EE344 : Final Report

Reflow Oven for Soldering SMD Components

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Contents

1 Introduction

A printed circuit board (PCB) is an electronic assembly used to create electrical connections between components. A surface-mount device (SMD) is an electronic device for which the components are mounted or placed directly onto the surface of the PCB. Reflow soldering is the process in which a solder paste is used to temporarily attach the SMD components to their contact pads, after which the entire assembly is subjected to controlled heat. The goal of the reflow process is for the solder paste to reach the desired temperature at which the particular solder alloy undergoes a phase change to a liquid or molten state, creating permanent solder joints.The aim of this project is to design and implement a reflow oven, which is a machine used for reflow soldering of SMD components to PCBs. It should be able to follow custom reflow profiles recommended by different manufacturers.The product designed by us would be much more economical than the commercially available products in the market. The package will have a 10cm $\times$ 10cm work station, where a PCB board can be placed for soldering SMD components.

2 Aim of the project

1. To design and implement a reflow oven, which is a machine used for reflow soldering of surface mount device (SMD) components to printed circuit boards (PCBs).

2. To design the PCB that will host the circuitry of the device, including power supply, a temperature sensor, switches, a micro-controller, indicators, a liquid crystal display (LCD) device, a cooling fan, a solid state relay (SSR) device, etc.

3. To program the micro-controller to turn off the heating element and indicators and to turn on the cooling fan when the hot plate has reached certain temperatures, after taking input from a temperature sensor.

4. To design the external packaging using computer aided design (CAD) and to use 3D printing techniques to build the completed package, which will have a 10cm $\times$ 10cm workstation, where a PCB board can be placed for soldering SMD components.

5. To make a product that would be much more economical than the commercially available products in the market. It should be able to follow custom reflow profiles recommended by different manufacturers.

3 Design Details

3.1 Subsystem setup

3.1.1 Electrical subsystem

Layout:

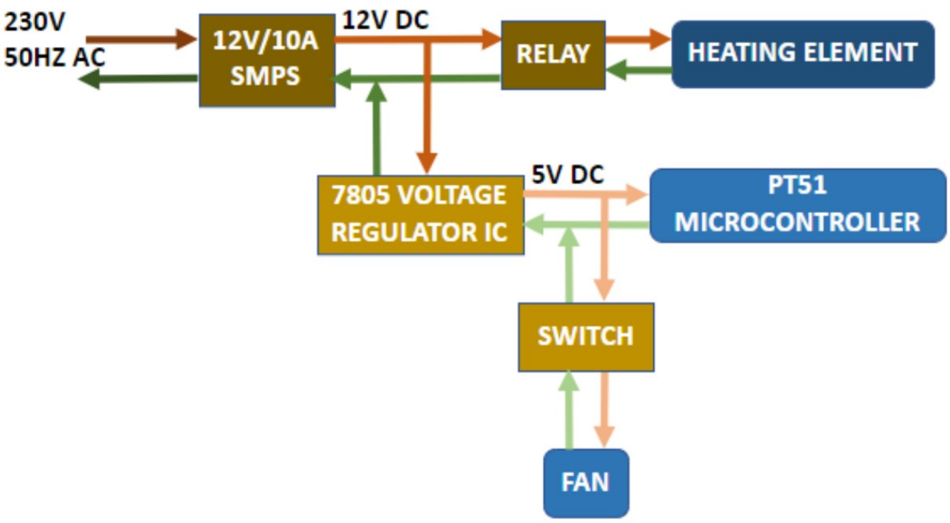


Figure 1: The Layout of the electrical subsystem

Components:

Component	Specifications
SMPS	230VAC, Output - 12V, 10A
Voltage Regulator	IC 7805
Micro-controller	Pt51
Switching Devices	Relay switch, MOSFETs(BS170)
Heating Element	Nichrome wire, 23 Gauge
Cooling Fans	5VDC, 0.2A, 2000RPM

Principle of operation:

The Switched-mode power supply (SMPS) connected to the wall socket (230VAC), draws a current of 10A at a potential of 12V. This is connected to the nichrome wire through a relay switch which takes input from the micro-controller. The switch allows passing of the current to the heating material when an input voltage (>3V) is applied from the micro-controller's port. A voltage regulator(LM7805) is connected to the 12V DC line and this outputs 5V, 1A to be used by the micro-controller, cooling fans, and indicators.

3.1.2 Mechanical subsystem

Layout:

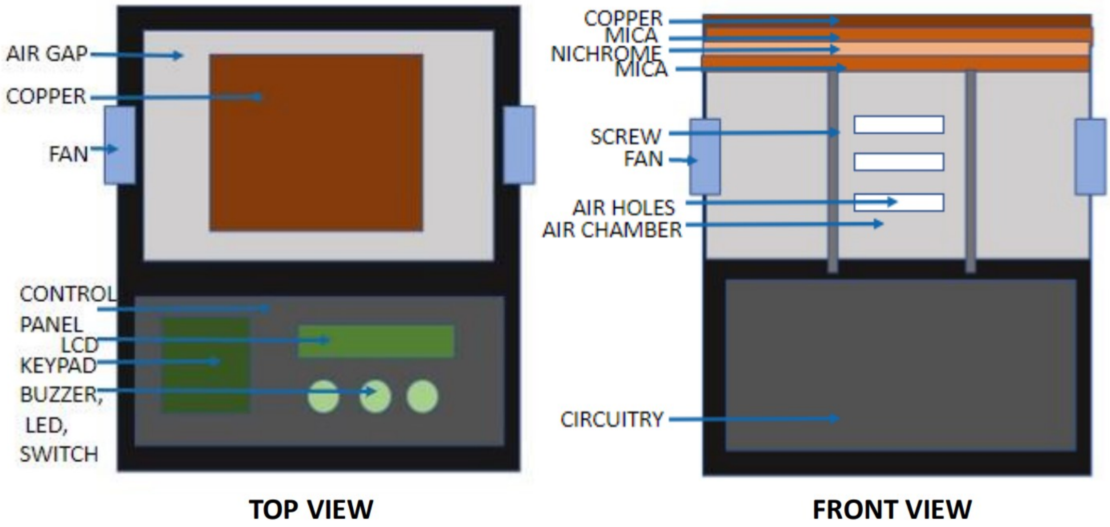


Figure 2: The Layout of the mechanical subsystem

Components:

Component	Specifications
Thermal Sensor	Pt100 (Thermistor)
Heating Element	Nichrome wire, 23 Gauge
Cooling Fans	5VDC, 0.2A, 2000RPM
Cooling Chamber	Air Chamber with slits
Electrical Insulation	Mica Sheets
Packaging	Lazer cut acrylic and wood
Heating Plate	Copper Plate 100x100x1 mm^3

Principle of operation:

The heating material, nichrome wire, cannot directly touch the copper plate as this will result in shorting of the wire and the current will start flowing through the plate as well. To overcome this, the nichrome wire is sandwiched between two mica sheets as mica is an excellent conductor of heat but an electrical insulator. So, the final heating module consists of the metal plate touching mica. The total heat capacity of this heating module comes out to be $\approx$ 54J/K.

The heat sink is just below this heating module, this is the air chamber of the oven, there are two cooling fans that only turn on when the system needs to cool down from the peak value. The heating module is held onto the base of the air chamber with four long screws. There are wire connections connecting the mechanical to the electrical subsystems.

The packaging is made of lazer cut acryllic and wood sheets. Wood is used in places where hot metal comes close to or touches the casing.

3.1.3 Control subsystem

THE REFLOW PROCESS

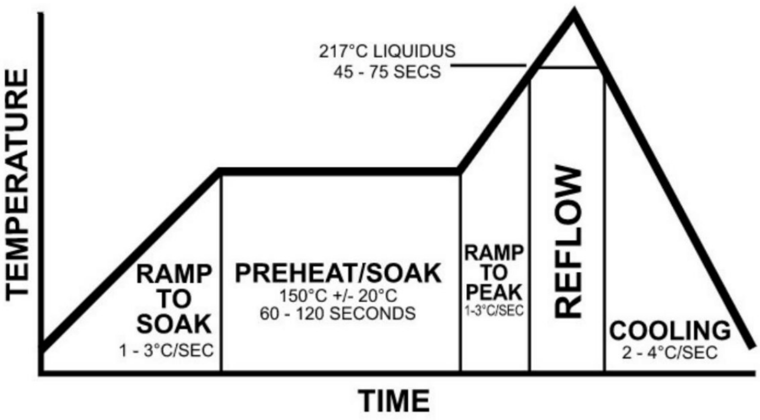


Figure 3: The temperature vs time curve of the reflow soldering process

The reflow soldering process has four main stages.

1. **The first heating stage** The temperature of the heating element rises steadily at the rate of 1-3 degrees Celcius per second until it reaches 150 degrees Celcius. In this stage, the current supply to the heating element is on and the fans are off.

2. **The soak stage** The temperature is maintained at 150 degrees Celcius for a period of 90 seconds by turning the supply to the heating element on and off. The fans remain off in this stage.

3. **The second heating stage** After the soak stage, the supply to the heating element turns on again and the temperature steadily rises at a rate of 1-3 degrees Celcius per second until it reaches the maximum temperature that had been set at the start of the process using a keypad.This maximum temperature is specific to the properties of the soldering paste that is being used and is specified on the container of the soldering paste.

4. **The cooling stage** Once the maximum temperature has been reached, the heating element turns off and the cooling fans turn on to cool the system quickly, at a rate of 2 to 4 degrees Celcius per second.

Control Flow:

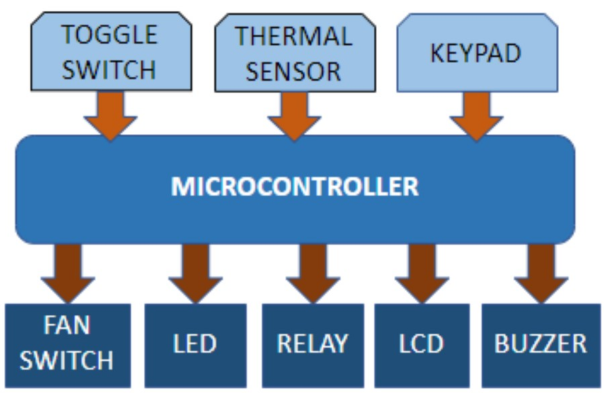


Figure 4: The control flow through the microcontroller

Components:

Component	Specifications
Micro-controller	Pt51
Thermal Sensor	Pt100 (Thermistor)
Switching Devices	Relay switch, MOSFETs(BS170), on-off switch, keypad
Indicators	LCD Display, LEDs, Buzzer
Heating Element	Nichrome wire, 23 Gauge
Cooling Fans	5VDC, 0.2A, 2000RPM
ADC	MCP 3008

Principle of operation:

The Pt100 resistor is connected to the nichrome wire using aluminum foil and will be heated by the wire. ADC MCP 3008 conveys the sensor data to the microcontroller digitally. The micro-controller calculates the temperature and decides the rate of heating to be implemented according to the stage of the reflow process. After the peak has been attained, the plate has to cool down with a rate of approximately 4°C/sec, this is where the cooling fans will be turned on by the MOSFETs(BS170) connected to the micro-controller.

The LCD module displays the current temperature and the stage of the reflow process the oven currently is operating in. LEDs and a buzzer are used for safety precautions, to warn users that the temperature of the plate is currently high. All of these tasks were implemented by the micro-controller. The peak temperature of the oven is set using the keypad.

