I-BOTTLE FINAL REPORT

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Abstract

The Induction Bottle, or I-Bottle, has been designed, tested, and implemented over 13 weeks to be a portable, easy to use liquid heating solution. A series of systems have been constructed to utilize magnetic induction technology with the goal of creating a dynamic magnetic field to excite a metal bottle and heat the liquid within. This bottle can be removed and taken with the heated liquid inside. Sensing modules and a custom-made PCB are responsible for monitoring the heat of the liquid, the heat of the bottle, and displaying the temperature data for the user to view. These systems connect to create a flow of power and data throughout multiple electronic devices.

Contents

1. Introduction

The I-Bottle is a system comprised of an induction coil that is powered by a 12 V car battery through a flyback converter, and a bottle with the outer layer of metal on the bottom two inches of the bottle removed. The liquid inside the bottle will be temperature monitored as well as temperature controlled by the user via a LCD screen and button pad respectively.

1.1 High Level Requirements

(1) Design a device which utilizes magnetic induction to heat a liquid container and implement systems to measure the temperature, enable portability, and isolate the heat distribution of the device.
(2) Create a custom PCB capable of implementing a control system to monitor the temperature of the I-Bottle components and override the system if the measurements reach dangerous levels.
(3) House the system in a compact way to encourage the ease-of-use aspect of the design.

2 Design

The block diagram in Figure 1 details the major systems we have developed, which include the induction system and the control system. Each respective system has subsystems which will be described later.

