Smart Bottle Firmware and Wireless Charging Integration

Justin Truong

Khanhthy Le

1 Grand Ave, San Luis Obispo, CA

September 8, 2023

Table Of Contents:

I. Abstract

In the past 3 decades, there has been a 60% increase of infants under the age of 2 who are considered obese [1]. The California Polytechnic State University, San Luis Obispo Child Development Department wants to research parents feeding habits and the Smart Bottle tool was built to aid this effort in finding the relationship between infant obesity and parent feeding habits. The Smart Bottle is a baby bottle meter attached to the bottom of the bottle. The goal of this device is to analyze the state of the feeding the parent is currently at and measure the amount of food the baby has consumed. The most recent iteration of the Smart Bottle (V5) is fully functional and attachable to infant feeding bottles to collect feeding data stored via SD card. V5 also implements a Bluetooth module for wireless data transfer, however, it does not have a User Interface.

This project looks to build Smart Bottle (V6) which implements a wireless charging module integrated alongside a User Interface (UI). The wireless charging allows for a fully sealed enclosure reducing the risk of any electrical hazards whereas the UI allows for faster duplex communication. Wireless charging will be implemented through inductive charging, a wireless energy transfer that uses electromagnetic induction to generate power. This project allows for the Child Development researchers to have a convenient method of data extraction while also protecting the consumers.

II. Introduction

Childhood obesity is at an all-time high in the United States, with 19.7% of children aged 2 to 9 being classified as obese in America [2]. To investigate the possible causes of childhood obesity, one key point that poses as the factor of interest is infant feeding trends and habits. With most infant feeding habits occurring from a bottle, it is only natural that researchers point in that direction when investigating potential trends in feeding habits and childhood obesity. The Smart Bottle serves as the data collection medium for this research initiative.

The stakeholders for this project include Dr. Allison Ventura, Cal Poly's Electrical Engineering Department, and Dr. Ben Hawkins. Dr. Ventura has led the Child Development research efforts to learn more about parents researching habits and is directly using our tool for analysis. Cal Poly's Electrical Engineering Department is sponsoring our efforts on this project. Dr. Ben Hawkins has been overseeing this project as a whole and is our advisor. While previous iterations of the Smart Bottle project exist, this newest version of the Smart Bottle will enhance the user experience and provide valuable data on feeding trends among infants.

The new iteration of this project, Smart Bottle V6, as mentioned before is looking to implement wireless charging. Some difficulties include limited space, time, and power. Several Qi wireless charging modules [5] will be evaluated and tested to meet the space and power constraints of the current Smart Bottle. The PCB must be modified to implement the module that is chosen, and from there, testing is necessary to ensure that the newly implemented module does not hinder the Smart Bottle's function. The Qi wireless charging method is a universal standard wireless charging method in the current market.

Smart Bottle V6 will also implement a UI to be able to pull data from the Bluetooth module. Constraints on this UI will include memory size of application on desktop and battery usage. The size must remain under 1 GB on desktop. The application must not affect battery usage to retain its 1-week battery life. This will be done by implementing a real time operating system into the firmware to maximize efficiency of data polling.

III. Background

The Smart Bottle is used as a tool to collect infant feeding data; thus, its main customers are parents of infants, and researchers. The device is meant to collect data for extended periods of time, frequently. On average, an infant will be fed every two to three hours, with most formula fed infants fed 8 to 12 times in 24 hours [3]. It is the Smart Bottle's goal to be able to record feeding data, such as the amount of formula consumed, during each one of these feeding events. Due to the frequency of these events, the Smart Bottle attachment must be one that can collect data accurately, be used without disturbing regular feeding events, and can retrieve collected data easily.

The customer requires a tool to be able to measure the amount of food the baby has consumed during a feeding period. The Smart Bottle must be simple to use, responsive, and not provide a cumbersome experience. It must be light enough to be comfortable to use for long periods of time. The data from the tool must be easy to extract and accurate. The tool must be able to analyze the phase of the feeding period. Lastly the tool must have a long battery life with a relatively short charging time. The exact specifications are listed in Table 1. As aforementioned, it is crucial that this tool can be attached to a baby bottle and record feeding trends without limiting or inconveniencing the infant feeding experience.

Figure 1: Current physical Smart Bottle attachment [4]

The most current version of this project is Smart Bottle V5, which fixed many problems with the previous iterations and is now fully functioning. The Smart Bottle is now able to accurately provide data measurements on feeding events and the amount of food fed, using a microcontroller unit and sensor hardware configurations. However, the only way to access data collected is through the SD card. Similarly, this version also uses a micro-USB charging point for charging the battery. A Bluetooth module was set up in the PCB but there was no communication interface/protocol implemented.

Since the Smart Bottle is attached to the bottom of a bottle of liquid, there comes the risk of electrical hazards if any of the PCB inside the enclosure gets wet. For this reason, an external charging port becomes a risk due to having an entry point into the PCB. With a wireless charging module, a solid enclosure can be implemented to be waterproof and eliminate this risk, providing a safer experience for Smart Bottle users. Currently, the only way to pull data from this device is to open the enclosure and access the SD card. This causes 2 problems: it is very cumbersome to continuously open and close the enclosure after every run, and to access data the user is required to have an SD card reader (which many people don’t own). However, with the utilization of a

Bluetooth module, all the user needs are a computer to download the app to access all the Smart Bottle data. This eliminates the need for the PCB to be exposed at any time and allows for the user to access the data with everyday tools. The UI could also allow for real time data collection which may prove to be valuable to the researchers.