PID control algorithm:

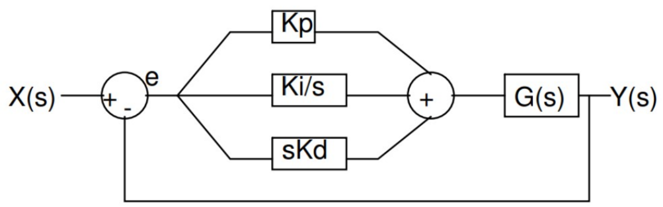


Figure 5: The PID control diagram

A proportional controller (Kp) will have the effect of reducing the rise time and will reduce ,but never eliminate, the steady-state error.An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot and settling time and improving the transient response

3.2 Overall Block Diagrams

Overall Layout:

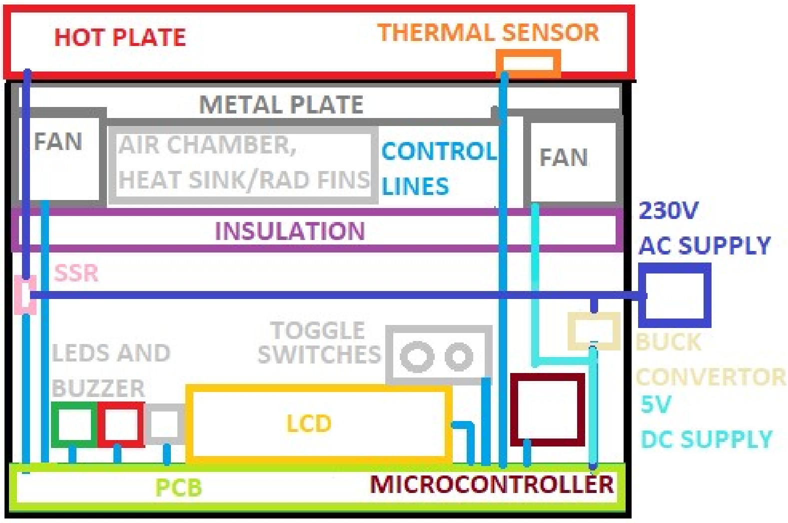


Figure 6: The overall layout of the Reflow oven

Interaction between subsystems:

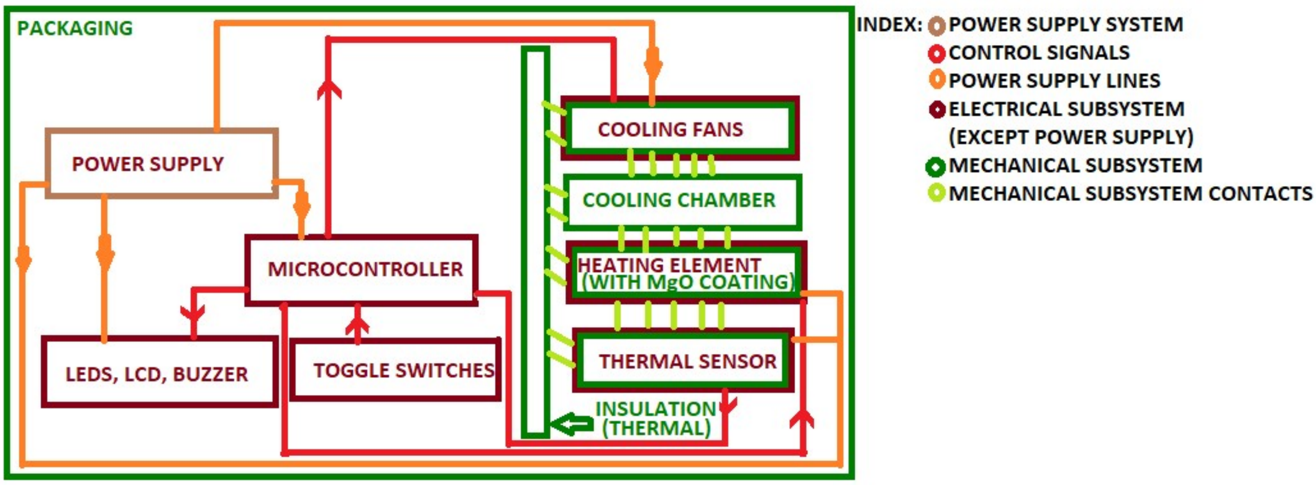


Figure 7: The placement of different subsystems

The subsystems are thermally isolated from each other as the operating temperature of the electrical subsystem is below 125°C whereas the mechanical subsystem's temperature can go as high as 300°C. The cooling fans and the Pt100 (Thermistor) sensor are the joining points of the two subsystems. The fans are controlled according to the reflow process and the Pt100 sensor is used to detect the temperature of the heating module throughout the whole reflow process.

3.3 Components Selected

3.3.1 NB-PTCO-045 Thermal Sensor (Pt100)

Specifications
Resistance at 0°C = 100 Ω,
Resistance Temperature Detector(RTD) Material = Platinum (Pt),
Operating Temperature = -30°C to 300°C,
Temperature Coefficient = 3850ppm/°C,
Mounting Type = Through Hole.
Justification The platinum sensors are to be used to measure high temperatures with significant accuracy. The soldering process requires maximum temperatures of the range ≈250°C, which are well within the range of the operating temperature of the sensor.

3.3.2 MCP 3008 ADC

Specifications
8 Channel 10-Bit Analog-to-Digital converter IC
Low power CMOS device
Temperature range -40°C to 85°C
Single Supply Operation
Maximum sampling rate of 200KSPS at V_{DD} = 5V.
Justification
10-bit analog-to-digital converter is a good fit for the temperature sensor as this will yield a resolution of 0.4°C for the temperature which is adequate for the reflow oven. The temperature range of the IC is high enough to handle the heat. Single supply IC such that it can be used in the reflow oven. Sampling rate high which is favourable.

3.3.3 Copper Metal Plate

Specifications
Dimensions = 100 x 100 x 1 mm^3,
Thermal conductivity = 401 W/(m.K),
Thermal expansion = 16.5 µm/(m.K) (at 25 °C),
Molar heat capacity = 24.440 J/(mol·K),
Melting point = 1084.62 °C.
Justification Copper metal plate has a low molar heat capacity which makes it a good choice for the heating plate. the heat capacity for this plate comes out to be 24.440 J/(mol·K) × 1.41 (mol) = 34.46 J/K.

3.3.4 Cooling Fans

Specifications
Dimensions = 40 x 40 x 10 mm^3,
Power input = 5V, 0.2 A,
Maximum Rotational Speed = 2000 RPM.
Justification Two fans will be fitted in the air chamber under the heating module. These are needed for the cooling period of the reflow process that requires a 4°C/sec decrease in the temperature. These will be powered by the micro-controller using a MOSFET switch.

3.3.5 Acryllic and Wood Packaging

Specifications
Thickness= 3mm
Justification The packaging sides were designed in Fusion360 and the packaging was constructed using lazer cutting, taking care to use wood for the sides which were close to or in contact with hot metal.

3.3.6 Mica Sheets (Electrical Insulation)

Specifications

Dimensions = 130mmx130mm

Net Weight of each sheet = 50g

Heat capacity of each sheet = 880 * 0.05 = 44J/°C

Justification

The dimension of the sheets are chosen to be greater than that of the copper metal plate, this is so that the metal plate which will retain all of the heat is a bit further away from the box and user. The sheets are light and have a low heat capacity and thus will be transferring most of their heat to the copper metal plate.

3.3.7 Long Screws

Specifications

Diameter=4mm; Length= 10cm

Molar heat capacity=25.09 J/mol K

Thermal conductivity 73 W/mk

Justification Long screws hold the heating module above the air chamber and are attached into the wood base of the air chamber.

3.3.8 LM7805 Voltage Regulator IC

Specifications:

Input voltage = 7V to 25 V; Output voltage = 5V +/-0.2V,

Output current = 1.5 A (max),

Junction temperature = 0°C to 125°C,

Temperature coefficient of output voltage = -1.1 mV/°C.

Justification: LM7805 takes input from 7-25V and outputs a voltage of 5V. This is required as the input to the oven is going to 24V, 10A and we would need to step down this to 5V, 1A for the microprocessor.

3.3.9 Switched mode power supply (SMPS) (230VAC to 12VDC)

Specifications

Convertes 230VAC to 12VDC; 2 supply outputs

Rated maximum current = 10A

Justification

Directly using the AC current to heat the copper plate will be hard and prone to mishaps, thus using a DC current simplifies this. The current rating is chosen such that the nichrome wire can reach atleast a temperature of 500°C for heating and correspondingly the voltage was chosen such that the power supplied is enough to reach the desired temperature in the required time. Both of the 2 output supplies are used where one is for the plate heating and the other is for the control subsystem.

3.3.10 Pt51 Micro-Controller

Specifications

All Ports P0-P3 accessible

Seperate headers for SPI and I2C

USB B powered and programmable

Justification

Pt51 board is chosen as the reflow oven does not require more than 4 ports. SPI and I2C are supported for the components such as the ADC and LCD display respectively. ROM available to store and execute the program for the reflow oven.

3.3.11 Nichrome Wire

Specifications

Electrical resistivity at room temp = 1 $\mu\Omega$/m,
Thermal conductivity = 11.3 W/m°C,
Temperature coefficient of resistance = 100ppm/°C,
Specific heat = 450J/kg°C,
Operating temperature = (max) 900 °C,
Gauge = 24.

Justification Nichrome wire, having a high resistance and a very low specific heat is ideal as a heating material for the reflow oven. Moreover, it can operate efficiently in 300°C, which is well within its optimum range.

3.3.12 16x2 LCD Display (I2C)

Specifications

16 Characters x 2 Lines; Green backlight,
HD44780 Equivalent LCD Controller/driver Built-In,
4-bit or 8-bit MPU Interface.

Justification The LCD module is required for displaying the different modes the oven is in, the temperature and, the time so far, which can be implemented on the 16×2 LCD module with i2c.

3.3.13 Circuit Passives (R, L, C)

Specifications

Resistors = 100Ω × 6, 470Ω × 9, 2.2 kΩ × 4, 10 kΩ × 3,
Capacitors = 0.1 μF × 11, 15 pF × 2.

Justification The values of the resistors and capacitors are chosen in accordance to the PTX datasheet.

3.3.14 Control Switches (Relay, BC547, IRF540)

Specifications

Relay(JQC-3FC/T73 12VDC) - Max switching voltage 28VDC, Max switching current 10A, Operation time = 8/10 ms. Temperature range = -40°C to 85°C.

Justification

The relay will be used to control the heating coil and will be switched by the microcontroller. The relay is rated for such high currents and voltages. The circuitry of the relay will be directly connected to the SMPS and will be controlled by switch made with IRF540, which is a power MOSFET, which in turn will be controlled by a GPIO pin from the microcontroller. Moreover, BC547 is used for controlling the fans as its current ratings and breakdown are well within the requirements.

3.3.15 Keypad and On-Off Switch

Specifications

Keypad - 3x4 input button keypad, 7 Connection Pins corresponding to the rows and columns of the keypad array.

Justification

On-Off switch which enables the turning On of the reflow oven. Keypad to input in the maximum temperature for the reflow oven to go up till.

3.3.16 Indicators (LEDs , Buzzer)

Specifications

Rating around 2V(forward) for each component

Justification The indicators are of correct rating as required.

3.4 Circuit Schematic

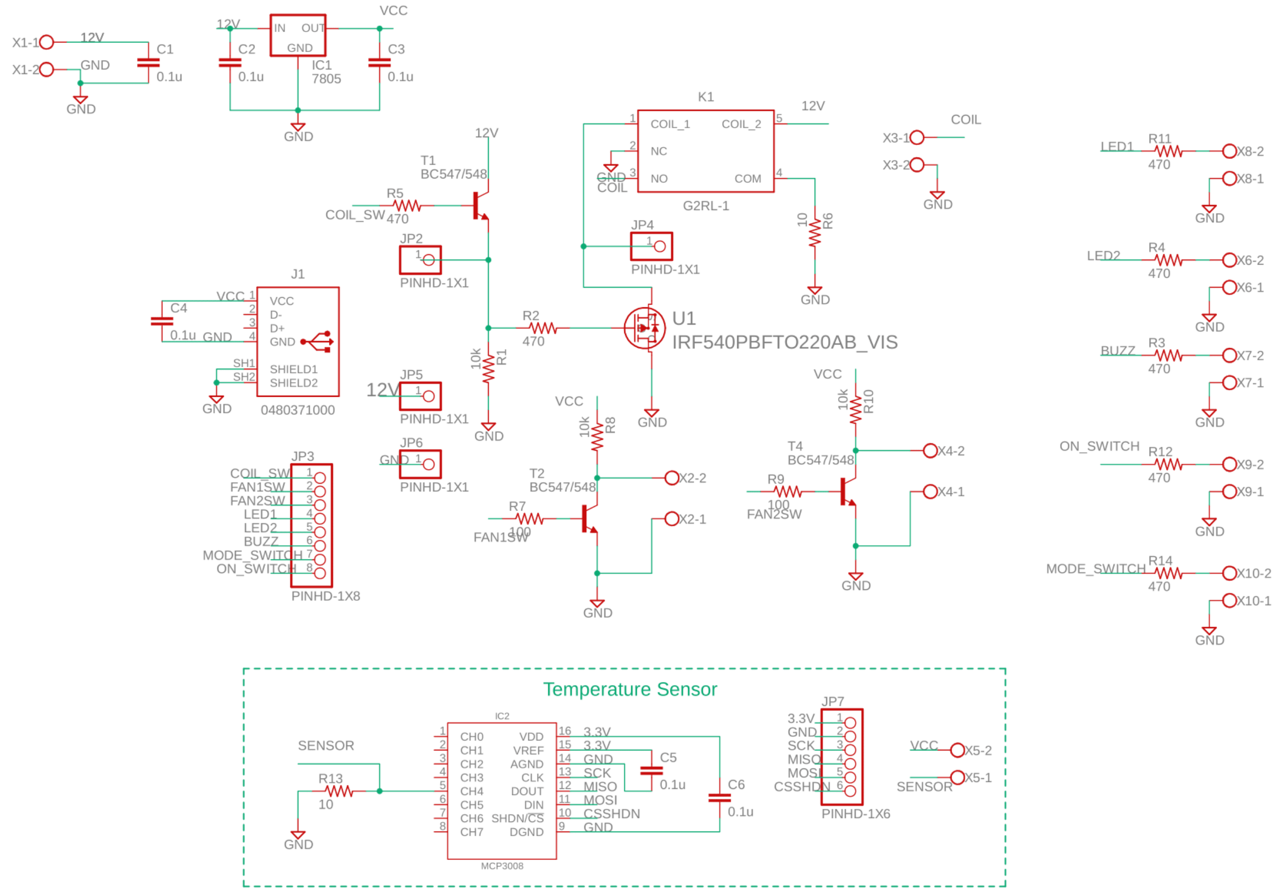


Figure 8: Complete Circuit Schematics

The Schematics consist of the relay-based switching circuit for the heating coil, transistor switches for cooling fans, 7805 IC & USB port to supply power to microcontroller, temperature sensor interfacing using MCP3008 along with interfaces for LEDs, buzzer & dip switches for controlling on/off & mode of operation.