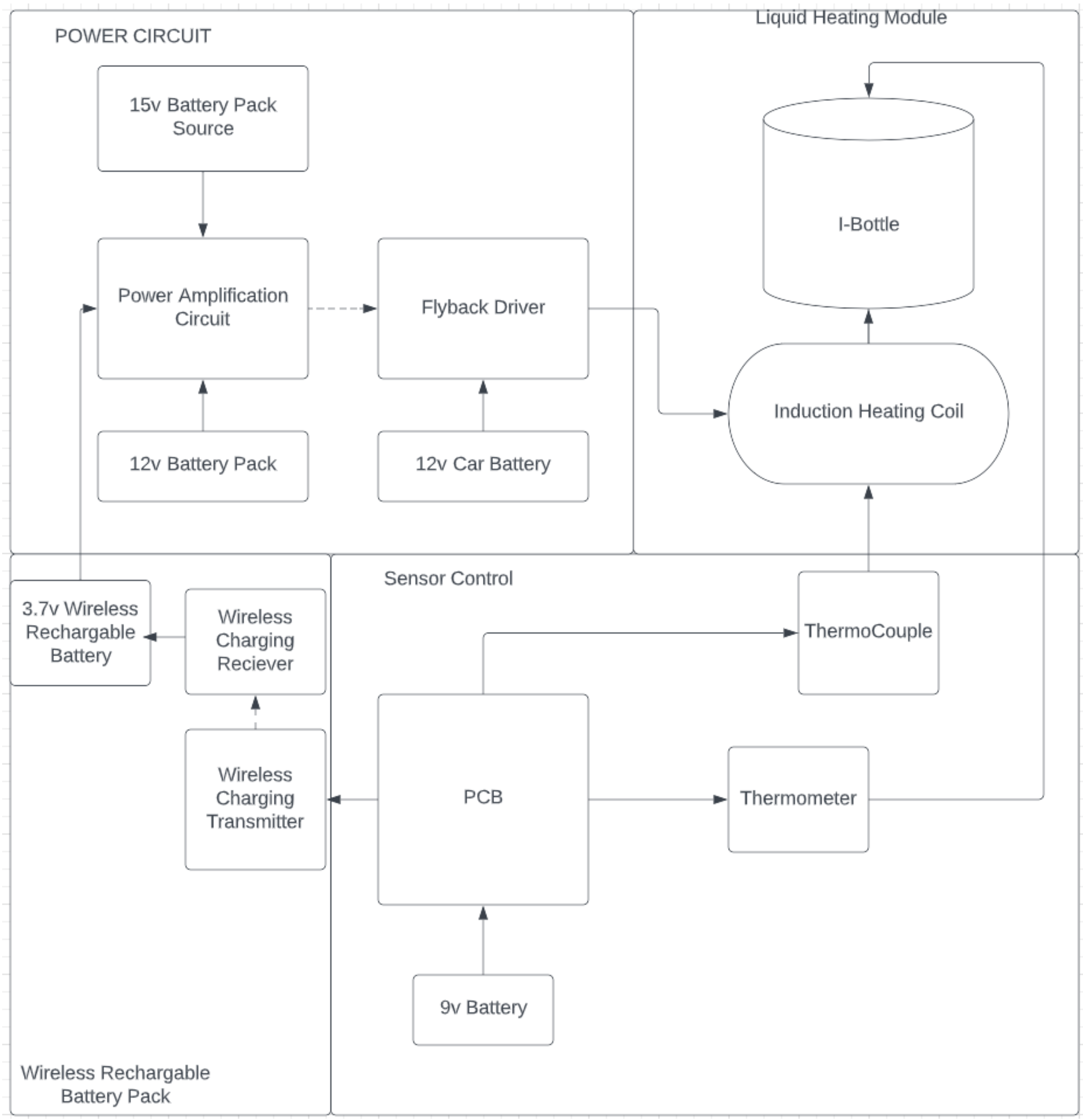

Figure 1: Block Diagram

2.1 Power Circuit

To generate a dynamic magnetic field around the bottle, multiple components needed to be powered at variable voltages and a power circuit was designed to compensate. A main battery source was the central point of design. Ensuring all systems could run on as few sources as possible lead to a circuit responsible for distributing and regulating the voltages.

2.1.1 Battery Source

The final project had one major hurdle when designing the power system; the Flyback DC to AC converter driving the magnetic field in the coil needed a high voltage, high current source. Multiple kinds of sources were tested, and while most of them burned out or couldn't properly supply the driver, a proper power source was eventually found. A 12 V car battery pack was used with enough current to properly power the flyback driver. Other sources considered include:

- 12 V Alkaline Battery Packs
- 9 V Li-ion batteries in series
- 3.7 V Li-Poly wireless rechargeable batteries
- Wireless magnetic induction wire pairs to send low voltage data signals (on/off)
- Combinations of these sources to power the custom PCB, sensors, and heat supply module

2.1.2 Amplification Circuit

Using the sources listed above, a circuit was designed to distribute the voltages and route them to the different modules. Sadly, this idea was never fully implemented after multiple failed tries and redesigns. If the flyback converter was not as power hungry as it was, requiring a minimum of 12 V, 2.5 A and having maximum ratings of 48 V, 20 A, then these circuits would been more applicable.

While most designs died off, some of this work was implemented into the Custom PCB in Figure 6 in the power section. A series of voltage regulators attached to one of the sources powered the microcontroller and all of the integrated circuits, while a digital to analog converter was added to send signals towards this amplification circuit for analog communication with the microcontroller.

2.2 Wireless Rechargeable Battery Pack

The original design had the induction coil, sensors, and other electronics running on Wireless Rechargeable, Lithium Polymer Batteries. These low voltage, small batteries had a variety of applications throughout design changes, but they served no purpose in the final design for the demo. Some applications included:

- A battery pack attached to the I-Bottle which would charge via magnetic induction when the system was inserted into the housing mechanism. This pack would power sensors, LEDs, and displays attached to the bottle.
- Using an amplifier circuit with Operational amplifiers and Bipolar Junction Transistors to power the induction coil all within the bottle. This would make it possible to maintain a constant, low magnetic field to keep the liquid heated. The recharge station would be an at home system with a traditional wall outlet adapter.

- Powering the custom PCB and sensors on a wireless recharging device which would read the temperature data on the I-Bottle and be easy to pick up and use. The charging station would be powered by the same source as the induction heating coil and Flyback Driver, while the bottle would be a separate system that interacts independently with the sensor device.

2.3 Liquid Heating Module

The liquid heating module is composed of the I-Bottle and induction heating coil. The I-Bottle is a modified vacuum insulated bottle with the outer layer of stainless steel removed on the bottom 2 inches of the bottle. This exposes only the inner layer of stainless-steel to the magnetic field generated by the induction coil. This results in the inside layer heating the liquid contained in the bottle, while ensuring the outside layer stays at a reasonable temperature to allow the user to pick up the bottle.

The liquid heating module requires signals and power from the control system and power circuit, respectively. Provided it is being controlled and powered, the induction coil will produce a magnetic field that focuses on the bottom of the I-Bottle, which is just the inner layer of the I-Bottle. This field will excite the electrons in the stainless-steel bottom and therefore heat the bottom of the bottle. This heat quickly transfers to the liquid contained in the bottle, thus heating the liquid.

