EE344 : Milestone 2

Reflow Oven for Soldering SMD Components

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1 Circuit Schematic

The Circuit schematic for the reflow oven consists of the general schematic of the micro-controller, the heating elements, the cooling fans, buttons, the Pt100 front-end connecting module, and the voltage regulator. These are given as follows,

1.1 General Schematic - Micro-controller

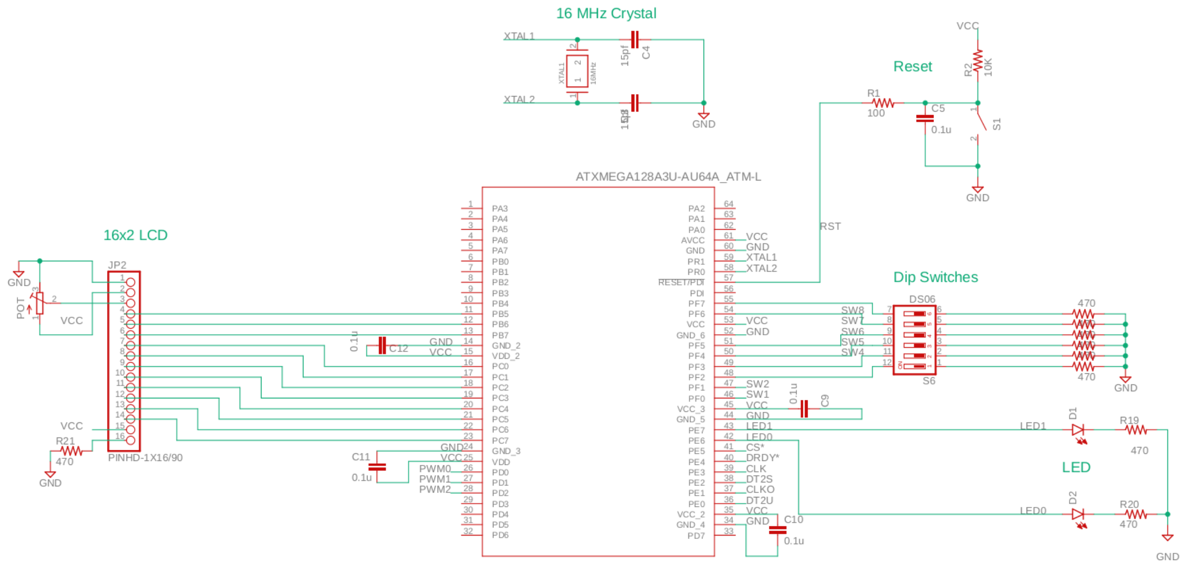

Figure 1: General Schematic

1.2 Heating Element

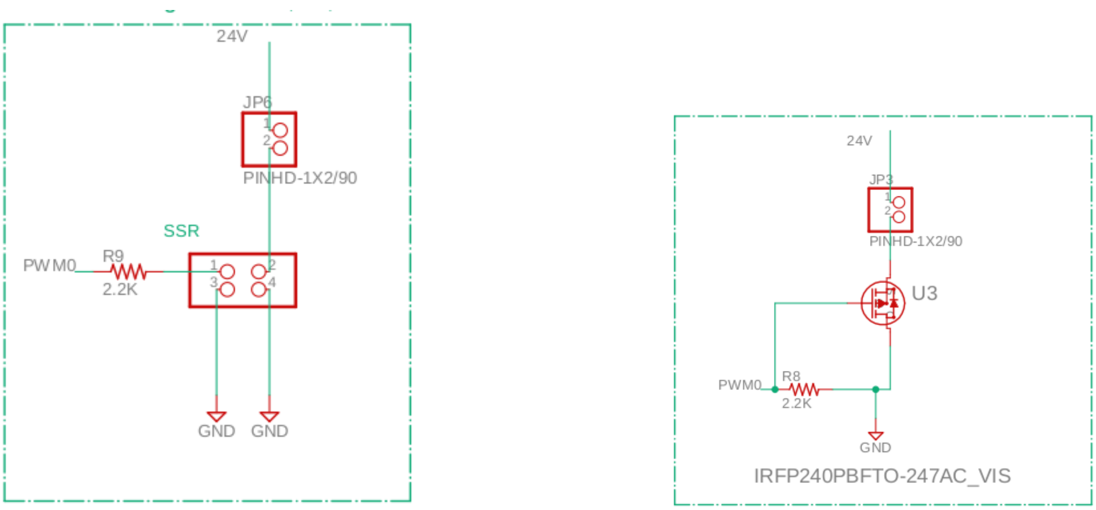

Figure 2: Heating element using a SSR(left) (OR) Power MOSFET

1.3 Cooling Fans

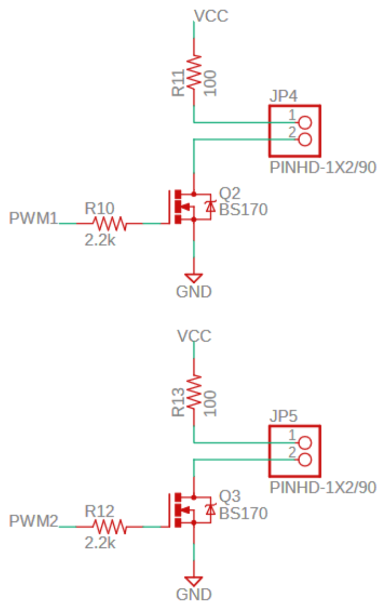

Figure 3: Cooling Fan Schematic

1.4 Buttons

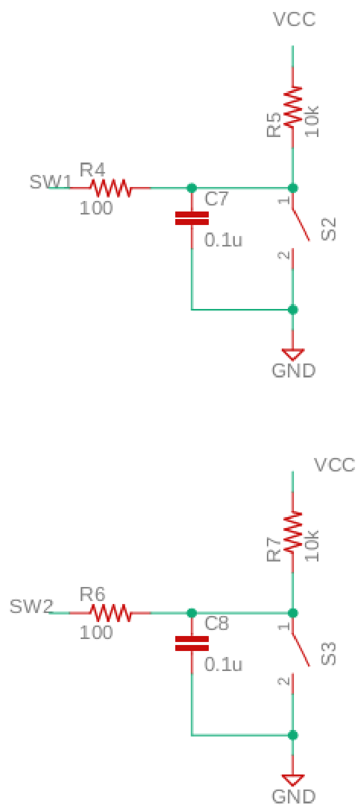

Figure 4: Schematic of the Buttons

1.5 Pt100 Front-end

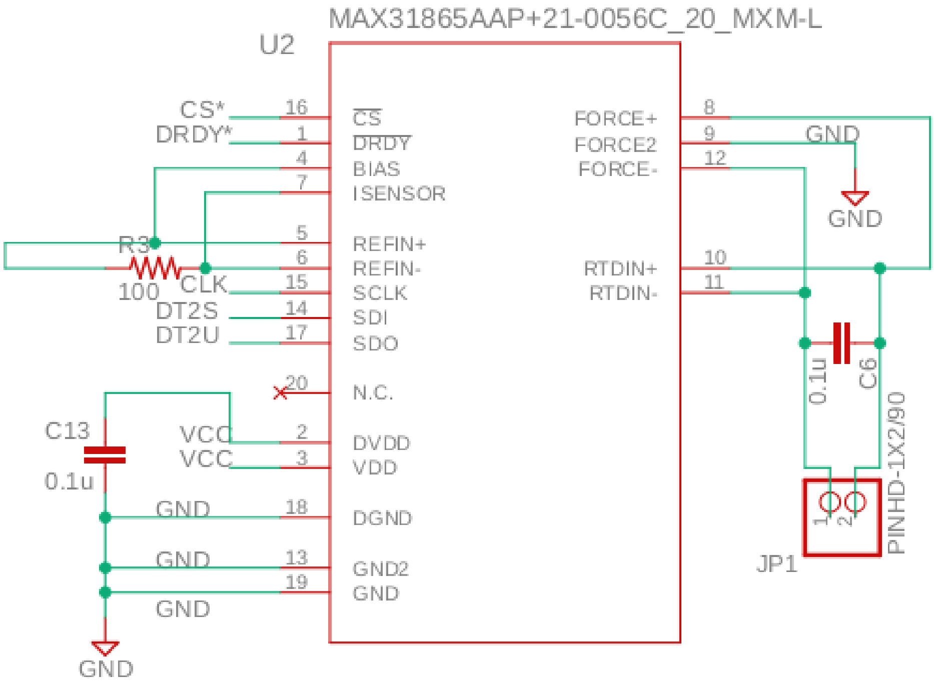

Figure 5: Schematic of Pt100 Front-end

1.6 Voltage Regulator

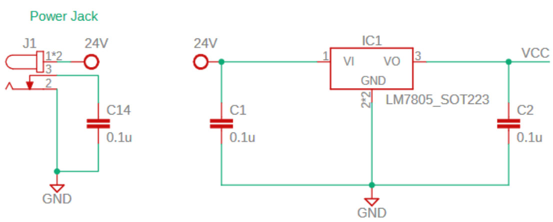

Figure 6: Schematic of the Voltage Regulator

2 Justification for Component Selection

Below are all the components that are needed for the reflow oven. Each component's specification and justification have been provided as follows,

2.1 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.