3.5 PCB Layout

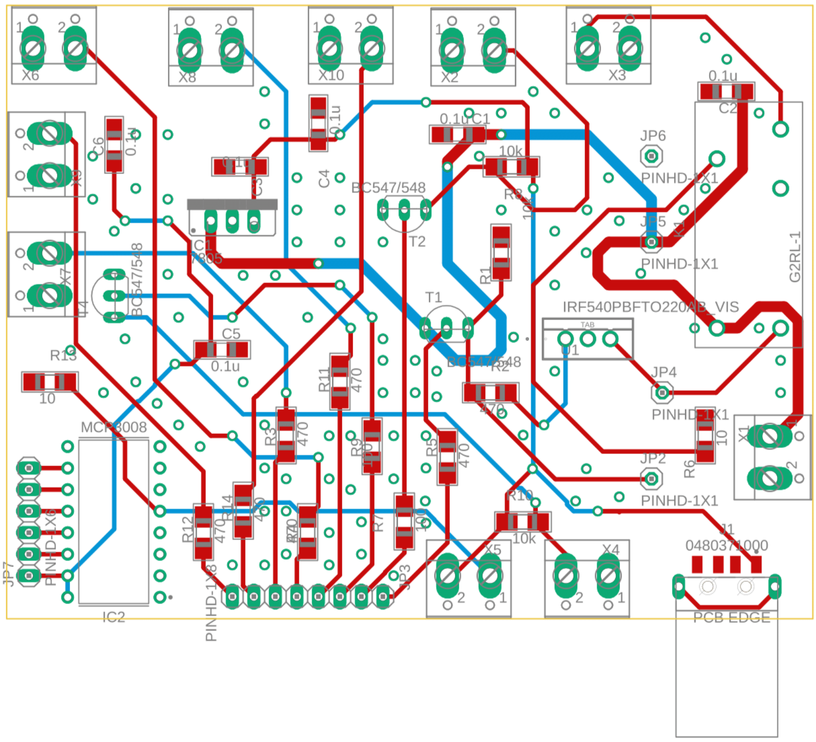


Figure 9: 2-layer PCB Layout

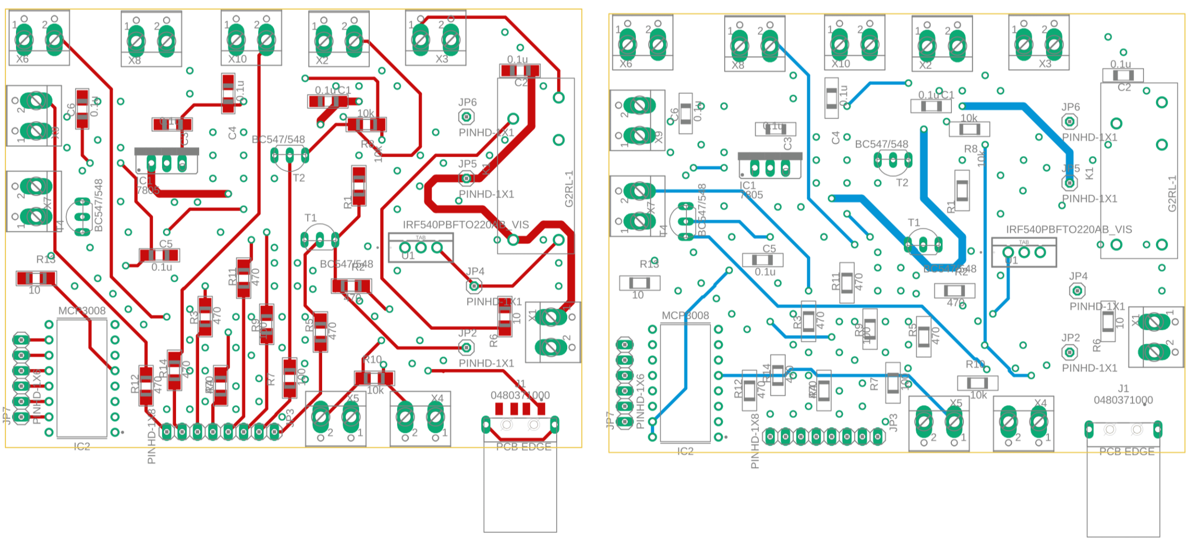


Figure 10: Top Layer (left) and Bottom layer(right)

3.6 CAD Design

Initially, we had planned to 3d print the packaging. However, due to its large size (It would take around 30 hours to 3d print), and to incorporate the different cooling chamber designs, we decided to lazer-cut each wall and then assemble the model according to the requirements.

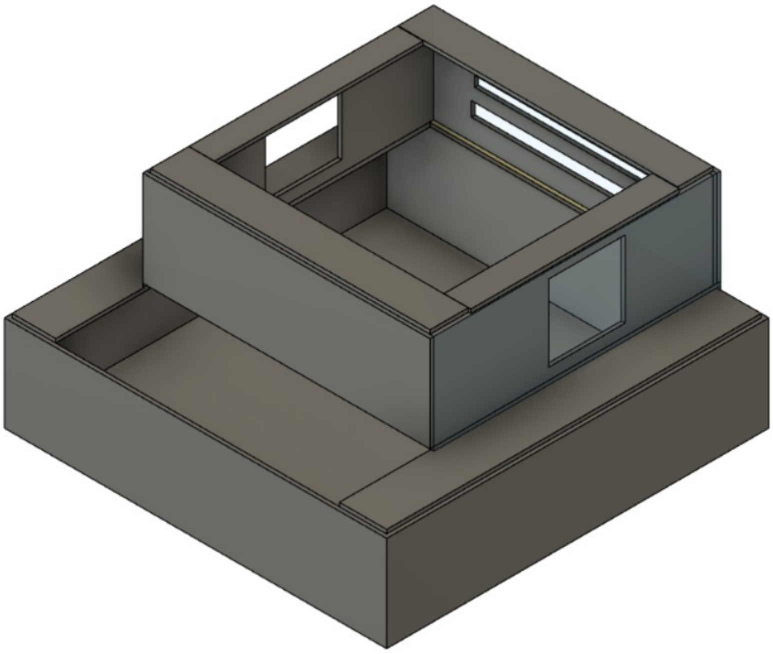


Figure 11: Initial 3D print design

The design has an upper air chamber (18.5 cm x 14.5 cm x 9 cm) and a lower chamber(18.5 cm x 25 cm x 7 cm) to hold the circuitry. Multiple different wall styles were designed for the air chamber (to accomodate different combinations of aluminium radiator, air slit and cooling fan locations). The top and bottom walls of the air chamber were made of 2mm thick wood as hot screws are screwed into the bottom wall and the top wall is very close to the heating coil. The remaining walls are lazer cut from 3mm thick acryllic sheets.

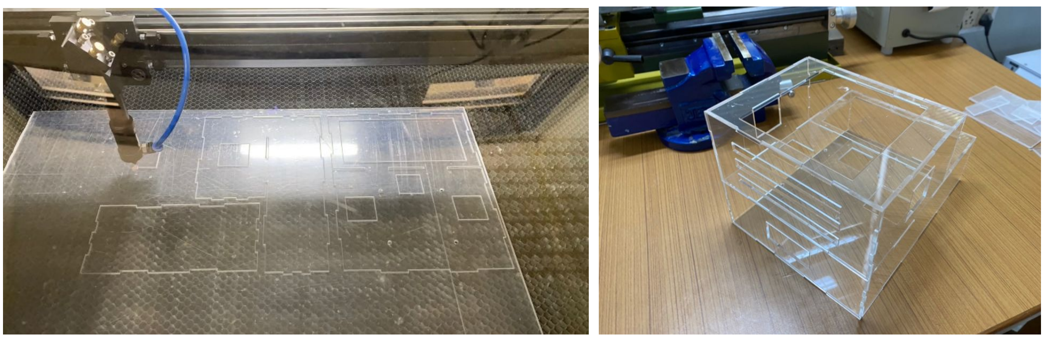


Figure 12: Lazer cutting acryllic (left) Final 3d model(right)

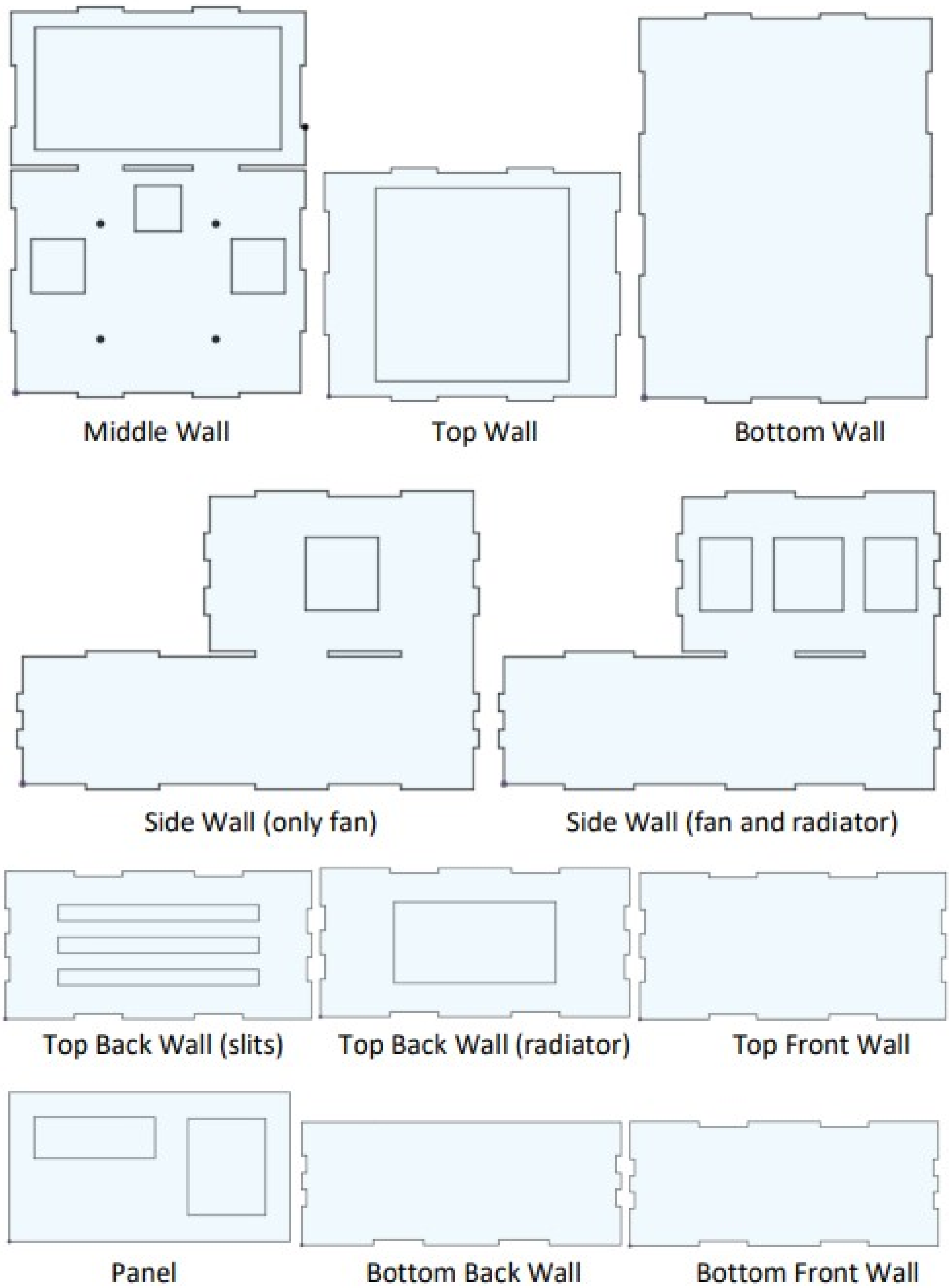


Figure 13: CAD design of all walls

4 Results and Observations

4.1 Testing Experiments

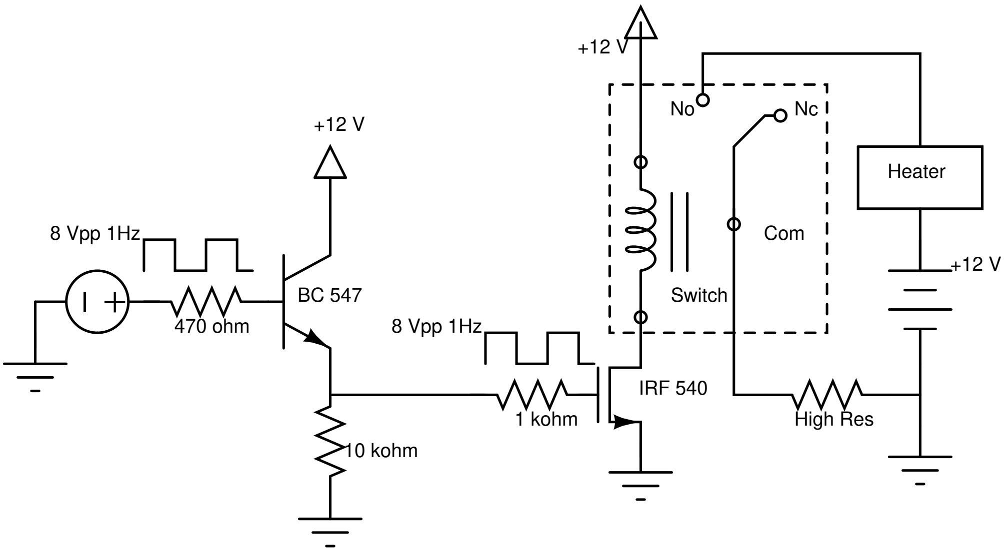
4.1.1 Experiment 1 - Switch Circuit Testing

Building and testing the switching circuit consisting of a BC547 transistor, JQC-3FC(T73) DC12V SPDT Relay and an IRF540 MOSFET.

