UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Multipurpose Temperature Controlled Chamber

Electrical & Computer Engineering

Senior Design Group 42

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Project Introduction

High Level Summary of Project

Problem:

People often store food without considering how its temperature will change, leading to instances where food is not thawed or frozen as intended, highlighting the need for an intelligent device to quickly cool or warm food without freezing or cooking it.

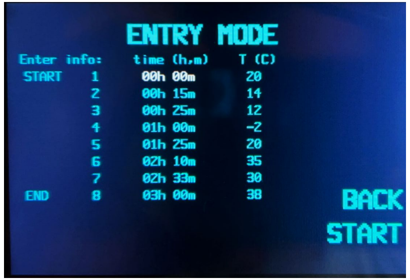
Solution:

Our solution is a **programmable temperature-controlled chamber** that:

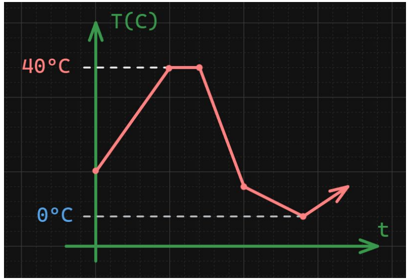
- ➢ Allows users to set a **temperature curve** for food items
- ➢ Has a **user-friendly interface** offering:
  - Standard Presets
  - Temperature Set and Hold
  - Detailed Temperature Curve Settings
- ➢ Designed for **consumer applications** as an affordable and compact alternative to existing expensive and bulky options on the market.

Project Explanation

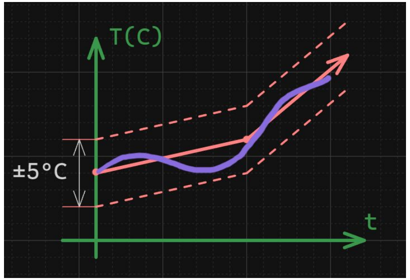
- ➢ The user will have the ability to **set a target final temperature**, **heating/cooling curve** and max/min temperature allowances through GUI on an LCD display.



- ➢ The device will have a temperature **floor of at most 0℃**, and a temperature **ceiling of at least 40℃**. (Including the ability to freeze pure water)



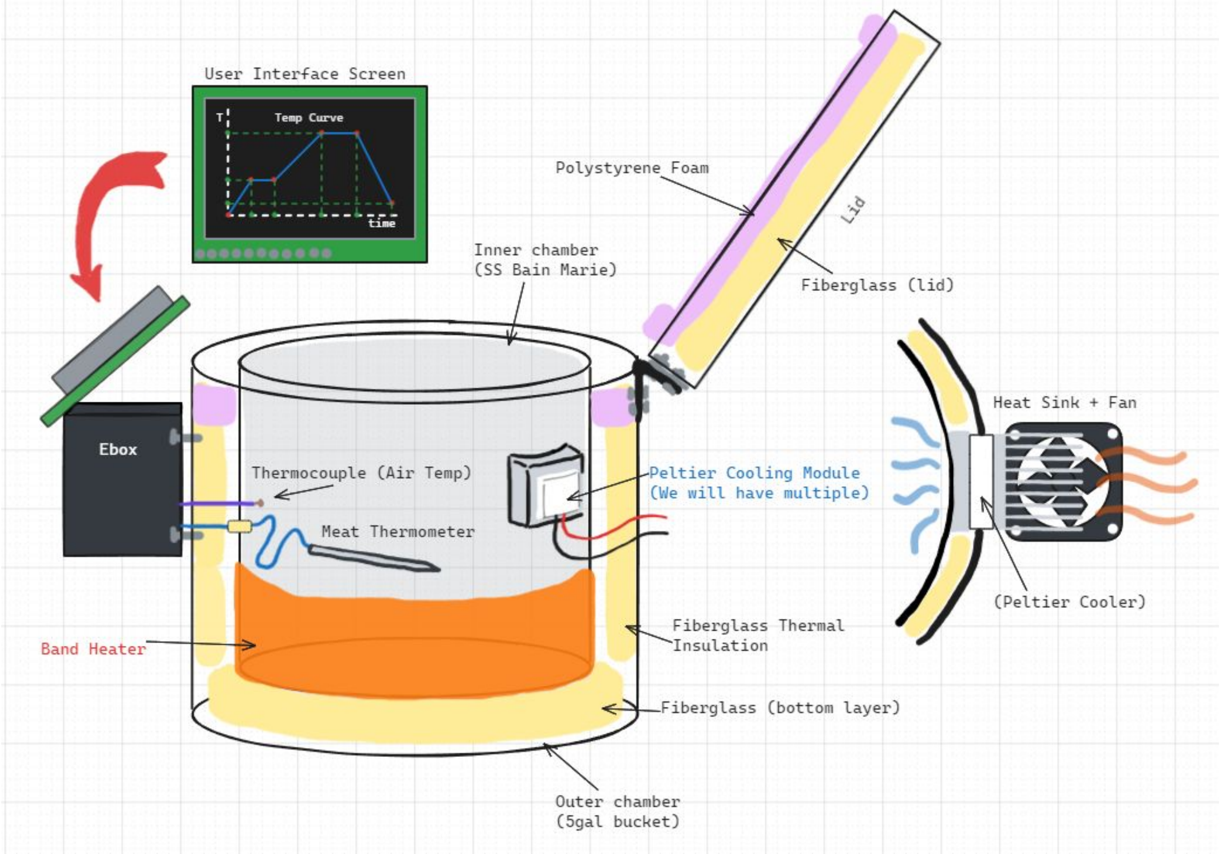
- ➢ The device will be able to hold temperature to **within ±5℃** of target temperature at any given time.



Design Overview

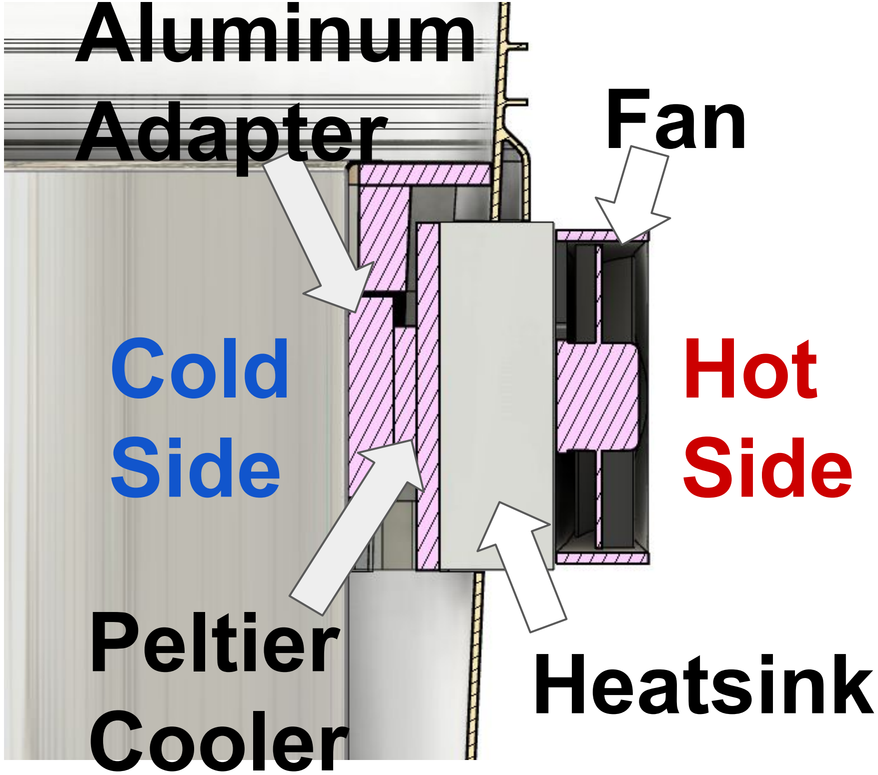
Summary of Project Subsystems

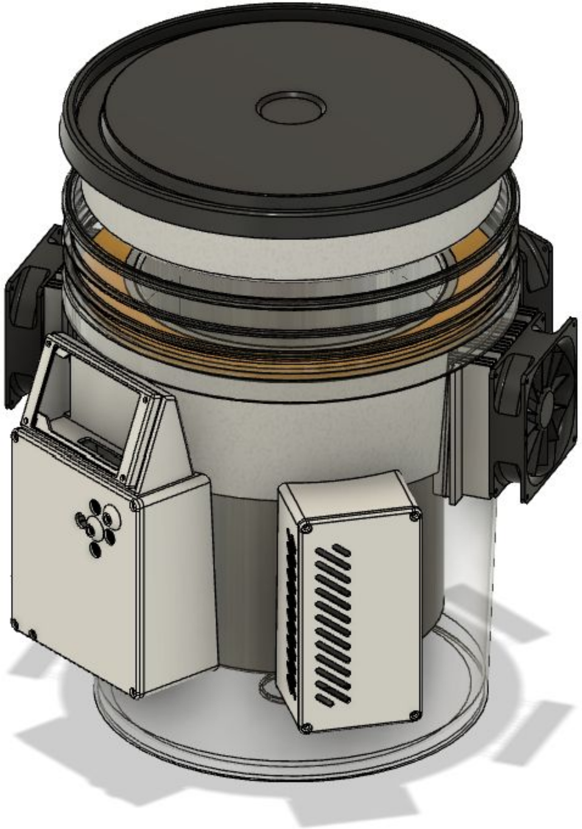
Visual Aid


User Interface Screen
T
Temp Curve
time
Polystyrene Foam
Lid
Inner chamber
(SS Bain Marie)
Fiberglass (lid)
Heat Sink + Fan
Ebox
Thermocouple (Air Temp)
Peltier Cooling Module
(We will have multiple)
Meat Thermometer
(Peltier Cooler)
Fiberglass Thermal
Insulation
Band Heater
Fiberglass (bottom layer)
Outer chamber
(5gal bucket)

