EE344 : Milestone 3

Reflow Oven for Soldering SMD Components

Faculty : Prof. Joseph John & Prof. Gaurav Kasbekar
RA Mentor : Sayali, TA Mentor : Radheshyam
March 23, 2023

Amruta Mahendra Parulekar, 20d070009
Sameep Chattopadhyay, 20d070067
Anmol Saraf, 200070007

Contents

1 Circuit Schematic

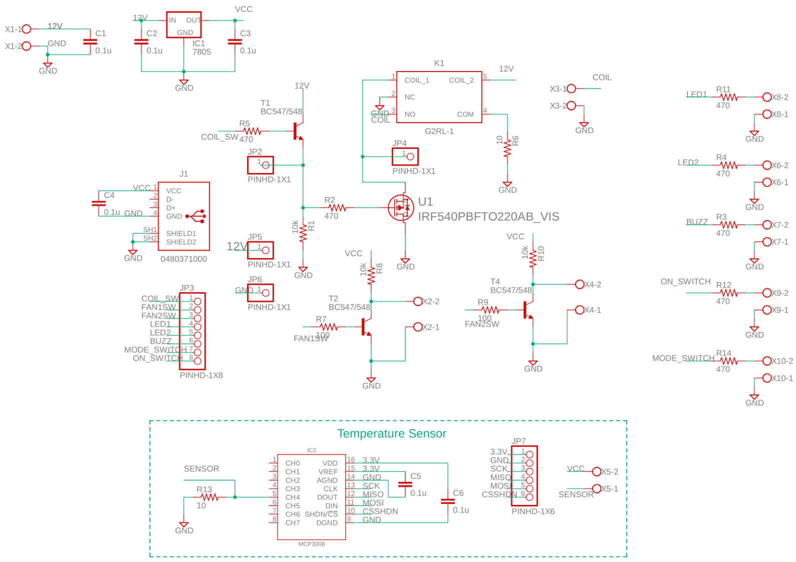


Figure 1: Complete Circuit Schematics

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.