Test setup

The circuit was set up as shown in the circuit diagram below and an oscilloscope was used to measure the voltage across the heating element.

Circuit diagram:



Test method

First, each element in the circuit was tested individually to check for faults. This was done by simply connecting a power supply across each element with required resistances and checking the current and voltage outputs using a multimeter.

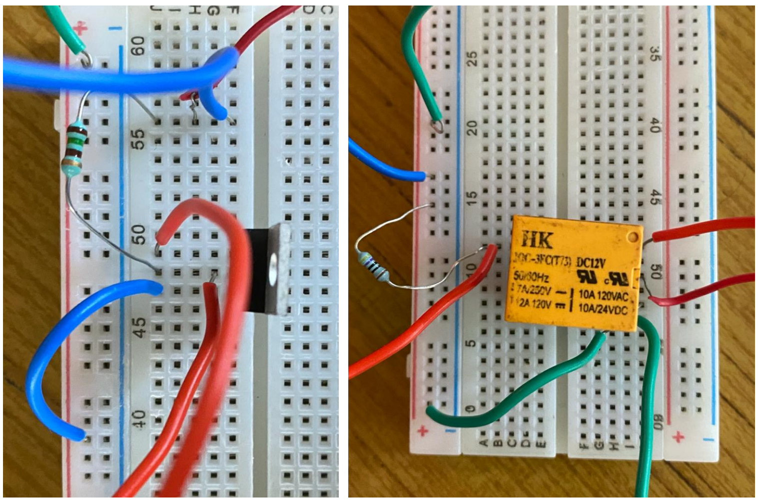


Figure 14: Individually testing the switching circuit components

Then, the entire circuit was constructed as shown in the circuit diagram. A 1Hz 8Vpp square wave input was given using a function generator and oscilloscope output was checked across the heating element.(A simple resistor of 10 ohm, which is the resistance of the nichrome wire, was used instead of the nichrome wire)

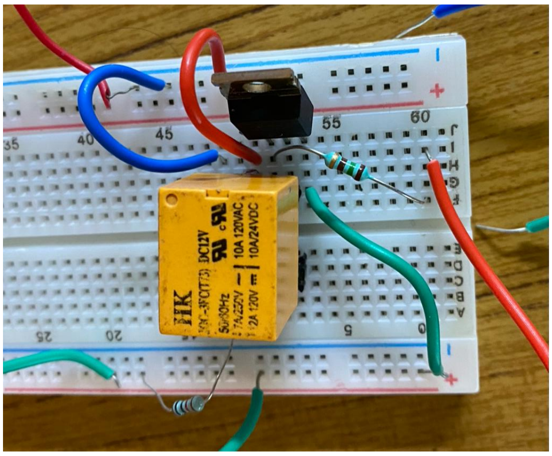


Figure 15: Testing the entire switching circuit

Test Results

The test was successful.

Observations:

- A switching sound was heard from the relay switch.
- The oscilloscope had a square wave output without much deformation.

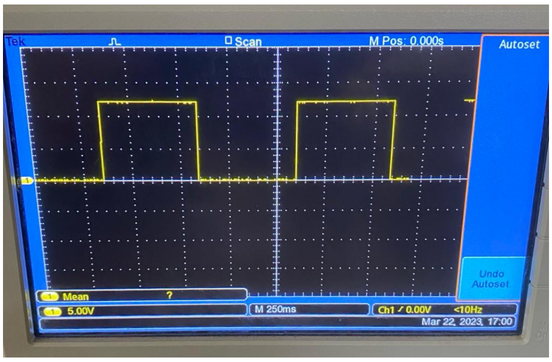


Figure 16: Oscilloscope output when the input is a square wave

Conclusions:

- The switch was able to function properly for an input voltage frequency of up to 5 Hz. Thus, we can conclude that the switching circuit will work for digital control signal inputs from the microcontroller.
- The switch is also able to handle up to 10 A current, which is more than the the current required by the heating element. Thus we can conclude that this switching circuit can be used in our solder oven to turn the heating element.

4.1.2 Experiment 2 - Heating Coil Characterization

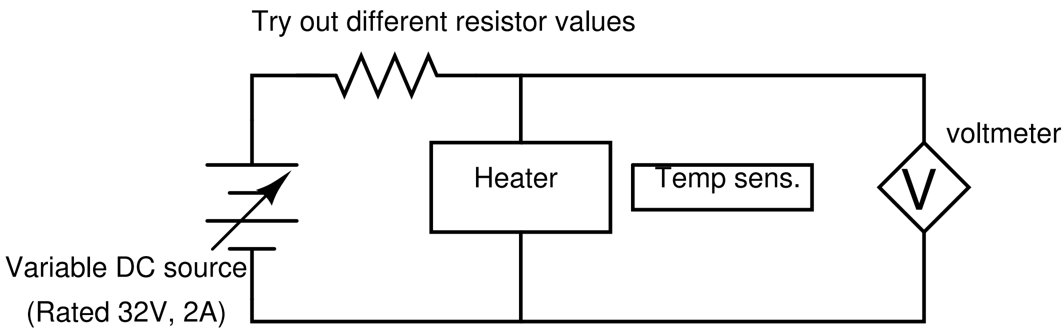
Connecting the heating coil to variable supply voltage to check the current and voltage it requires to heat up to different temperatures and the time required to do so.

Test setup:

Note:

- At the time of this experiment, due to the unavailability of the Switched Mode Power Supply (SMPS) and due to thermal and electrical safety reasons, we used a variable DC supply for characterizing the coil. We note that the current produced by this DC supply was much lower (1.62A) than that produced by the SMPS (upto 17A) and due to this, the temperature only went up to 60 degrees Celsius.
- This experiment will be repeated using the SMPS once the nichrome coil has been coated with insulating MgO powder and sandwiched compactly between the copper plates for electrical and thermal safety.

Circuit diagram:



Test method

The heating coil was connected across a variable DC source(Rated 32V, 2A), with a resistor in series with it. The voltage and resistance values were varied.The temperature sensor was used to measure the temperature of the heating coil, by wrapping the coil on the pt100 module and displaying the temperature on the LCD.

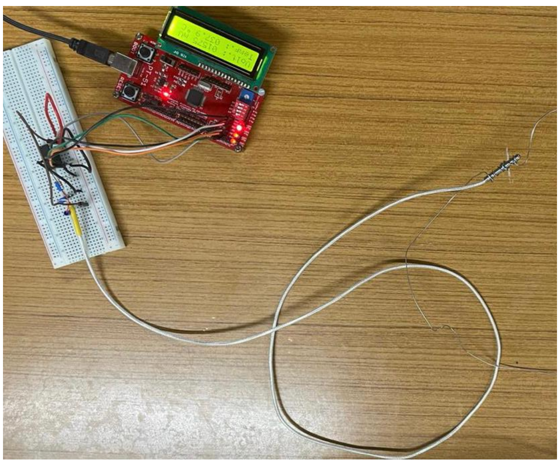


Figure 17: Measuring the nichrome wire temperature

Test results

The test was not successful.

Observations:

- When the coil was wrapped around the pt100sensor, the resistance of the load reduced, because the sensor is electrically conducting.
- Additionally, since the source current rating was only 2A, we were not able to supply enough power to heat the coil to a high temperature and we could only go to about 60 degrees celsius.

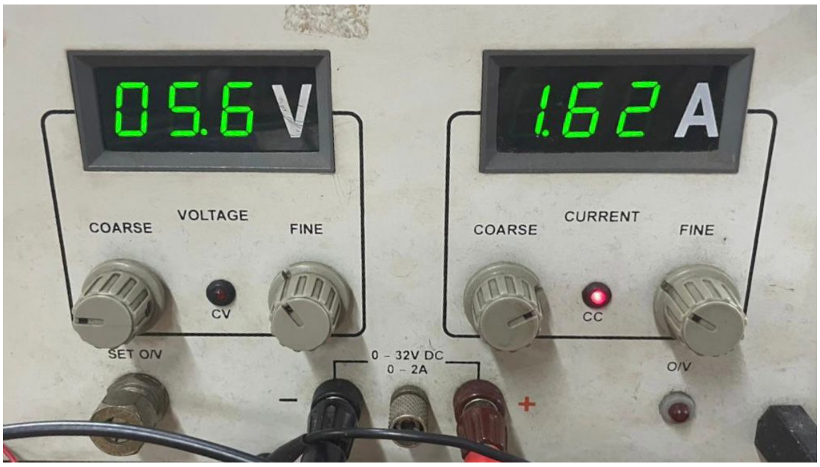


Figure 18: The voltage and the current drawn from the DC supply

Conclusions:

- For electrical safety, we will have to put a mica sheet between the nichrome heating element and the copper plate to prevent any chances for shorting.
- For thermal safety, we will also have to coil the wire and use the copper plates and thermally insulating holders.
- When this is done, we can use the SMPS, which has a high enough current rating to supply the required power to heat the wire up to 300 degrees Celsius.
- This is calculated as follows using the Nichrome calculator:
- For 24 gauge and 0.75m wire, the total resistance is 4.1117 ohm. The resistance per feet at 300 degrees celsius will be 1.671 ohm. With 12V supply voltage, the current will be V/R=2.9185A, and the power will be V*I=35W, which is more than the power required to heat the wire to 300 degrees Celcius.
- An alternate solution to draw higher power from the fixed voltage would be to take five 0.2m long nichrome wire pieces in parallel, as then they will have low resistance and draw high current and power.

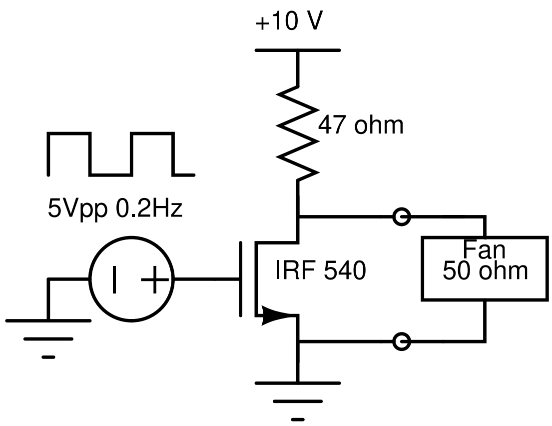
4.1.3 Experiment 3 - Cooling Fan Testing

Building and testing the switching circuit for the cooling fans and checking if they turn on and off correctly according to the input control signals.

Test setup

The circuit was set up as shown in the circuit diagram below and an oscilloscope was used to measure the voltage across the fan.
An NMOS - IRF 540 was used to switch the fan on and off. .

Circuit diagram:



Test method

The resistance of the cooling fan was measured and it was found to be around 50 ohm. Using this, we calculated that a resistance of 47 ohm, when attached at the drain, would allow the fan to get an input voltage of 5V, which is its rated voltage, when it is to be turned 'ON'. For the remaining time, the fan will receive insufficient voltage and will remain 'OFF'.

First, a square wave of 10 V amplitude and frequency 0.2Hz was supplied at the input using a function generator.

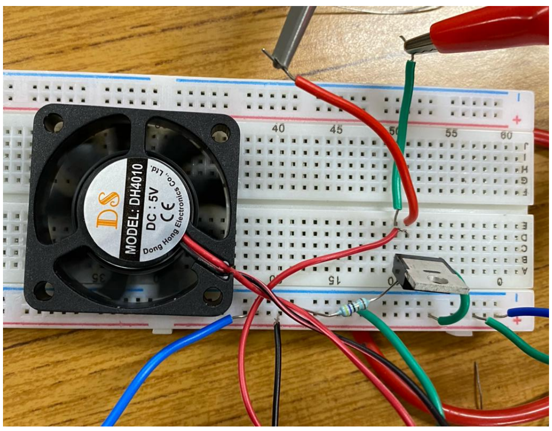


Figure 19: The fan when input is from the function generator

Next, the microcontroller was used to give the input signal at the gate instead of the function generator.

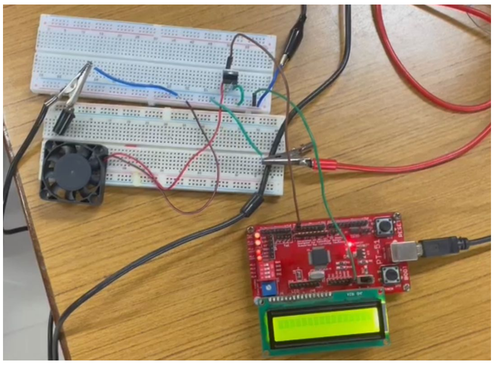


Figure 20: The fan when input is from the microcontroller

Test results

The test was successful

Observations:

- In both cases, the fan turned on when the input to the gate was a high positive voltage and off when the input to the gate was low volage. We could observe the fan and even count the seconds when it was on and off. This frequency matched the input square wave frequency.
- The oscilloscope had a square wave output. There was some noise in the oscilloscope wave, but the fan was turning on and off despite the noise.
- Videos of the observations have been attached at the end of the report.