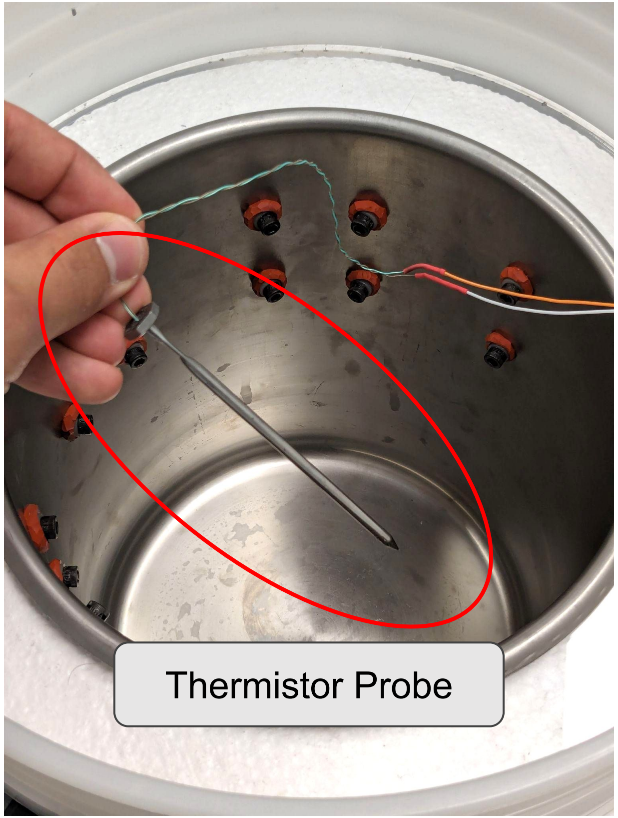

MAIN MENU
CHANGE
TEMP SCALE
CHANGE
COLOR
LET'S COOK!

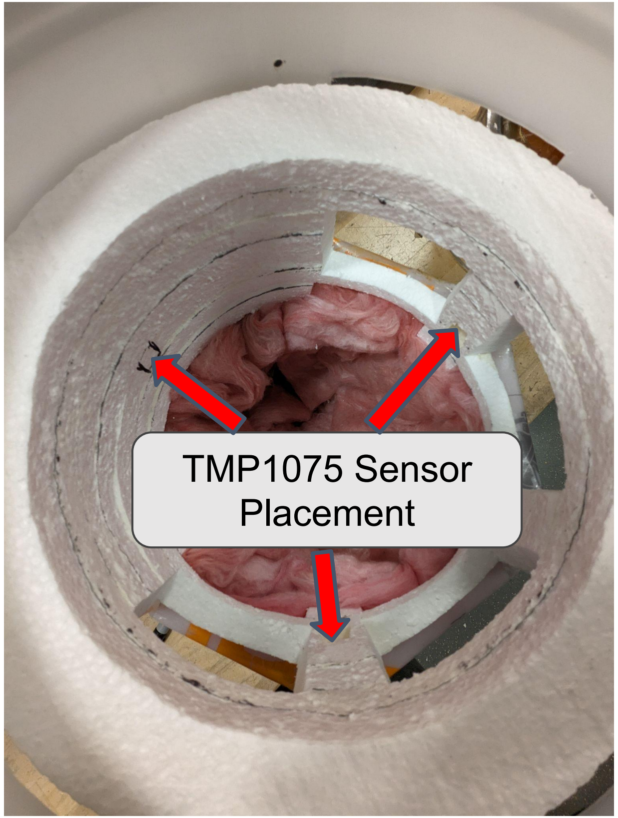
Mechanical Design





Temperature Sensors





Cooling Subsystem

Testing Peltier Coolers Using Programmable Power Supply

- ➢ Verify Peltier Coolers work using a known voltage and observable current
- ➢ Test chamber temperature performance without needing the power electronics to work

Difficulties with Peltier Coolers

- ➢ When screwing in the heatsinks to clamp down on the Peltier coolers, an audible “ting” was heard.
- ➢ After removing the heatsink, we noticed a visible fracture in the Peltier cooler.
- ➢ Fractured Peltier coolers would fail several minutes into being run.

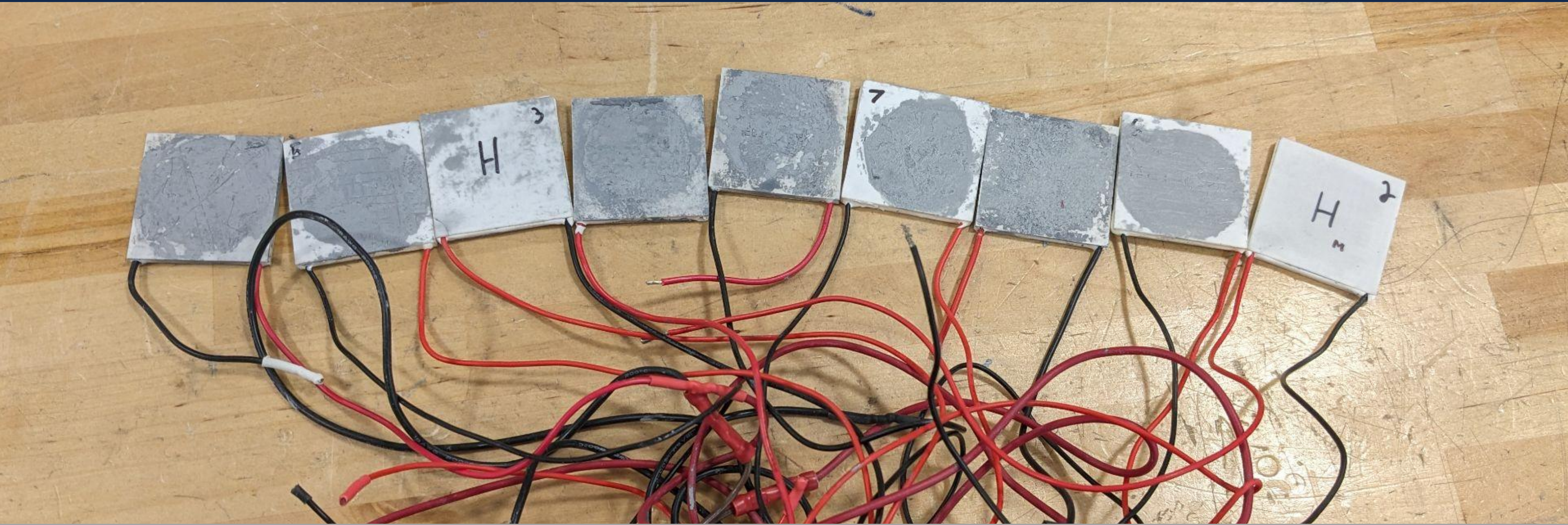
Cracked Ceramic

↓

Peltier Fails Open

How Many TECs Broken?

In total, we broke 13 Peltier coolers, almost all of which were due to mechanical fracturing.



Solution to Peltier Cooler Problem

- After some trial and error, we found the best solution to be the addition of a thermal pad on the adapter side of the Peltier Coolers.
- We think mechanical fracturing was caused by curvature in the surface of the Peltier adapters.

Results:

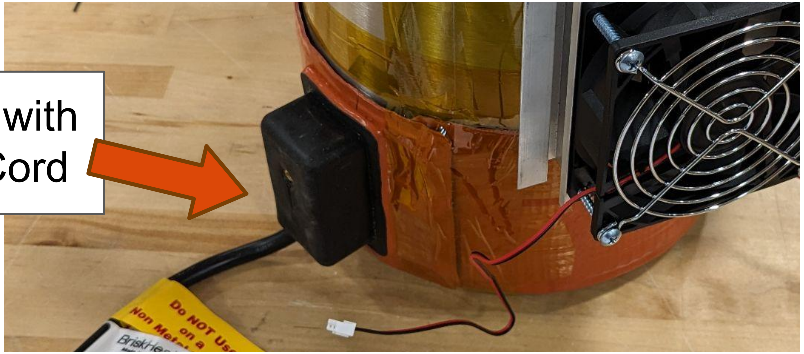
- After applying this solution to all four Peltier coolers, we were able to reach temperatures below 0℃