Figure 2

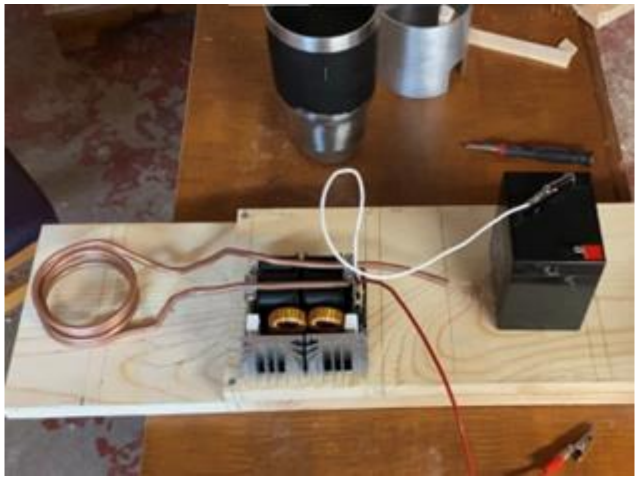

Figure 3

2.4 Control System

When designing the control system, the main goal was to utilize user input and readings from our temperature sensors to control the power level of our induction system. We wanted to physically separate this block from the liquid heating module since we were dealing with liquids, which can easily damage electronics. On an abstract level, the control system itself has multiple subsystems which are all dependent on each other, making it logical to group these subsystems together into one major control system.

The control system simultaneously waits for user input and reads the current temperature of the liquid. The user input is the desired temperature of the liquid, and the sensor subsystems measure the current temperature of the liquid. Based on the differential between the desired and current temperature, the microcontroller will determine how much power needs to be routed to the induction coils to match the current temperature of the liquid to the desired temperature.

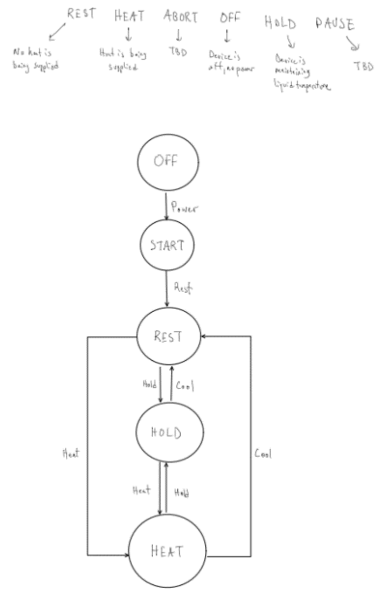

Figure 4

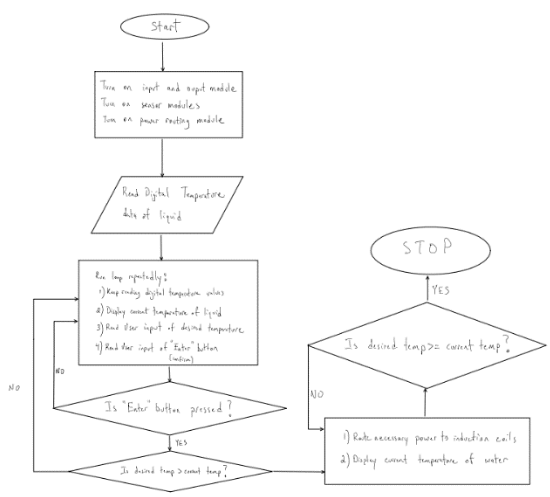

Figure 5

Figure 4 details a basic flowchart of our I-Bottle control system state machine. This basic state machine has five states: OFF, START, REST, HOLD, HEAT. This basic state machine has three main transitions, which include heating, cooling, and holding the temperature of the liquid.

The advanced state machine shown in Figure 5 is a more comprehensive and descriptive state machine that applies more specifically to our I-Bottle system. It describes our state machine relating more to the specific data that we will be receiving from our sensors and describes our system in 9 states rather than 5.

The control system is comprised of 4 subsystems: power, sensor, user interface, and microcontroller, as shown in Figure 6. The power subsystem regulates the voltage and current being supplied by a 9 V battery to provide the necessary 5 V or 3.3 V our components require. The sensor subsystem reads temperature data from our liquid being heated and our induction coil to determine the current temperature of our liquid as well as ensure the coil doesn't overheat. The user interface subsystem reads desired temperature as user input from a button pad and displays the current temperature on the LCD for the user to view. The microcontroller subsystem is interconnected with the other three subsystems and requires a voltage regulator as well as a reset button.