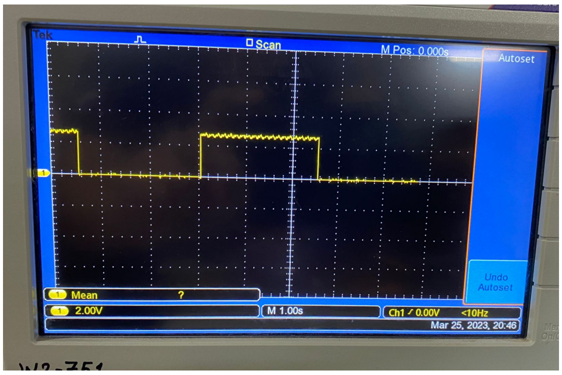


Figure 21: Output of the mosfet acting as a switch

Conclusions:

- Due to the inertia of rotation of the fan, it takes a small amount of time to stop rotating, once the input voltage is turned off. Hence, the input sequence should have time period around 5 seconds, so that the fan gets time to stop. This small delay must be accounted for while writing the control signal code for the fans.
- The fan is and its switch is able to handle and work with the voltage and current of the microcontroller control signals as it works when the microcontroller is used to control it.

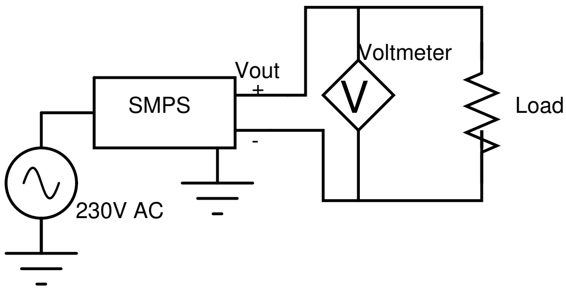
4.1.4 Experiment 4 - Power Supply Testing

Checking the output voltage and current of the Switched Mode Power Supply (SMPS) module by using a multimeter and understanding the connections to be made from the module to the rest of the circuit.

Test setup

The SMPS module will be used to convert 230V AC supply to 12V DC suppy. Its rated current is 17A, which is sufficient to take the heating coil till 300 degrees celsius according to our calculations.

Circuit Diagram



Test method

We used a power cable to connect the SMPS module to the 230V aAC supply. We studied the terminals of the SMPS module and then used a multimeter to ensure that the output voltage was 12V. We also passed current through a resistance to check that it was DC current of the right magnitude.

Test results

The test was successful

Observations:

- The multimeter measured 12V DC voltage and the SMPS had taken 230V AC input.
- The output current was DC and varied according to the resistance taken. It readily went to high values like 10A, thus it will be sufficient to heat the heating element.

Figure 22: The SMPS module terminals

Conclusions:

- The SMPS module works perfectly and is ideal for our power conversion requirements.

4.1.5 Experiment 5 - LCD interfacing

The first experiment with the microcontroller was to interface the LCD JHD 162A Module with the AT89C5131A(Pt51) development board. This would be used throughout the experiment to view the state of the reflow process, view the temperature and other such verification tasks throughout the experimentations and during the running of the project.

Test Setup
The test setup for this experiment is very simple; it uses the PORT2 on the Pt51 board to send the data to the LCD module. The LCD module decides what to do with the data (either use the data as an instruction or write the data) using the control bits sent from PORT1[2:0]. The communication established between the LCD module and the Pt51 board follows the i2c protocol.

Test Method
The methodology employed for LCD interfacing was the i2c protocol. In this protocol, all communications are controlled by an EN pin which transmits or receives data based on the status of an RS pin for the time the EN pin is set. A set of commands is sent for initializing the LCD module to start the screen, clear the screen set the writing mode, and move the cursor to the start of the screen.

Test Results
The test was successful
Observations:

- We were able to successfully interface the LCD module with the Pt51 board and obtain a clear and correct LCD display.

Figure 23: LCD interfacing using the Pt51 board

Conclusions:

- Thus, now we can interface other circuit elements and verify the interfacing using the LCD as an output.

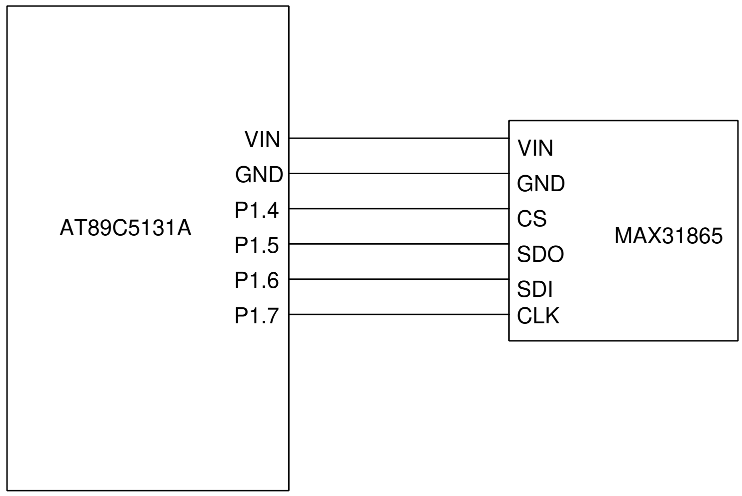
4.1.6 Experiment 6 - Interfacing the MAX31865 Module

The next experiment was to interface the Pt100 using the MAX31865 module; we used the same Pt51 development board as before. The 3-wire Pt100 was connected to the MAX31865 board and the board was interfaced using the PORT1 SPI pins.

Test Setup

The test setup was connecting the MAX31865 with the Ptx128 using PORT1. The GND and VIN pins were directly connected to the board's GND and VIN pins. Next, the CS pin on the MAX31865 was connected to the P1.4 port on the Pt51 board. Similarly, the SDI, SDO, and CLK pins are connected to the P1.5, P1.6 and P1.7 ports corresponding to the respective functions.

Circuit Diagram



Test Method

To communicate with the Pt51 board, we first initialised the SPI configuration where the SPCON register was set to 0x5f to enable the SPI, set the board as master, set clock polarity to '1', set the sampling to be done when rising edge is encountered and finally set the frequency of sampling to be $f_{clk}/16$.

To read data from the module, first, we select the Slave by setting it to low, then send the data by setting it in the SPDAT register and finally set the slave select back to high. The value will be stored in the SPDAT register after the SPSTA.7 interrupt flag is set to '1' to indicate data transfer completion. To write data to the MAX31865 module we first send the register address of the location to write and then send the value to be written following the same method.

Test Results

The test was not successful

Observations:

- The MAX31865 module was not sending data in time according to the protocol defined by the microcontroller. The value received was fixed and not changing with the temperature.
- For this, we also tried the Ptx128 development board, but the interfacing failed.

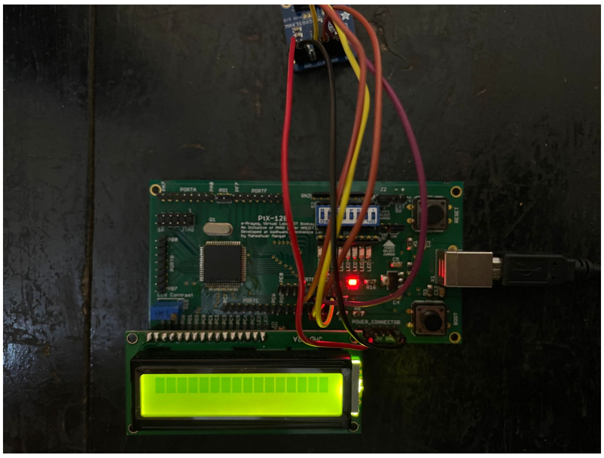


Figure 24: Failed interfacing with the Ptx128 Microcontroller

Conclusions:

- Due to time constraints, we shifted to using an ADC for calculating the temperature values, as it would take longer to fix the MAX31865 interfacing.

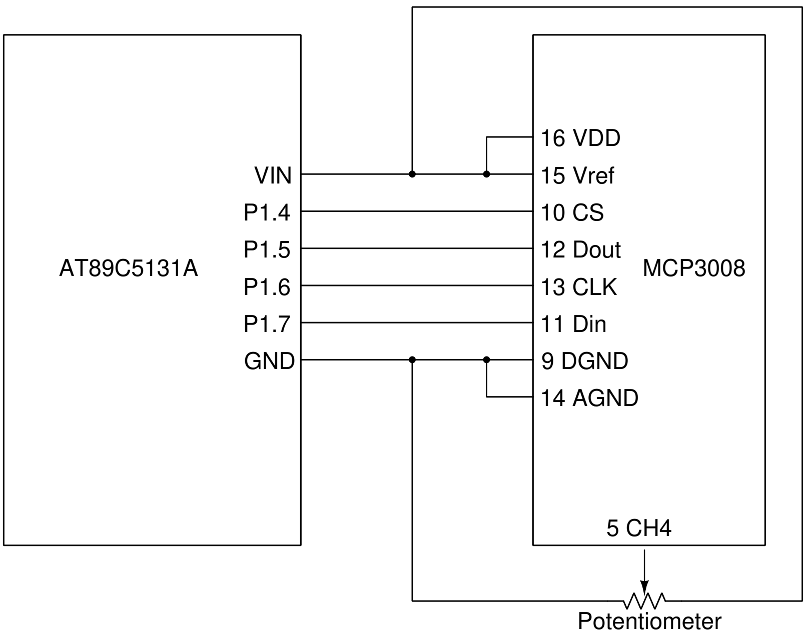
4.1.7 Experiment 7 - Interfacing MCP3008 ADC

After the experimentation to interface the MAX31865 module with the Pt51 development board failed, we chose to use an external ADC to calculate the temperature of the Pt100 sensor. The interfacing would be established using the SPI ports on PORT1 of the development board. We will use a potentiometer to check if the interfacing with the microcontroller is working correctly.

Test Setup

The SPI is established using the same pins as used for the MAX31865 module; all the connections are the same according to the MCP3008 pin diagram.

Circuit Diagram



Test Method

The methodology was similar to the last time. The SPI was enabled using the same concept and principles. For sending the data to MCP3008, we send 3 Bytes of data packaged as 4 Bytes and receive 10 Bits of data in return. A potentiometer is connected between GND and VDD and the middle pin is connected to pin 5 (CH4) of the MCP3008 IC. This is where the data is read from using the microcontroller.

Test Results

The test was successful.

Observations:

- The The ADC MCP3008 was interfaced properly with the microcontroller.
- The code was working properly, and upon adjusting the knob of the potentiometer, the value of the voltage at the middle pin of the potentiometer changed accordingly.
- The output on the LCD module displays the volt value of the potentiometer voltage divider and the temp parameter is just the voltage value as the Pt100 has not been added yet.

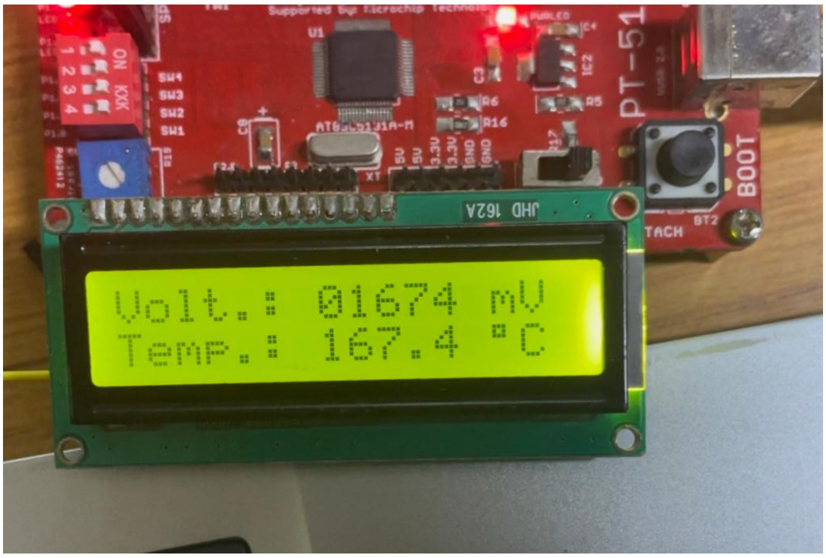


Figure 25: ADC MCP3008 Interfacing with Pt51

Conclusions:

- We can use the ADC MCP3008 with the Pt51 development board to complete temperature sensing.
- MAX31865 module will now be replaced with the MCP3008 ADC, and the Pt100 sensor will be used to sense the temperature using a voltage divider.

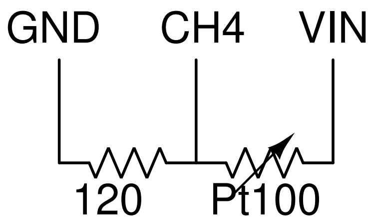
4.1.8 Experiment 8 - Temperature Sensing with Pt100

Using the ADC MCP3008, the task is to now sense the temperature using the Pt100 module. The Pt100's resistance changes with the temperature and thus we will use this to calculate the temperature.

Test Setup

The setup for this part is that the Pt100 and a 120Ω resistor will be connected in series between the VIN and GND of the MCP3008 ADC. The intersection point of the Pt100 and the 120Ω resistor is connected to the CH4 pin of the ADC. The same setup for the ADC will also be used for the experiment with MCP3008 for this temperature sensing experiment.