2.2 MAX31865ATP+T Resistance to Digital IC

Specifications
Accuracy = ±0.5°C(Max),
Supply Voltage = 3V to 3.6V,
Operating Temperature = -40°C to 125°C,
Mounting Type = Surface Mount.
Justification MAX61865 is a resistance-to-digital converter specifically optimized for Platinum resistance temperature detectors(RTDs). The digital value of the resistance sent to the micro-controller will be used to calculate the temperature of the plate using the temperature characteristics of the PT100 resistor. The module will be on the PCB and thus will be well in its operating temperature range.

2.3 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.

2.4 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.

2.5 Magnesium Oxide Powder (Electrical Insulation)

Specifications
Melting point = 2,852 °C,
Thermal conductivity = 45–60 W/mk,
Heat capacity = 37.2 J/mol K,
Electrical resistivity = 10^{16} ohm.m.
Justification Electrically, magnesium oxide is an insulator but thermally it conducts heat efficiently as the heat capacity is very low. Magnesium oxide is going to be added around the nichrome wire as an electrical insulation meanwhile conducting heat to the copper plate.

2.6 LM7805 Voltage Regulator IC

Specifications:
Input voltage = 7V to 25 V,
Output current = 1.5 A (max),
Junction temperature = 0°C to 125°C,
Output voltage = 5V +/-0.2V,

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.

2.7 Power Adapter (230VAC to 24V, 10A)
Specifications
Input voltage = 230 VAC,
Output voltage = 24 VDC,
Output Current = 10 A.
Justification The copper plate with nichrome wire and magnesium oxide requires as high as 240W power to heat at a 3°C/sec gradient to reach the peak of the reflow process. The power adapter outputs 24V, 10A from a 230 VAC input which satisfies the power requirement for the circuit. AC source directly is avoided as it causes grounding issues and needs to be optically isolated from the micro-controller circuitry.

2.8 ATxMega128A3U Micro-Controller
Specifications
Operating voltage = 1.6 – 3.6V,
Eight 16-bit timers/counters,
128KB flash program memory,
One USB device interface,
Two sixteen channel, 12-bit, 2msps Analog to Digital Converters,
16-bit real time counter (RTC) with a separate oscillator.
Justification The ATxMega128A3U has USART which is to be used to communicate efficiently with the MAX31865ATP+T module. It will be used to control the heating of the nichrome wire to maintain the reflow process using a Solid State Relay (OR) a Power MOSFET.

