# Toaster Reflow Oven (Easy Bake PCBs)

ECE 445 – Design Document

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# 1 Introduction

## 1.1 Problem

Surface Mount Devices (SMD) are electrical components used on Printed Circuit Boards (PCBs). These tiny components can be as small as 0.016in by 0.008in and are attached to the PCBs via a process called soldering. Hand soldering, the most common soldering process, is a very time-consuming task that can produce many errors or bad connections as this is a skill that requires practice and knowledge of the subject. The size of some of the more common SMD components, "0805, …, 0603, or 0402" compound the difficulty of the soldering process as precision is required to successfully solder the component without damaging anything [1]. As a result, testing and debugging often require many hours due to imperfect solder joints, which decreases efficiency and productivity. Thus, a tool called the reflow oven was created to improve the efficiency and reduce the errors of hand soldering. A new technique, reflow soldering, was invented alongside the reflow oven and allows for one to hundreds of SMD components to be attached to the contact pads on a PCB using controlled heat. This process uses thermal profiles to accurately melt the solder and create near perfect joints. Although it is an excellent technology, it is one that has very limited access. Most reflow ovens are commercial units with large price tags that individuals or small business owners have capital for. While there are consumer products, these too have high prices that do not provide results expected at such a price. Do-it-Yourself (DIY) kits to convert a toaster oven into a reflow oven exist as well, but they are never in stock due to part shortages and come with their own set of issues. Additionally, the consumer models and DIY kits do not offer any sort of advance features such as stopping the reflow process if the components move during the reflow process causing a failed connection.

## 1.2 Solution

As a solution to the issues of availability, price, decreasing the rate of error and increasing efficiency we are creating our own DIY kit that will address the concerns. We will design our kit using the parts that are commonly in stock as to best avoid having issues with part shortages. Next, we will develop the kit to be used on almost any toaster oven if it meets a basic requirement of providing 1000W or greater. This wattage is necessary as a requirement for the reflow process is for the heating chamber to achieve a temperature of over 250°C to ensure that the solder will reach a liquified state. Finally, our biggest improvement will be adding a camera with a top-down view to oversee the reflow process. This camera paired with some image recognition software will determine if components move too far off the contact pads and then alert the user and stop the reflow process as to not create poor solder joints.

## 1.3 Visual Aid

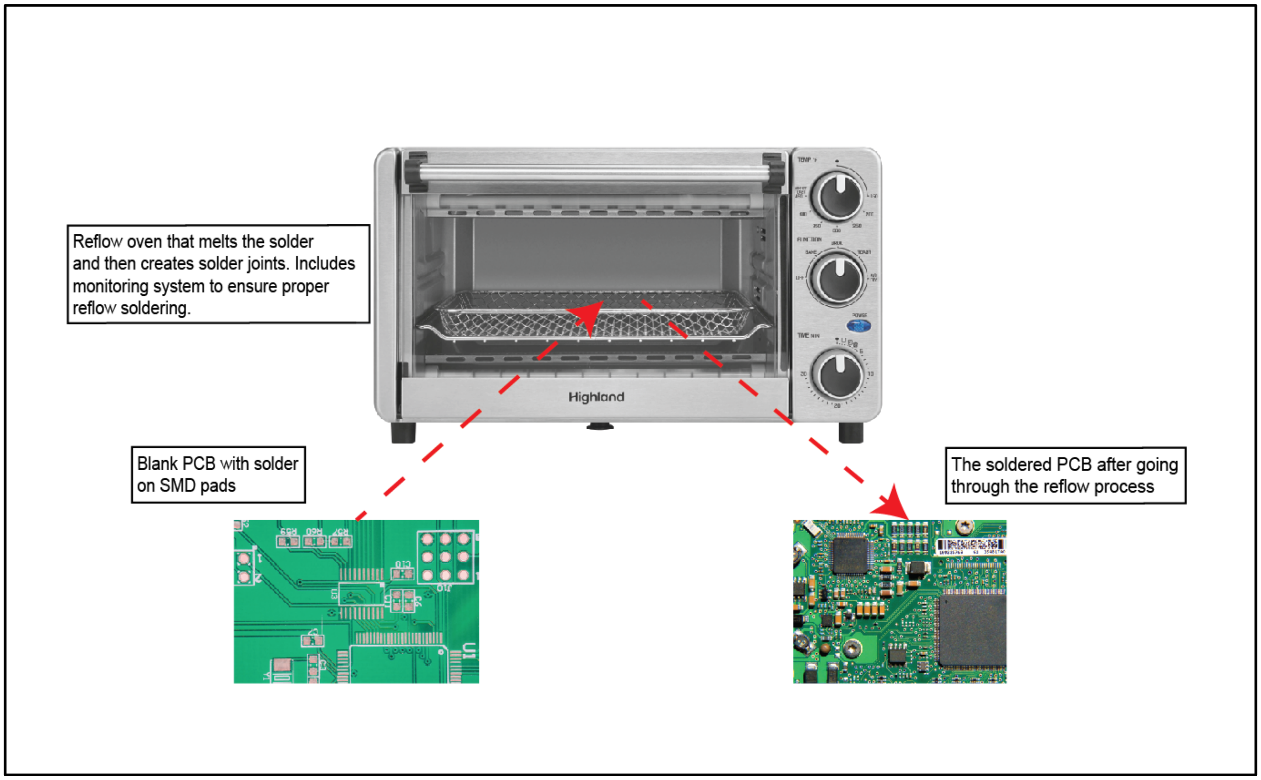


*Figure 1: What a common reflow oven achieves.*

Consumer level reflow ovens for consumers tend to have very simple interfaces consisting of three to four buttons which making it difficult and clunky for users to change their profile provided the machine has this feature. There are very few changes that a user can make on the existing consumer level machines. Our goal is to provide users with the freedom to easily customize their settings by having a touchscreen and a sleek user interface which is shown in Figure 2. Another feature that will be added is a camera module, which is shown in Figure 2. This module will help ensure that the soldering process is successful by tracking the components to verify they do not move too far and end up outside of the contact pads on the PCB.