Heating Subsystem

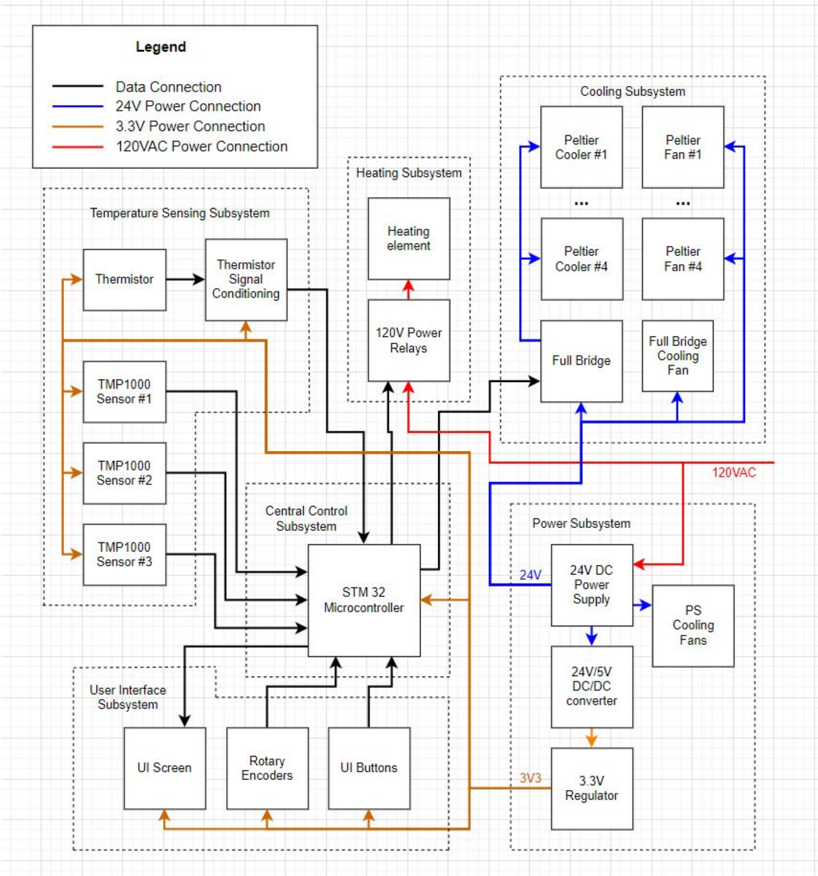
Testing Heating Band

- At first, the heating band was a little too powerful, so we used its built-in temperature knob to reduce its power
- Chamber easily achieved greater than 40℃

Heating Band with 120V Power Cord



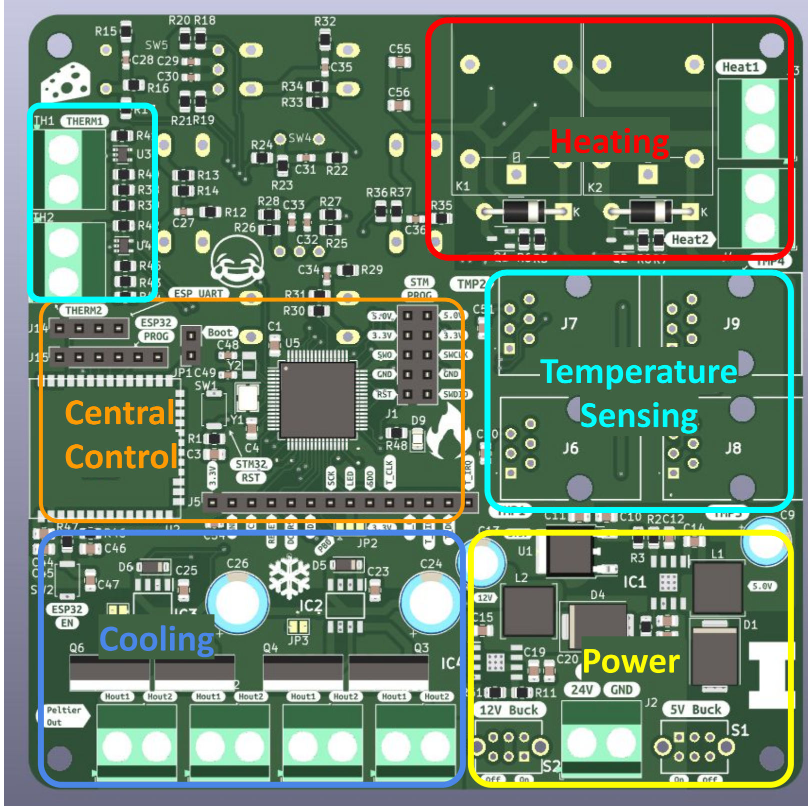
Block Diagram

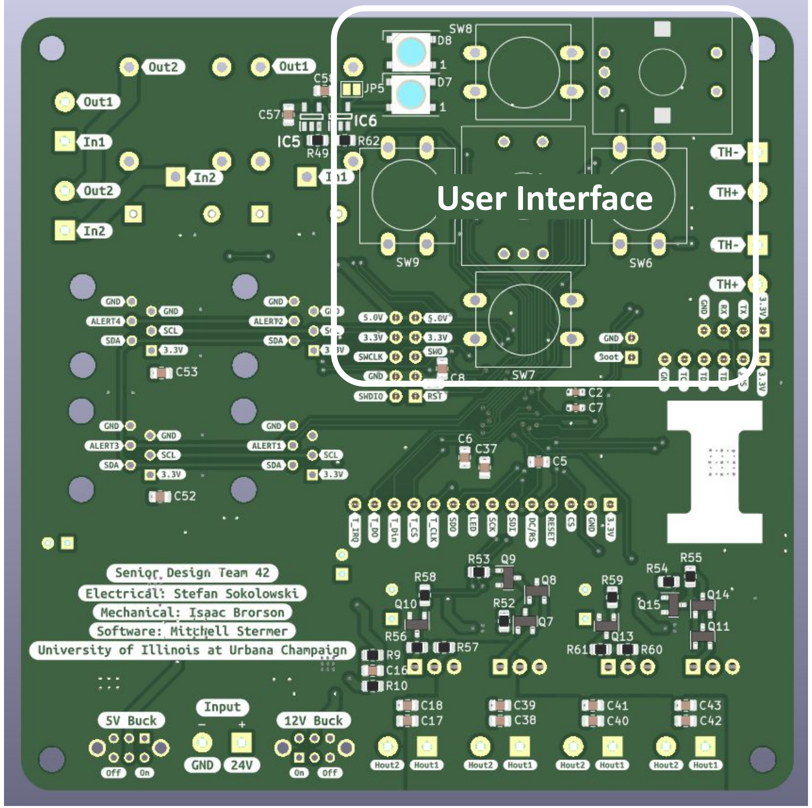


Subsystems

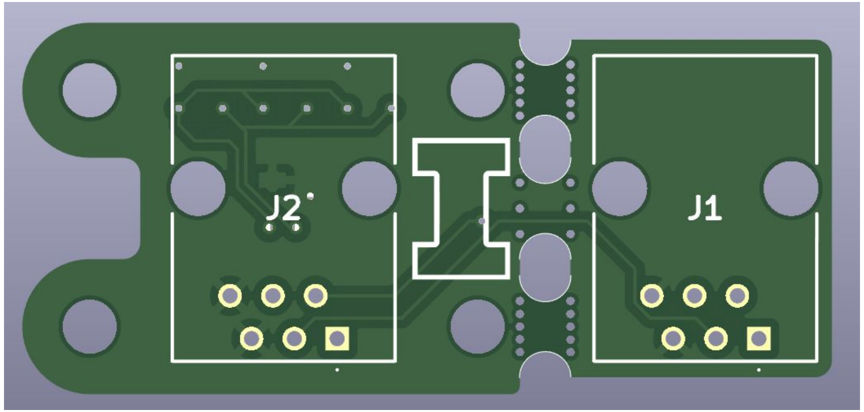
- ➢ Power Subsystem
- ➢ Central Control Subsystem
- ➢ Temperature Sensing Subsystem
- ➢ Heating Subsystem
- ➢ Cooling Subsystem
- ➢ User Interface Subsystem