2.9 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 as this is well within its optimum range.

2.10 16x2 LCD Display (with 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.

2.11 Circuit Passives (R, L, C)

Specifications
Resistors = $100\Omega \times 6$, $470\Omega \times 9$, $2.2\ k\Omega \times 4$, $10\ k\Omega \times 3$,
Capacitors = $0.1\ \mu F \times 11$, $15\ pF \times 2$.
Justification The values of the resistors and capacitors are chosen in accordance to the PTX datasheet.

2.12 Control Switches (SSR, BS170)
Specifications
BS170 - N-type, max I_D = 500mA, Typ V_{th} = 2.1V, Breakdown = 60V, $R_{DS} = 1.2\Omega$.
Solid State Relay - Input = 3-200V DC , Output = 5-220V DC, Rated current = 10A.
IRF3205 - N-type, max I_D = 110A, V_{th} = 2-4V, Breakdown = 55V, $R_{DS} = 8\ m\Omega$.
Justification A Solid State Relay is needed for controlling the heating material as a normal MOSFET will not be able to handle the load. Moreover, BS170 is used for controlling the fans as its current ratings and breakdown are well within the requirements. IRF3205 is a power MOSFET and can be used in place of the SSR, it has high current tolerance and a very low ON resistance which makes it a good switch to be used for the heating plate. SSR and IRF3205 can be used interchangeably for the heating plate.

2.13 DIP Switch
Specifications
Type = 6 way SPST(Single Ple Single Throw),
Rating = 30V, 0.15A.
Justification A 6-way DIP switch has enough modes for the reflow oven and the maximum rating of the switch is well beyond the working conditions of the oven.

2.14 Indicators (LEDs , Buzzer)
Specifications
Rating around 2V(forward) for each component
Justification The indicators are of correct rating as required.

2.15 Heat Sink
Specifications
Aluminum Heat Sink = 40x40x20 mm^3.
Justification The heat sinks are to decrease the temperature efficiently such that the heating plate does not heat the micro-controller.

3 Principle of Operations for the Subsystems

The reflow oven has two major subsystems, namely the electrical and the mechanical subsystem. The electrical and the mechanical subsystems are isolated by each other as the operating temperature for the electrical subsystem has to be kept below 125°C, meanwhile, the mechanical subsystem operates till a maximum temperature of 300°C. These are described below,

3.1 Electrical Subsystem

The electrical subsystem consists of the micro-controller and the control switches which send signals to the mechanical parts of the oven in accordance to the reflow process.

3.1.1 Components

The components and their specifications involved are as follows,

Component	Specifications
Power Adapter	Input - 230VAC, Output - 24V, 10A
Voltage Regulator	IC 7805
Micro-controller	AtxMega128A3U AU
Thermal Sensor	Pt100 (Thermistor)
Switching Devices	SSR, MOSFETs(BS170), DIP switch
Indicators	LCD Display, LEDs, Buzzer
Heating Element	Nichrome wire, 24 Gauge
Cooling Fans	5VDC, 0.2A, 2000RPM
Resistance to Digital Converter	MAX31865ATP+T

3.1.2 Principle of Operation

The power adapter connected to the wall socket (230VAC), draws a current of 10A at a potential of 24V. This is connected to the nichrome wire through a Solid State Relay which takes input from the micro-controller. The Solid State Relay allows passing of the current to the heating material when an input voltage (>3V) is applied from the micro-controller's port. Since the Solid State Relay works using infra-red light-emitting diodes and sensors, the load is optically isolated from the input and therefore the micro-controller is safe from the high current used in the heating plate. A voltage regulator(LM7805) is connected to the input power source parallel and this outputs 5V, 1A to be used by the micro-controller, cooling fans, and indicators.