Circuit Diagram



Test method

The methodology was to use a voltage divider with a close enough resistance value to use the voltage point value and calculate the resistance of the Pt100 module at a particular temperature. The formula to calculate the resistance is,

$$R = 120 \cdot \frac{3.30V - V_{adc}}{V_{adc}}$$

Using this resistance value calculated, the temperature can be easily calculated using the Pt100 characteristic equation,

$$R = 100(1 + 3.9827 \times 10^{-3}T - 5.875 \times 10^{-7}T^2)$$

Therefore, we can now sense the temperature using the ADC and a voltage divider. The resistances and voltage values were measured and calibrated to get more accurate temperature values as they were off by 6 °C with the ideal values.

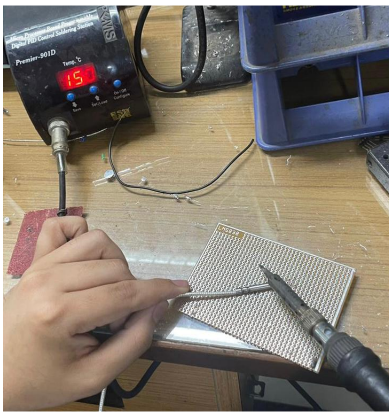


Figure 26: Using the soldering iron to heat the pt100 sensor

After this, we used a soldering iron to heat up the pt100 module and see whether it could sense higher temperatures. We set the soldering iron at 150°C.The temperature values were noted down along with their timestamps and then plotted.

Test results

The test was successful

Observations:

- The Pt100 can now be used to calculate the temperature, which changes with changing the temperature.
- The temperature recorded by the pt100 sensor rose steadily as it heated up due to the soldering iron.
- The temperatures recorded ranged from 35 to 140°C, after which the experiment was ended.
- Videos of the observations are attached at the report's end.

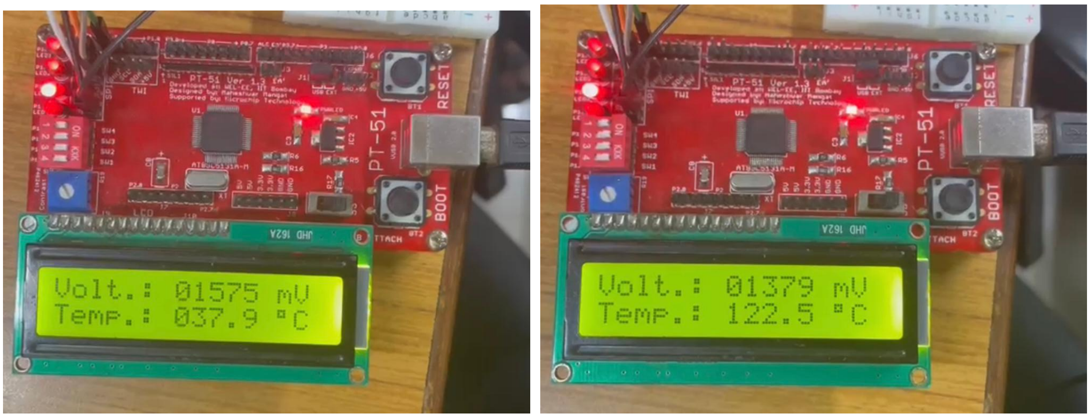


Figure 27: Temperature measurements at the starting and ending of the experiment

Conclusions:

- The ADC MCP3008 can be used for temperature sensing along with the voltage divider and Pt100.
- The resolution of Pt100 was around 0.3°C which is low and thus good for PID control of the temperature in the reflow process.
- The observations and plots of the temperature values vs time of the pt100 module when in contact with a soldering iron set at 150 degrees celsius can be seen below:

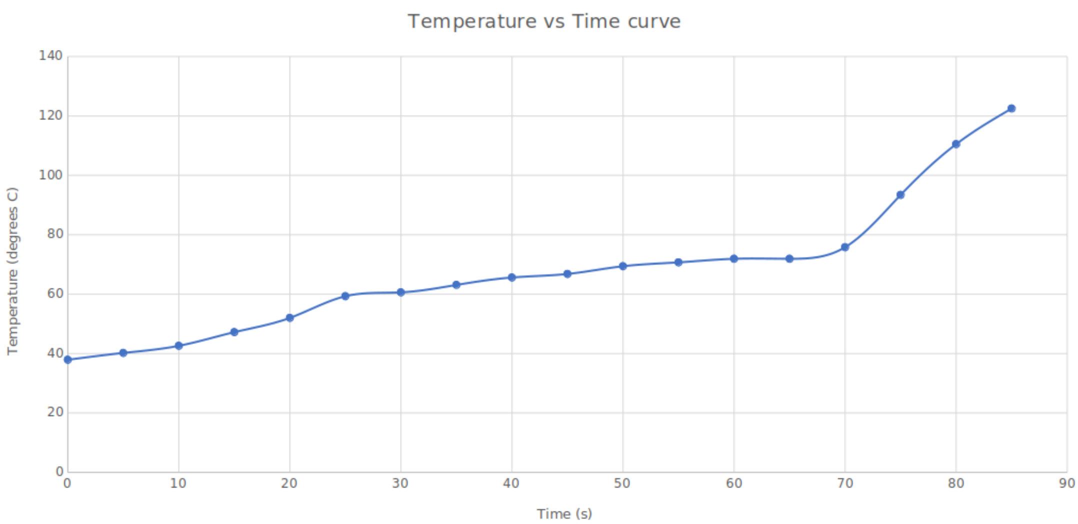


Figure 28: Temperature vs time plot when sensor is heated by soldering iron

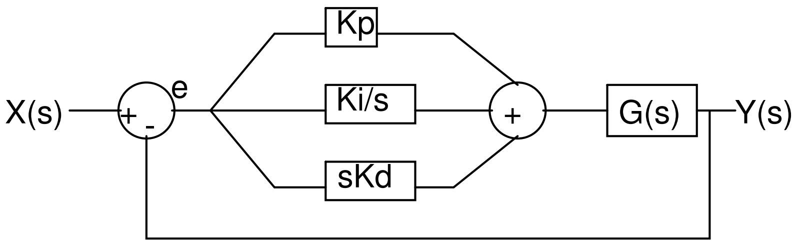
4.1.9 Experiment 9 - PID control design

Designing a PID control algorithm to turn off the heating when the temperature reaches a certain threshold, to turn on the fans when the temperature reaches a different threshold and to hold the temperature constant in the desoldering mode.

Test setup

The input signal to the microcontroller had the temperature measured by the sensor and its outputs were the control signals which decided whether the hot plate and fans should remain on or off.

Block Diagram



Test method

Logic:

- Error was taken as the difference between the current temperature and the setpoint required temperature.
- The integrator was implemented by adding up all previous errors until the current time.
- The differentiator was implemented by subtracting the previous error from the current error and dividing by the time elapsed between the previous reading and the current one.
- The result of the PID controller block was fed into the input again as feedback.

The controller expression:

$$K_p e + K_d \frac{de}{dt} + K_i \int_0^t e(t)dt \tag{1}$$

Test results

The test was partially successful

Observations:

- The PID control logic has been written and it is able to send control signals to turn the hot plate and the cooling fans on or off based on the setpoint temperatures.

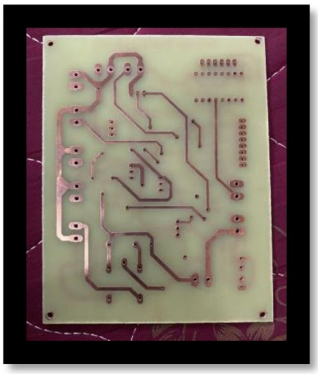
Conclusions:

- The true test for the control code will be when the entire module is built and when the temperature actually goes up to 300 degrees Celcius
- We have a basic code for temperature control, which will now be modified according to the reflow oven needs.

4.2 Problems Faced and Their Solutions

4.2.1 PCB trace width

Problem:
We required higher a current SMPS for the heating element and the PCB traces that we had printed out may not be able to handle that current.



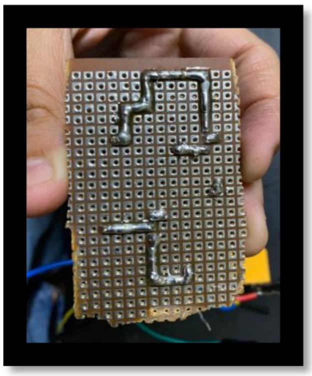


Figure 29: The printed PCB traces (left) and the recreated circuit on a perforated board(right)

Solution:
All of the circuits were reconstructed on perforated boards. Traces were created using solder iron. The high-power circuitry such as the switch circuit was implemented separately using thick wires.

4.2.2 Heating Element Shape

Problem:
During the initial experiments, the heating element would not go over 180 degrees C.

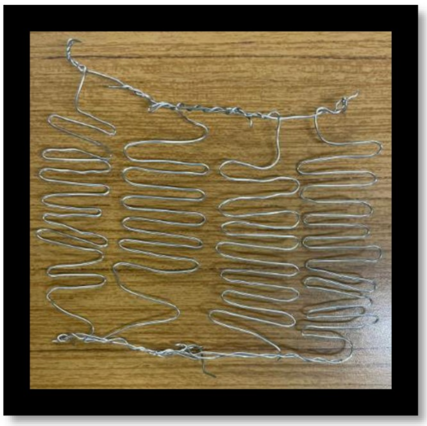


Figure 30: Initial heating coil(left); the final heating element after a series of experiments(right)

Solution:
Multiple versions of the heating elements were tried out, of various resistances, wire lengths, and arrangements. A thick copper plate was used to increase the heat capacity and retain heat.

4.2.3 ADC Issues

Problem:
The MAX31865 module was not sending data from Pt100 in time for both Pt51 and Pt128x. (Refer to experiment 6 and 7)

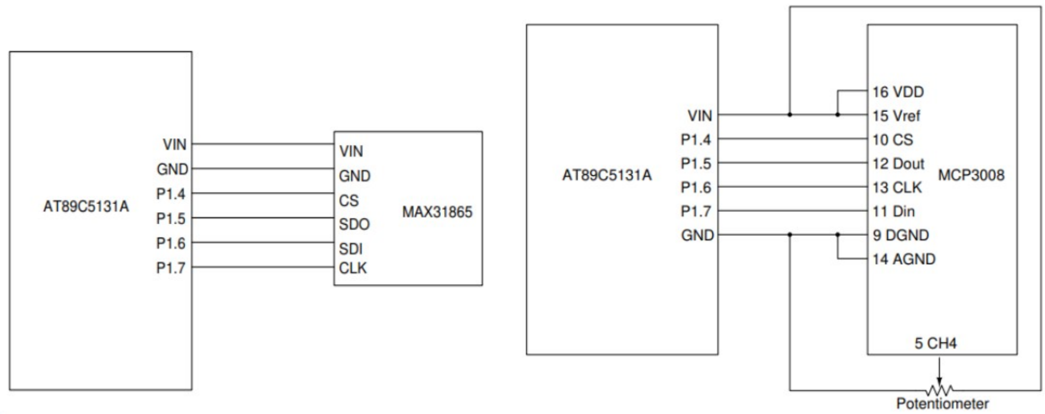


Figure 31: MAX31865 interfaced with Pt128x (left) MCP3008 ADC interfaced with Pt51(right)

Solution:
We shifted to using an ADC MCP 3008 with Pt51 for calculating the temperature values from the Pt100 sensor

4.2.4 Heat Protection

Problem:
A major problem was to protect the casing and circuitry from heat.

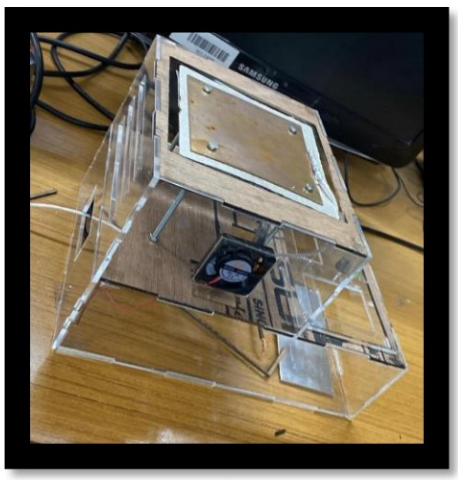


Figure 32: The top and bottom walls of the air chamber are wood

Solution:
The casing walls closest to the hot plate and in contact with the screws were made of wood instead of acrylic.Fans, a cooling chamber, and air slits were used for the dissipation of heat

4.3 Assembly of Subsystems

4.3.1 Experiment 10 - Final Microcontroller Program

The final program on the microcontroller contained all the sub-programs needed to run the reflow oven. The SPI interfacing the ADC to read the data of the Pt100 was interfaced using the P1.4-P1.7 GPIO pins. The LCD Display was interfaced using the P2 port for sending the data to the LCD display and P1.0-P1.2 for the I2C communication protocol for the display. The Fans and the relay GPIO pins are mapped to P1.0-P1.2, respectively. Finally, the remaining GPIOs are mapped accordingly to the LEDs, Buzzer, On-Off Switch, and other such devices. The GPIO mapping can be shown as below, the open pins are either connected to indicators or are left unused.

