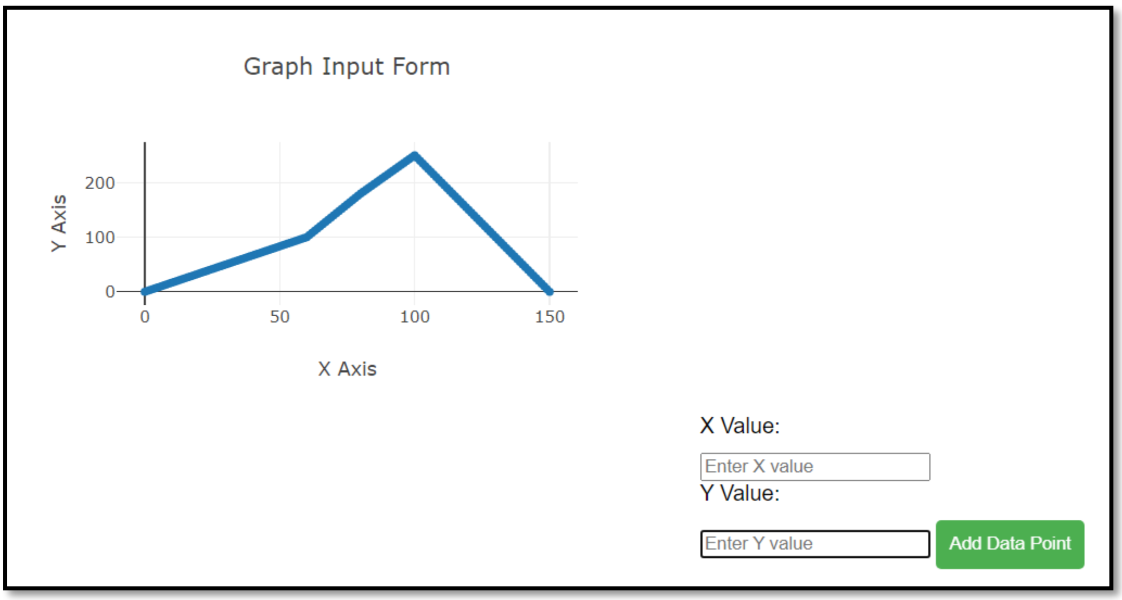
Webpage we created:



This is a simple webpage created by us to get data from browser. URI for the specific webpage is "/get_data".

X represents time in seconds and Y represents Temperature at that time according to reflow profile.

In the "/preview" URI, user can add multiple points using similar form and the webpage uses linear interpolation to fill in the rest data points. Example, if (0,0) and (5,5) is given using html form, the preview will be shown as [(0,0), (1,1), (2,2), (3,3), (4,4), (5,5)].



Example of reflow profile generated using "/preview" URI

As included in figures, webpage generates required reflow profile and it can be obtained in ESP-01 as array.

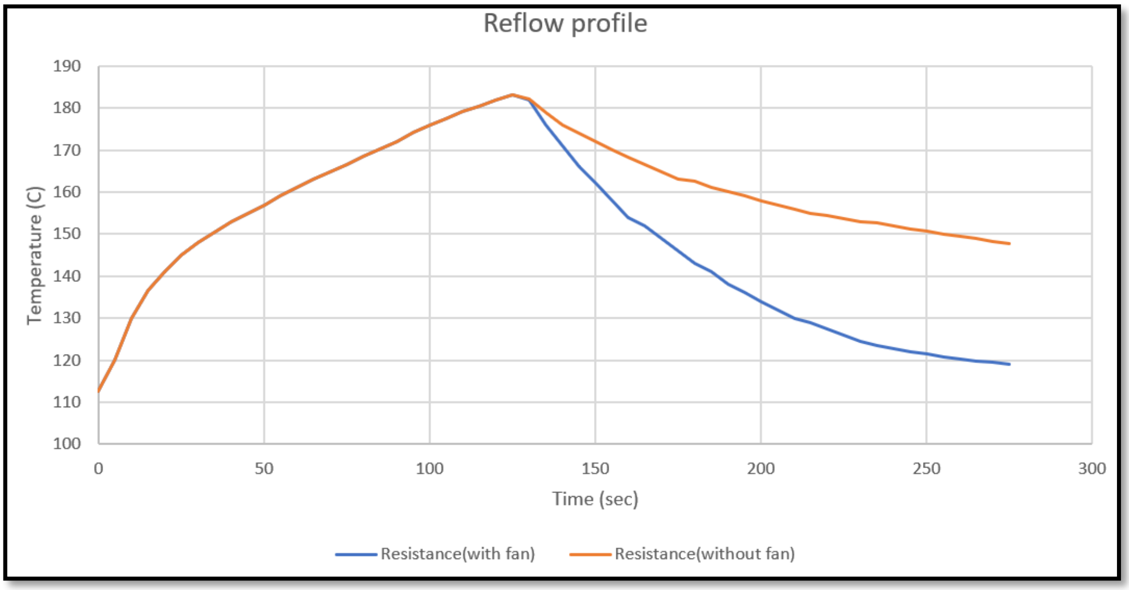
Integrated circuit testing:

The pin output was high(nichrome coil on) till the ADC value 3500 which corresponds to 2.84V in multimeter(across pt100) where soldering wire melts on the copper plate. The output was triggered to low when the feedback sensor (temperature sensor) output reaches 3500 i.e., 2.84V.