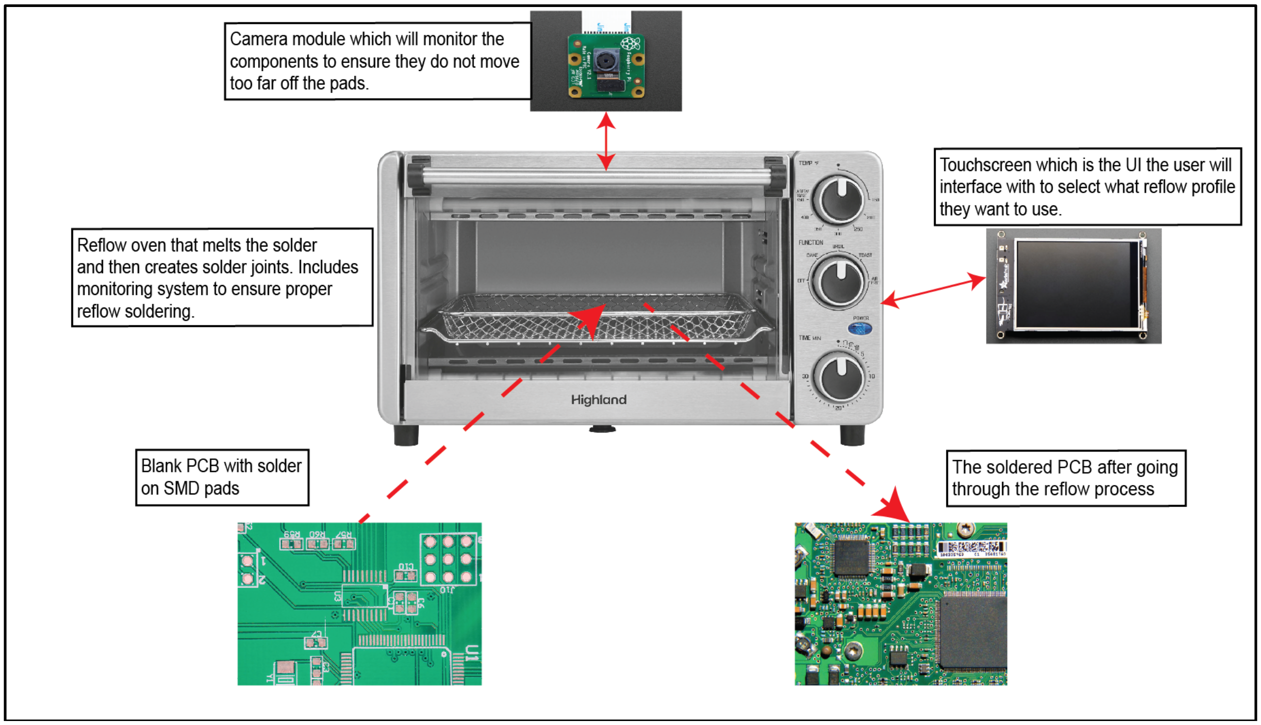


*Figure 2: Added features (touchscreen & camera monitoring) our reflow oven will have.*

## 1.4 High Level Requirements

Our DIY reflow oven has three requirements for it to be considered a success. These requirements are:

1. The reflow oven must be able to solder PCBs with a margin of error of 10%.
2. The camera system of the reflow oven must be able to detect when a component covers less than 50% of the pad.
3. The reflow oven must be able to reach temperatures of 270°C with a tolerance of ± 10°C.

# 2 Design

## 2.1 Block Diagram

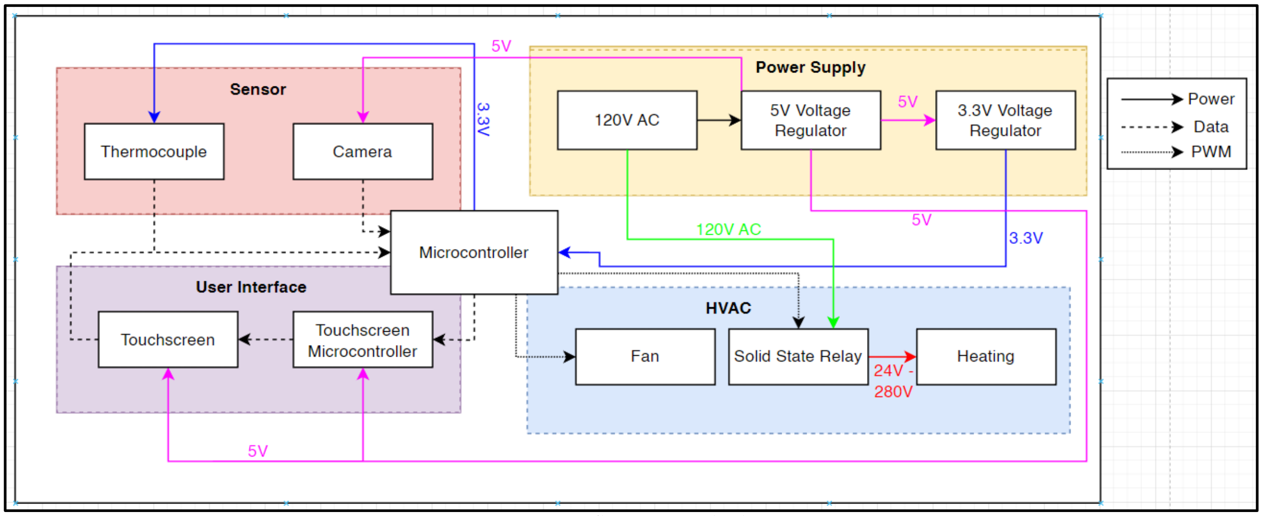


*Figure 3: DIY Reflow Oven Block Diagram*

## 2.2 Subsystems Overview

### 2.2.1 Sensors Subsystem

The sensor subsystem consists of the thermocouple circuit and the camera. These sensors communicate data to the microcontroller, which then uses the supplied data to update the status of the touchscreen, fan, and solid-state relay. The microcontroller relies on these sensors to understand whether our product is functioning as intended. It is imperative that these sensors provide accurate and meaningful information to our microcontroller. We will also discuss the microcontroller in this section, as the majority of its time and effort will be spent on reading the values from these sensors and executing the corresponding commands to the rest of the design. The microcontroller is the brain of the operation and must communicate effectively with the other components.

The thermocouple circuit shown in Figure 4 [2] takes the readings acquired by the thermocouple and converts them into meaningful data to be sent to the microcontroller via SPI. This circuit uses the MAX31855 Cold-Junction Compensated Thermocouple-to-Digital Converter, which enables the conversion of the thermocouple data into readable SPI data for the microcontroller [3]. For a K-type thermocouple, we want to connect the chromel wire to T+ and the alumel wire to T-. This circuit also requires ferrite beads labeled as FB1 and FB2 to reduce the electromagnetic interference between the leads and the rest of the circuit.

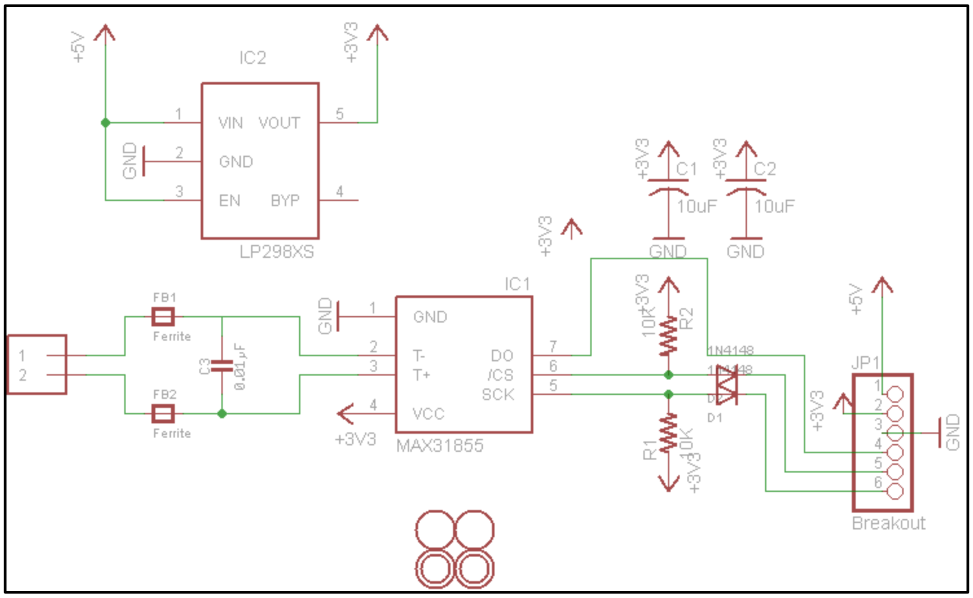


*Figure 4: Thermocouple Circuit Design*

The next sensor is the camera. We have chosen the ArduCAM-M-2MP camera, as seen in Figure 5 [4]. This camera uses an SPI interface to communicate with the microcontroller and I2C for sensor configuration [5]. It requires a 5V input power supply, uses 70mA in normal mode, and 20mA in low mode. It has a resolution of 2

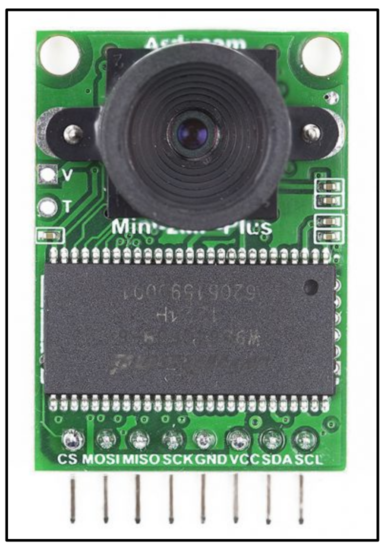


*Figure 5: SPI Camera*

megapixels with an array size of 1600x1200.