Table I: Customer Requirements

Customer Requirement	Engineering Specification	Justification
a) Easy to use	1) There are two or fewer steps to turn on	Parents are more likely to use devices with less steps involved, therefore leading to better data collection
	2) Wake time is less than 1s	Quick wake time allows for increased measurement and collection accuracy
	3) Attachment is lightweight	A lightweight attachment allows for a more comfortable feeding experience for parents
b) Data is accessible	4) Data storage solution is standard	Standard data storage and Bluetooth allow for accessibility using only laptops or phones.
	5) Data can be accessed via Bluetooth	
c) Data is accurate	6) Feeding events are registered as soon as the bottle is lifted	The Smart Bottle is intended to be used in a research setting, therefore the data collected must be accurate and present to researchers that request it.
	7) Feeding angle is accurate within 10º	
	8) Volume measurement is accurate to 1mL	
	9) Time measurement is accurate within 10s	
d) Long battery life	10) LiPo battery lasts more than a week on one charge	Charging the Smart Bottle requires its disassembly, therefore maximizing the lifespan of the LiPo Battery minimizes user error.
	11) LiPo battery completes a full charging cycle in less than one hour	Being able to charge the battery quickly increases the Smart Bottle's usage as the bottle can charge in feeding downtime.
	12) Wireless charging integration	Wireless charging eliminates the need for a charging port which reduces the risk of electrical shock.
e) Friendly User Interface	13) Data be accessible within 1s of request	Faster response allows for a more interactive user experience and researchers waste less time extracting data.
List of Customer Requirements: a) Easy to use b) Data is accessible c) Data is accurate d) Long battery life		

Table II: Engineering Specifications

Spec #	Parameter	Target (units)	Tolerance	Risk (H, M, L)	Compliance	Test Equipment Needed
1	Steps to turn on	2 steps	<	L	A, T, I	None
2	Device wake time	1 s	<	L	A, I	None
3	Weight of attachment	500 g	<	M	A, T, I	Weight Scale
4	Standard Data Storage Solution	N/A	N/A	L	A, T, I	None
5	Bluetooth Accessibility of Data	N/A	N/A	M	A, T, I	Computer
6	Feeding Event Accuracy	100%	5%	M	A, T, I	Computer, SD Card Reader
7	Feeding Angle Accuracy	5º	±10º	M	A, T, I	Computer, SD Card Reader
8	Feeding Volume Accuracy	1 mL	<	M	A, T, I	Computer, SD Card Reader
9	Feeding Time Accuracy	10 sec	<	L	A, T, I	Computer, SD Card Reader
10	LiPo Battery Life	7 Days	>	M	A, T, S, I	Wattmeter
11	LiPo Battery Charging Time (full charge)	1 hour	<	M	A, T, S	Stopwatch
12	Wireless Charging Integration	N/A	N/A	M	A, T, I	None
13	Bluetooth Data Retrievability	3	<	L	A, T, I	Computer

IV. Functional Decomposition

A UART communication protocol will be used for Bluetooth integration and an inductive power charging method will be used for the wireless charging module. UART was chosen due to not requiring a clock line, simple communication protocol, and full duplex capabilities. An inductive power charging method, specifically Qi charging, was chosen due to its universal charging aspect as well as the ability to buy the module off the shelf. The vastness of Qi modules offered in the market is a great contender as different sized modules can be purchased to meet current PCB constraints of the Smart Bottle.

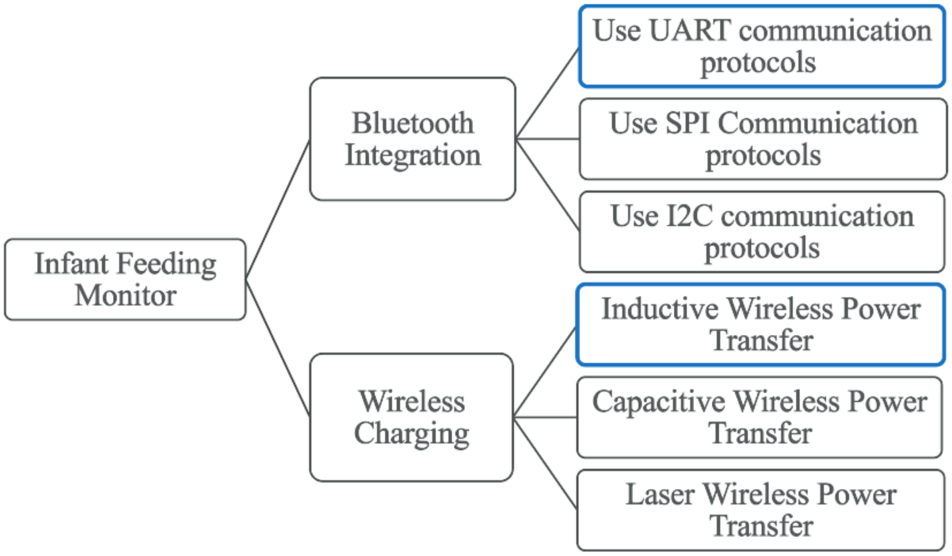

Figure 2: Functional Decomposition

Figure 3: Level 0 Block Diagram

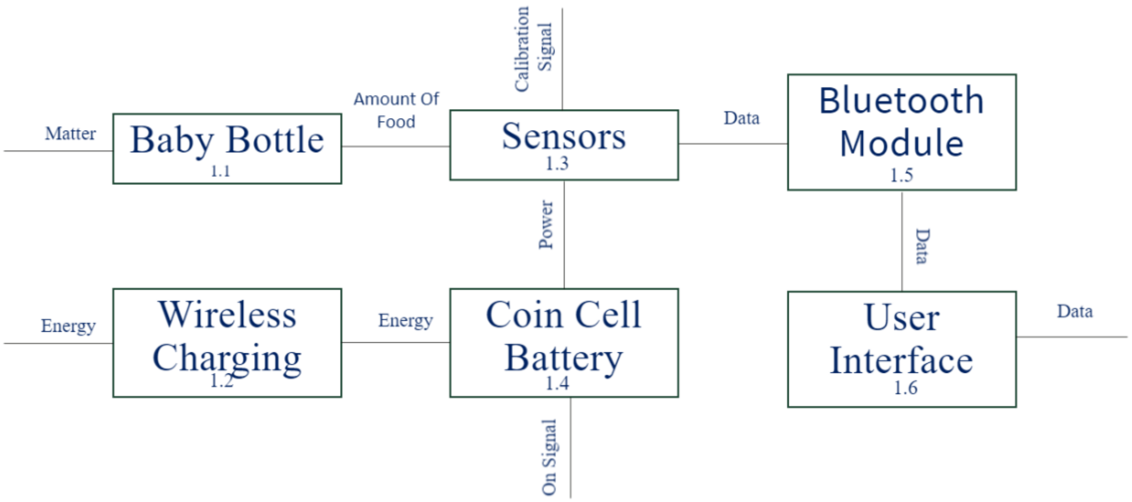

Figure 4: Level 1 Block Diagram

Table III: Level I Modules

	1.1	1.2	1.3	1.4	1.5	1.6
Module	Baby Bottle	Wireless Charging	Sensors	Coin Cell Battery	Bluetooth Module	User Interface
Input(s)	Matter	Energy	Amount of food, calibration signal	Energy, ON signal	Data	Data
Output(s)	Amount of food	Energy	Data	Power	Data	Data
Functionality	Tool for baby to consume food	Charge battery	Measure amount of food eaten by baby	Main power source	Collects data from data bus and sends to UI	Collects Bluetooth data and provides it in a presentable state

V. Estimated Costs & Budget

Due to all the testing equipment being bought to test the previous version of the Smart Bottle, the only purchases needed for this project would be the two wireless charging modules (the Qi and RX TX induction charging modules) and the newly designed PCBs. These chargers would be implemented in Module 1.2 (Table III) and are needed to charge the coin cell battery. We are planning on purchasing one of each charger.