2 PCB Layout

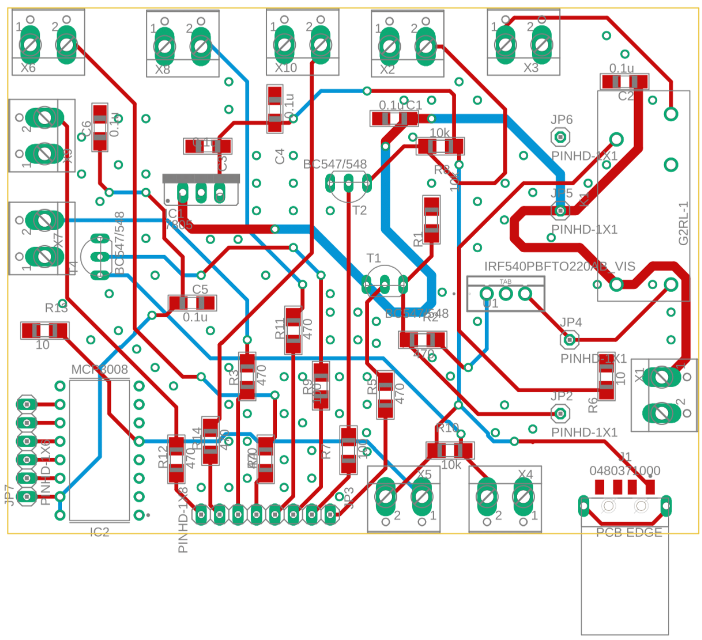


Figure 2: 2-layer PCB Layout

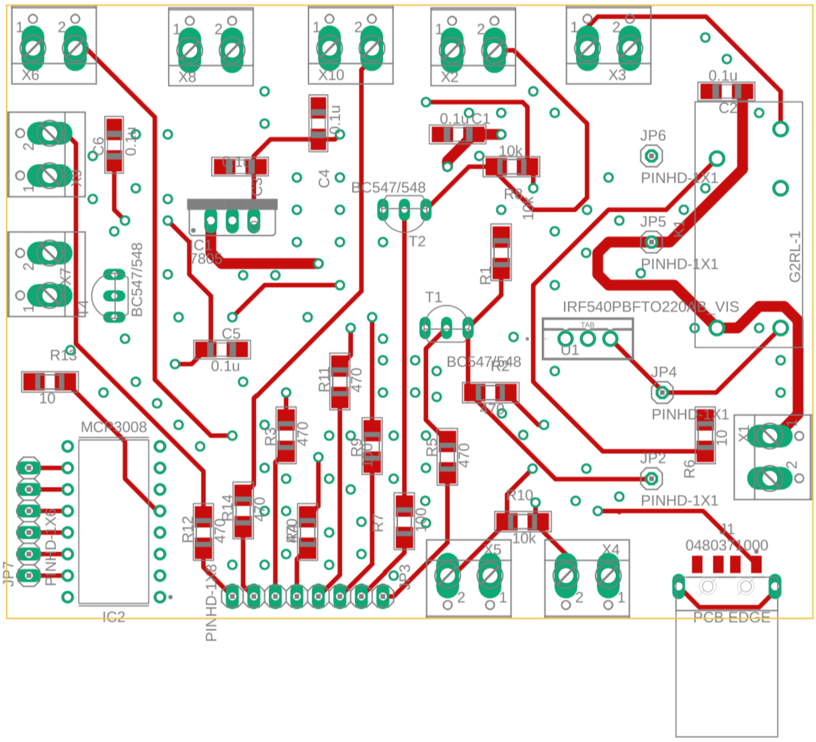


Figure 3: Top Layer

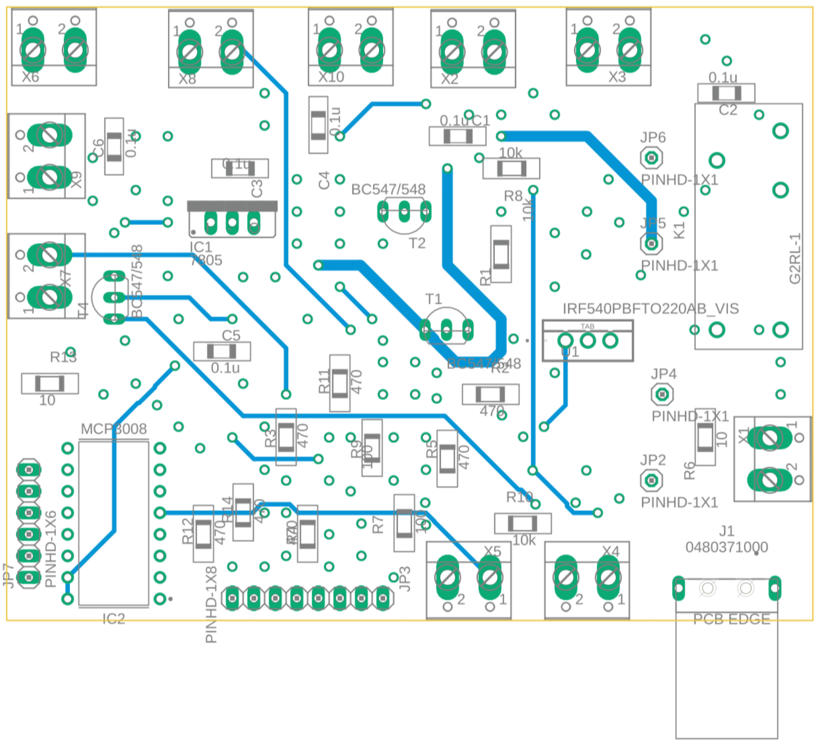


Figure 4: Bottom Layer

3 CAD Design

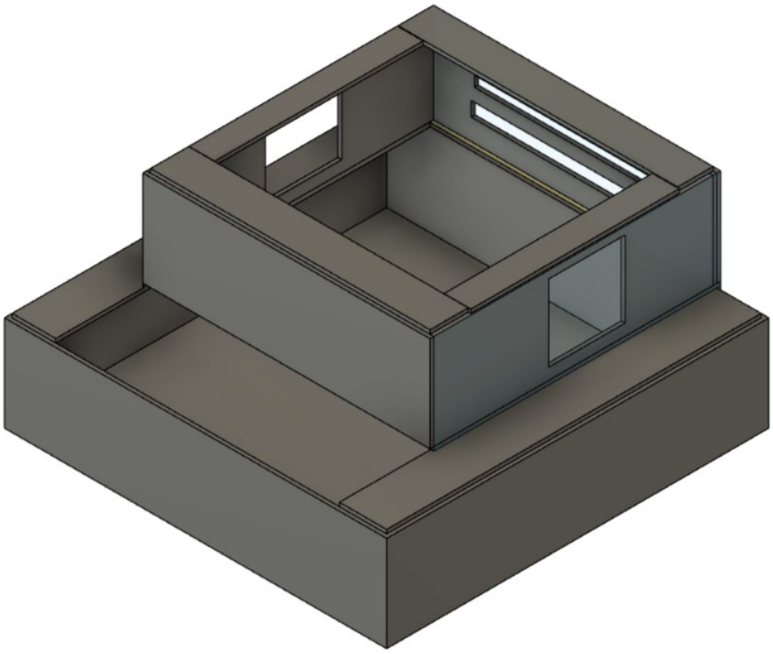


Figure 5: Isometric view

Holes have been created for the hot plate,fans,air inlets and LCD,LED,buzzers and switches. The top cuboid is 15cm*15cm*5cm and contains the air chamber. The bottom cuboid is 20cm*20cm*5cm and holds the circuitry.Care has been taken to leave extra space between the hotplate and the wall of the packaging