The feedback input was also displayed on the TFT screen. The value ptvolt is relevant for the testing it shows the ADC value of the voltage across Pt100.

The voltage drop across the Pt100 was stuck at 1.1V when relay transitions to on due to the inductive nature of relay coil. (Somehow it was affecting other circuits.) We added a 10μF capacitor in parallel with the relay coil to provide sudden current requirement.

We obtained the following reflow profile of temperature from two experiments:
1. With cooling mechanism (Fan is switched on, after temperature of the copper plate reaches desired value.
2. Without cooling mechanism (Fan is switched off for the entire time of experiment)



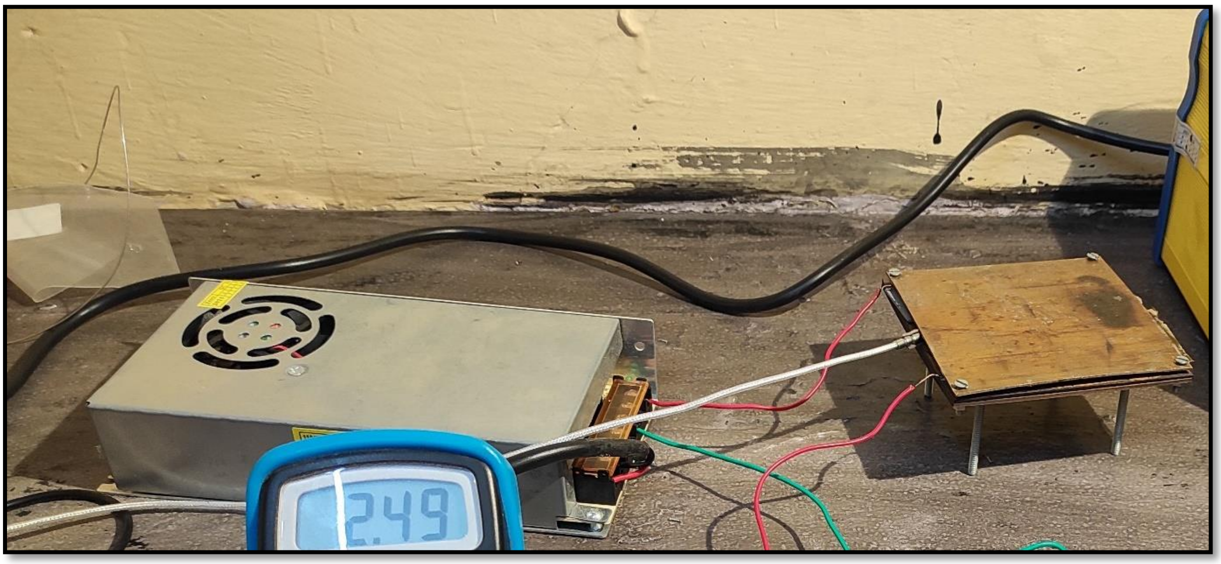
With the voltage divider circuit, we are able to control the temperature of the copper plate. Pt100 has sufficient precision to control the temperature required in this project.

With the above above-mentioned assembly connected to 15V voltage source (SMPS). PT100 is used to measure copper plate temperature.