The Qi charging module costs $14.95 and the Rx Tx induction charging module costs $39.95. The PCB will cost roughly $20 from OSH Park at $5 per square inch, with the previous design being four square inches. We can assume that the dimensioning of the design will not change as it is designed to fit the 3D printed sleeve that houses the Smart Bottle. We are assuming no state sales tax or shipping costs as they are to be undetermined, as well as no costs for the 3D printed housing as these resources are available free of charge at Cal Poly.

The typical costs for a wireless charger range from $10 to $50. The average salary of a recent EE graduate in California is $77,255 [7] which totals to be $37.14 an hour. According to the Gantt chart we will put in 444 hours per person, totaling 888 hours for the whole project. This brings the cost of labor for this project to $32,980.32. The total project cost is estimated to be $33,055.22 (labor and purchasing costs).

Table IV: Project Costs & Justifications

Part	**Description**	**Unit Cost**	**Total Cost**	**Justification**
Ada Fruit QI Charger [5]	Thin and smart inductive charging system that works with standard inductive charger base	\$14.95	\$14.95	Universally most popular charging module that is used in standard wireless charging modules. The receiver chip outputs 5V and 500 mA, so it is easy to implement to our system.
Rx Tx Induction Charger [6]	Air-core transformer that outputs 5V and 1.3A max	\$39.95	\$54.90	Another type of wireless charging that allows for more customization, allows for more room for design decisions.
Redesigned PCB via OSH Park [8]	Updated PCB with ports to account for wireless charging	\$20	\$74.90	Includes three copies per order, necessary for implementing and testing a new PCB design that allocates space and power for a wireless charging module.

VI. Wireless Charging Implementation

It was crucial to ensure that the wireless charging capability did not interfere with the option to also charge via USB. The method of implementing wireless charging involved charging the LiPo battery directly. To charge the LiPo battery via wireless charging, it was necessary to understand the characteristics of the battery and wireless charger receiver. The wireless charging receiver module used was the Adafruit Universal Qi Wireless Receiver Module with the LiPo battery used being specified at 3.7V and 400mAh. The charging cut-off voltage of the LiPo battery is rated at 4.2V, with a standard charge time of approximately 4 hours.

A design change to consider was for the case in which the user may wirelessly charge and charge via USB at the time, and how that charging could be regulated. To account for this use case, the LTC4412 Low Loss PowerPath Controller was implemented, and an evaluation board was created to characterize its power switchover capabilities. Additionally, a current sink circuit was designed to properly drain the LiPo battery for testing, verification, and characterization.

A. LTC4412 Low Loss Power Path Controller

The primary function of the LTCC4412 Low Pass PowerPath controller is to provide control over the choice of power source when charging the LiPo battery. The implementation of the LTC44122 addressed concerns about users potentially plugging in the wall charger to charge the LiPo battery, while simultaneously utilizing the wireless charger. The Low Pass PowerPath controller facilitates the simultaneous use of the main charging method (wall charger) alongside the secondary charging method (wireless charger), without any conflicts, ensuring that only the wall adapter charges the LiPo battery. An evaluation board for the LTC4412 was not within budget for this project, however, Analog Devices provides a schematic for the chip and from there we created our own evaluation board (Figure 5). From there, we were able to create the board shown in Figure 6, to test the LTC4412 chip.