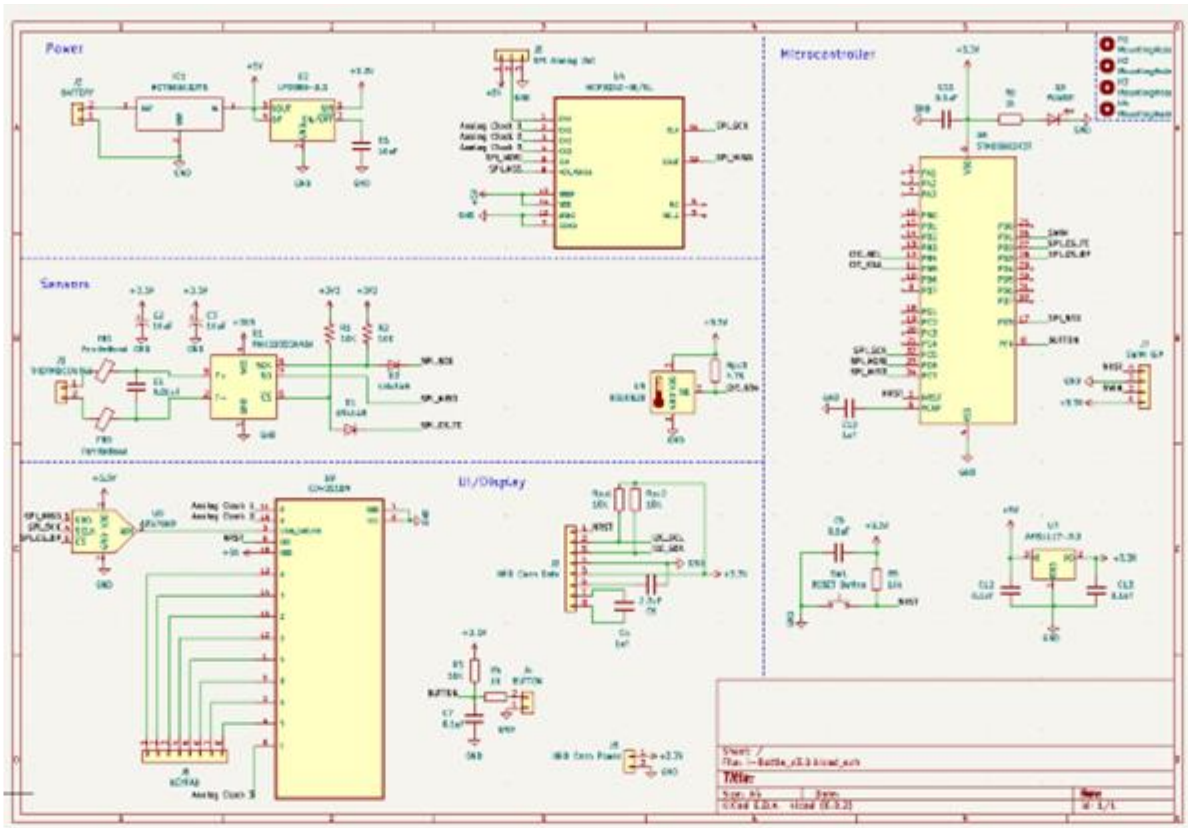

Figure 6

Figure 7 shows the steps taken when planning the PCB board layout of components. These design choices were made based on the location of certain pins on the microcontroller as well as the location of important sensors such as the liquid temperature sensor and the thermocouple.