The Pt100 resistor is connected to the nichrome wire using an aluminum heat block and will be heated by the wire. It will be interfaced with the thermal sensor(MAX31865) which will output the resistance of the Pt100 resistor digitally to the micro-controller. 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 DIP switch takes in the mode selected for the oven to be operated in. The LCD module will display the current temperature, the mode and the stage of the reflow process the oven currently is operating in. LEDs and a buzzer will be used for safety precautions, to warn users that the temperature of the plate is currently high. All of these tasks will be implemented by the micro-controller.

3.1.3 Modes of Operation

There will be three different modes the oven will be operating in, namely 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 equally heat all the components of the PCB. Then again the temperature is increased 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.

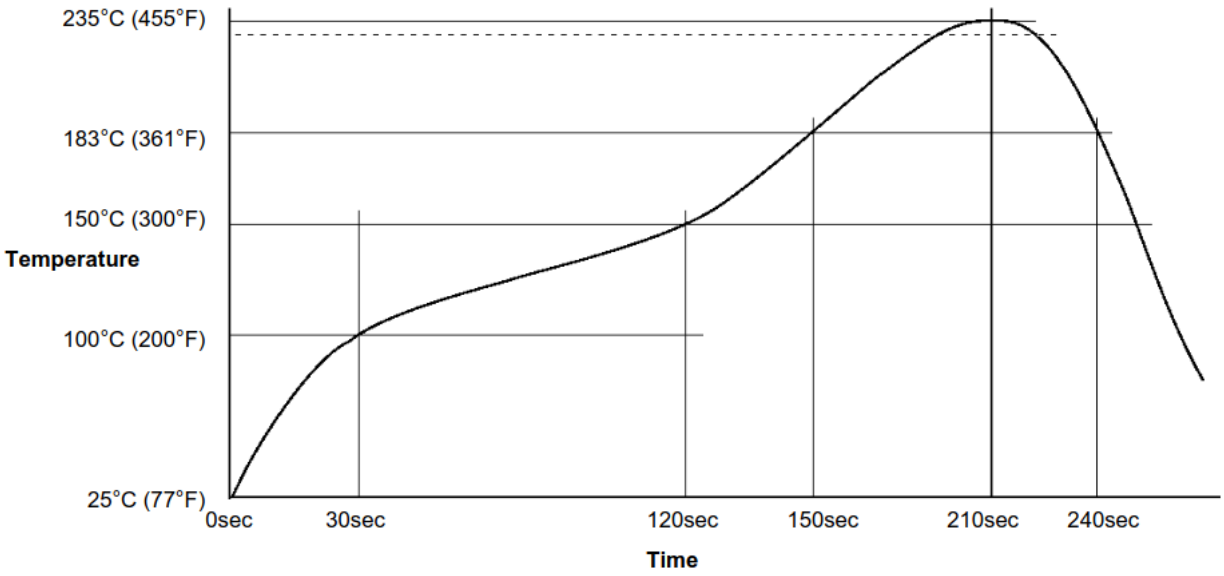

Figure 7: Reflow Process of Sn63/Pb37 *Source*: chipquick.com

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.