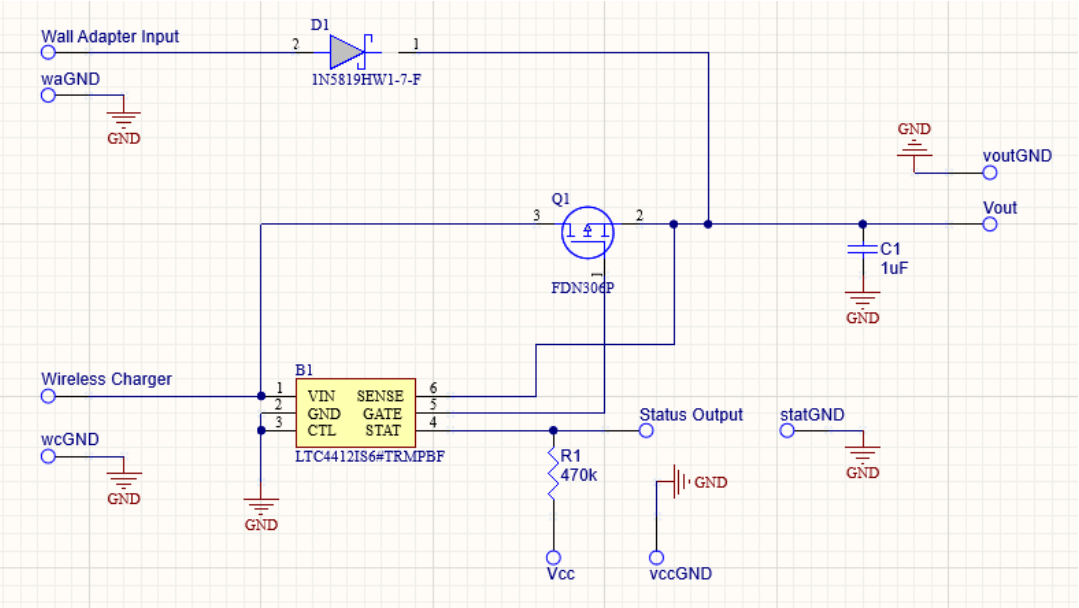

Figure 5: LTC4412 Evaluation Board Schematic

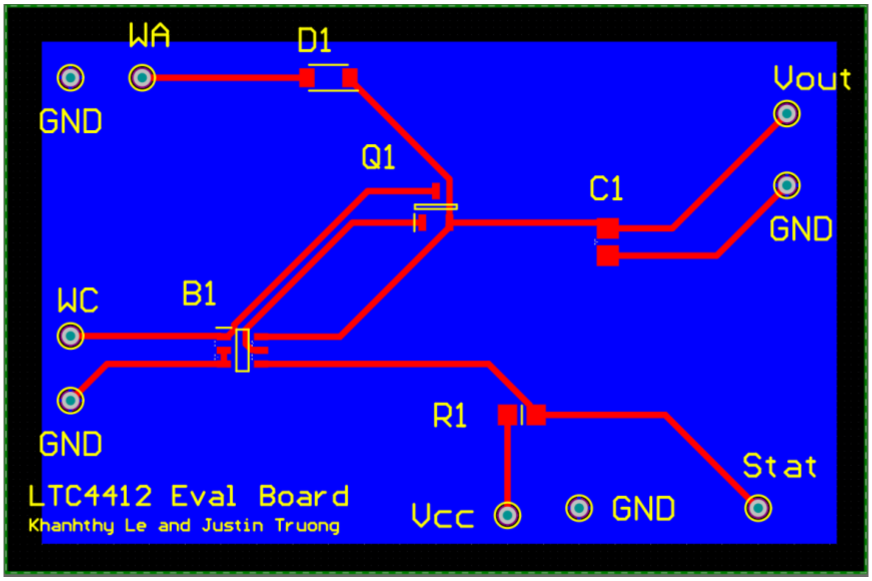

Figure 6: LTC4412 Evaluation Board

This design uses the conventional application of the PowerPath controller, where a PMOS transistor oversees selecting between two charging methods. The PMOS drain is linked to the wireless charging line, while the gate is connected to the corresponding pin on the power path controller. The source is subsequently linked to the controller's sense pin, the input from the wall adapter, and the load.

When the wireless charger is connected, the PowerPath controller turns while using the wireless charger as a power source. The MOSFET is then switched on, causing the load to be pulled up by the drain-source diode of the MOSFET, then charging the battery with the wireless charger.

In cases where solely the wall adapter is plugged in, the PowerPath controller is never turned on and bypassed, and the load is directly powered. If both the wall adapter and the power path controller are concurrently connected, the sense pin of the controller detects the high signal on the wall adapter line. The sense pin is pulled up by the Schottky diode and the power path controller deactivates the PMOS MOSFET, driving the ‘stat’ pin of the controller low. This state indicates the utilization of the primary charging source.

There were 3 user cases that were considered for charging. The first case is where the user decides to charge the device using a wall charger via micro-USB port, shown in Figure 7 and Figure 8. We used a 5V power supply to simulate a wall charger and saw that when connected, it takes about 16ms for the charging circuit to turn on.

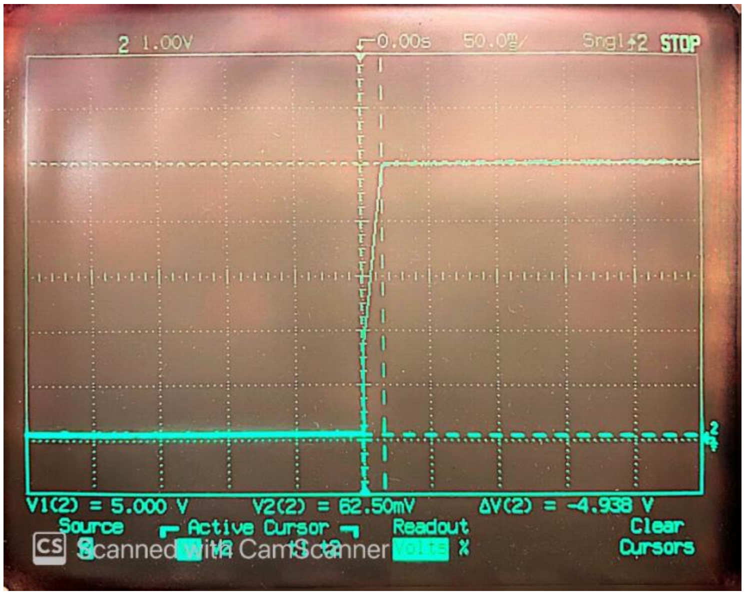

Figure 7: Wall Charger Step Response Voltage Reading

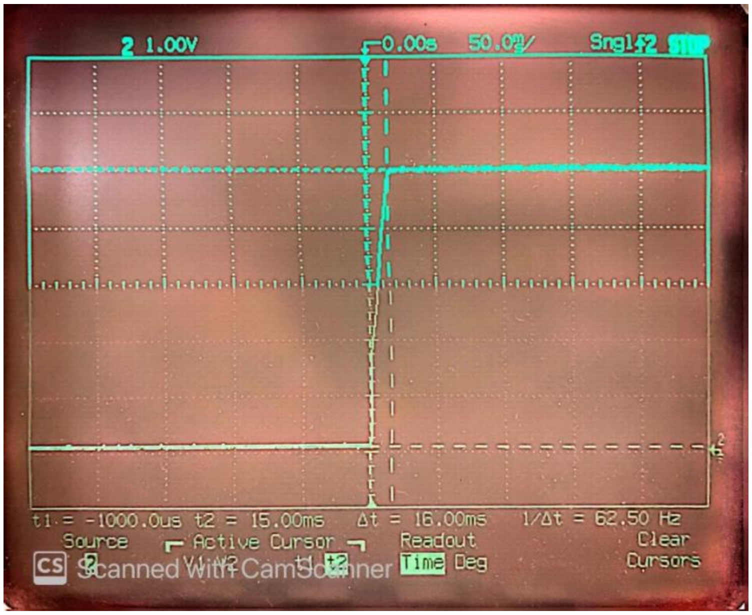

Figure 8: Wall Charger Step Response Time Reading

The second case is where the user decides to charge the device using a Qi wireless charger. The voltage reading (Figure 9) is inconsistent, but we see that it most consistently goes to 7V-8V. This is due to the Qi wireless charger being unloaded. The Qi wireless charger takes roughly 3.6ms (Figure 10) for the charging circuit to turn on, 77.5% faster than it takes to start the wall charger.