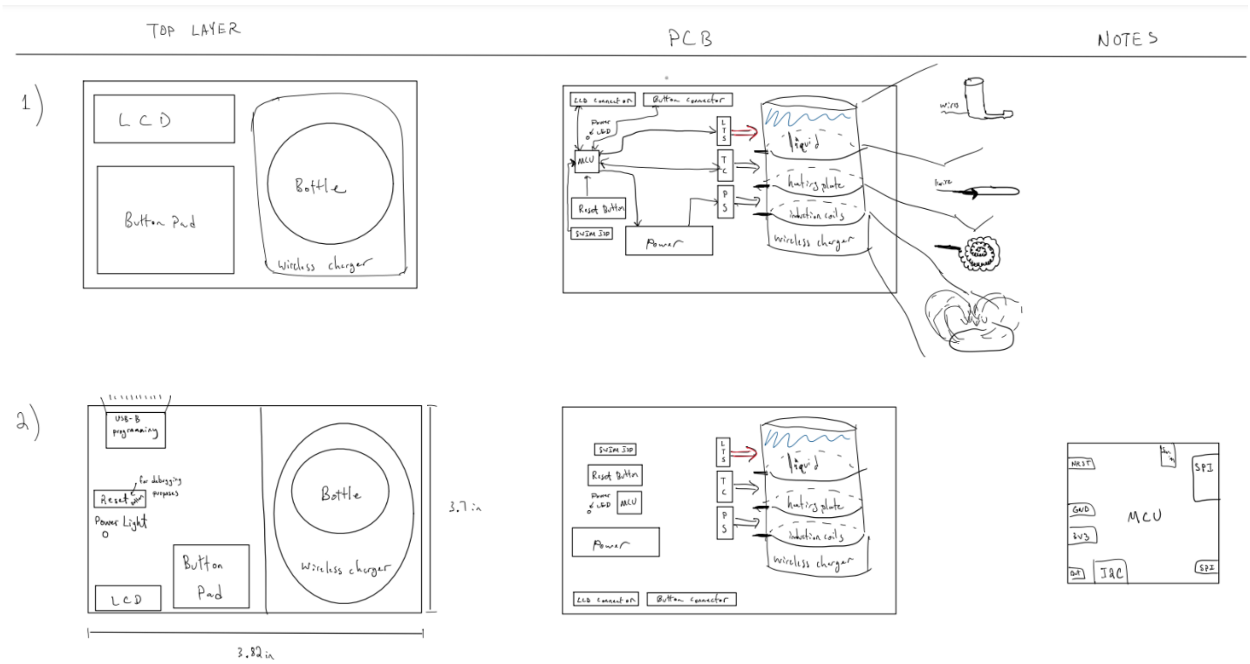

Figure 7

Figure 8 and figure 9 show the completed PCB design. Figure 8 contains tracks and Figure 9 shows only the components.