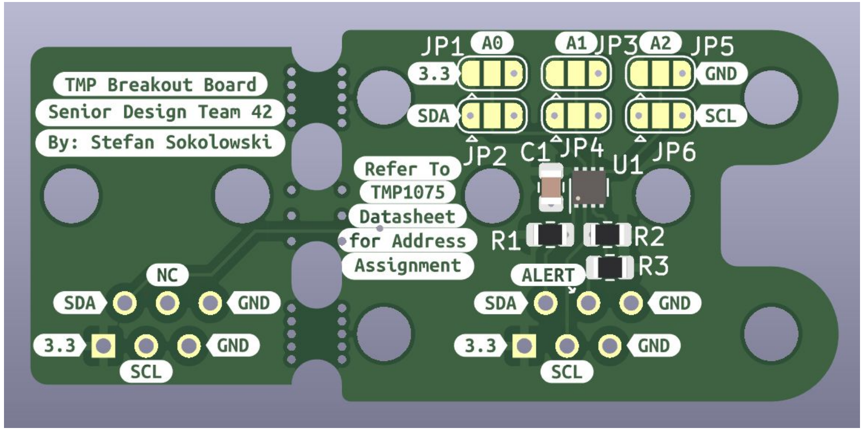
PCB Design - Main Board



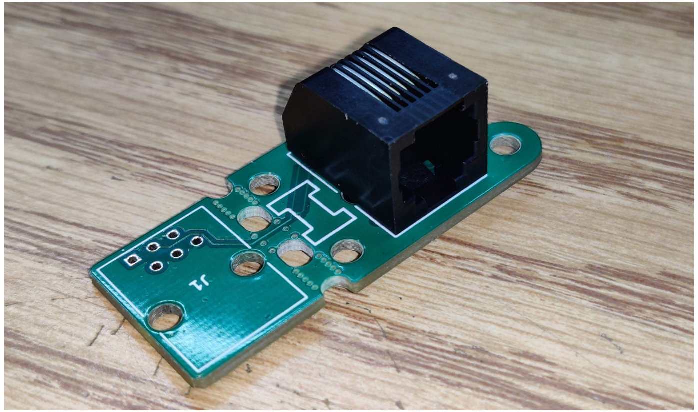


PCB Design - TMP Sensor Breakout

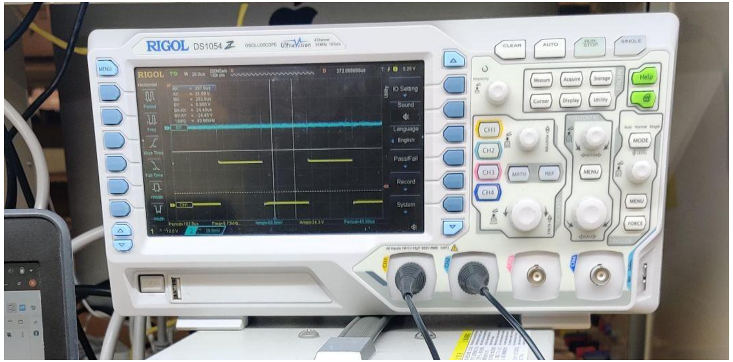


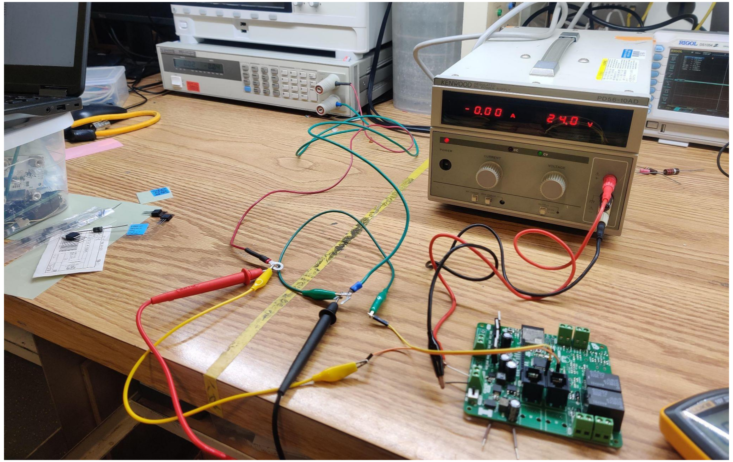


- ➢ Mouse Bites for Separation
- ➢ Proprietary RJ-12 Connector for SPI
- ➢ Address Selection Through Jumpers
- ➢ Decoupling Cap and Pull up Resistors
- ➢ TMP 1075 Sensor on Back



PCB Verification





Power System Verification:

- ➢ 24V Power Supply - Verified at 100W ✓
- ➢ 12V Buck - Verified at 5W ✓
- ➢ 5V Buck - Verified at 10W ✓
- ➢ 3.3V LDO - Verified at 1W ✓

Cooling System Verification:

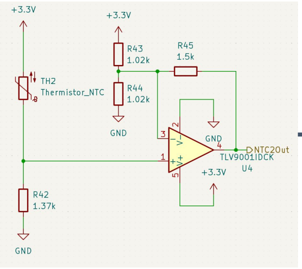
- ➢ 50% PWM Output - Verified on Oscilloscope ✓

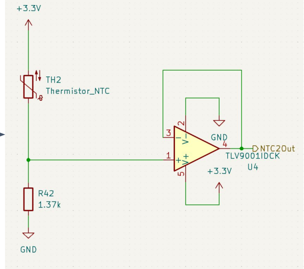
Heating System Verification:

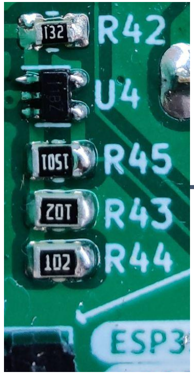
- ➢ Relay Switching - Verified using Multimeter ✓

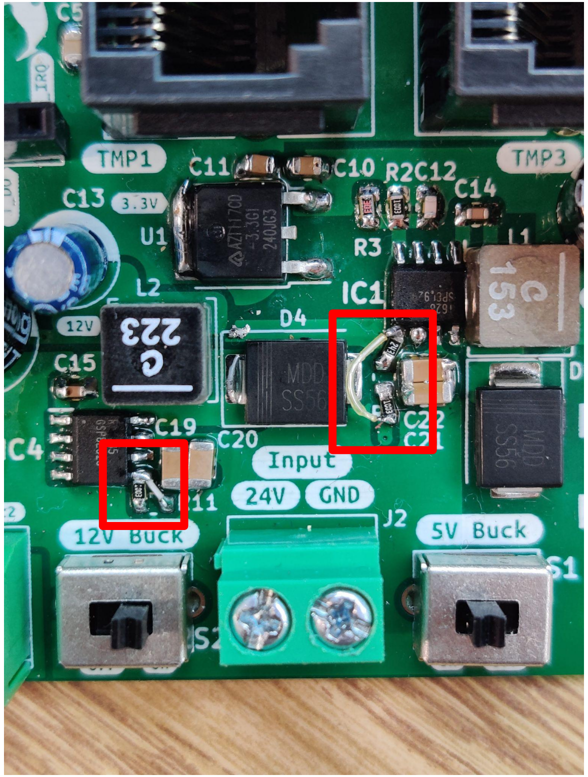
Version 1 PCB Issues

- **Buck Chip Enable Pin**
  - Enable pin initially tied to 24V, datasheet stated it must be 5.5V or below
  - Resistor divider added in rev. 2 of board
- **Thermistor Sensing Circuit**
  - Taken from Ti reference design
  - Didn’t work because thermistor value unknown
  - Replaced it with voltage mirror circuit and solved tuning in software

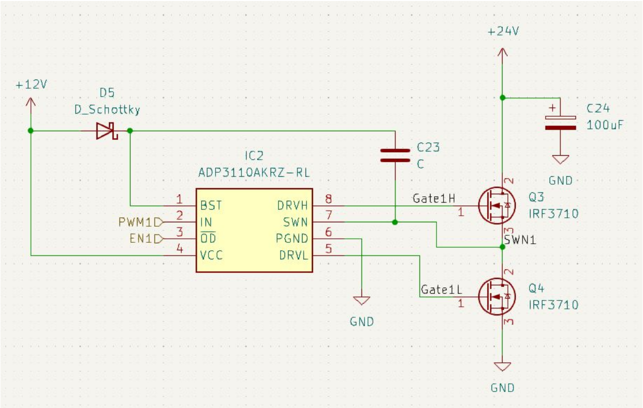






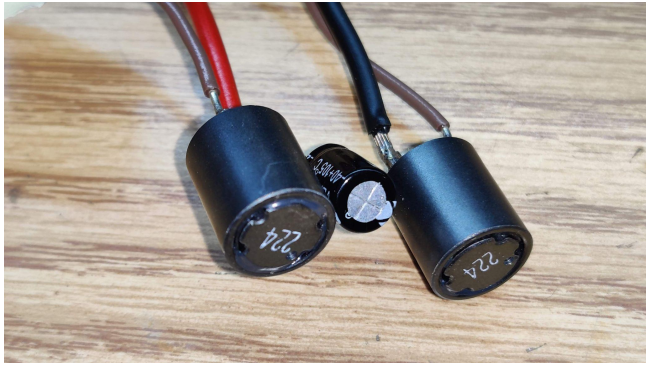


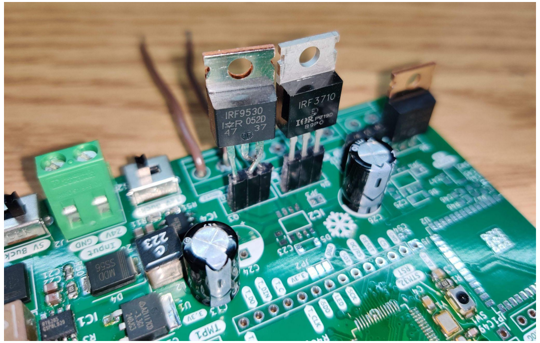
Half-Bridge Nightmare - V1 PCB Issues

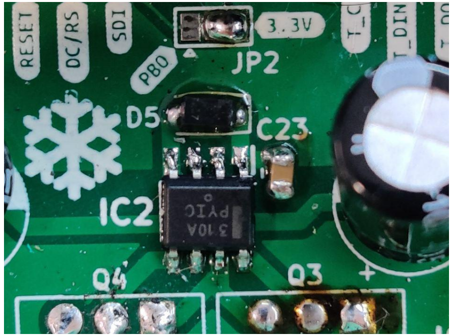


Bootstrap Issue

- **Problem:** Gate drivers explode when output capacitance is added
- **Cause:** The node in the bootstrapped half bridge MUST be connected to GND for some time in order for bootstrap cap to charge. Bootstrap cannot have capacitance directly on output.
- **Solution 1:** Add inductor in series with capacitor
- **Solution 2:** P+N channel half bridge