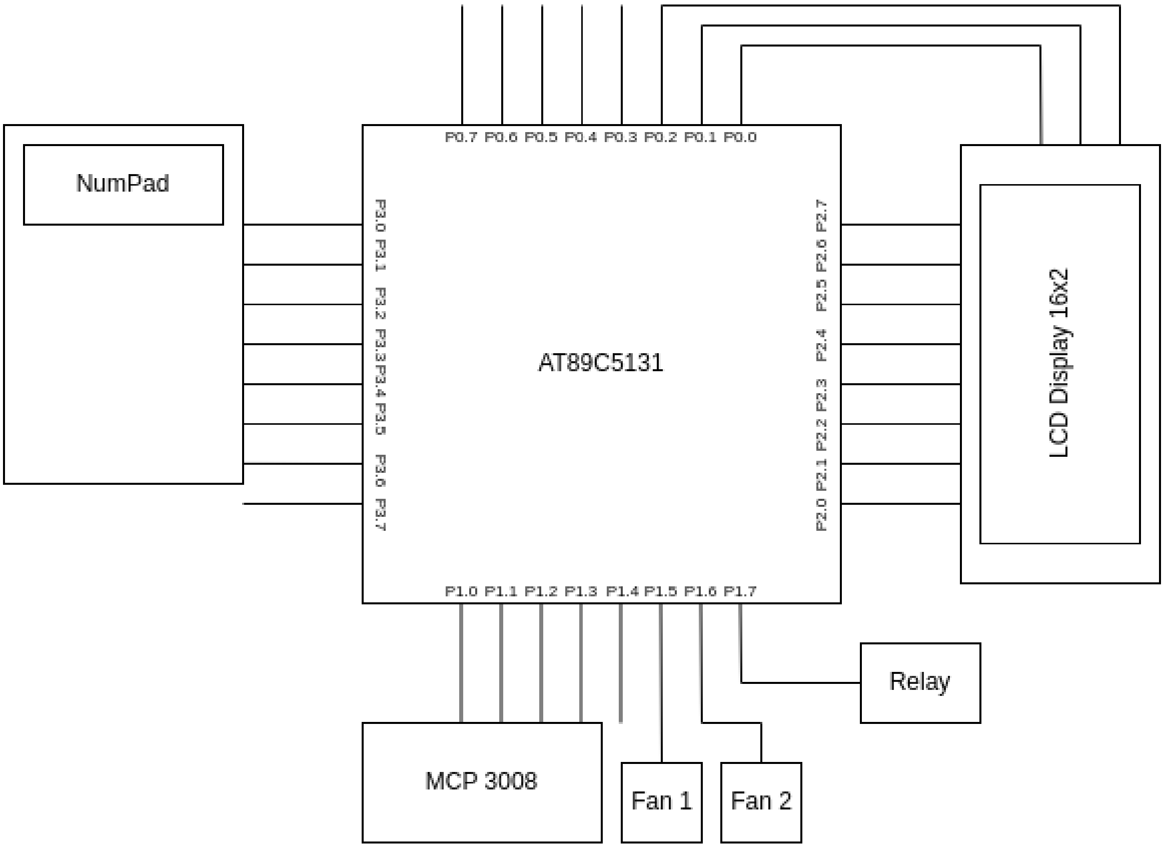


Figure 33: GPIO connections of the AT89C5131

Finally, the LCD interfacing, ADC interfacing, NumPad interfacing were all combined in the program. The GPIO pins for the fans, relay, and other indicators are initialized and set accordingly to the modes. The temperature calculation function is defined as follows,

```
unsigned int temp_cal(void){
        unsigned int x;
              x = adc(4);
              adc_pin_val = x*(3.3*1000.0/1023.0)/1000.0;
              adc_data = (unsigned int) (adc_pin_val*1000);

              //using the voltage divider formula to find the resistance of
              //the Pt100 with 120 ohm in parallel
              resistance = ((3.3 - adc_pin_val)/(adc_pin_val))*119.2;
              //passing the coefficients of the pt100 module to extract the temperature
              temperature = quad_solver(-0.0000005875, 0.0039827, 1.0 - (resistance)/102.2);
              x = (unsigned int) (temperature*10);
              return x;
}
```

Therefore, using the calculated temperature of the plate, the program defines 3 modes, first where the plate is heated constantly till it reaches the 150°C mark. Then the temperature is maintained between 150°C and 180°C for a duration of 90 seconds. Finally, the last state takes the plate to the maximum temperature taken from the user and then starts cooling down the plate as soon as it reaches it. Below is an example of such mode defined in the program. This is the first mode that checks if the device is below 150°C and is on the start of the curve.

```
		// if the temperature has not reached 150 degrees ever then the relay is turned on
		// and the fans are turned off, this is the rise to soak state of the reflow process
		if(x < 1500 && !preheat_mode){
			lcd_cmd(0x80);
			lcd_write_string("  RISE TO SOAK  ");
			RELAY = 0;
			FAN1 = 0;
			FAN2 = 0;
			lcd_cmd(0xC0);
			lcd_write_string(display_msg4);
			display_msg3[0] = adc_ip_data_ascii[1];
			display_msg3[1] = adc_ip_data_ascii[2];
			display_msg3[2] = adc_ip_data_ascii[3];
			display_msg3[4] = adc_ip_data_ascii[4];
			lcd_write_string(display_msg3);
		}
		//here after the temperature has once reached the 150 mark it should stay there for around 90 sec
		//in the temperature range of 150-180 degrees. Here a switching mode is created where the relay
		//is switched accrodingly to maintain a temperature between 150-180 degrees for 90 secs
```

Finally, the slave devices were programmed to communicate with the master device using communication protocols such as SPI and I2C. These codes are provided in the ‘spi.h‘ and ‘lcd.h‘. The numpad was interfaced using the rows and columns of the numpad, alternatively setting the rows as high or '1' to check which button has been pressed. The code for the numpad interfacing and spi interfacing used by the ADC MCP 3008 is given as follows,

```
void numpad_init(void){

	PIN1 = 1;
	PIN4 = 1;
	PIN5 = 1;
	PIN6 = 1;
}

char read_numpad(void){

	PIN1 = 0;
	if(PIN2 == 0) return '1';
	else if(PIN0 == 0) return '2';
	else if(PIN4 == 0) return '3';
	PIN1 = 1;

	PIN6 = 0;
	if(PIN2 == 0) return '4';
	else if(PIN0 == 0) return '5';
	else if(PIN4 == 0) return '6';
	PIN6 = 1;

	PIN5 = 0;
	if(PIN2 == 0) return '7';
	else if(PIN0 == 0) return '8';
	else if(PIN4 == 0) return '9';
	PIN5 = 1;

	PIN3 = 0;
	if(PIN2 == 0) return '*';
	else if(PIN0 == 0) return '0';
	else if(PIN4 == 0) return '#';
	PIN3 = 1;

	return '/';
}
```

```
unsigned long int spi_trx(unsigned long int spi_data_tx){

	unsigned long int spi_data_rx;
	unsigned char spi_data_3, spi_data_2, spi_data_1;

	transmit_completed = 0;
	SPDAT = (spi_data_tx >> 16)%256;
	while(!transmit_completed);
	spi_data_3 = temp_spi_data;

	transmit_completed = 0;
	SPDAT = (spi_data_tx >> 8)%256;
	while(!transmit_completed);
	spi_data_2 = temp_spi_data;

	transmit_completed = 0;
	SPDAT = (spi_data_tx)%256;
	while(!transmit_completed);
	spi_data_1 = temp_spi_data;

	spi_data_rx = (spi_data_3 << 16) + (spi_data_2 << 8) + spi_data_1;
	return spi_data_rx;
}

void spi_interrupt(void) interrupt 9{

	switch(SPSTA & 0xf0){
		case 0x80:
			temp_spi_data = SPDAT;
			transmit_completed = 1;
			break;
```

4.3.2 Experiment 11-Heating module assembly and testing

Created the heating module consisting of the nichrome wire sandwiched between mica sheets laid under the copper metal sheet. Tested if the heating is even throughout the plate. Checked that the gradient($\approx 3°C/sec$) needed for the reflow process is achieve

Multiple arrangements of nichrome wire were tried out for the heating module. Each nichrome arrangement was sandwiched between two mica sheets and the resistance was measured. If the resistance was above a safe value(to prevent excess current from being drawn from the SMPS), then the SMPS was used to supply curent to the heating module and the temperature reached was measured using the PT100 sensor. After multiple such tries, an optimal heating module was identified, whose nichrome wire arrangement and testing stage can be seen below.

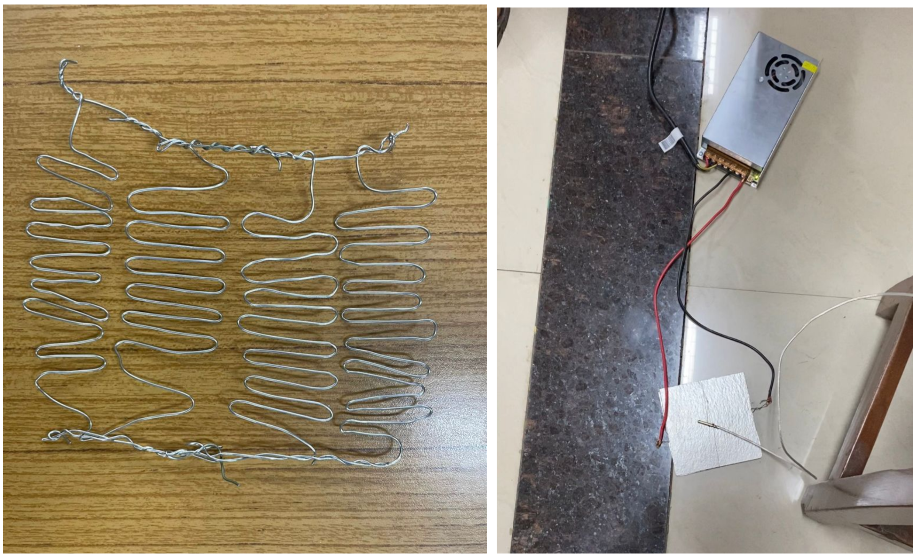


Figure 34: The nichrome wire layout(left) and the final heating module with mica sheets(right)

After this, the heating module was screwed on to the CAD design, and the copper plate was screwed on top of it. The Pt100 sensor was attached using an aluminium foil. Aluminium is a good conductor of heat. The foil was embedded into the heating module, so its temperature was approximately the same as that of the heating module. Th Pt100 sensor was covered by this foil to allow maximum surface area to be heated (leading to an accurate temperature measurement.)

The temperature went up to 300 degrees Celcius and we were able to melt solder wire on the module (as can be seen below)

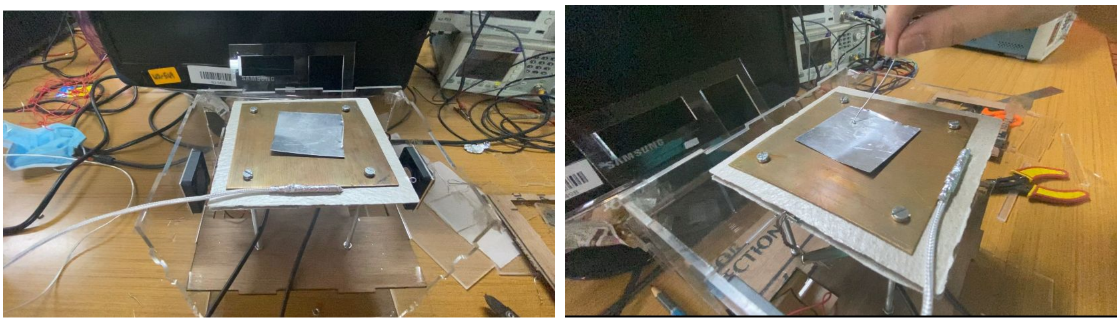


Figure 35: The final heating module setup(left) and melting of solder wire on it(right)

4.3.3 Experiment 12-Cooling system assembly and testing

Tested whether with the fans on full thrust in the air chamber, a decrease of $\approx 4°C/sec$ is achievable near the peak of the reflow process.

The final air chamber was constructed with fans at the side and air slits at the back. A few different configurations of the air chamber were considered, including one with aluminum radiators, one with one fan facing inwards(pushing air in), and the other fan facing outwards(pushing air out). However, it was found that the air chamber with slits at the back and two fans at the sides, facing outwards, satisfied the system requirements.