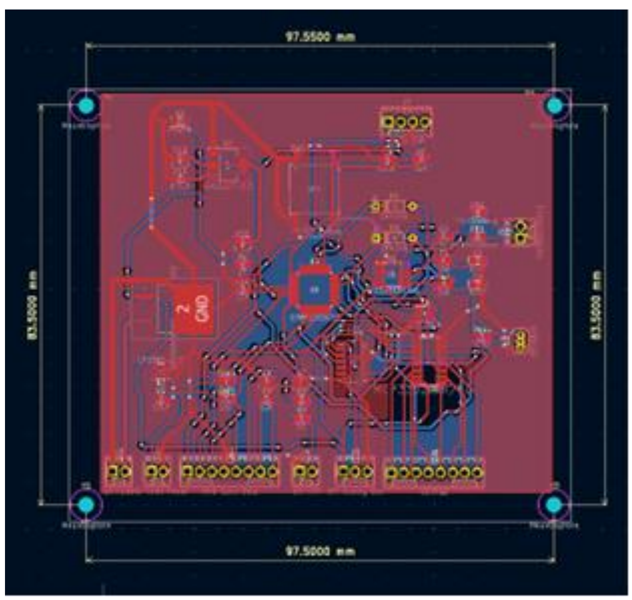

Figure 8

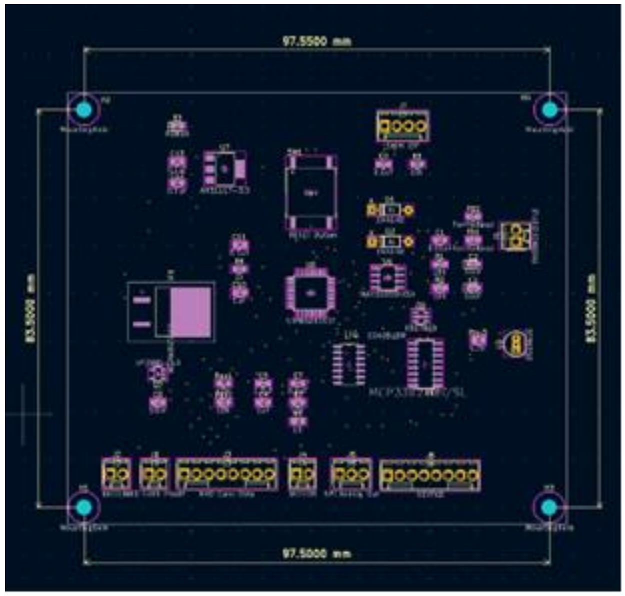

Figure 9

3. Design Verification

3.1 Verification Tables

Table 1 Control System Verification Table

Requirements	Verification
A. Perform calculations with sensor data to send current and desired temperature to LCD display B. Use calculated temperature differential to route necessary power to heating coils.	a. Simulate current and desired temperature situation to test calculation of temperature differential and ensure that sufficient power is supplied to heating coils. b. Measure temperature of coils to check that power supplied aligns with temperature of coils.

This RV table relates to our control system, more specifically our STM8S003K3 microcontroller. The DS18B20 liquid temperature sensor performed as expected, and properly read the temperature of the water in the I-Bottle.

Table 2 Induction Heating Verification Table

Requirements	Verification
A. Use the Flyback converter to generate a variable magnetic field and heat up the inner layer of the cup B. Verify the heat transfers from the stainless steel to the	a. Measure temperature with Thermal Couple and test if heat dissipates from the steel b. Use the liquid temperature sensor to find difference in temperature

Table 3 System Verification Table

Requirements	Verification
A. Interconnect the system and enable free flow of power and data B. Utilize heating and sensing technology together to create a functioning system which can control the heat flow to the liquid	a. Observe voltage readings and data outputs between subsystems to ensure connections b. Use live temperature data and physical observations to validate interconnected subsystems.

3.1.1 Tolerance Analysis

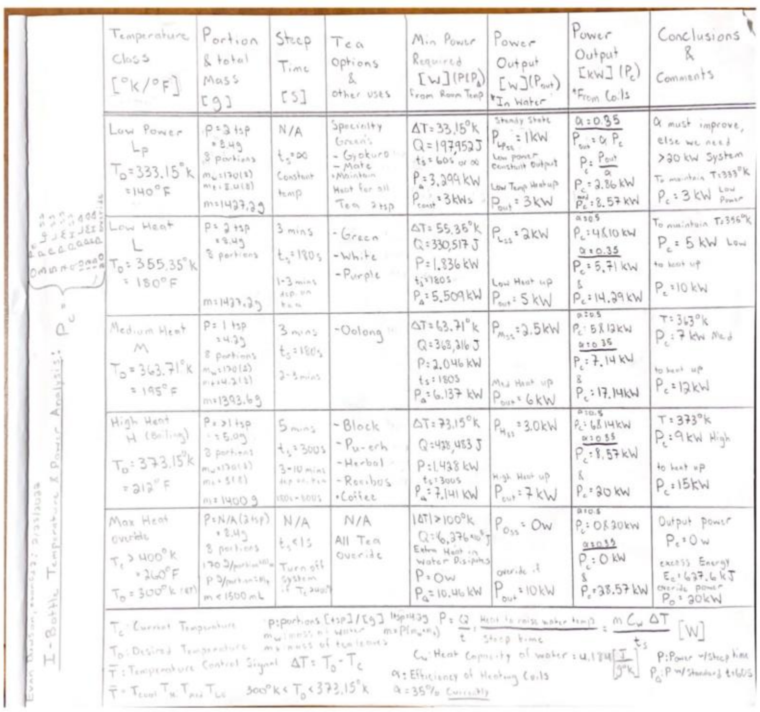

Figure 10

3.2 Design Testing

Figure 10 details the readings taken by the DS18B20 sensor as it was placed in the water being heated and then removed. The x axis represents time, and the y axis represents temperature in Fahrenheit. As you can see, the temperature rises at a consistent rate until the sensor is removed from the heat and then begins to drop at a consistent rate as well.