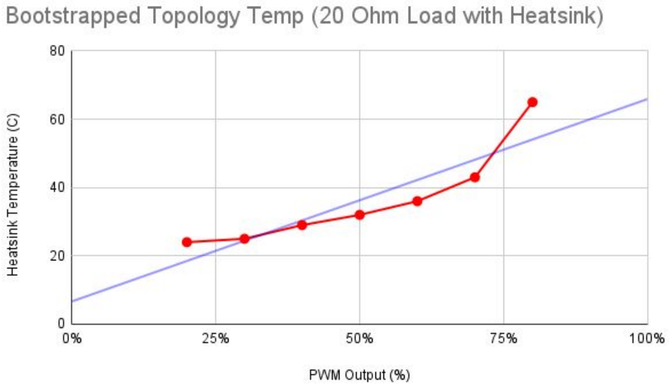


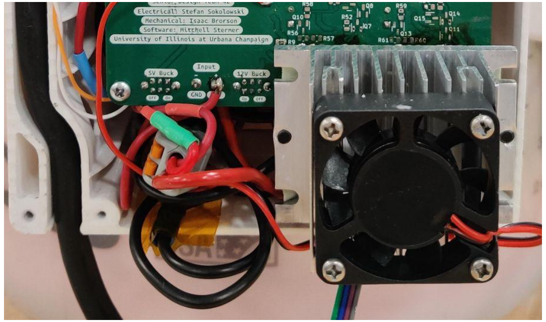


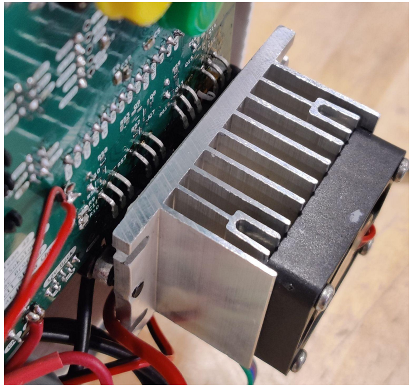
Half-Bridge Nightmare - V2 PCB Issues

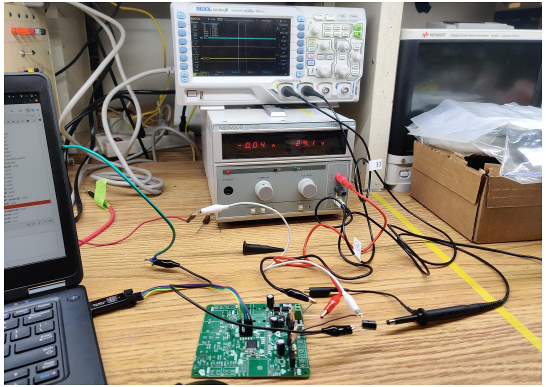
Overheat Issue

- **Problem:** MOSFET overheat during operation at high currents
- **Cause:** Not 100% confident but most likely shoot through+ringing in combination with rds at high current spikes caused by switching into inductor
- **Solution 1:** Run MOSFETs at lower PWM cycle and lower load
- **Solution 2:** Add proper heatsink

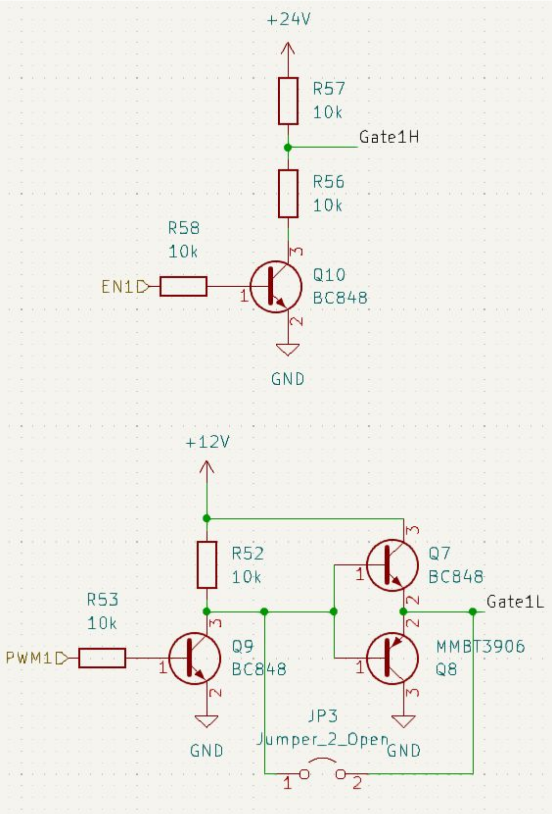








Half-Bridge Nightmare - End Solution

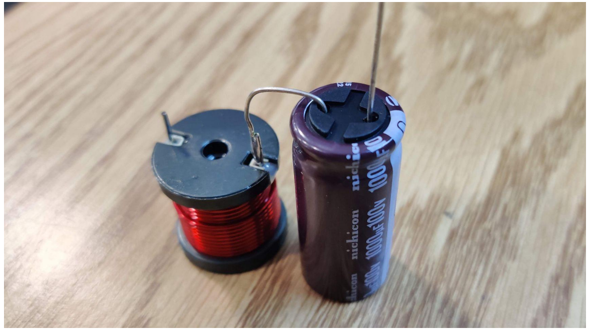


Back to Bootstrapped

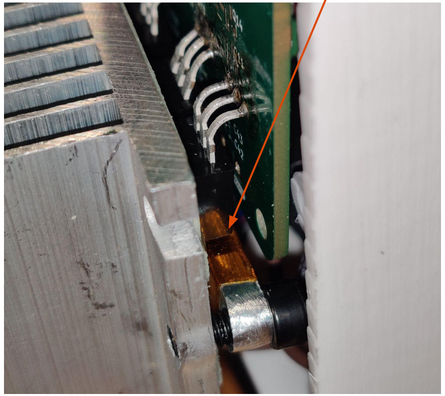
- ➢ Not confident in BJT circuit handling gate charge at our frequency (not thoroughly tested due to lack of time)
- ➢ P+N MOSFETS hotter than bootstrapped layout
  - ○ 150C vs 75C (50% PWM, no heatsink, 20 Ohm Load)
- ➢ LC network with higher current limit and more capacitance

Heatsink Added

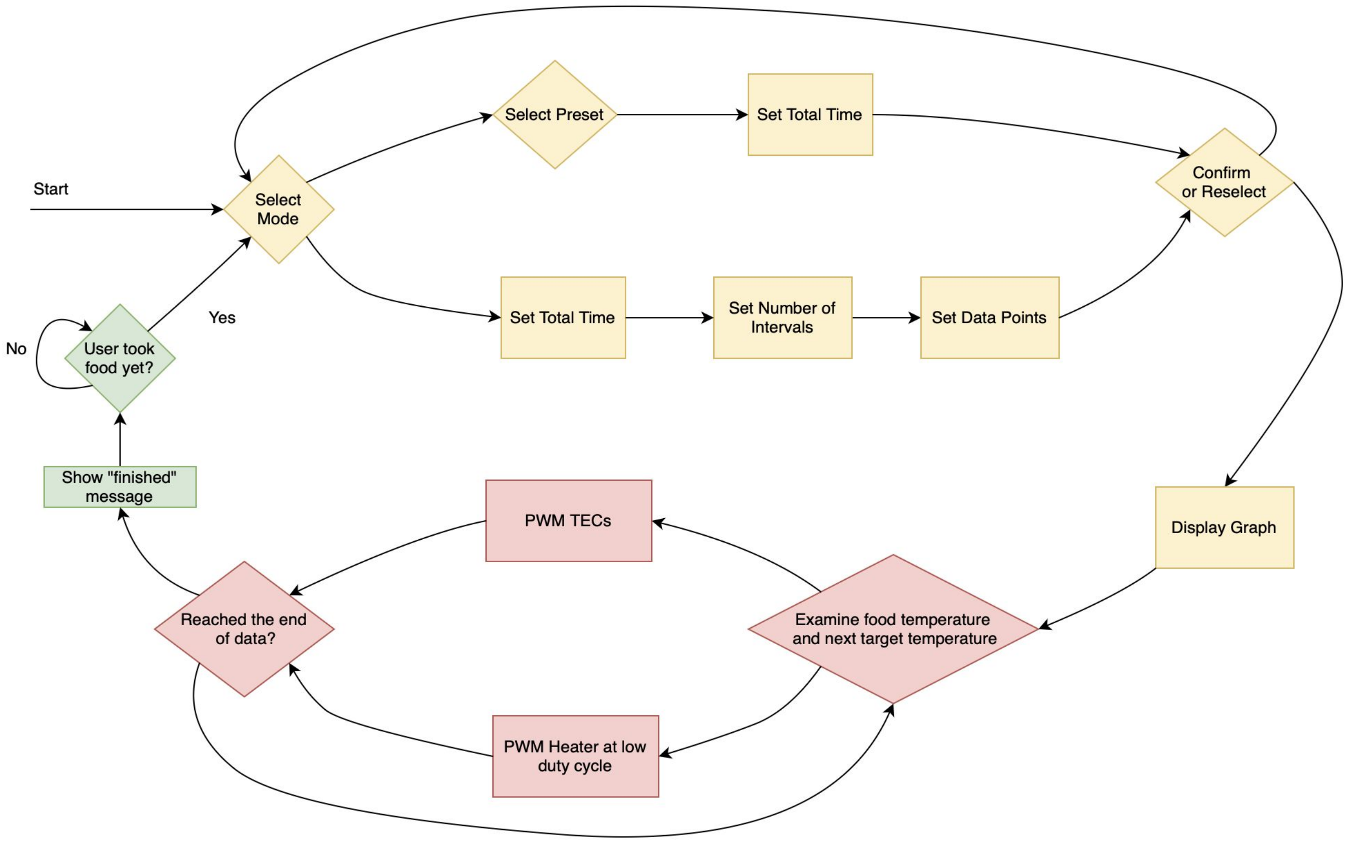
- ➢ Beefy heatsink and fan added
- ➢ Isolated from MOSFETs