The microcontroller is the final part of the sensor subsystem. We have decided to use the LPC1774FBD144,551 microcontroller. This microcontroller communicates with the MAX31855 through SPI, the camera through SPI and I2C, and the touchscreen through SPI. It will also generate a PWM signal for the buckboost converter, which is required for the solid-state relay, and by extension, the heating unit. It will also create a PWM for the fan. This microcontroller, shown in Figure 6, operates at 120MHz, has three SPI interfaces, three I2C interfaces, one USB controller, 109 GPIO pins, two general-purpose PWMs, and runs on 3.3V [6].

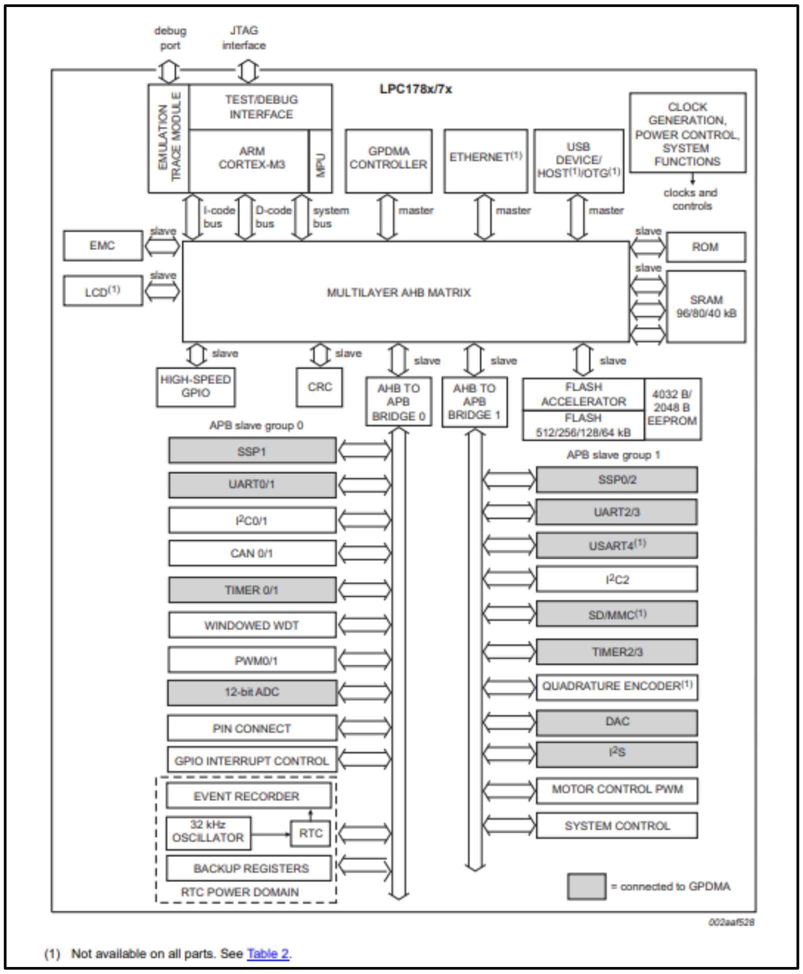


*Figure 6: Microcontroller Block Diagram*

*Table 1: Requirement Verification Table for Sensors and Microcontroller*

| **Requirement** | **Verification** |
|---|---|
| 1. Thermocouple must be accurate within ± 2°C | 1. Assemble the thermocouple circuit and make the appropriate connections to the microcontroller.<br>2. Place the thermocouple in an environment with a known temperature (recommend room temperature).<br>3. Power the thermocouple circuit and the microcontroller with 3.3V |

| | |
|---|---|
| | 4. Print the measured values on the console and check they are within 2°C of the known temperature |
| 1. Thermocouple must be able to give a temperature every 0.5 ± 0.1 second | 1. Assemble the thermocouple circuit and make the appropriate connections to the microcontroller.<br>2. Power the thermocouple circuit and the microcontroller with 3.3V<br>3. Take ten consecutive measurements from the thermocouple and calculate the time difference between each consecutive measurement.<br>4. Print the largest time difference to the console and record it.<br>5. Make sure this value is less than 0.6 seconds. |
| 1. Camera must be able to detect when a component is covering less than 70% of its corresponding pad | 1. Connect the appropriate pins from the camera to the microcontroller.<br>2. Place a model or real PCB with a component ≤70% covering a pad.<br>3. Power the camera with 5V and the microcontroller with 3.3V.<br>4. Take a picture of the board and analyze the data on the microcontroller.<br>5. Verify that the microcontroller can see that the component is covering less than 70% of its pad.<br>6. Repeat with a component covering more than 70% of its pad and verify that the microcontroller sees that the component is covering more than 70% of the pad. |
| 1. Camera must be able to send a frame once every 0.5 ± 0.1 second | 1. Connect the appropriate pins from the camera to the microcontroller.<br>2. Power the camera with 5V and the microcontroller with 3.3V.<br>3. Take ten consecutive pictures from the camera and calculate the time between pictures.<br>4. Print to console the largest of these time gaps.<br>5. Verify that this time gap is less than 0.6 seconds. |
| 1. Microcontroller digital output pins must correctly output a 1 or 0 for a corresponding voltage of ≥ 3.0V and ≤ 0.2V respectively. | 1. Power on the microcontroller using 3.3V.<br>2. Set the output of all the pins to be 0.<br>3. Probe each pin with a voltmeter and verify that the voltage is less than 0.2V.<br>4. Repeat steps 2 and 3 by setting all the pins to 1 and verifying the voltage on each pin is greater than 3.0V. |
| 1. Microcontroller digital input pins must correctly read a 1 or 0 for a corresponding voltage of ≥ 3.0V and ≤ 0.2V respectively | 1. Power on the microcontroller using 3.3V.<br>2. Attach to all pins a voltage of 0.2V.<br>3. Set all digital pins to be inputs, print the values to the console, and verify that all values are 0.<br>4. Repeat steps 2 and 3 by attaching a voltage of 3.0V across all the pins and verifying that all pins read a 1. |
| 1. Microcontroller can produce a variable PWM signal at a frequency of 100kHz | 1. Power on the microcontroller using 3.3V. |

| | |
|---|---|
| | 2. Attach an oscilloscope probe to the output of the PWM in use.<br>3. Set the duty cycle to 50%.<br>4. Verify that the frequency and duty cycle are correct.<br>5. Repeat steps 3 and 4 for varying duty cycles. |

### 2.2.2 HVAC Subsystem

The HVAC subsystem is responsible for heating and cooling the chamber of the toaster oven based on data received from the microcontroller. The microcontroller uses the temperature reading from the thermocouple and the current phase of the reflow process to determine whether to turn on the fan or the heating system.