Figure 9: Wireless Charger Step Response Voltage Reading

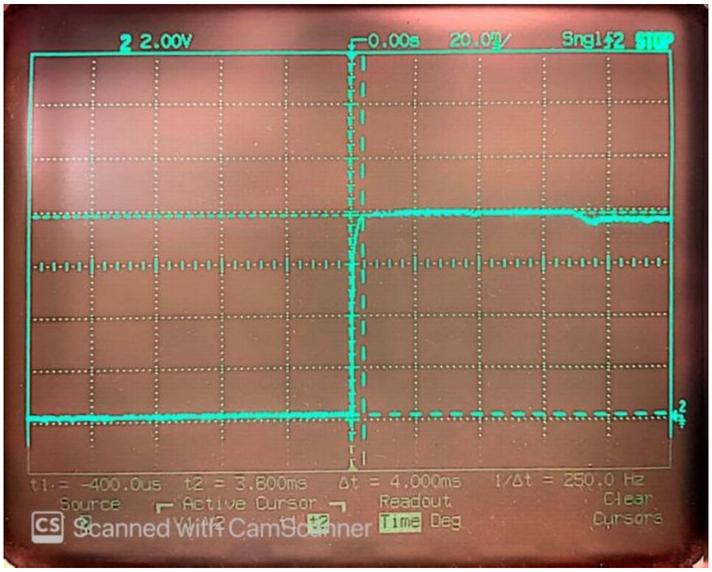

Figure 10: Wireless Charger Step Response Time Reading

The third case is where the user decides to charge the device using a Qi wireless charger while already connected to the wall charger. In Figure 11 and Figure 12, we see that voltage goes to 10V in about 2ms. Checking that the stat pin goes high when the wireless charger is connected shows the user that only the wireless charger is being used when connected.

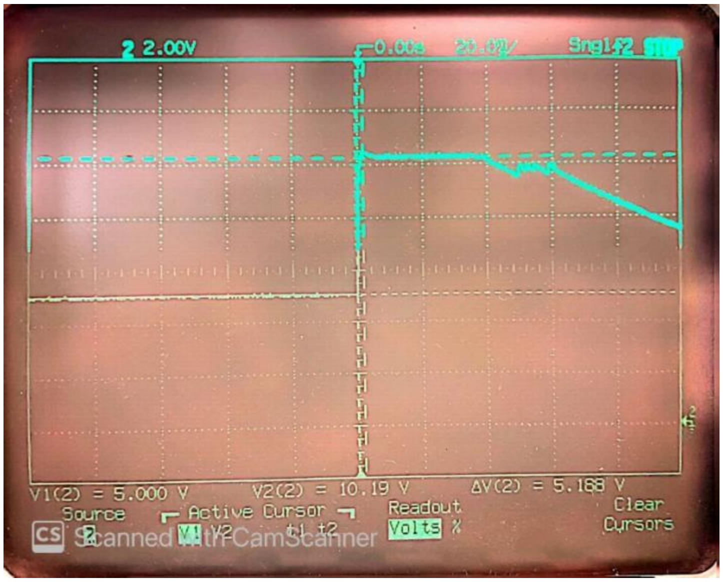

Figure 11: Wireless Charger Connected While Wall Charger Connected Step Response Voltage Reading

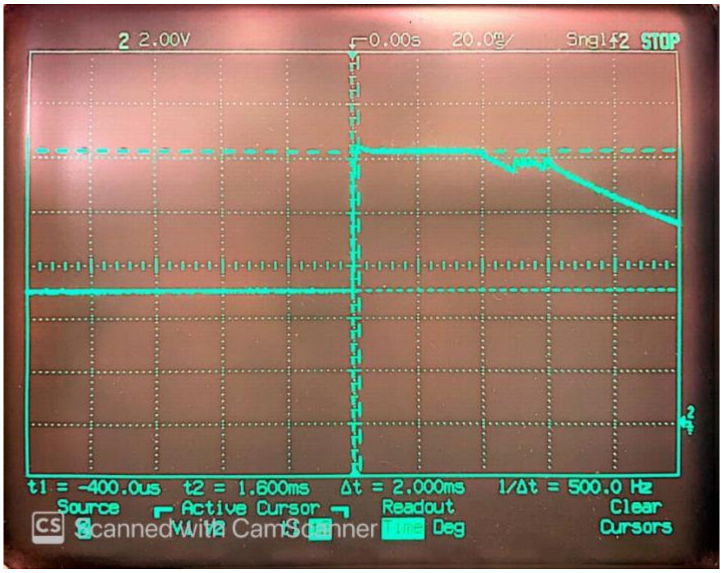

Figure 12: Wireless Charger Connected While Wall Charger Connected Step Response Voltage Reading

B. PCB Redesign

A new version of the Smart Bottle PCB was fabricated to accommodate the implementation of the LTC44122, as well as the attachment of the Adafruit Qi wireless charging receiver. It was necessary that this new design allowed the wireless charging receiver to sit on top of the Smart Bottle PCB without interfering with previously implemented measurement capabilities.

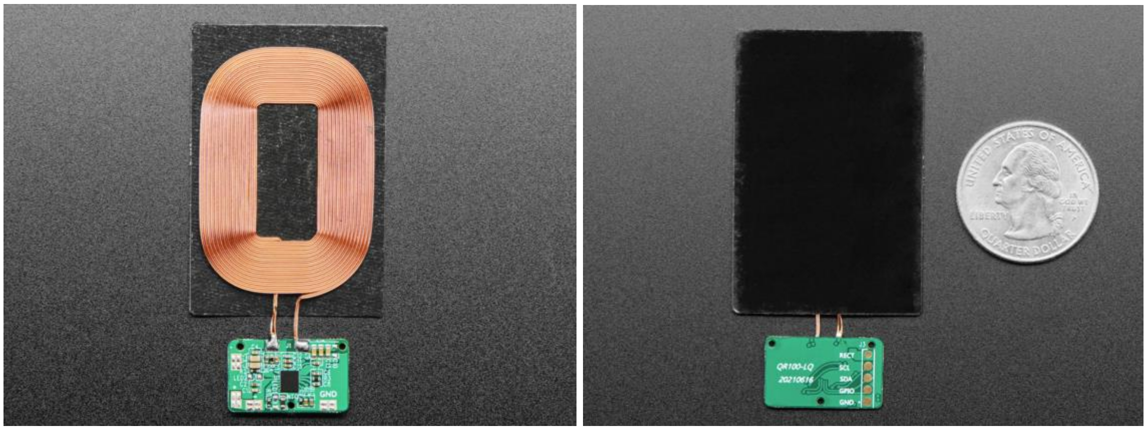

Figure 13 (left) & Figure 14 (right): Adafruit Qi Wireless Charging Module, top (left) and bottom (right) [5]

The Adafruit Qi wireless charging module consists of a chip attached to a copper back panel. The chip is to be the component attached to the redesigned PCB, and the back panel is to be tucked under the new PCB. Board real estate was the main obstacle of this redesign, and we found it necessary to increase the radius of the PCB to accommodate for the large wireless receiver module. The previous iteration of the Smart Bottle was a compact, hand wired design, with 61mm diameter. The new design has a 68.6mm diameter, enough space to accommodate for the 19mm x 12mm x 1.3mm [same reference as photo] wireless charger chip size. There are no Eagle libraries that contain a five pin, 1mm pad connector. As a result, five SMD test points (Figure 15) had to be scaled on the new board's design to accommodate for the five contact points on the Adafruit Qi Wireless Charging Module.