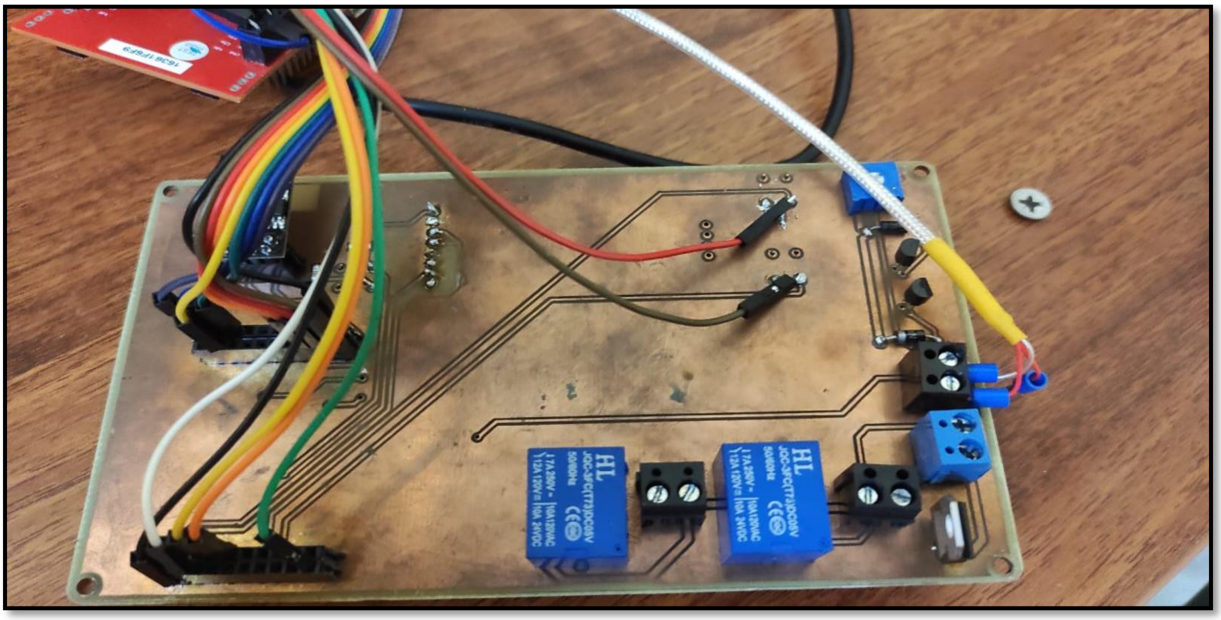
a. Current Drawn = 4.8 A
b. Time Taken for temperature to rise 250°C = 130 seconds
c. For temperatures above 280°C, wooden sheet starts burning as asbestos sheet is unable to create enough temperature gradient.

d. Long Screws create sufficient temperature gradient such that other end can be mounted on PLA enclosure.

Heating element successfully reaches sufficient temperatures fast enough to follow standard reflow profile and melts Solder wire.



PCB that we designed:



17. Conclusion:

10cm X 10cm Soldering hot plate was built. We demonstrated soldering and de-soldering of component on ESP01 board. We have successfully developed local web-interface using ESP-01 Wi-Fi module. All the components were housed in an enclosure. All objectives mentioned in the problem statement were completed.

18. Future work:

1. User Interface:
   Screen-touch TFT screen can be used, which will make our model more interactive. Push-buttons can be avoided with touch-screen.

2. Heating Element:
   Area where nichrome wire is connected to copper wire gets oxidized after 10 cycles. Thicker copper wires need to used.
   Wooden sheets can be replaced with CNC machined steel plates with proper electrical insulation which will eliminate the wood burning and smoke problem.

3. Web interface:
   Style of web-page can be improved.
   Note: Current code uses Plotly CDN from this link for plotting graph. A lite version of this CDN can be implemented so that no Internet connection is required to run the Web Interface. After this ESP-01 Wi-Fi mode can be changed from Station (STA) to Access Point (AP).

4. PCB:
   Some of the PCB routes are not connected. Communication between ESP01 and Tiva C is not working because of that. At some points top and bottom layers of the PCB are not connected, eg. Connectors. So, we have used jumper wires at these points. PCB cab be manufactured from industrial PCB manufacturer to make PCB more robust.

5. Controlling over WiFi:
   Using the web interface through ESP01, TIva C will get an array of the format [time: temperature].
   [time: temperature] - time is in seconds and temperature in C.
   This part has several bugs, which we could not resolve within given time frame.

19. Link to demo videos:

All the essential files/videos are in this folder:
https://drive.google.com/drive/folders/1hkzOSJ5yrxFGMIBhelCKWo8H-GT9ofpd?usp=sharing

20. Bill of Material or BOM:

Index	Component	Price
1	SMPS 12V 10A	Rs. 885
2	Buck Convertor	Rs. 70
3	ESP01	Rs. 120
4	Tiva C	Rs. 4700
5	ST7735 1.8-inch screen	Rs. 600
6	BC547 (x2)	Rs. 4
7	1N4007 Diode (x2)	Rs. 4
8	Relay (220V 10A/5V DC) (x2)	Rs 40
9	PT100 Temperature sensor	Rs. 140
10	Nichrome wire 22 AWG	Rs. 20
11	Copper plate	Rs. 360
12	Cooling fan	Rs. 66
13	Mica sheet	Rs. 35
14	Asbestos sheet	Rs. 35
15	Wooden sheet	Rs. 50
16	Screw terminal block connector (x4)	Rs. 60
17	Push button (x4)	Rs. 40
18	Small drone motor with propellor	Rs. 100
19	Mounting Screws	Rs. 50
20	PLA filament	Rs. 100
21	Resistors, capacitors	Rs. 50

22	Jumper Wires	Rs. 50
23	Potentiometer	Rs. 10
	Total	~ Rs. 7600