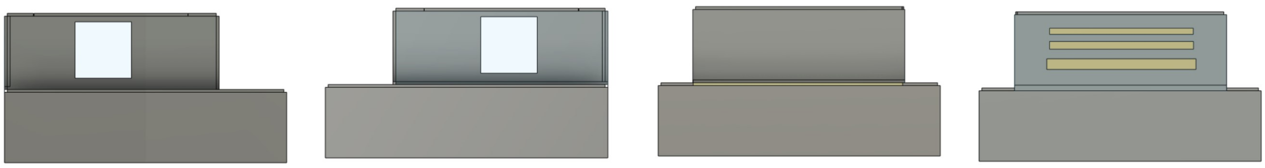


Figure 6: Side views, front and back view

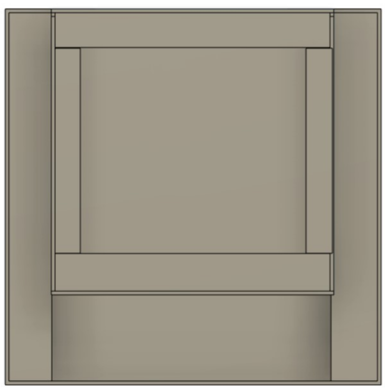


Figure 7: Top view

4 Experiments conducted

4.1 Block Diagram and percentage testing

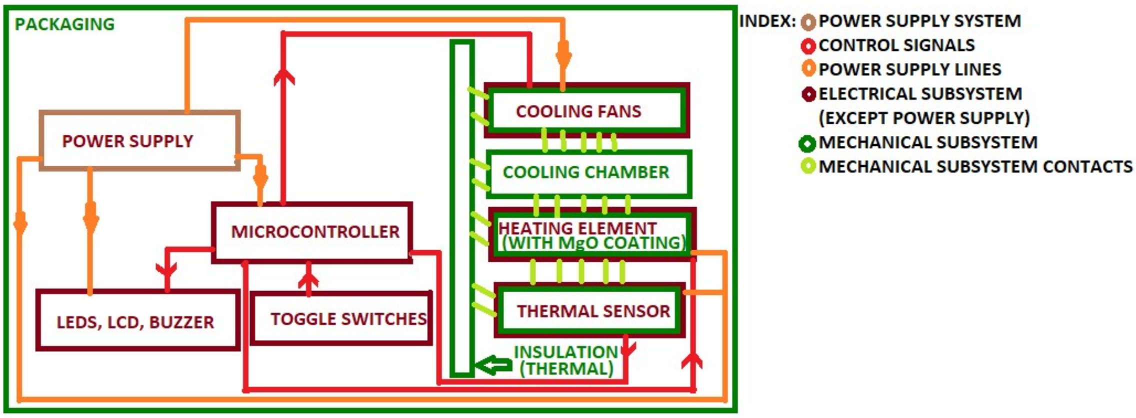


Figure 8: Interconnection and Layout of the Subsystems

Block	Percentage Tested	Explanation
Power supply	100 %	The SMPS has been tested and is able to supply the required voltage and current for heating the coil
LCD	100 %	LCD interfacing complete
ADC	100 %	ADC interfacing complete
Thermal sensor	100 %	The thermal sensor can correctly measure temperature and display on the LCD
Switch circuits	100 %	The switches of the cooling fan and hot plate were tested and were working correctly
Microcontroller	80 %	The microcontroller has been interfaced with the LCD and ADC. The PID control code has been written and the microcontroller is able to control the peripherals. The only thing left is to build the final package.
Cooling fans	80 %	The cooling fans were tested, only their efficiency in cooling after construction of the entire package is left to be tested.
Packaging, cooling chamber, insulation	50 %	The Design of the packaging is complete, it needs to be constructed.
Heating element	50 %	The temperature of the heating element, once it is sandwiched between the two plates and coated with MgO needs to be measured. For now it has been tested with a variable voltage DC source.
LED, buzzer, toggle switches	0 %	These can only be tested when the entire system has been constructed