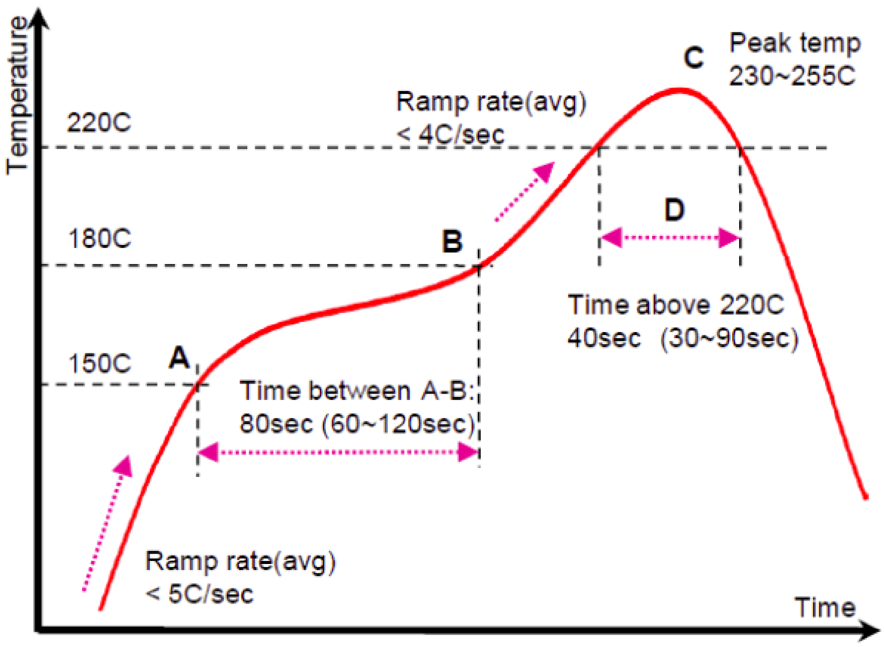

Figure 8: Reflow Process of SAC305 *Source*: 7pcb.com

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.

3.2 Mechanical Subsystem

The mechanical subsystem consists of the heating material and how it should be implemented such that heat does not seep into the electrical subsystem.

3.2.1 Components

The components and their specifications involved are as follows,

Component	**Specifications**
Thermal Sensor	Pt100 (Thermistor)
Heating Element	Nichrome wire, 24 Gauge
Cooling Fans	5VDC, 0.2A, 2000RPM
Cooling Chamber	Heat Sink, Air Chamber
Electrical Insulation	Magnesium Oxide Powder
Thermal Insulation	Cotton pads
Heating Plate	Copper Plate 100x100x1 mm^3

3.2.2 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 will be covered in MgO powder, which is an excellent conductor of heat but an electrical insulator. So, the final heating module will consist of the metal plate touching the magnesium oxide powder in which the nichrome wire is embedded inside. The total heat capacity of this heating module comes out to be ≈ 54J/K.

The heat sink will be just below this heating module, this will be the air chamber of the oven, there will be two cooling fans that will only turn on when the system needs to cool down from the peak value. Finally the air chamber will be isolated from the electrical subsystem by cotton pads. There will be wire connections passing through this insulation connecting the mechanical to the electrical subsytems.

3.3 Interaction Between the 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 through out the whole reflow process. A block diagram of the reflow oven can be seen as below,

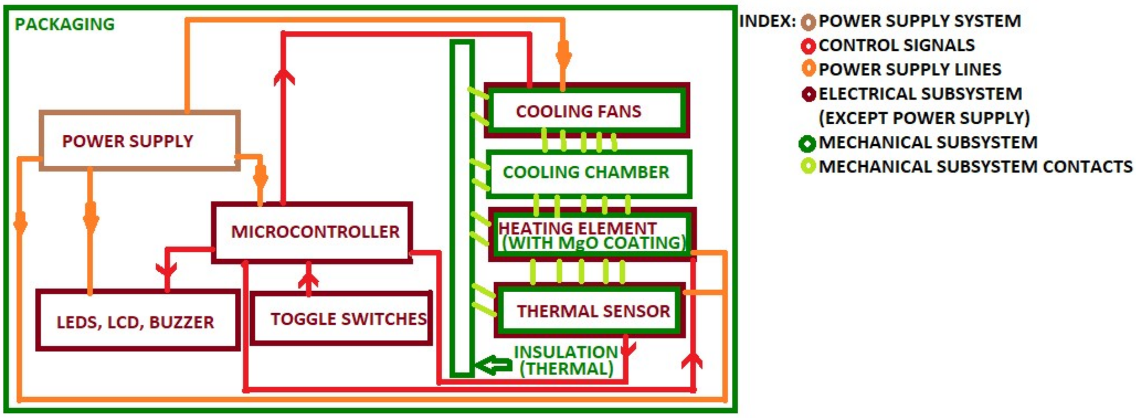

Figure 9: Interconnection and Layout of the Subsystems

4 Preliminary analysis

Most of the electrical components had not arrived, thus we were not able to perform any preliminary analysis for the reflow oven. However, the different analysis to be done as the components arrive are as follows,