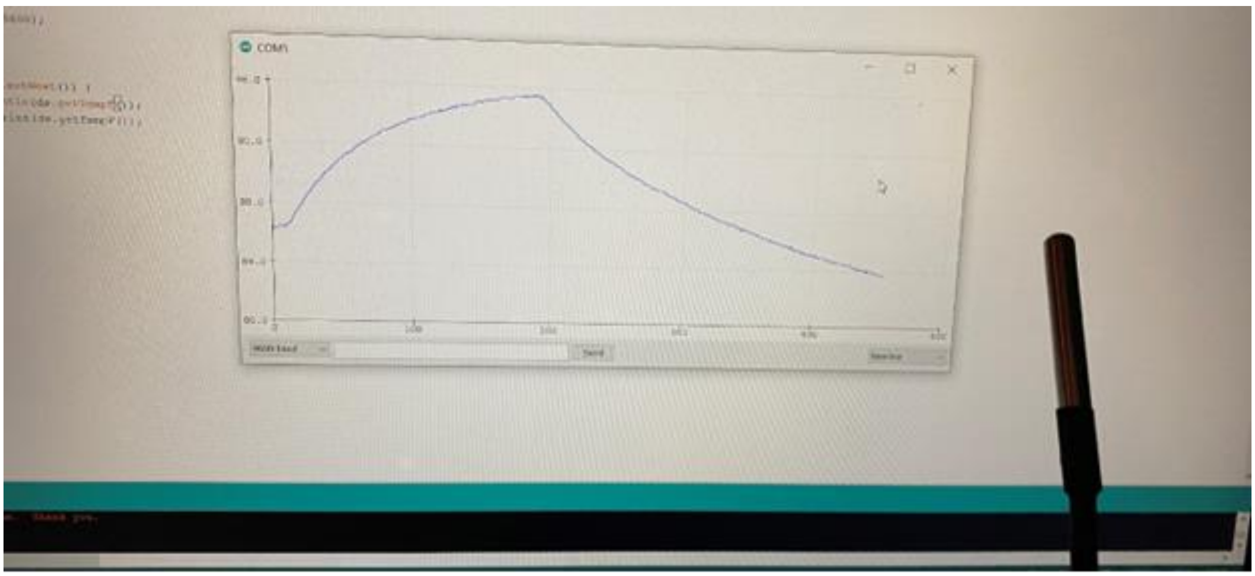

Figure 11

The thermocouple was supposed to be integrated into the project but due to PCB complications, it ended up not functioning properly. If it were to be integrated, the thermocouple would have measured the temperature of the induction heating coils to ensure they stayed below a maximum temperature threshold. The LCD screen was also supposed to be integrated into the project but failed to function correctly. If properly integrated, the LCD would have displayed the current temperature of the liquid in the I-Bottle. The LCD was tested with an Arduino microcontroller and displayed sample text. Finally, the button pad, if properly integrated, would have allowed the user to manually input the desired temperature of their liquid, resulting in the necessary power being routed to the induction coils to match the current temperature to the desired temperature.

To test the power electronics and heating module, a multimeter was used to measure voltages along the electricity pathway. The sources were tested directly to ensure the voltages had not dropped and cells had not burned out. The ICs were tested across different pins relative to ground, and the voltages were calculated and checked against measurements. In the end, all testing was done by measuring the heat transfer from the coil through the bottle and to the liquid, as seen above. While the power electronics designs are great for future implementations, they sadly did not make it into the final project for the demonstration and presentation.

3.3 Alternative Design Choices

Alternative design decisions include integrating batteries into our liquid heating module, allowing the bottle to operate independent of the base plate that houses our power circuit and control system. Physically, this describes a bottle with a battery and miniaturized induction system that can maintain the temperature of whatever liquid it is holding. To summarize, this alternative design option is a more portable and contained object that still meets the requirements that our current design does.

4. Costs

4.1 Parts

Table 4 Project Cost

Component name or Number	Quantity	Price
3245 Thermocouple Type-K	1	9.95
MAX31855 Thermocouple-to-Digital Converter	1	7.76
DS18B20 Waterproof Thermometer	1	9.95
NHD-C0220BiZ LCD display 20x2	1	13.49
27899 Parallax 4x4 Matrix Membrane Keypad	1	9.95
CD4051BM Single 8 Channel Analog Mux/DeMux	1	1.13
STM8S003K3 MCU	1	2.13
AMS1117-3.3 1A Low Dropout Voltage Regulator	1	2.12
MC7805CD2TG	1	0.82
LP2985-3.3 150 mA, Low-Noise, Low-Dropout Regulator	1	1.06
MCP3302 Quad Channel SPI Interface	1	5.56
ADS7868 ADC	1	2.06
MFBW1V2012-801-R Ferrite Bead	2	0.1
polarized 10 uF cap	2	0.72
1 uF capacitor_smd	2	0.18
2.2 uF capacitor_smd	1	0.19
0.01 uF == 10 nF capacitor_smd	2	2.01
10 uF capacitor_tantalum_smd	2	0.85
0.1 uF == 100 nF cap	6	0.29
1N4148 diode_tht	2	0.1
Ferrite Bead 1 uH inductor_SMD	2	0.41
10k resistor	6	0.16