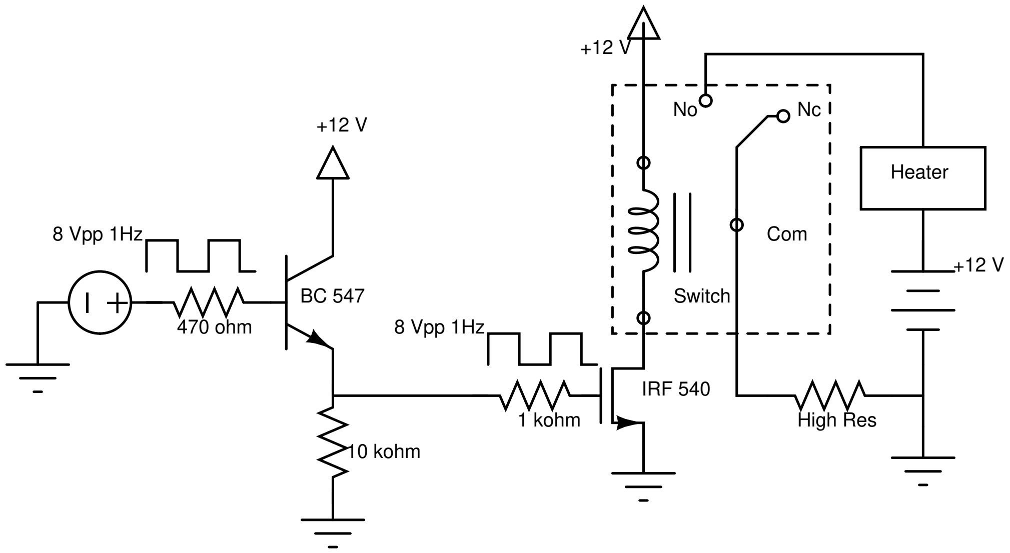
4.2 Experiment 1 - Switch Circuit Testing

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.

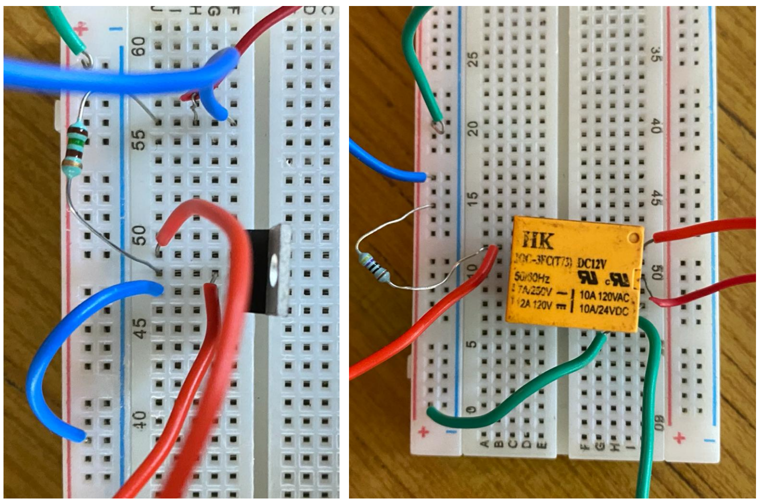


Figure 9: Individually testing the switching circuit components

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)

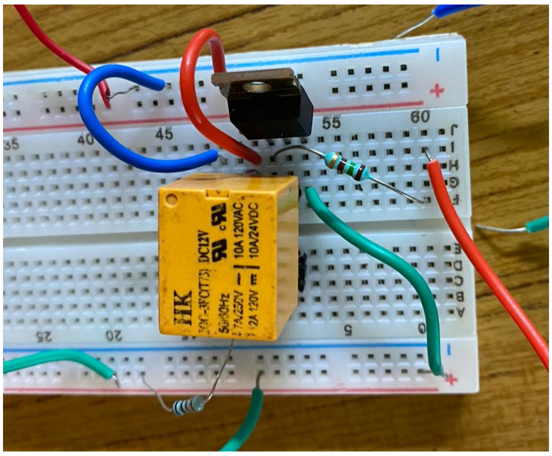


Figure 10: Testing the entire switching circuit

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.

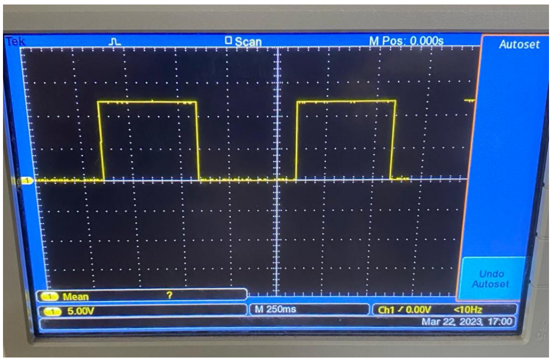


Figure 11: Oscilloscope output when the input is a square wave

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.