#### 2.2.2.1 Cooling and Ventilation

The fan system has two objectives. It consists of a generic 5V computer fan that is controlled via a Pulse Width Modulation (PWM) signal to adjust the fan speed. The first objective of the variable fan speed is to cool the chamber to the required temperature depending on the current phase. The second objective is to guide the smoke, produced from the melting flux in the solder, into a charcoal filter that removes toxic smoke that "can result in occupational asthma or worsen existing asthmatic conditions; as well as cause eye and upper respiratory tract irritation" [7] The PWM signal originates from the microcontroller's PWM pins at 3.3V, connects to a 3.3V-5V

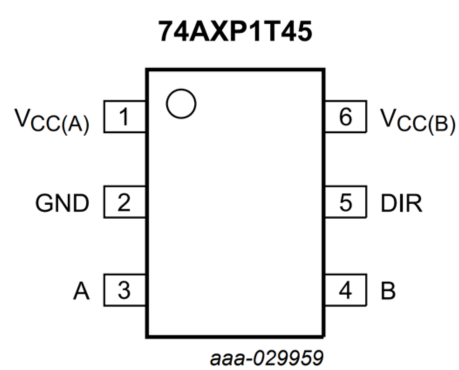


*Figure 7: 74AXP1T45 Schematic*

level shifter, 74AXP1T45, and then allows the 5V fan to spin at variable speeds, effectively cooling the chamber and filtering out smoke from the solder.

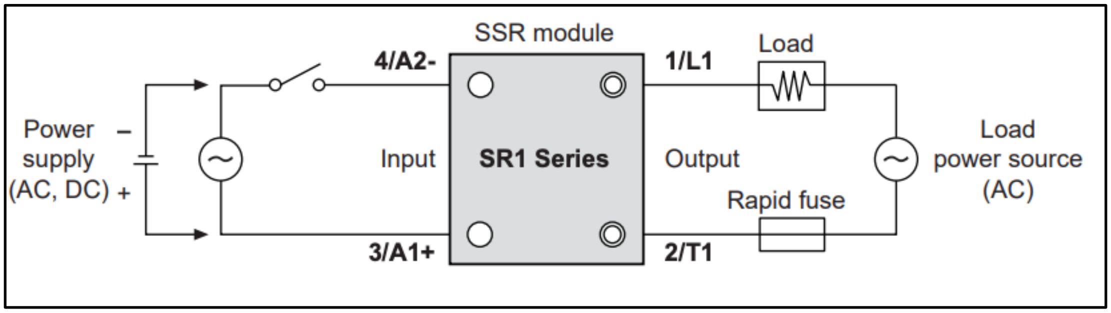


*Figure 8: Solid State Relay Circuit*

### 2.2.2.2 Heating System

The heating system consists of an SR1-1210 Solid State Relay, as shown in Figure 8, which cuts the one-phase power from the wall to the toaster oven. It also takes a PWM input from the LPC1774FBD144 microcontroller that connects to a custom-built boost converter similar to the one shown in Figure 9 to get a variable output (4VDC – 40VDC).

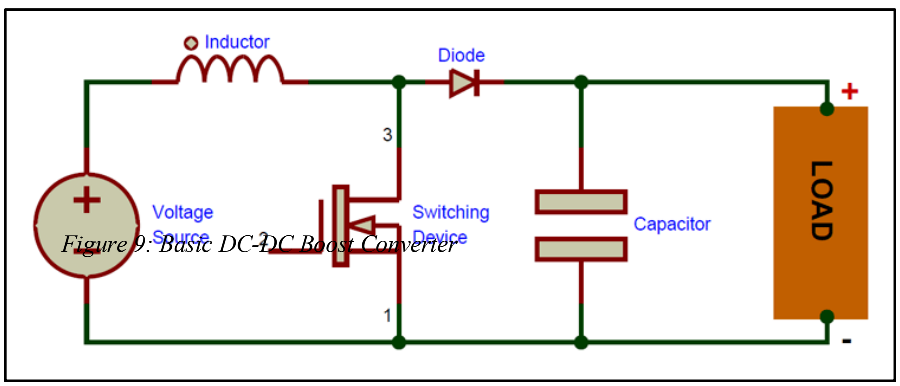


*Figure 9: Basic DC-DC Boost Converter*

This boost circuit's variable output serves as an input for the solid-state relay, which provides the toaster oven heating coils with AC voltage. Precise temperature control (24VAC – 240VAC) is possible by limiting the AC voltage, allowing better control of the reflow process. Following the JEDEC classification of reflow profiles more closely, shown in Table 2, is achievable using this method as the temperature control is more accurate.

*Table 2: JEDEC Classification Reflow Profile*

| Profile Feature | Sn-Pb Eutectic Assembly | Pb-Free Assembly |
|---|---|---|
| Average ramp-up rate (Tsmax to Tp) | 3° C/second max. | 3° C/second max. |
| **Preheat**<br>- Temperature Min ($Ts_{min}$)<br>- Temperature Max ($Ts_{max}$)<br>- Time ($Ts_{min}$ to $Ts_{max}$) (ts) | <br>100 °C<br>150 °C<br>60-120 seconds | <br>150 °C<br>200 °C<br>60-180 seconds |
| Time maintained above:<br>- Temperature ($T_L$)<br>- Time ($t_L$) | <br>183 °C<br>60-150 seconds | <br>217 °C<br>60-150 seconds |
| Peak Temperature (Tp) | See Table 4.1 | See Table 4.2 |
| Time within 5°C of actual Peak Temperature (tp)[2] | 10-30 seconds | 20-40 seconds |
| Ramp-down Rate | 6 °C/second max. | 6 °C/second max. |
| Time 25°C to Peak Temperature | 6 minutes max. | 8 minutes max. |

*Table 3: Requirement Verification Table for HVAC*

| Requirements | Verification |
|---|---|
| 1. When the user begins the reflow process, the coils should begin to heat the chamber and follow the specified profile that was chosen within ±10°C | 1. Verify that the correct PWM signal is coming from the microcontroller by attaching one wire from the oscilloscope to the output pin of the microcontroller and then the other wire to ground.<br>2. Verify that the input to the boost circuit is a 3.3V PWM signal with the specified duty cycle by measuring the input pin of the MOSFET against ground.<br>3. Check the output voltage from the boost circuit and ensure that the value is a PWM signal with a minimum voltage of 4VDC or a maximum voltage of 40VDC by placing the leads of the oscillator on the output of the diode and ground.<br>4. Next, measure the output value of the solid-state relay by placing the positive lead of a multimeter on the output of the solid-state relay and then the ground lead of the multimeter to a ground or metal surface. The voltage should be within the range of 24V-240V AC.<br>5. Finally, measure the temperature that is relayed by the thermocouple in the toaster oven and compare it with what the profile states it should be at. This value should be within ± 10°C. |

| | |
|---|---|
| 1. When the reflow process reaches ± 10°C peak temperature the fan will turn on at 7600 ± 10% RPM. | 1. When the thermocouple returns a temperature that is ± 10°C of the peak temperature of the profile, the microcontroller will send a PWM signal to the level shifter. Verify that the correct PWM signal is coming from the microcontroller by attaching one wire from the oscilloscope to the output pin of the microcontroller and then the other wire to ground.<br>2. Check that the voltage coming from the level shifter is 5V ± 15% by placing the positive lead of a multimeter on the output of the lever shifter and the ground lead on a ground. This is because the fan has a minimum voltage of 4VDC and maximum of 5.75VDC.<br>3. Next, verify that the fan is spinning within the expected range (7600 RPM ± 10%) by placing one lead of an oscilloscope on the Tachometer or 3rd pin of the fan and then getting the frequency and dividing by 3600 to get the RPM. |
| 1. 10 – 30 seconds after reaching the peak temperature ± 5°C the fan will run at 8300 ± 10% RPM. | 1. When the thermocouple returns a temperature that is ± 5°C of the peak temperature of the profile, the microcontroller will send a PWM signal to the level shifter. Verify that the correct PWM signal is coming from the microcontroller by attaching one wire from the oscilloscope to the output pin of the microcontroller and then the other wire to ground.<br>2. Check that the voltage coming from the level shifter is 5V ± 5% by placing the positive lead of a multimeter on the output of the lever shifter and the ground lead on a ground.<br>3. Next, verify that the fan is spinning within the expected range (8300 ± 10% RPM) by placing one lead of an oscilloscope on the Tachometer or 3rd pin of the fan and then getting the frequency and dividing by 3600 to get the RPM. |