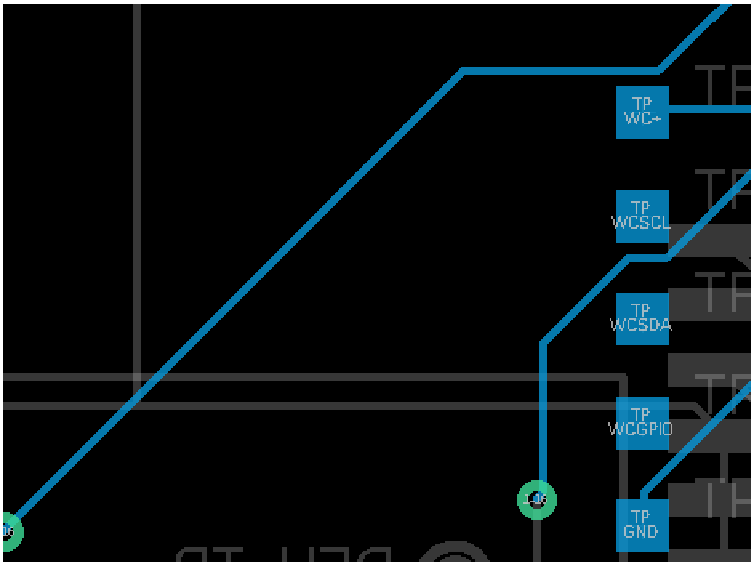

Figure 15: Adafruit Qi Wireless Charging Module Contact Points on New PCB

VII. PCB Fabrication

The PCB was redesigned on Eagle and ordered through JLCPCB with a stainless-steel solder stencil. Using a solder stencil allowed for a more efficient method of picking and placing the components. A laser cut, wooden board with a cutout the size of the PCB and a lip, was created by Dr. Hawkins to allow us to place components with ease. The cutout held the PCB on a 1mm lip so that components could be placed on both sides. The stencil was secured by tape on top of the PCB and a plastic card smoothed a thin layer of solder paste onto the stencil. We were able to look for any potential bridged connections and wipe them away with isopropyl alcohol or scrape it off the board with a razor. Once the components to be put on the PCB were inventoried and organized, they were hand placed onto the board. We had opted to assemble the bottom layer of the board first, as the top layer consisted of components that would make it difficult to keep the PCB level.

The best method for soldering the components into place proved to be by using the reflow oven. The solder paste used for this project had a eutectic melting point of 137˚C (278˚F) and it was necessary to reflect this on a reflow oven temperature curve. There was no information sheet for this solder paste, therefore the temperature curve had to be manually adjusted.

With the design consisting of a two layered board, it was necessary to reflow solder one side at a time. To reflow solder the second layer of the board, the board was to be flipped over and propped on top of an aluminum foil nest to avoid the components on the already soldered side of the board from falling off. Any components that were not properly attached via the reflow oven were hand soldered. Other hand soldered components included the larger ones (such as the wireless charging receiver and USB charging connectors) as well as any other SMD components that may have fallen off due to a poor connection.

VIII. Testing and Verification

A. Characterizing Wireless Charging Module: Current and Voltage vs Distance

Using the setup pictured in Figure 16 we were able to characterize the current and voltage vs distance of the Adafruit Qi Wireless Receiver. A Qi wireless charging transmitter was held stationary on a rail as the Qi wireless charging receiver was moved back in 1 mm increments, with a stationary ruler as a reference. Digital multimeter 1 (DMM1) was attached in series with a 10kΩ resistor measuring current and Digital multimeter 2 (DMM2) was attached parallel to the load measuring the voltage across the load. From our experiment we concluded that the wireless charging module was able to provide constant voltage and current up to 12mm. The Adafruit Qi Wireless Receiver is rated to produce an output voltage of 4.8V – 5.2V and our findings in Table 6 confirm this.

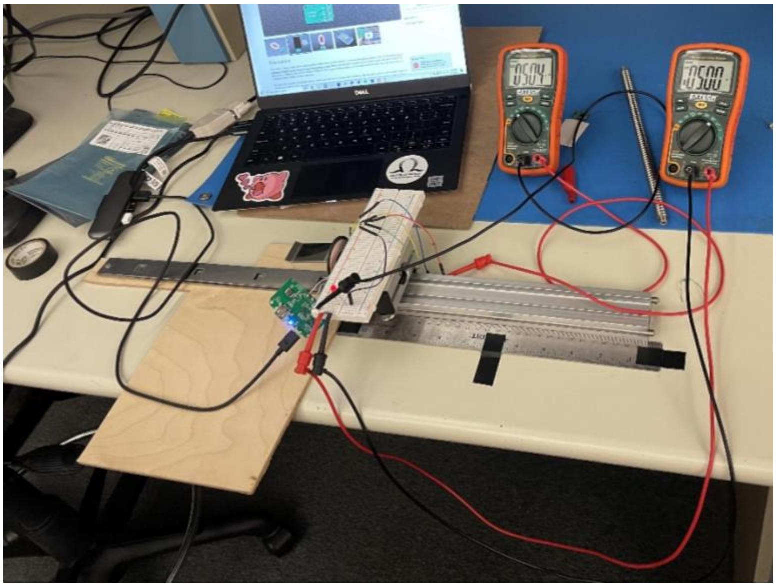

Figure 16: Qi Rx Distance vs. V & I Characterization Setup

Table V: Qi Rx Distance vs. V & I

Distance between Rx & Tx (mm)	**V_{DC} (V)**	**I (µA)**
0	4.83	490
1	5.03	508
2	5.04	510
3	4.95	500
4	4.94	499
5	4.92	498
6	4.90	494
7	4.96	502
8	4.95	488
9	4.98	496
10	4.93	496
11	4.90	492

Although our characterization test shows electrical power transfer capabilities of up to 12mm, this is under the circumstance that there is no material between the transmitter and the receiver.