4.3 Experiment 2 - Heating Coil Characterization

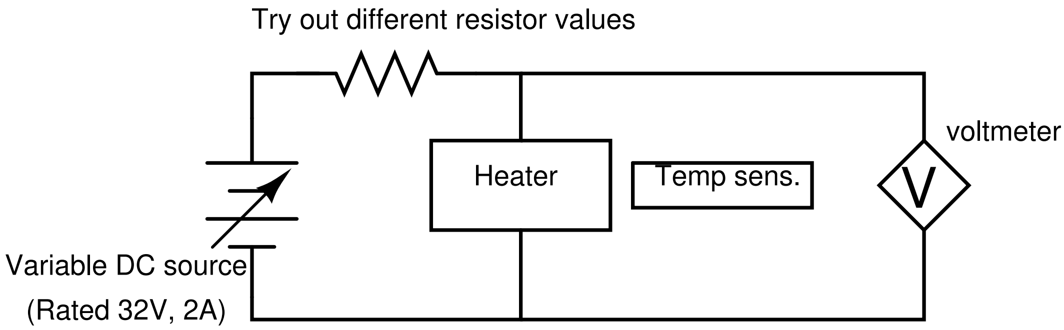
Connecting the heating coil to variable supply voltage to check the current and voltage it requires to heat up to different temperatures and the time required to do so.

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.

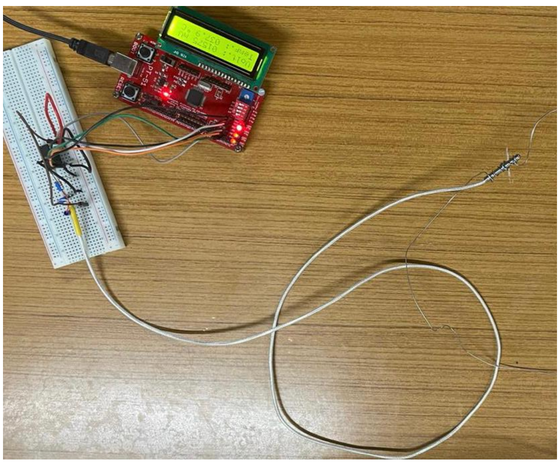


Figure 12: Measuring the nichrome wire temperature

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.

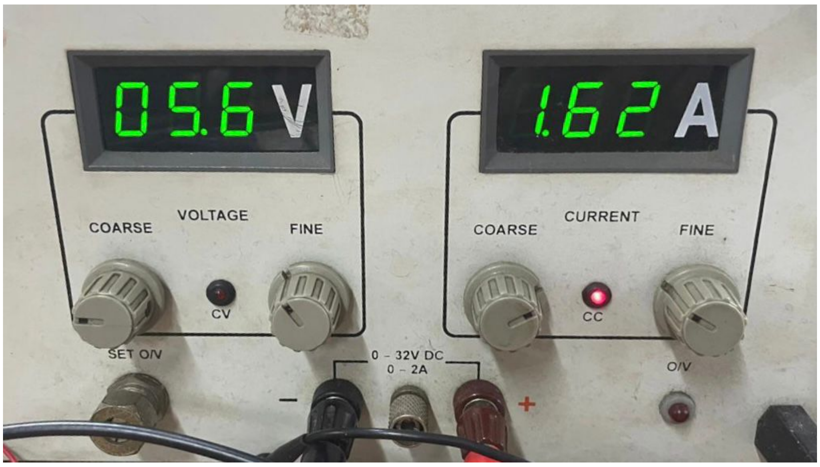


Figure 13: The voltage and the current drawn from the DC supply

Conclusions:

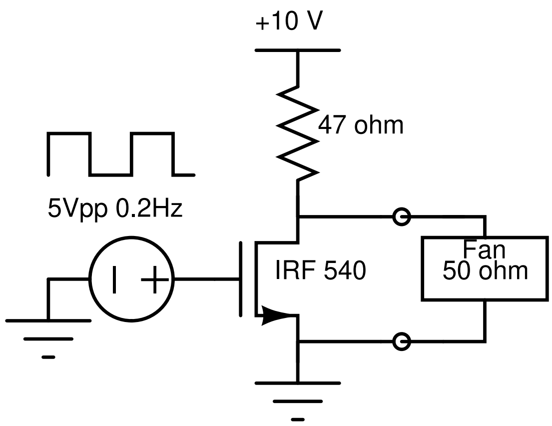
- For electrical safety, we will have to coat the nichrome wire with electrically insulating MgO powder, so that it does not get electrically shorted and its resistance does not change.
- For thermal safety, we will also have to coil the wire and use the copper plates and thermally insulating holders.
- 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 upto 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.