## 2.2.3 User Interface Subsystem

The user interface subsystem consists of the touchscreen as well as the touchscreen microcontroller and is responsible for providing the user with an interface to our reflow oven. In this project, the user interface subsystem will be implemented through a touchscreen. This subsystem will be powered by 5V, and we will include a 3.3V regulator in this module since the internals of this touchscreen operate off 3.3V. The 3.3V regulator is on board so no additional work will need to be done to incorporate this.

Both touchscreen and the display use SPI interface and they both have separate chip selects to avoid any sort of merging or conflicts. The following table outlines some of the performance metrics and criteria that were established to ensure the effectiveness and reliability of this subsystem.

*Table 4: Requirements Verification Table for User Interface Subsystems*

| Requirements | Verification |
|---|---|
| 1. Register 95% ± 5% of user inputs | 1. Build a simple 'touch screen test' application that just serves as a drawable blank canvas.<br>2. Use stylus to draw on the touchscreen and visually ensure that all inputs are getting registered |
| 1. Verify there are minimal 'dead zones' in the touch screen module to affect user inputs | 1. Utilize the same 'touch screen test' application.<br>2. Draw over the entire screen to make sure no spots cannot take in user inputs |
| 1. Have the ability to Create, Read, and Update preset soldering profiles with a maximum of three profiles | 1. Store some soldering profiles on the SD card.<br>2. Ensure that the display can read these preexisting profiles.<br>3. Edit an existing profile and ensure that the changes are permanent.<br>4. Create new soldering profile and ensure that the profile gets stored and remains in the UI. |

### 2.2.4 Power Supply Subsystem

The power supply subsystem is responsible for providing power to all the electronics on our board, as well as for the heating and cooling of the toaster oven. This subsystem includes the toaster oven's 120V AC power supply, a 5V regulator, and a 3.3V regulator.

The 5V regulator is powered by the 120V AC wall outlet and uses the LinkSwitch-TN2 to obtain a 5V DC output. The 5V output is necessary to power the fan and the solid-state relay of the HVAC subsystem. The circuit shown in Figure 9 from the LinkSwitch-TN2 datasheet converts the AC input to a 12V DC output [8]. To achieve a 5V output, we need to adjust the values of R1 and R3 in the resistor divider network such that the FB pin of the LinkSwitch-TN2 sees a voltage level of 2.00V. This requires R1 to be 7.5kΩ and R3 to be 5kΩ.

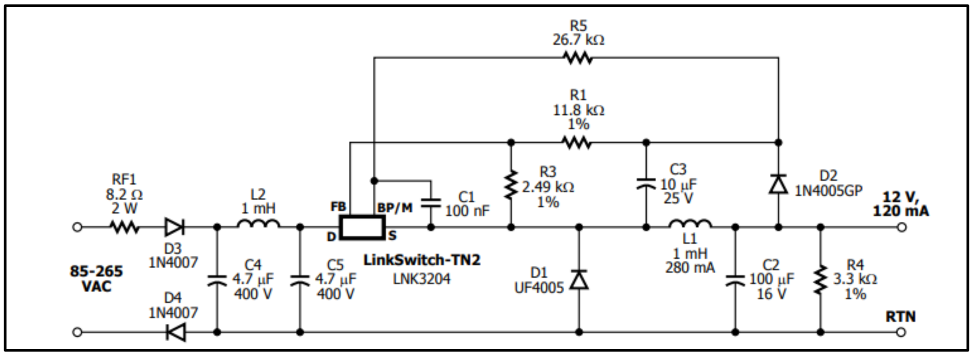


*Figure 9: LinkSwitch-TN2 12V Voltage Regulator Circuit*

The 3.3V regulator is supplied by the 5V output of the 5V regulator and is used to power the remaining electronics, such as the microcontroller, thermocouple, camera, touchscreen, and touchscreen microcontroller. For this, we will use the LP2981 shown in Figure 10 from its datasheet [9]. The requirement table for this component is also provided in Table 5, as shown previously.

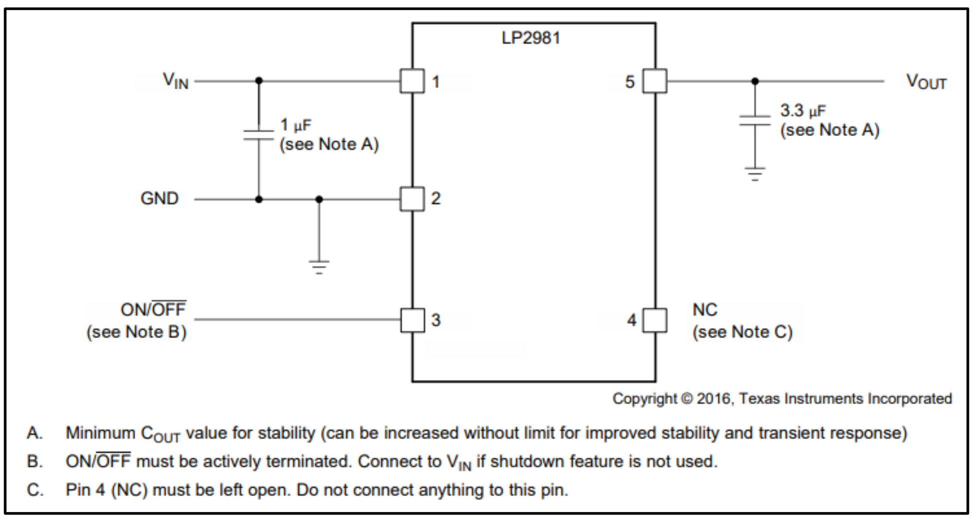


*Figure 10: LP2981 Common Application Setup*

*Table 5: LP2981 Parameters*

| PARAMETER | DESIGN REQUIREMENT |
|---|---|
| Input voltage | 5 V ±10%, provided by an external regulator |
| Output voltage | 3.3 V ±5% |
| Output current | 100 mA (maximum), 1 mA (minimum) |
| RMS noise, 300 Hz to 50kHz | < 1 $mV_{RMS}$ |
| PSRR at 1kHz | > 40 dB |

*Table 6: Requirement and Verification Table for the Power Supply*

| Requirements | Verification |
|---|---|
| 1. 5V regulator circuit outputs 5V ± 10% for a 120V AC power supply. | 1. Attach a 100Ω resistor across the output of the 5V regulator circuit.<br>2. Connect the 5V regulator circuit to the 120V AC power supply.<br>3. Measure the voltage magnitude across the output with an oscilloscope and verify it is within the range of 4.5V to 5.5V. |
| 1. 3.3V regulator outputs 3.3V ± 0.3V given a 5V ±10% input. | 1. Attach a 100Ω resistor across the output of the 3.3V regulator.<br>2. Apply a 4.5V DC voltage source to the input.<br>3. Measure the output voltage with an oscilloscope and verify that the voltage is between 3.0V and 3.6V.<br>4. Repeat steps 2 and 3 applying a 5.5V DC voltage source to the input. |

## 2.3 Software Design

### 2.3.1 Touchscreen User Interface

The TFT LCD 3.2’ RGB SPI display will be programmed using the C programming language, and we will use the Visual Studio Code IDE to develop a user interface that allows users to fully customize their experience or select from a set of pre-built profiles. To achieve this, the touchscreen will take the user's touch input.