Experiment 1
Interface the Pt100 module (MAX31865) with the Micro-controller and configure the resistance to temperature conversion function. The interfacing can be completed using SPI and USART which will be finalised upon testing using the development board of the micro-controller.

Experiment 2
Create the heating module consisting of the nichrome wire covered in magnesium oxide laid under the copper metal sheet. Test the if the heating is even throughout the plate and calculate hysteresis evolved due to layered schematic. Check if the gradient(≈ 3°C/sec) needed for the reflow process is achievable.

Experiment 3
With the fans and on full thrust a decrease of ≈ 4°C/sec is achievable near the peak of the reflow process. This should be accompanied with an air chamber and heat sinks.

Experiment 4
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.

Experiment 5
Create a switch using both Solid State Relay and IRF3205 and check for contingency if any will working with 24V, 10A power source.

5 Risk Mitigation or Contingency

Anticipated Problem	Likelihood	Mitigation Strategy
The 3D printed body gets heated due to the metal plate and the material starts melting.	High(The melting point of the printing material is around 180-200°C whereas the plate can go upto 260°C).	We plan to thermally isolate the metal plate from the outer packaging using support corners with insulation cotton or fibreglass.
The LM7805 Voltage regulator can get damaged due to the 24V supply being high.	Moderate(The maximum Voltage rating of the LM7805 IC is 25V).	Device will be replaced by a higher rated voltage regulator.
The lower PCB circuitry gets damaged by the heat of the copper plate.	Low(The copper plate is seperated by a heat sink, an air chamber and two fans).	More insulation can be added using insulation cotton or fibreglass.
Thermal expansion of the copper plate can strain the packaging.	Low(The thermal expansion coefficient of copper is quite low to affect).	Add support corners and keep a gap between the copper plate and the outer packaging.
SSR may not be able to control the temperature precisely and may cause a huge hysterisis in the heating module.	Moderate(Continuous switching of SSR might not be as quick as expected and may result in delayed action).	The SSR will be replaced with a power Mosfet IRF3205, which meets the required parameters.
The code may be too big for the flash memory of the micro-controller.	Moderate(As there are 3 different modes and we have to interface LCD display, fans and LEDs).	Optimize code but if not possible then add a RAM for extra memory and interface that with the micro-controller.

References

[**1**] http://ww1.microchip.com/downloads/en/devicedoc/atmel-8386-8-and-16-bit-avr-microcontroller-atxmega64a3u-128a3u-192a3u-256a3u_datasheet.pdf

[**2**] https://www.digikey.in/en/datasheets/maxim-integrated/maxim-integrated-max31865

[**3**] https://www.te.com/commerce/DocumentDelivery/DDEController?Action=showdoc&DocId=Data+Sheet%7FPTF-FAMILY%7FA3%7Fpdf%7FEnglish%7FENG_DS_PTF-FAMILY_A3.pdf%7FNB-PTCO-045

[**4**] https://www.sparkfun.com/datasheets/Components/LM7805.pdf

[**5**] https://www.onsemi.com/pdf/datasheet/mmbf170-d.pdf

[**6**] https://www.infineon.com/dgdl/Infineon-IRF3205-DataSheet-v01_01-EN.pdf?fileId=5546d462533600a4015355def244190a

[**7**] https://www.7pcb.com/blog/lead-free-reflow-profile

[**8**] https://www.pcbcart.com/article/content/lead-free-reflow-soldering.html

6 Schematics