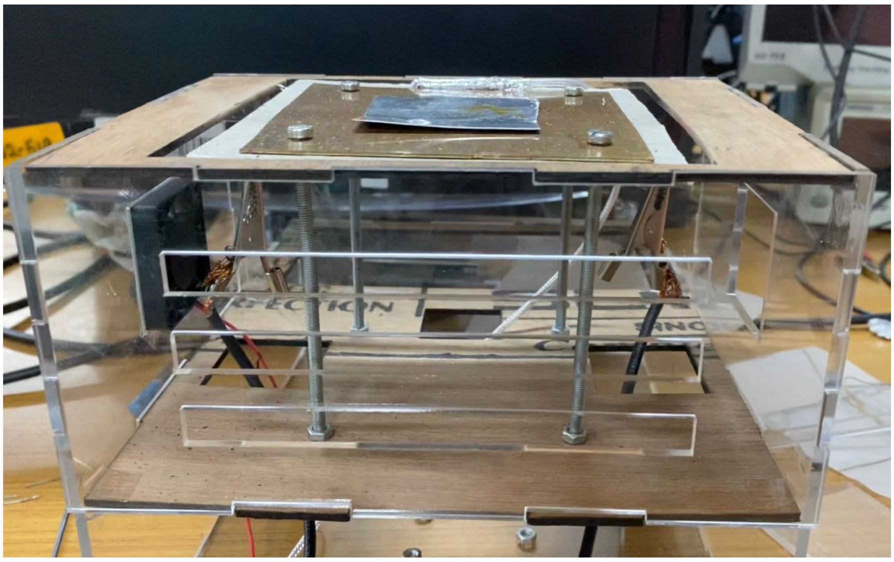


Figure 36: The final air chamber

The temperature of the heating plate was measured for the heating and cooling processes, and the temperature vs time curves were plotted for the heating and cooling processes. They were found to satisfy the system requirements(1-3 degrees Celcius per second slope for heating and 2-4 degrees Celcius per second slope for cooling)

The heating (heating element on, fans off) gradient was found to be 1.44 degrees Celcius per second, and the cooling (heating element off, fans on) gradient was found to be 2.07 degrees Celcius per second

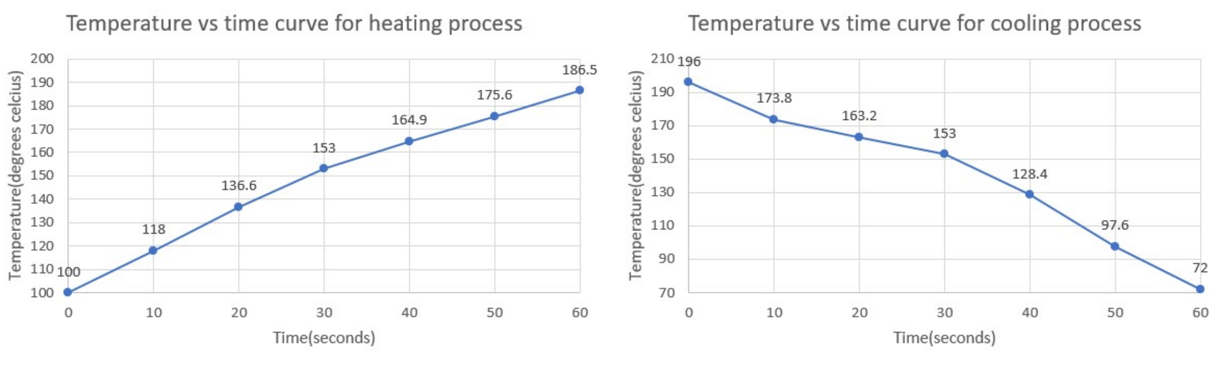


Figure 37: The temperature vs time plots for the heating and cooling process

4.3.4 Experiment 13-Final model assembly and testing

Put the entire package together. Tested all the subsystems to make sure that they were working together. Tested whether the hot plate is able to solder and desolder SMD components successfully.

The final model was constructed, and all of the subsystems worked together as intended.

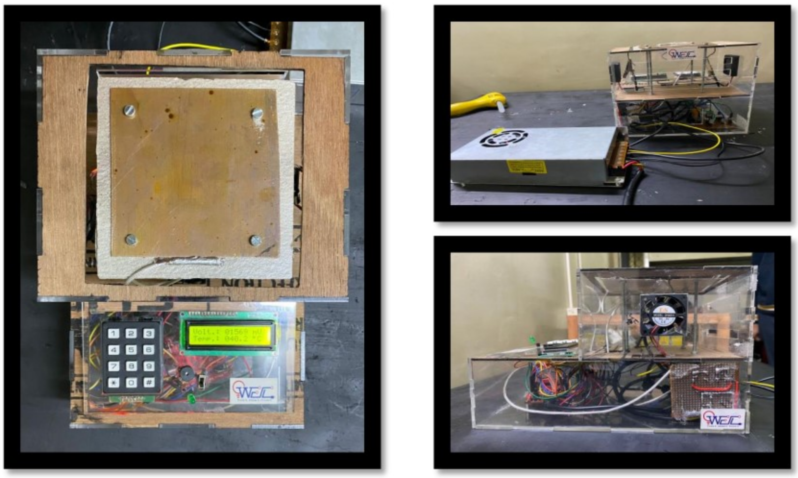


Figure 38: The front, top, and side views of the final module

First, solder paste is applied on a PCB (here tin sheet) and an SMD component is placed on top of it. After this, the user enters the maximum temperature based on the properties of the solder paste used. Then the heating process begins, and the temperature rises at a rate of 1.44 degrees Celcius (expected 1-3 degrees Celcius). When the temperature reaches 150 degrees Celcius, it is maintained between 150 and 180 degrees Celcius by turning the heating element on and off. The fans remain off during this period. Then, the temperature rises again up to the maximum set temperature. Once the peak has been reached, the heating element turns off and the cooling fans turn on. Then the setup cools at a rate of 2.07 degrees Celcius(expected 2-4 degrees Celcius) The solder paste hardens and the SMD is found to be soldered to the PCB.

Reflow oven Working Video link

We plotted the temperature vs. time curve of the entire process using video recordings and found it to approximate match the required temperature vs time curve.

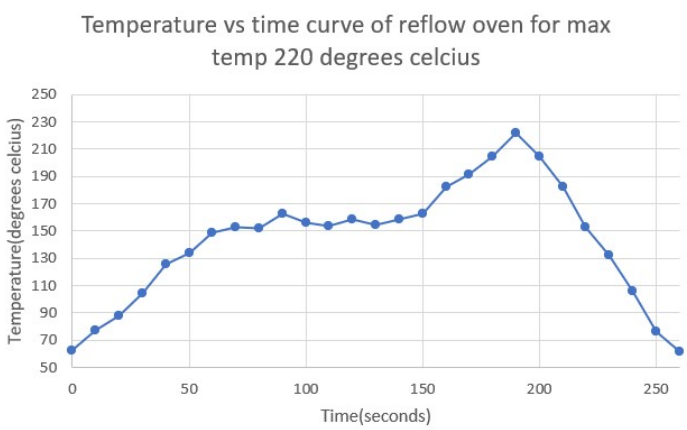


Figure 39: Temp vs time plot of the reflow oven when max temp set at 220 degrees Celcius

5 Bill of Materials

Part Name	Quantity	Net Price
Cooling Fan - 5VDC 0.136 A	2	₹299
MIKROE-2885 Temperature Sensor	1	₹892
Mica Sheets for heat insulation	2	₹150
Copper Plate	1	₹420
MCP 3008-ADC	1	₹255
SMPS 240VAC, Output 12V, 10A	1	₹750
4x3 Number Keypad	1	₹180
16x2 LCD Display	1	₹200
Nichrome Wire (24 Gauge)	1	₹200
DIP Switch	1	₹14
BC 547 NPN Transistors	3	₹30
IRF 540 NMOS Transistors	1	₹75
JQC-3FC 12V 10A Relay	1	₹16
3 inch Metal Screws	4	₹24
Metal Contacts for Heating Element	2	₹60
LM7805 Voltage Regulator	1	₹10
Buzzer for audio indication	1	₹28
RED LED - 3mm Diffused	1	₹5
Breakout Board	1	₹35
PT51 Microcontroller Board	1	N.A.
Printed Circuit Board	1	N.A.

The above bill of materials excludes the outer packaging (made of acrylic & wood), passive components (resistors & capacitors), wires, and miscellaneous things like wires & adhesive. The cost of components like the PT51 board and PCB lab-manufactured PCBs are also not included.

Total Cost: **₹3700** Approx. (as per BOM)
Total Expected Cost: $\leq$ **₹6000** (including all components & packaging)

6 Conclusion and Future Work

6.1 Presentation Video

The presentation video (last two minutes) contains a recorded compilation of all of the processes in the working of the reflow oven.

LINK

6.2 Conclusion

A total of less than ₹6000 was spent on the materials for the oven. Commercially accessible items for the same purpose, however, are on an industrial scale for factories and plants and cost around ₹3,00,000. In contrast, products for single PCBs are much smaller(20mm x 20mm) and cost around ₹30,000. So, our reflow solder oven offers a usable soldering station of size 100mm x 100mm and is very economical compared to already existing competitors.

6.3 Future Work

We can add three different modes the oven will operate lead-based reflow soldering, lead-free reflow soldering, and desoldering. These are explained below,

Lead-based Reflow Soldering The most common lead-based solder available in market is the Sn63/Pb37 solder. The reflow process for this type of solder involves first preheating the station to 100°C in 30secs. After this, the temperature is gradually increased to 150°C in the interval 30-120secs. This is done gradually so to heat all the components of the PCB equally. Then again, the temperature increases rapidly to a peak value of 235°C, crossing the melting point at °C. This is completed in the interval 120-210sec. After this, the PCB has to be cooled down immediately at a rate of <4°C/sec and needs to reach the melting point in the next 30secs.

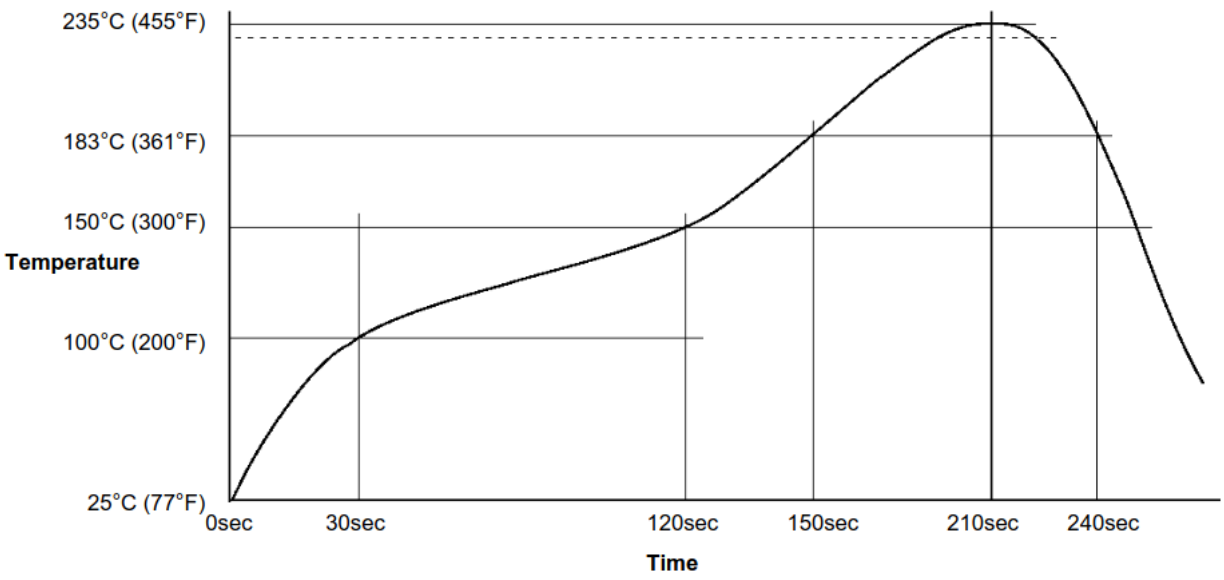


Figure 40: Reflow Process of Sn63/Pb37 *Source*: chipquick.com

Lead-free Reflow Soldering The most common lead-free solder used widely is the SAC305. The reflow process is quite similar to the lead-based reflow process, except that here it is first preheated to 150°C, then gradually heated to 180°C in 80secs. Finally, after this, it is rapidly heated to a peak of 240°C crossing the melting point of 220°C. After it reaches the peak the temperature should rapidly drop down with a slope of < 4°C/sec. The solder should only be above its melting point for a total of 40secs.

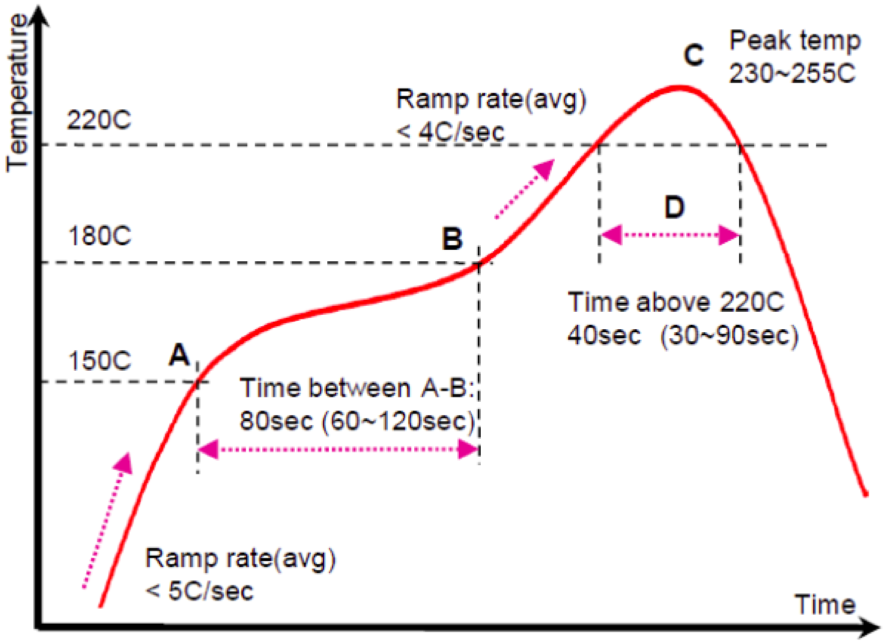


Figure 41: Reflow Process of SAC305 *Source*: 7pcb.com

Desoldering The desoldering is quite simple compared to the reflow soldering method. In this, the plate is heated as high as 260°C and for a time not exceeding 10secs. This is acceptable as this has enough temperature to melt the solder without damaging the components of the PCB.