When the interface starts, it will display a list of all the pre-built profiles in the system. From this screen, the user can either add a new profile or select a pre-existing one. If the user chooses to add a new profile, they must input the profile name, time, and temperature. If the user selects a pre-existing profile, they will be taken to another screen that displays the profile's settings, along with a button to start the process.

A decision tree illustrating this user interface can be found in Figure 11.

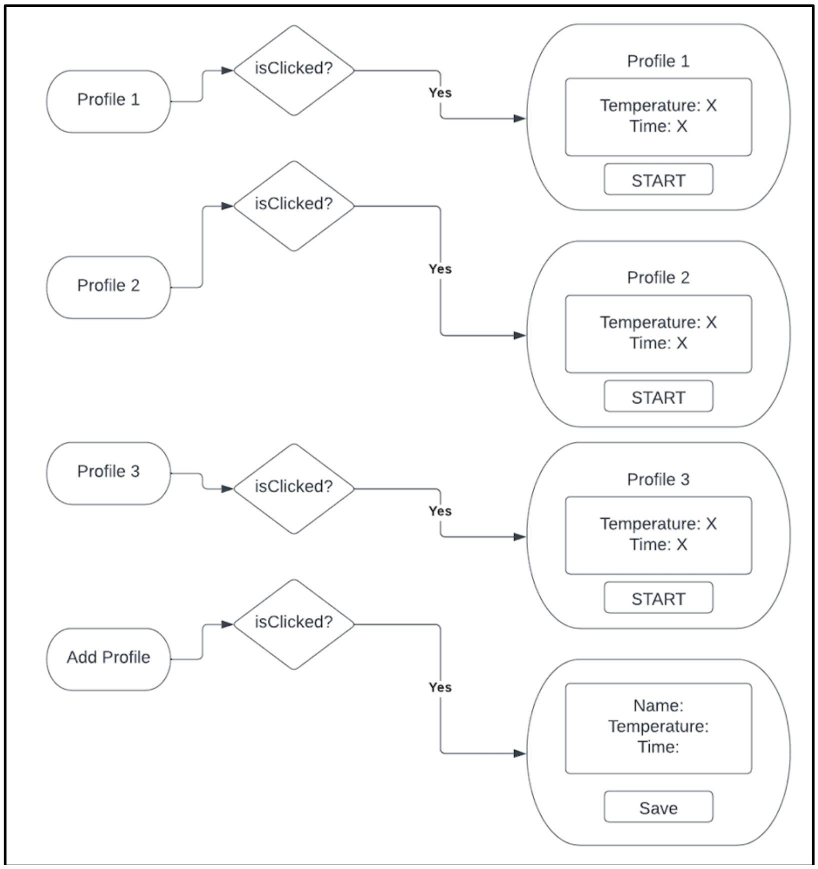


*Figure 11: Touchscreen User Interface Decision Tree*

### 2.3.2 Component Slip Detection

The component slip detection system consists of a camera that will send data to the microcontroller and will determine if the soldering is going as intended. We will be programming this such that the distance between the component and the pad will constantly be measured. This data will be sent to the microcontroller and will conditionally stop the process if the requirements are not met. A diagram of this process can be seen below in Figure 12.

In particular, we will use OpenCV to measure certain aspects of the current picture to determine whether or not a slip has occurred. This process will be done by always keeping an object with a known measurement in the picture and using a "pixel per metric" ratio to estimate the amount of slip that has occurred.

| Requirements | Verification |
|---|---|
| 1. Camera component can successfully take a picture and send data back to the microcontroller. | 1. Connect camera to microcontroller<br>2. Take a picture<br>3. Ensure the picture has been sent to the microcontroller and can be viewed |
| 2. Slip Detection algorithm successfully measures distances given a known distance | 1. Input a given known distance in the frame<br>2. Have the algorithm return a measure of another known component (not inputted into the algorithm)<br>3. Verify that the measurement from the algorithm matches with the true measurement |
| 3. Slip Detection successfully halts the process when in a 'slipped' state | 1. Manually put the system into a failed state<br>2. Ensure that the algorithm detects that this is a failed state and halts the process. |

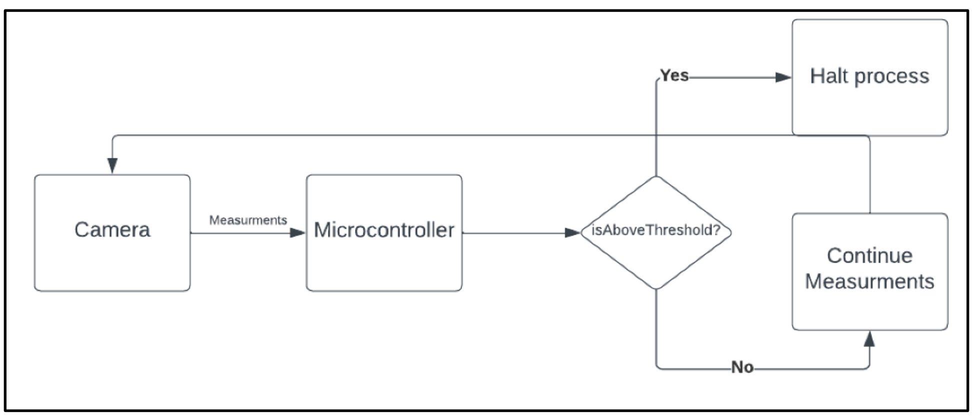


*Figure 12: SMD Component Slip Detection*

## 2.4 Commercial Component Selection

### 2.4.1 Toaster Oven

For our toaster oven we are using an old toaster oven that a group member had in their apartment. It fit the minimum requirements of 1000W. It is also on the smaller size for toaster ovens, meaning that it would be better for quicker and even heating of the internal chamber. We are going this route to show that expensive components are not necessary and that old used up toaster oven can be repurposed into another functional tool instead of ending up in a landfill.

### 2.4.2 Touchscreen

For our touch screen we are using a commercially available touch screen module, namely, the TFT LCD 3.2’ 240x320 RGB SPI Display with Touchscreen. The package includes an LCD touchscreen display and a stylus. This touchscreen operates internally at 3.3 Volts and contains an SD card socket for storage. We chose this touch screen because it is much cheaper than other commercially available touch screens and will drive the overall price of our product down. This is especially important since one of the goals of this project is to keep costs small to justify our project over comparable off the shelves reflow ovens on the market.

## 2.5 Tolerance Analysis

One important aspect of our product is the thermocouple circuit because without this sensor, we are unable to measure the temperature within our oven and therefore cannot make any adjustments to the heat. This means that the PCB will not set correctly, and the baking of the PCB will be a failure. The thermocouple circuit must be able to meet two basic requirements which are 1) the thermocouple must be accurate within ± 2°C and 2) the thermocouple must be able to give a temperature reading every 0.5 ± 0.1 seconds. For the first requirement we can look at Figure 13 and notice that we only want to operate between 0°C and 300°C for our product which means we will have a maximum error of around 1.6°C [10].