B. Characterizing LiPo Battery

To characterize the LiPo battery, it was necessary to create a current sink. Figure 17 shows the current sink design implemented and Figure 118 shows the physical board. The objective of this design was to use the NMOS transistor like a variable resistive load. The parallel resistive network above sums to is about 14.4Ω which allows the max current load to be 291mA.

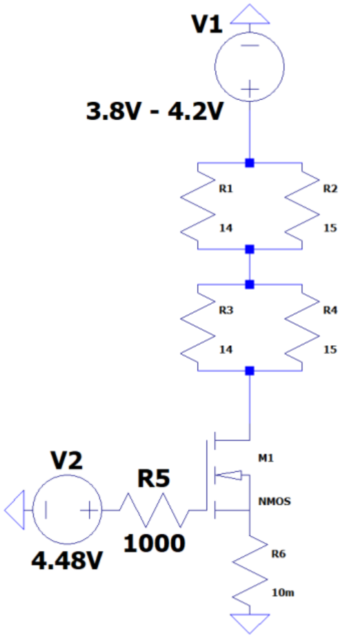

Figure 17: LiPo Battery Current Sink Schematic

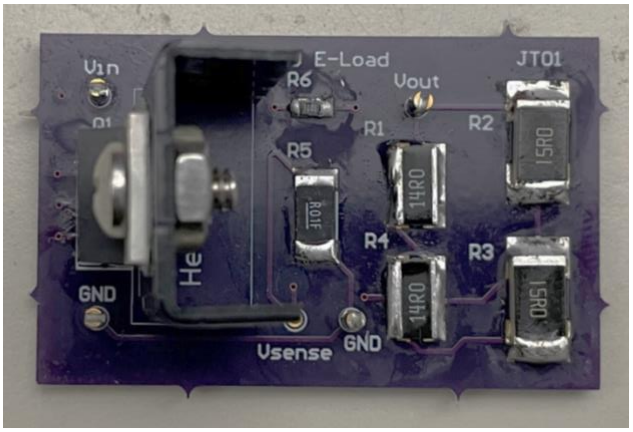

Figure 18: LiPo Battery Current Sink Board

The LiPo battery is rated to be 400mAh at 1C meaning that it is recommended to charge/draw up to 400mA. The amount of current load can be adjusted to the gate voltage, which is powered by the power supply to use the ohmic property of the transistor. We chose to use the IRFZ44EPBF, a power NMOS transistor, due to its relatively large ohmic region (compared to other transistors) and for its power dissipation capabilities. It also has a built-in heat sink which we were able to easily attach a SIL pad and an external heatsink to draw out the temperature. The transistor needed to be able to handle at least 1.21W as its component dissipated most of the power due to its impedance being much greater than the resistive network above.

All the resistors chosen are power precision resistors rated for 2W-3W. R5 is a 1KΩ resistor added to the gate of the transistor to control the current going into the gate of the resistor. R6 is a current sensing resistor used to be able to measure the voltage across to determine the current. Due to the resistor being on the low side of the circuit, the voltage was too low to be measured by any of our instruments and it was more feasible to use an ammeter to measure the load current. When discharging the battery from 4.1V–3.8V, it took about 43 minutes to discharge at 139mA.

C. Wireless Charging vs. USB Charging

We compared the characteristics of a simulated wall charger to that of a wireless charger. To simulate a wall charger, we used a power supply set to 4.2V and limited the current to 400mA. This is done because the battery is rated 400mAh and 1C meaning that you can only charge/discharge at a rate of 400mA. The PowerPath evaluation board was utilized with the power supply and the wireless charger connected to the board. A bread board was placed in between the pads of the wireless charger to simulate the distance between the housing of the Smart Bottle adapter. On the battery description on the Adafruit website, the battery outputs 4.2V at full capacity and 3.8V when empty. Therefore, these characteristics determine when the battery was drained vs full. For testing purposes, we measured the time it took for each charger to charge the battery from 3.8V to 4.1V.