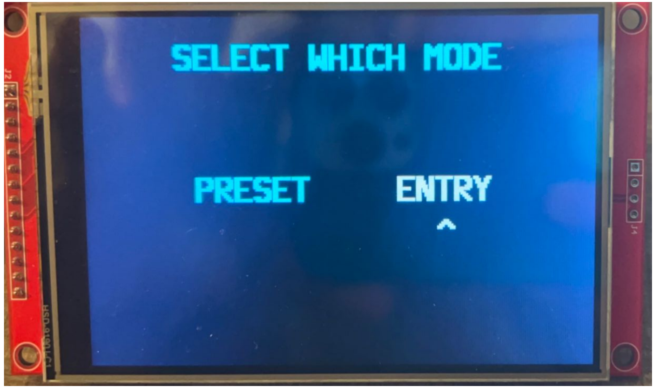
Kapton

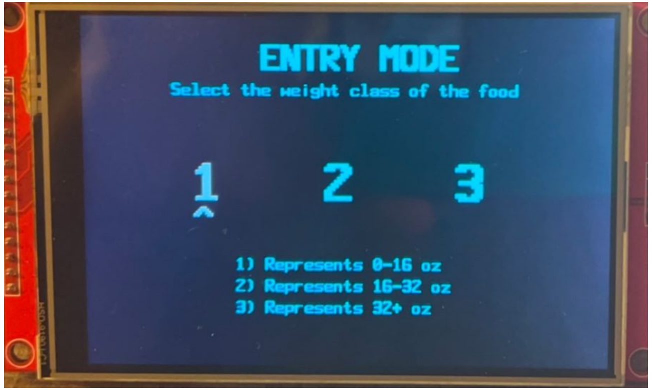


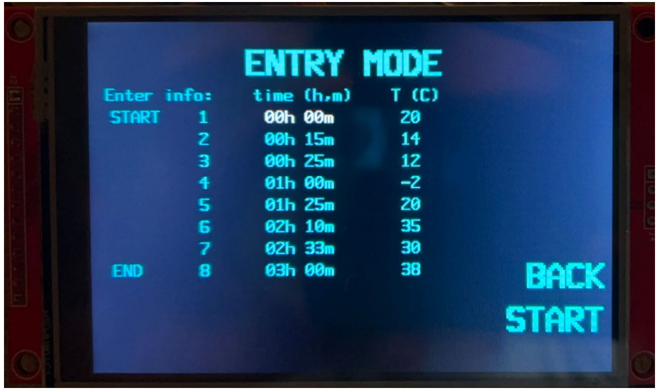
Software Design



User Interface Menus







Software Verification (1st HL Requirement)

User Interface Subsystem Verification

- Buttons and Encoders - Echo test uploaded to STM✓
- Storing User Data Display Graph✓

Temp Sensing Subsystem Verification

- I2C Temp Sensor and Thermistor - Printed to Screen and Verified with external infrared temperature gun✓

Clock and Temperature Control ✓

- Screen - Tested with Screen uploaded and✓ verified with a Real Clock

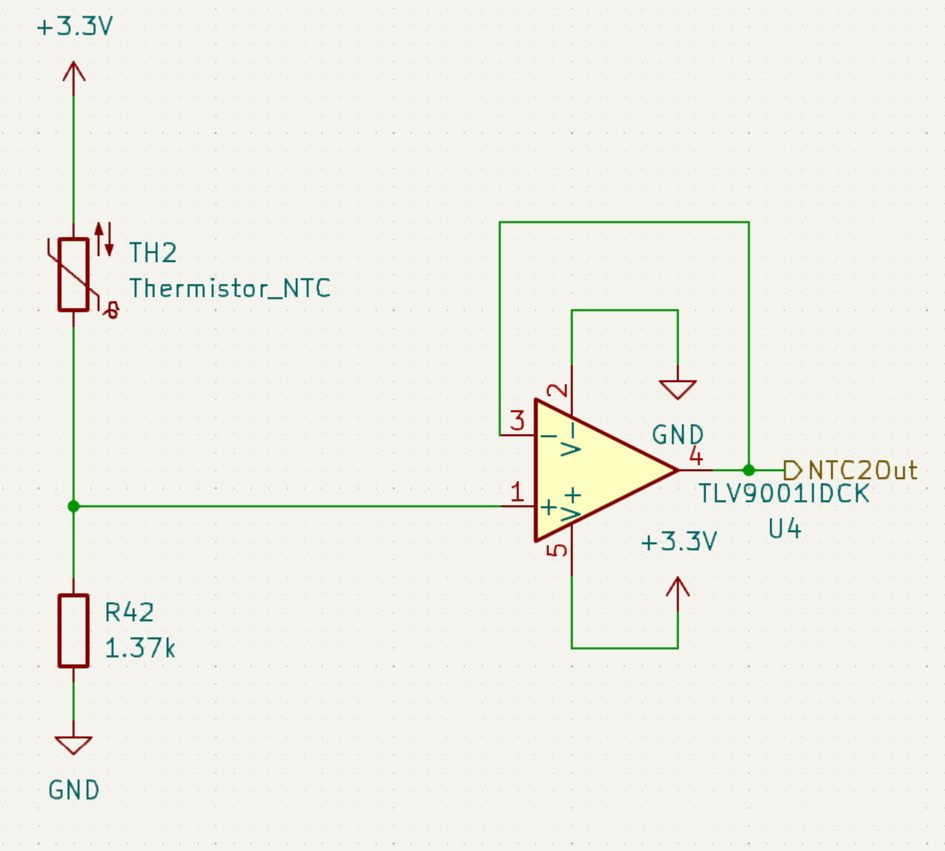
Index	0	1	2	3	4
VALID_TIMES (minutes)	0	10	13	37	40
VALID_TEMPERATURES (Celsius)	28	40	40	15	15

$$ppd_C = \frac{319 - v_{\text{offset}} - y_{\text{start}}}{45 - (-15)} = \frac{y_{\text{end}} - y_{\text{start}}}{60}$$

$$ppd_F = \frac{319 - v_{\text{offset}} - y_{\text{start}}}{120 - 0} = \frac{y_{\text{end}} - y_{\text{start}}}{120}$$

$$ppm = \frac{x_{\text{end}} - h_{\text{offset}}}{\text{VALID\_TIMES[n-1]}}$$

More on Analog Thermistor



$$R_1 = R_0 e^{\beta(T_1^{-1} - T_0^{-1})}$$

$$T_1 = \frac{BT_0}{T_0 \ln\left(\frac{R_1}{R_0}\right) + B} - 273$$

$$V_0 = 3.3\left(\frac{1.37}{1.37 + R_1}\right)$$

$$R_1 = \frac{(3.3 - V_0)(1.37)}{V_0}$$

R0 = 10k
B = 3500 K

Larger B parameter -> lower temperature dependance

How Fast Can We Reach Zero? (2nd HL Requirement)