4.4 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.

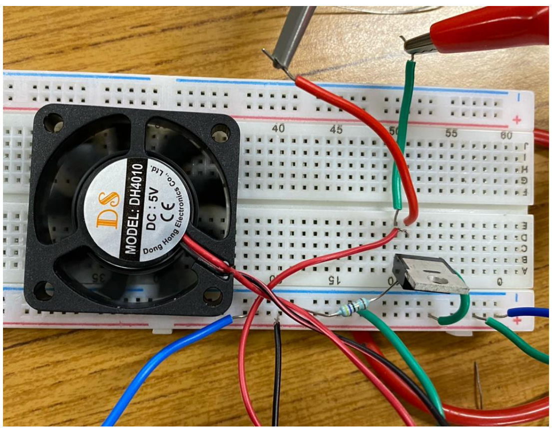


Figure 14: The fan when input is from the function generator

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

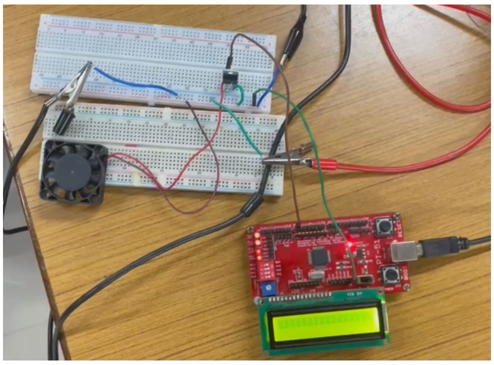


Figure 15: The fan when input is from the microcontroller

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.

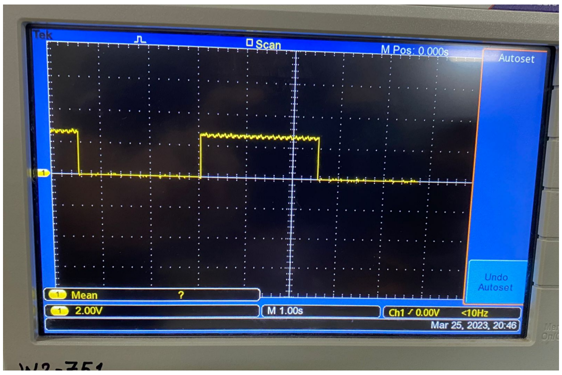


Figure 16: Output of the mosfet acting as a switch

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.

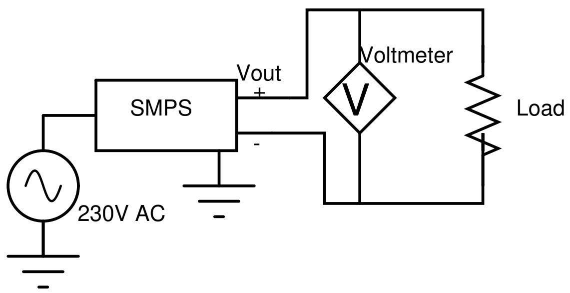
4.5 Experiment 4 - Power Supply Testing

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 17: The SMPS module terminals

Conclusions:

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

4.6 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 clear and correct LCD display.

Figure 18: 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.

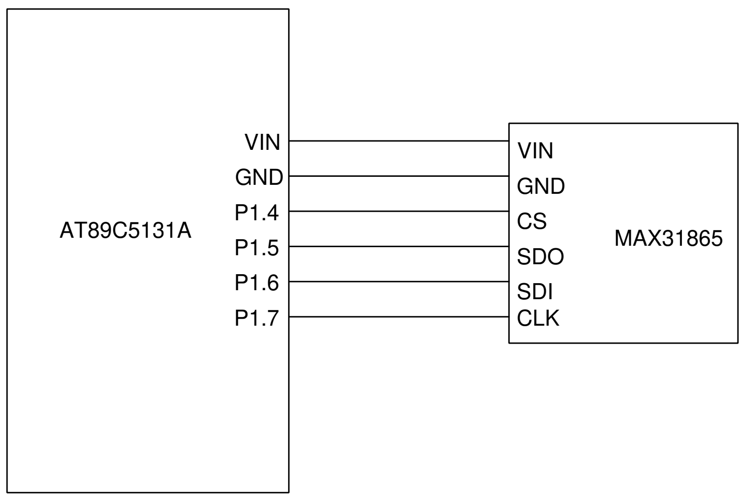
4.7 Experiment 6 - Interfacing the MAX31865 Module

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.