1k resistor	2	0.42
4.7k resistor	1	0.46
LED_SMD	1	0.61
Qi Wireless charging transmitter	1	26.95
Wireless Recharging Battery 3.7 V 2500 mAh	1	14.95
Wireless Recharging Battery 3.7 V 1200 mAh	1	9.95
Induction Heating Board Module	1	33.91
Qi Wireless Charging Reciever	1	14.95
Qi Wireless Charging Pair	1	9.95
Battery Charging Module	1	6.95
TOTAL		190.09

4.2 Labor

Cost = $40/hour * 10 weeks * 10 hours/week * 2 people * 2.5 = $20,000.00

Cost / person = $40/hour * 10 weeks * 10 hours/week * 2.5 = $10,000.00

Machine shop hours cost:

Cost = $40/hour * 2 weeks * 5 hours/ week * 2.5 = $1000

5. Conclusion

To summarize, the I-Bottle has functionality. The bottle heats up with induction technology and can display the temperature of the liquid inside the bottle. Our PCB would have allowed the bottle to function independently without an external device, but due to complications we resorted to using an Arduino microcontroller to measure the temperature of the liquid.

5.1 Accomplishments

1. We found a proper power supply that could provide the necessary voltage and more importantly amperage that our flyback driver needed to power the induction coils. This was the most difficult task for our group as we initially attempted to boost the voltage and amperage of weaker batteries with a power amplification circuit but ended up frying chips in the process.

2. We successfully designed and redesigned a PCB that was supposed to act as our control system. Although the PCB ended up not functioning, the process of designing it from the ground up was very rewarding and taught us a lot about the design of PCBs. If the opportunity to design another PCB, the design would allow for more flexibility when testing the PCB and would not be as set in stone as the current PCB we have.

3. We spent about a month in the brainstorming process when building out the I-Bottle idea. It was very interesting going through this process as we were able to think about both realistic and futuristic goals for the I-Bottle. The realistic goal evolved from a rechargeable heating bottle into a portable bottle that could be heated with induction technology. The futuristic goal deals with integrating this technology into the homes and vehicles. We believe this product can be optimized to fit into the cupholders of electric vehicles and allow everyone driving to work to have their beverage at the perfect temperature.

5.2 Uncertainties

5.3 Ethical considerations

Safety Concerns

Our main concern with the I-Bottle was the heating element. This heating element is a coil that will operate at a low, medium, or high temperature. A max temperature threshold was set so that when our heating plate reaches this temperature, our induction coil will stop being powered.

Our secondary concern was the bottle tipping or falling when connected to the base plate. We ended up securing our flyback converter to the wooden plank it sat on with screws. Since our coil was screwed into our flyback converter, this ensured that the coil didn’t move and provided a stable base to place our bottle into. We also worked with the machine shop to build an aluminum shell that encased the main coil loop. This aluminum shell was hammered into the wooden plank to secure it.

Our base plate ended up being two wooden planks that were drilled together. The top wooden plank was slightly shorter so that the flyback converter could be elevated and provide room for the induction coil to rest on the bottom wooden plank. We chose wood since it's not magnetic and could withstand high temperatures before catching fire. It was also very sturdy and could easily be finished with a waterproof glaze. Some future additions include adding walls around the base plate and in between our main blocks of devices to separate our modules.

5.4 Future work

The I-Bottle has a myriad of utilizations given the right technology and engineering. A few ideas to implement the Induction Bottle in new and innovative ways are as follows:

- Miniaturizing the design into a portable heating system with wireless rechargeable batteries, to keep liquid at a desired temperature at any time. The base plate would be made to charge the batteries, while the induction heating technology would be built into the bottle, with heat proofing and pressure control to prevent malfunctions.
- The system works when running on a car battery and taking this route to consolidate the design into a car would be a logical decision. The induction heating system would be added into a cup holder, while the bottle would be made to contain the heat transferred and only operate when in the cup holder.

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