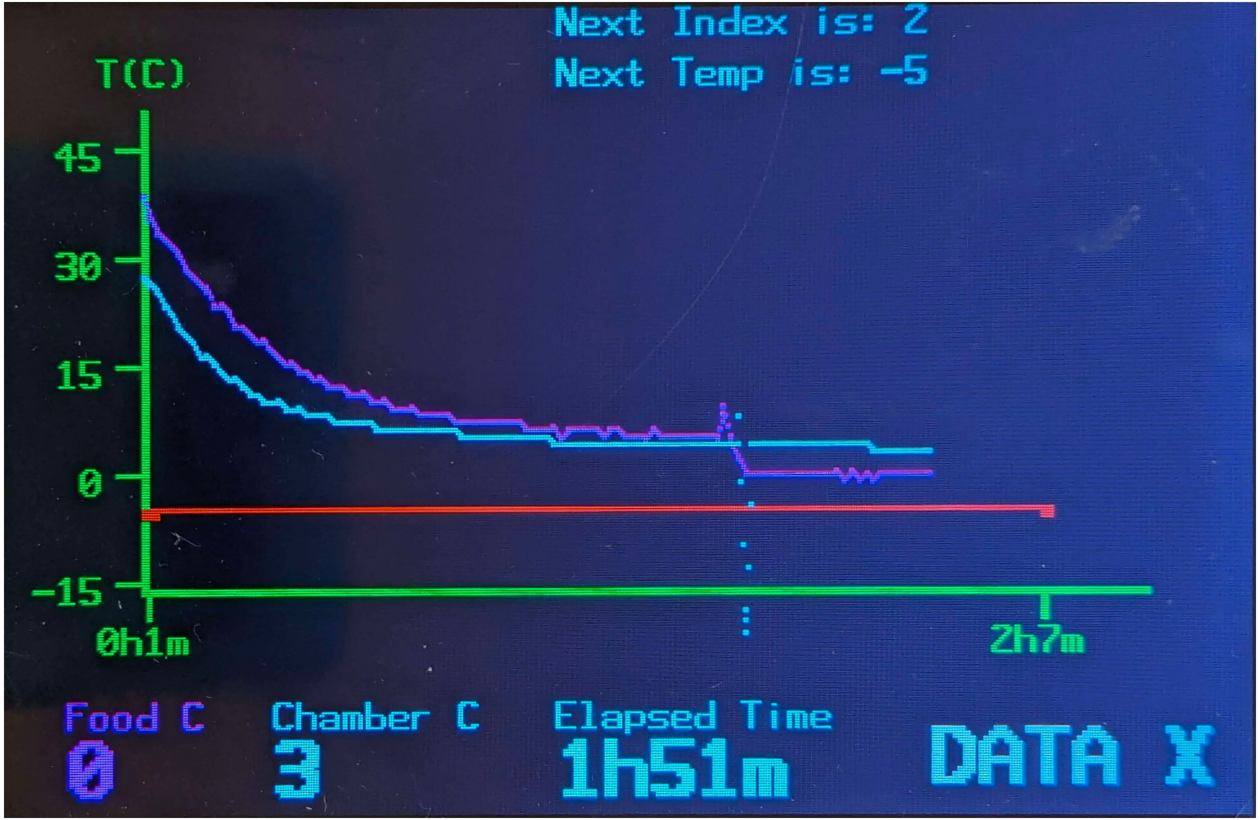
Red - Desired Heating Curve

Purple - Food Temperature

Blue - Chamber Temperature

Elapsed Time on Horizontal Axis

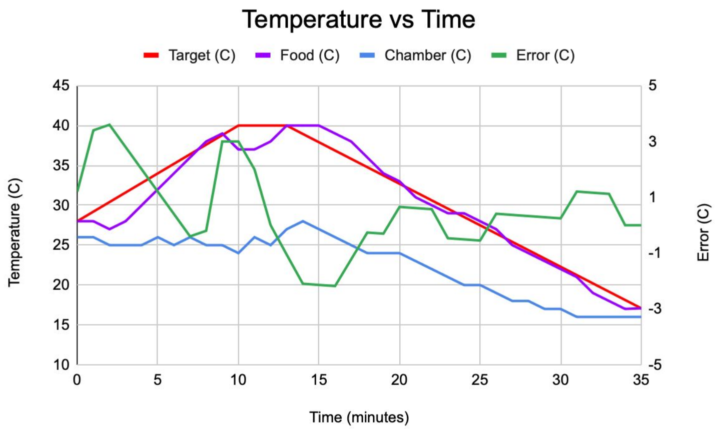
User has the option to edit the heating curve <u>during</u> operation by selecting “DATA” or cancel by selecting “X”

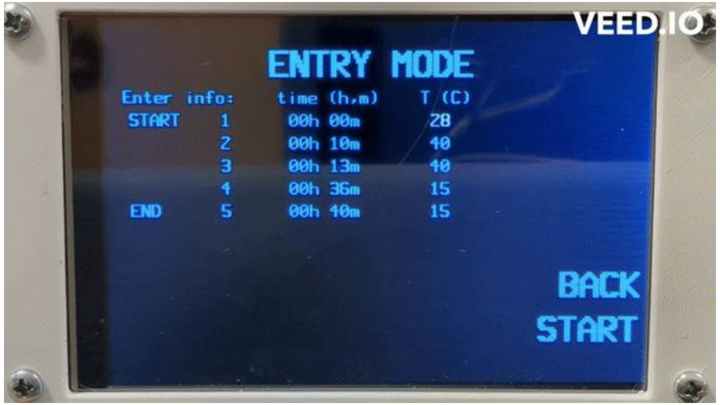


Error Tolerance (3rd HL Requirement)

Error Comparison

Time (m)	Target T (C)	Food T (C)	Chamber T (C)	Error ΔT (C)
0	28	28	26	1.2
1	29.2	28	26	3.4
2	30.4	27	25	3.6
3	31.6	28	25	2.8
4	32.8	30	25	2
5	34	32	26	1.2
6	35.2	34	25	0.4
7	36.4	36	26	-0.4
8	37.6	38	25	-0.2
9	38.8	39	25	3
10	40	37	24	3
11	40	37	26	2
12	40	38	25	0
13	40	40	27	-1.057
14	38.943	40	28	-2.098
15	37.902	40	27	-2.139
16	36.861	39	26	-2.18
17	35.82	38	25	-1.221
18	34.779	36	24	-0.262
19	33.738	34	24	-0.303
20	32.697	33	24	0.656
21	31.656	31	23	0.615
22	30.615	30	22	0.574
23	29.574	29	21	-0.467
24	28.533	29	20	-0.508
25	27.492	28	20	-0.549
26	26.451	27	19	0.41
27	25.41	25	18	0.369
28	24.369	24	18	0.328
29	23.328	23	17	0.287
30	22.287	22	17	0.246
31	21.246	21	16	1.205





Conclusions

Successes and Future Improvements

Project Success

All of our high level requirements were met:

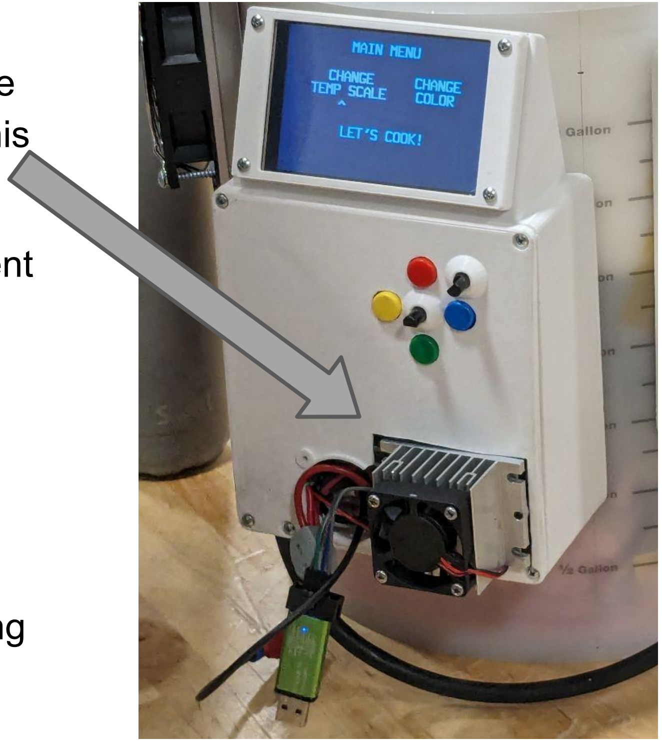
- We achieved temperatures below 0℃ and above 40℃.
- The user interface provides the user a convenient way to set whatever temperature curve they want.
- The device kept food within 5℃ of the set temperature.

Other Notable Successes:

- The power supply provided sufficient power and didn’t overheat.
- The electronics were neatly contained in two eboxes.
- The device turns on and is ready to operate as soon as the user connects the power cord.

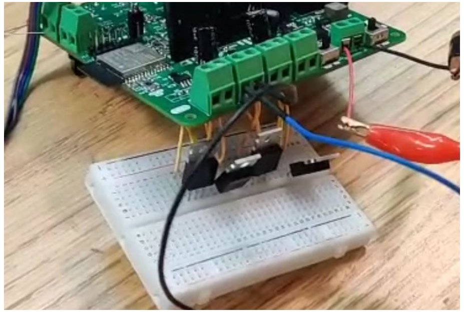
Future Mechanical Improvements

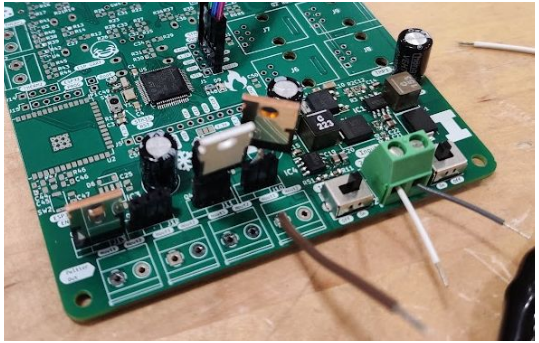
- We were forced to cut a hole in the main board ebox to accommodate a heatsink to cool the full bridge MOSFETs. If we had the time, we would redesign the ebox to make space for this heatsink.
- We'd like to add a status RGB LED to clearly indicate the current operation being performed. (Heating / Cooling / Ready)
- Replace stainless steel bain-marie with an aluminum inner chamber to reduce thermal gradient across chamber. The aluminum has a much higher thermal conductivity, and would work to even out temperature differences.
- Increase the number of Peltier coolers to improve rate of cooling