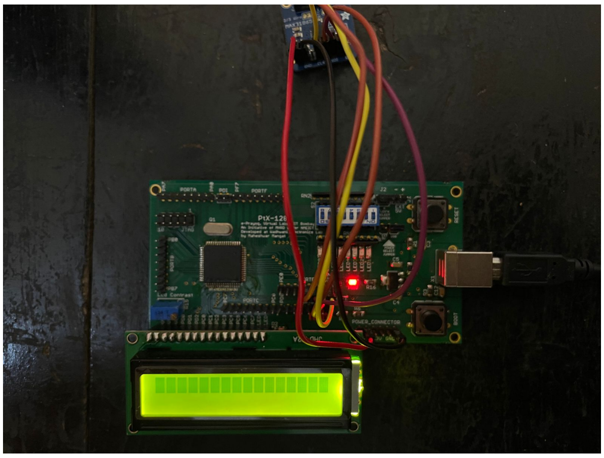


Figure 19: Failed interfacing with the Ptx128 Microcontroller

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.

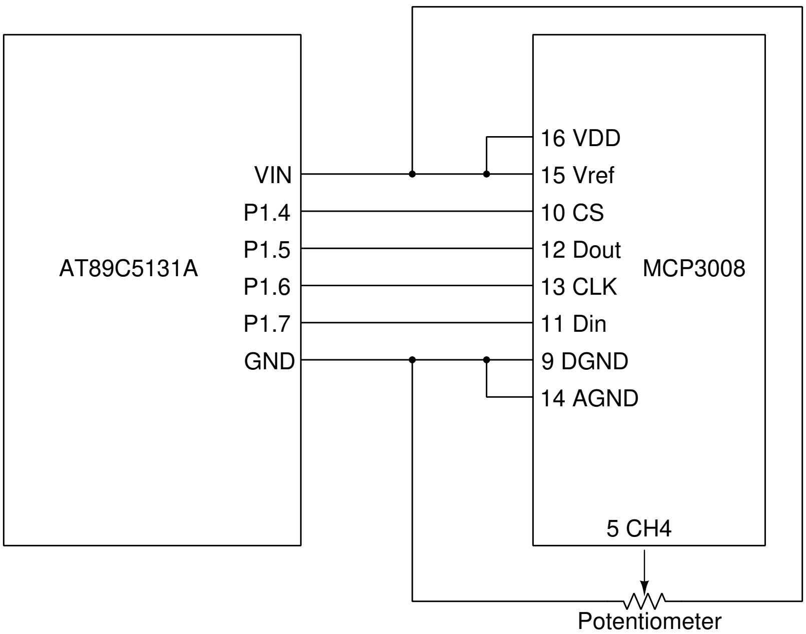
4.8 Experiment 7 - Interfacing MCP3008 ADC

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.

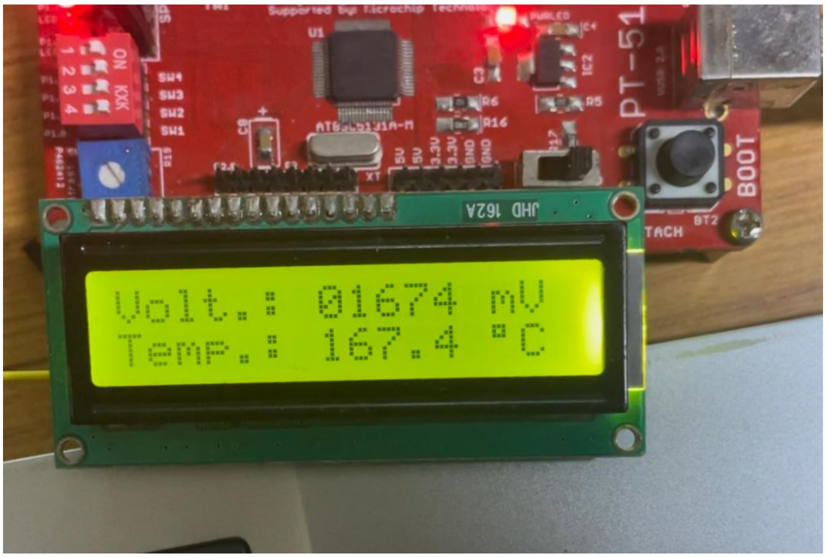


Figure 20: ADC MCP3008 Interfacing with Pt51

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.

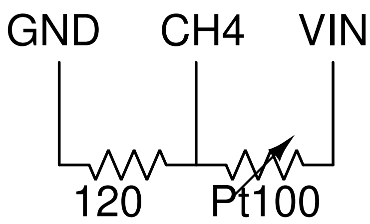
4.9 Experiment 8 - Temperature Sensing with Pt100

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.