**Thermocouple Accuracies**

The accuracy of a thermocouple depends on many factors including but not limited to electrical interference and the purity of the metals used.

| Temperature | B Type | E Type | J type | K Type | N Type | R Type | S Type | T Type |
|---|---|---|---|---|---|---|---|---|
| -200$^0$C | - | - | - | 3 | 3 | - | - | 3 |
| -100$^0$C | - | - | - | 2.5 | 2.5 | - | - | 1.5 |
| 0$^0$C | - | 1.7 | 1.5 | 1.5 | 1.5 | 1 | 1 | 0.5 |
| 200$^0$C | - | 1.7 | 1.5 | 1.5 | 1.5 | 1 | 1 | 0.8 |
| 400$^0$C | - | 2 | 1.6 | 1.6 | 1.6 | 1 | 1 | - |
| 600$^0$C | 1.5 | 3 | 2.4 | 2.4 | 2.4 | 1 | 1 | - |
| 800$^0$C | 2 | 4 | - | 3.2 | 3.2 | 1 | 1 | - |
| 1000$^0$C | 2.5 | - | - | 4 | 4 | 1 | 1 | - |
| 1200$^0$C | 3 | - | - | 9 | 9 | 1.3 | 1.3 | - |
| 1400$^0$C | 3.5 | - | - | - | - | 1.9 | 1.9 | - |
| 1600$^0$C | 4 | - | - | - | - | 2.5 | 2.5 | - |

*Figure 13: Thermocouple Accuracies*

The second requirement relates to the speed of the MAX31855 to be able to send two sets of data within the span of at most 0.6 seconds. From the MAX31855 datasheet we can notice that each batch of data is 32 bits long and transferred through SPI to the microcontroller. The microcontroller has a minimum oscillation of 1MHz which will allow for 32 bits to be sent in 32µs which is well within the time frame to take in two measurements.

The most important part of this project is the heating element and the circuits that control this process. Without the heating, there would be no soldering of the components to the PCB. We also need to closely follow the recommended temperature cures provided in the JEDEC table in Table 2. These requirements have a pre-heating stage where you can only climb up in temperature by 3°C every second. As we have a 1000W toaster oven, the following calculations to find the time to heat 10L of air at 10°C to 13°C were made to ensure that we could, in a theoretical world, satisfy the previously mentioned requirements.

$$Energy = specific\ heat\ capcity\ of\ item * mass\ of\ item * change\ in\ temperature => \ Q = mc\Delta T \quad (1)$$

$$m = density * volume = 1.2466 * 0.01 = 0.012466\ kg \quad (2)$$

With this equation, I was then able to find that the specific heat capacity of air (c) was 1.006 kJ per kg*C, the mass of air at a density of 10°C is 0.0124kg as show in Equation 2, and the change in temperature (ΔT) is 3°C. Then, solving for Q, we get that the total amount of energy required to heat 3L of air at 10°C to 13°C is 0.125kJ.

$$Q = 1.006 * 0.012466 * 3 = 0.037622388kJ \quad (3)$$

We can then find the time required to heat the 10L of air as we have the wattage of the toaster oven. This is because watts are equal to joules per second as power is equal to the energy transferred per second. We then divide the energy found in Equation 3 by 1000 joules per second to get 0.00003762 seconds to heat up 10L of air by 3°C.

$$time = \frac{Q}{W} = 0.037622388kJ * \frac{1\ second}{1000J} = 0.00003762\ seconds \quad (4)$$

The theoretical math checks out and our 1000W toaster oven will be powerful enough to heat our chamber at 3°C. The reason as to why the starting temperature was 10°C was because as the temperature heats up, the more spread apart molecules become and the less energy they require heat up. Another consideration is that there are theoretical calculations—assuming a perfect world and isolation—so there the actual time to heat 10L of air from

10°C to 13°C will not be exactly 0.00003762 seconds as heat is lost to the surrounding air because the toaster oven does not provide a tight seal and as well other laws of thermodynamics are being applied at the same time.

## 2.6 Cost Analysis

### 2.6.1 Parts Cost

*Table 7: Bill of Materials (BOM) for Project*

| **Description** | **Manufacturer** | **Part #** | **Qty** | **Price/Unit** | **Subtotal** | **Link** |
|---|---|---|---|---|---|---|
| IC MCU 32BIT 128KB FLASH 144LQFP | NXP USA Inc. | LPC1774FBD144,551 | 1 | 16.31 | 16.31 | Link |
| IC TRANSLTR BIDIRECTIONAL 6TSSOP | Nexperia USA Inc. | 74AXP1T45GWH | 1 | 0.45 | 0.45 | Link |
| SSR RELAY SPST-NO 10A 24V-240V | AUTONICS | SR1-1210 | 1 | 17.00 | 17.00 | Link |
| FAN AXIAL 40X10.6MM 5VDC WIRE | CUI Devices | CFM-4010-03-22 | 1 | 10.01 | 10.01 | Link |
| N-CHANNEL 60-V (D-S) 175C MOSFET | Vishay Siliconix | SQJ464EP-T1_BE3 | 1 | 1.01 | 1.01 | Link |
| Toaster Oven | Bella | SO-312093_14413_BELLA-4-slice-toaster-oven | 1 | 44.99 | 44.99 | Link |
| Temperature Sensor Development Tools Thermocouple Type-K Glass Braid Insulated Stainless Steel Tip | Adafruit | 3245 | 1 | 9.95 | 9.95 | Link |
| IC CONV THERMOCOUPLE -DGTL SOIC | Analog Devices Inc./Maxim Integrated | MAX31855KASA+T | 1 | 8.31 | 8.31 | Link |
| ArduCAM-M-2MP-Plus | Arducam | B0067 | 1 | 25.99 | 25.99 | Link |
| IC OFFLINE SWITCH MULT TOP 8DIP | Power Integrations | LNK3204P | 1 | 0.76 | 0.76 | Link |
| IC REG LINEAR 3.3V 100MA SOT23-5 | Texas Instruments | LP2981-33DBVR | 1 | 0.56 | 0.56 | Link |
| RES 10K OHM 1% 1/10W 0603 | YAGEO | RC0603FR-1010KL | 2 | 0.10 | 0.20 | Link |
| RES 7.5K OHM 1% 1/10W 0603 | YAGEO | RC0603FR-107K5L | 1 | 0.10 | 0.10 | Link |