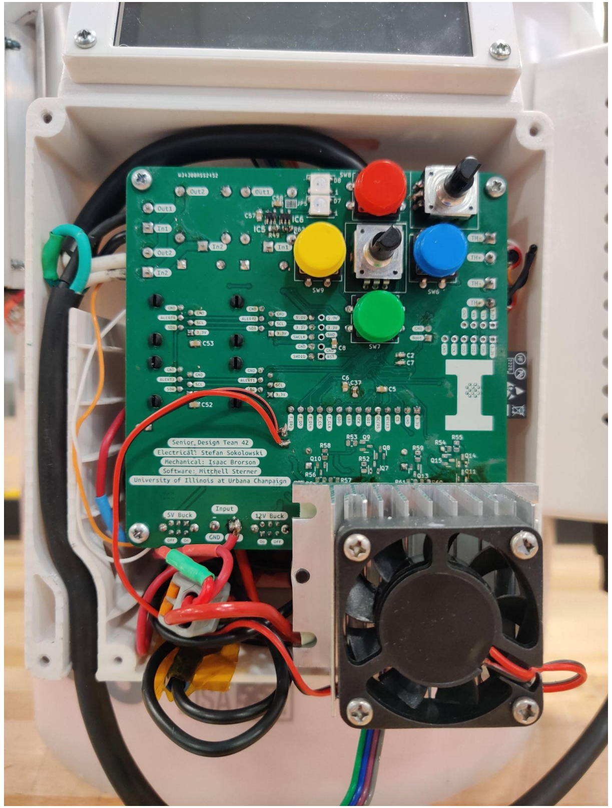


Future Electrical Improvements

- Improved Half-Bridge Setup
  - Gate driver isolation
  - Larger output capacitance
  - MOSFETS with higher current rating
- Current and Voltage Sensing on Output
- Move Connectors to the Top
- Breakout Board for Buttons







Future Software Improvements

- Improve Interface System
- Run more tests on PID temperature control to prevent overshoot from heater

```
int kp = 90;   int ki = 30;   int kd = 120;
```

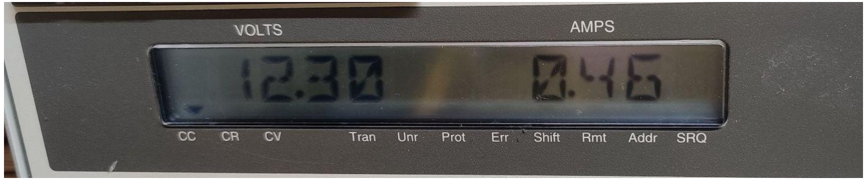
- Add safety detection with added hardware
- Use Display Touchscreen for alternate input
- Integrate ESP32 Coprocessor
  - Syncing of clock with internet and setting temperature curves through web portal

Thanks For Your Attention!

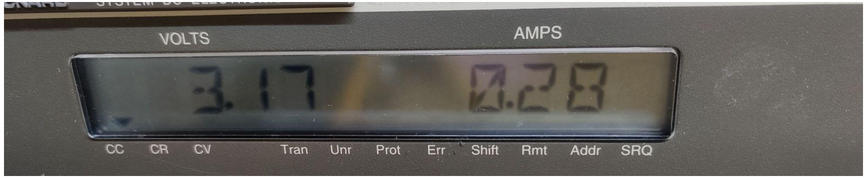
Any Questions?

Power Verification Proof

23.73V*4.28A=101.6W



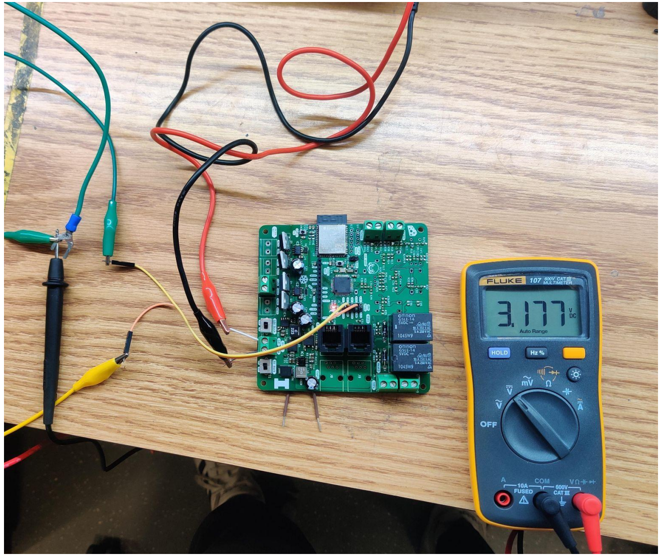
12.3V*.46A=5.67W

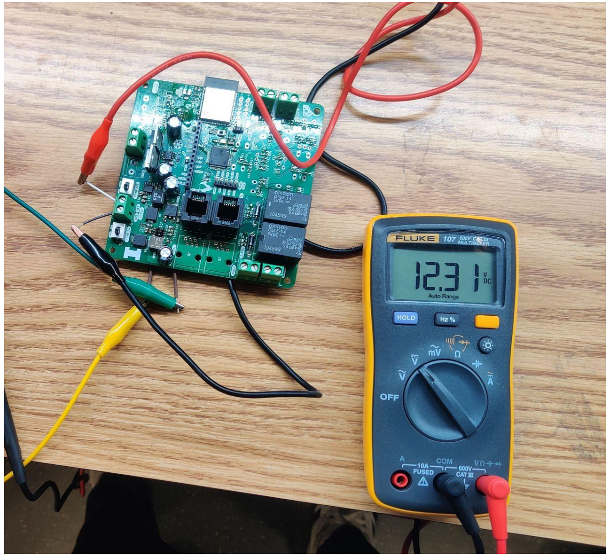


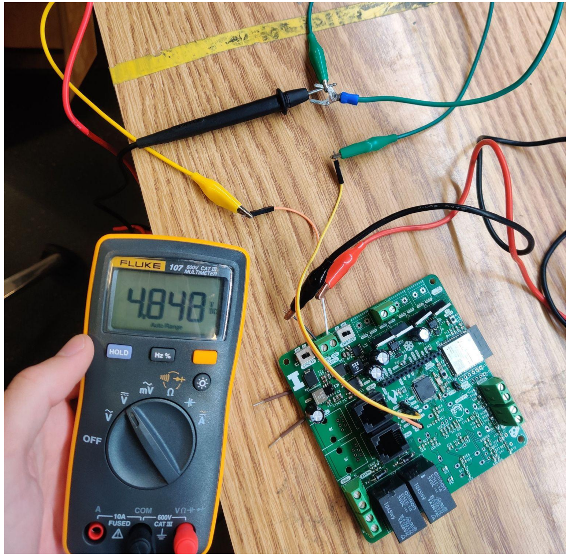
3.17V*.28A=0.89W

4.15V*1.97A = 8.176W

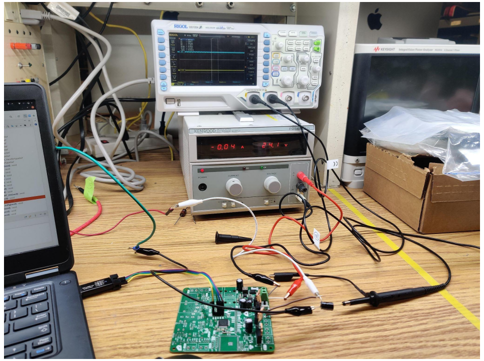
Power Verification Proof

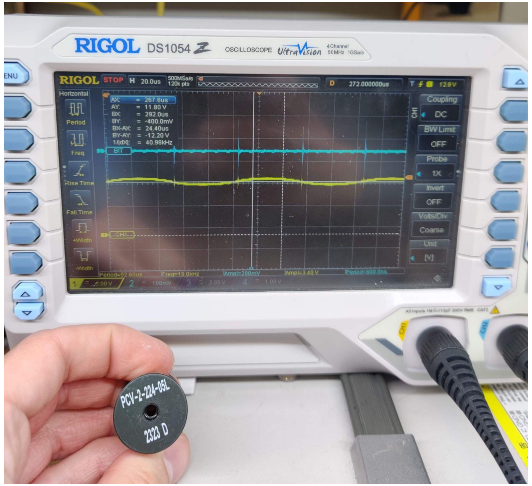


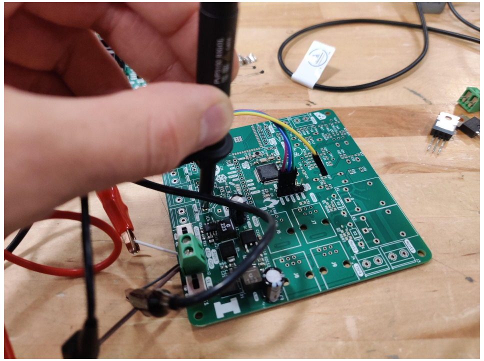


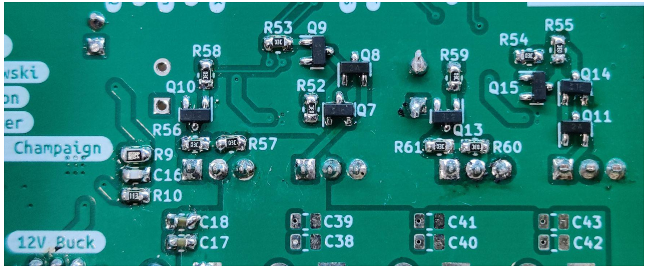


Half Bridge Verification Proof







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