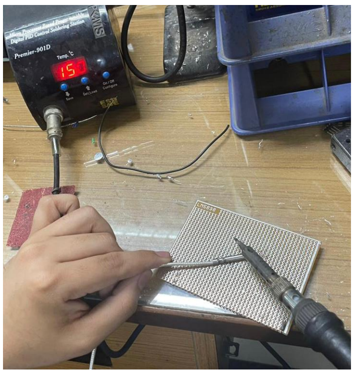


Figure 21: Using the soldering iron to heat the pt100 sensor

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.

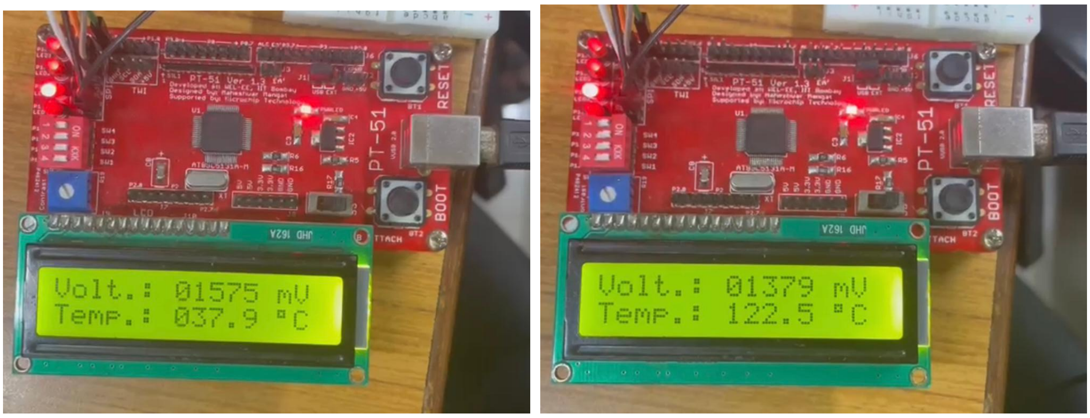


Figure 22: Temperature measurements at the starting and ending of the experiment

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:

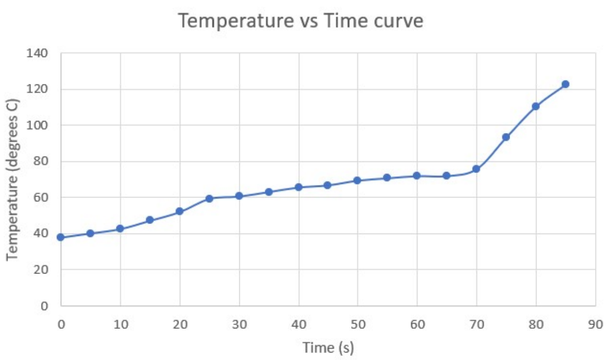


Figure 23: Temperature vs time plot when sensor is heated by soldering iron

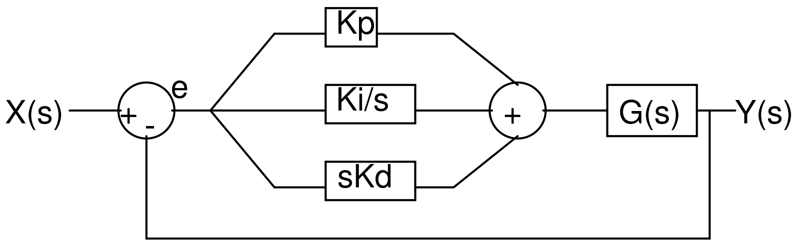
4.10 Experiment 9 - PID control design

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 previous error from 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 a 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.

5 Next steps

5.1 Timeline

Date	Experiment to be completed
30/3/23	**Experiment 10 -** Write the program for implementing the reflow process on the micro-controller for all the three modes of operation. Try both proportional controller and PID controller.
3/4/23	**Experiment 11 -** Created the heating module consisting of the nichrome wire sandwiched between mica sheets laid under the copper metal sheet. Tested the if the heating is even throughout the plate. Checked that the gradient($\approx 3°$C/sec) needed for the reflow process is achieved
7/4/23	**Experiment 12 -** Tested whether with the fans and on full thrust a decrease of $\approx 4°$C/sec is achievable near the peak of the reflow process. This should be accompanied with an air chamber and heat sinks.
11/4/23	**Experiment 13 -** Put the entire package together. Tested all the subsystems to make sure that they are working together. Tested whether the hot plate is able to successfully solder and desolder SMD components.

6 Link to video demo:

- Video Showing Working of Cooling fan
- Video Showing Working of Cooling fan with Microcontroller
- Video Showing Working of Temperature sensor