| | | | | | | |
|---|---|---|---|---|---|---|
| RES 5K OHM 0.1% 1/10W 0603 | YAGEO | RT0603BRE075KL | 1 | 0.40 | 0.40 | Link |
| RES 26.7K OHM 1% 1/10W 0603 | YAGEO | RC0603FR-0726K7L | 1 | 0.10 | 0.10 | Link |
| RES 3.3K OHM 1% 1/10W 0603 | YAGEO | RC0603FR-103K3L | 1 | 0.10 | 0.10 | Link |
| RES 8.2 OHM 1% 2W 2512 | YAGEO | RC2512FK-7W8R2L | 1 | 0.59 | 0.59 | Link |
| CAP CER 0.1UF 50V X7R 0603 | Samsung Electro-Mechanics | CL10B104KB8NNNL | 2 | 0.10 | 0.20 | Link |
| CAP CER 10UF 25V X5R 0603 | Samsung Electro-Mechanics | CL10A106MA8NRNC | 3 | 0.26 | 0.78 | Link |
| CAP FILM 4.7UF 10% 400VDC RAD | KEMET | R60MR44705040K | 2 | 3.42 | 6.84 | Link |
| CAP TANT 100UF 10% 16V 2917 | KEMET | T491D107K016ATAUTO | 1 | 1.69 | 1.69 | Link |
| FIXED IND 1MH 280MA 2.37 OHM TH | KEMET | SBC3-102-281 | 3 | 1.24 | 3.72 | Link |
| FERRITE BEAD 750 OHM 0603 1LN | Laird-Signal Integrity Products | HZ0603B751R-10 | 2 | 0.12 | 0.24 | Link |
| 400MW SURFACE MOUNT SWITCHING DI | ANBON SEMICONDUCTOR (INT'L) LIMITED | 1N4148W | 2 | 0.10 | 0.20 | Link |
| DIODE GEN PURP 1KV 1A SOD123FL | SMC Diode Solutions | 1N4007FL | 2 | 0.14 | 0.28 | Link |
| DIODE GEN PURP 600V 1A DO204AL | Vishay General Semiconductor – Diodes Division | 1N4005GP-E3/54 | 1 | 0.50 | 0.50 | Link |
| DIODE GEN PURP 600V 1A DO41 | onsemi | UF4005 | 1 | 0.38 | 0.38 | Link |
| TFT LCD 3.2″ 240×320 RGB SPI Display with Touchscreen | Proto Supplies | DSP-17 | 1 | 18.95 | 18.95 | Link |
| MOSFET 2N-CH 50V 0.2A EMT6 | Rohm Semiconductor | EM6K34T2CR | 1 | 0.39 | 0.39 | Link |
| TERM BLK 2POS SIDE ENTRY 5MM PCB | Würth Elektronik | 691137710002 | 3 | 0.41 | 1.23 | Link |
| TERM BLK 4POS SIDE ENTRY 5MM PCB | Würth Elektronik | 691137710004 | 1 | 0.77 | 0.77 | Link |
| TERMINAL BLOCK, SCREW TYPE, 5.00 | CUI Devices | TB001-500-08BE | 1 | 1.29 | 1.29 | Link |

The total for all the electrical components is $129.30. If we include the MSRP price for the toaster oven the total becomes $174.29. The MSRP price for the toaster oven has been included but was purchased for a cheaper price on 3rd party sites such as Craigslist and Facebook Marketplace. It is recommended and expected that the toaster oven will be purchased on such sites to save on costs and recycle old machines. We will also need to include a 9% sales tax and an 5.5% shipping cost estimate to bring the total up to $199.87.

$$(174.29) + (174.29 \cdot .09) + (174.29 \cdot .055) = \$199.56 \quad (5)$$

### 2.6.2 Labor Cost

Given that the average salary of a computer engineer and an electrical engineer that graduated from the ECE department from UIUC in 2021 was $105,352 and $80,296 respectively, the average salary is $92,824 [11]. Then, given that we work 40 hours a week and 52 weeks in a year, the hourly salary becomes $44.63/hour.

$$\frac{10{,}5352+80{,}296}{2} = 92{,}824 \quad \frac{92{,}824}{40*52} = 44.63 \quad (6)$$

Then, the total cost for one team member at a rate of $44.63/hour would be equal to $21,422.40. Then the total labor cost for three team members will be $64,267.20.

$$\frac{\$44.63}{hr} * \frac{30hrs}{week} * 16\,weeks = \$21{,}422.40 \quad (7)$$

### 2.6.3 Total Cost

The total cost for this project will include the Labor Costs for all three team members—$64,267.20— and the cost for the parts—$199.56—which will total $64,466.76 for the whole project.

## 2.7 Schedule

*Table 8: Schedule for Assigned Work for the Project*

| Week | Bhaven Shah | Zak Kaminski | Raghav Narasimhan |
|---|---|---|---|
| 2/27 | Design Review<br>Order Components<br>Design PCB | Design Review<br>Design PCB | Design Review<br>Understand how to setup and use the microcontroller |
| 3/6 | Test modules<br>Design Enclosure for PCB | Pass PCB Audit<br>Test modules | Code interface with thermocouple, camera, and touchscreen<br>Program PWMs |
| 3/13 | Assemble PCB<br>Debug | Assemble PCB<br>Debug | Program Touchscreen |
| 3/20 | Design Updated PCB | Design Updated PCB | Program Profiles and HVAC control |
| 3/27 | Debug | Pass PCB Audit<br>Debug | Debug |
| 4/3 | Debug | Debug | Debug |
| 4/10 | Team Contract<br>Assemble PCB<br>Create Demo | Team Contract<br>Assemble PCB<br>Create Demo | Team Contract<br>Create Demo |

| | | | |
|---|---|---|---|
| 4/17 | Mock Demo, Final Demo, Final Presentation, Final Paper | Mock Demo, Final Demo, Final Presentation, Final Paper | Mock Demo, Final Demo, Final Presentation, Final Paper |
| 4/24 | Final Demo, Final Presentation Slides, Final Paper | Final Demo, Final Presentation Slides, Final Paper | Final Demo, Final Presentation Slides, Final Paper |
| 5/1 | Final Presentation & Final Paper | Final Presentation & Final Paper | Final Presentation & Final Paper |

## 2.8 Risk Analysis

After analyzing our block diagram, we have narrowed down two blocks that pose the highest risk. These two blocks include the sensor system as well as the HVAC system. As stated previously, the HVAC system is responsible for heating and cooling the reflow oven so that the desired temperatures are reached for the solder to work as intended. From personal experience as well as research, we can see that soldering requires extremely high temperatures (up to 700 degrees Fahrenheit) [12]. This can pose a risk to our users as these high temperatures could be extremely dangerous if they are not contained properly.

With the high internal temperatures of the reflow oven, another risk that we face is potential fire. The coils can get very hot and could potentially burn the user as well as catch on fire. We plan to mitigate these risks by monitoring the entire process from start to finish with the use of the camera to ensure that nothing goes wrong, and all the heat is being contained in a safe manner.

The other block that poses risk is the microcontroller. From our block diagram, we can see that the microcontroller will have to handle data from several different sensors. One of the more important pieces of information this microcontroller takes in is information from the camera as it determines whether the surface mount is occurring correctly or not. This poses risk since the microcontroller could get overloaded and not accurately process the information from the camera. Additionally, we need to ensure that the microcontroller is powerful enough to perform the image detection we need to prevent any sort of accidental soldering from happening. Since this is a critical piece of information, it is important that the microcontroller distinguishes this and prevents any risk from occurring. We plan to mitigate these risks by picking our microcontroller accordingly so that it has the appropriate amount of compute power to handle all these tasks without overloading.

# 3. Ethics and Safety

From looking at our block diagram, we recognized that the block that poses the most danger to our user's safety is the HVAC system. As stated previously, this block is responsible for getting the reflow oven to reach very high temperatures in order to perform the solder properly. In reaching these high temperatures, a lot of safety issues could arise such as the entire reflow oven combusting or the user getting burned by accidentally touching a component that gets very hot.

In addition to this, there are various health risks with soldering. One of these risks includes rosin exposure [13]. Rosin exposure comes from the solder flux and when soldering occurs, the flux produces smoke which can cause irritation in the eyes, throat, and lungs. It can also cause other issues such as nose bleeds and headaches. Our user's safety is our highest priority, and we will take the appropriate actions to ensure that we will "hold paramount the safety, health, and welfare of the public" [14]. In order to prevent our users from getting exposed to these dangerous fumes we will ensure that any fumes are contained, and the user is not directly exposed to any of these fumes. Additionally, we will heavily emphasize the use of proper lab ware when operating our reflow oven. These include masks, gloves, and goggles.

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