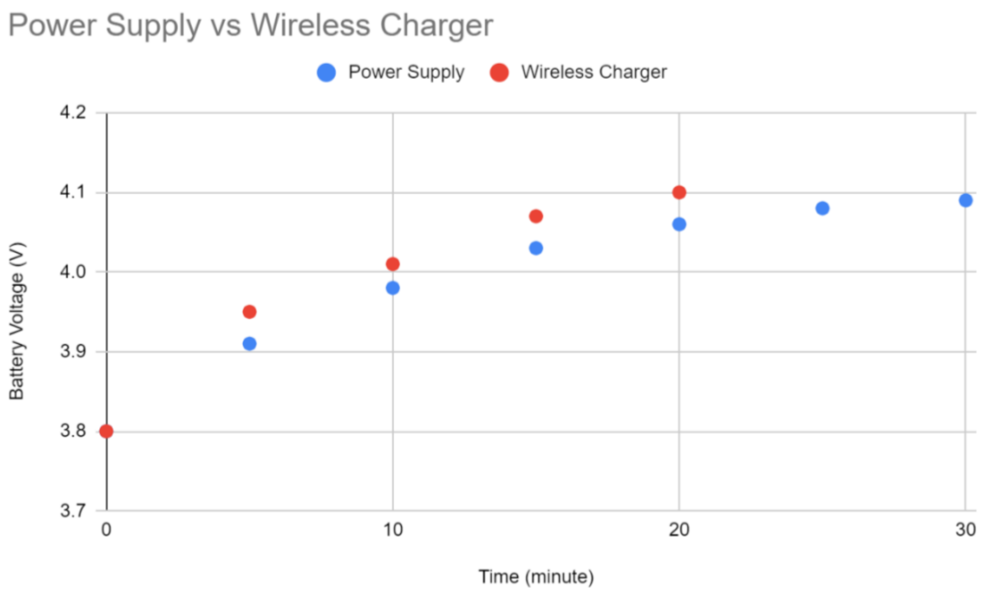

Figure 19: Battery Voltage vs. Time of USB Charging and Wireless Charger

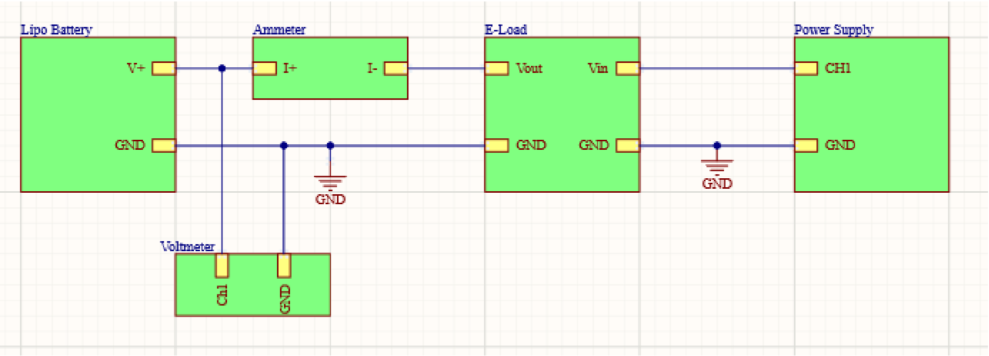

Figure 20: Discharging Battery with Wireless Charger and Power Supply

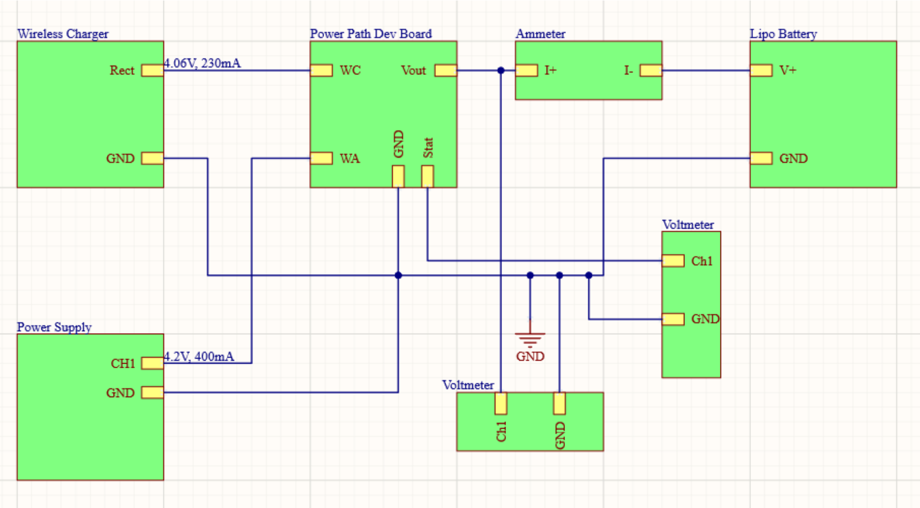

Figure 21: Charging Battery with Wireless Charger and Power Supply

From this experiment, we were surprised to see that the wireless charger (20 mins) charged the battery 33% faster than the power supply (30min). This was surprising due to the output voltage of the wireless charger being 4.04V and the charging current was 250mA. In contrast, the power supply was set to 4.2V with a current limit of 400mA. Now, the power supply often adjusts either the output voltage or the output current, to meet the input limitations to safely charge the LiPo battery. Another interesting result was that the output voltage of the wireless charger was 4.04V. This was a positive result, since previously when unloaded, the wireless charged output voltage could spike all the way to 10V, potentially burning out the battery. But with the output voltage being within a safe range for the battery, a voltage regulator is not needed to condition the output voltage of the wireless charger.

IX. Results

A. Hardware

The PCB fabrication process proved to be the most time-consuming part of this project. An initial inventory of the project was created early in the development process, however the large number of components required to manufacture the board resulted in some discrepancies. The most time-consuming part of the project included lead times for missing components. Upon fabrication, it became immediately obvious that an incorrect footprint for the MCU was used. The correct footprint for the MCU was QFN, with contact pads tucked under the chip, therefore it was difficult to solder as there came the risk of damaging or desoldering the components around it on the board. Once the correct MCU was placed on the board, the only way of testing the functionality of the hardware was to connect it to the battery.

We found that there was not enough allowance for the cable, as the micro-USB connector was too far away from the edge of the board, and that the only way to remediate this was by cutting out a part of the PCB. This was the result of not moving the micro-USB footprint when redesigning the board layout in Eagle. There posed a risk of damaging the traces on the other side of the board when doing so, and after multiple attempts, the PCB lifted. The most feasible plan of action was to refabricate the PCB and thus a second board was manufactured. The second board manufactured proved to be a more reliable testing unit as it allowed for the correct MCU to be reflow soldered on, as well as ensuring that the components surrounding the MCU were less likely to be damaged in the process.

The second PCB showed promising results as when it was connected via USB, the charging indicator LED had lit up. The next task was to attach the Adafruit Qi wireless charging module to the board. It was difficult to attach the Qi wireless chip directly on top of the board and its contact points, therefore we found that the best option was to connect the chip to the PCB using wire. Upon attaching the wireless charging module to the PCB, the contact pads on the PCB lifted due to movement of the wireless charging board. We were not able to scrape at the PCB to create a new trace for the wireless charging module as there was limited space on the board to do so. When the battery was briefly connected to the PCB with the wireless charging module there was a 5V charge. Although we were unable to test the wireless charging capabilities of the Qi wireless charger connected to the board, we were able to measure the battery characteristics of the wireless charger and the USB charger independently.

Although we were unable to test the wireless charger on the new PCB, our characterization tests for the wireless charger show that theoretically the wireless charger would be able to charge the battery when attached to the PCB. The main concern for attaching the wireless charger onto the PCB was the risk of overheating and damaging the circuit, however, we found that the output voltage of the wireless charger to be within range of safe operating temperatures for the battery itself.

B. Software Specific Hardware Changes

For the initialization process of the Bluetooth module, we decided to keep the process of initializing through the JTAG interface. This was due to having limited ports on the MCU to initialize a bit bang protocol. It seemed inefficient to do otherwise, due to the module only needing to be flashed once built. Some hardware changes that were made to improve the initialization process included removing the 0Ω resistor short connection between the MCU reset and the Bluetooth reset button. This forces the developer to reset both modules at the same time regardless. We also implemented several new test points connected to some of the Bluetooth module pins:

BLE_SWDIO, BLE_RESET, and DFU. BLE_RESET and DFU test pins could be set high to reset the Bluetooth module.

Two out of the three pins were connected to the Bluetooth module to facilitate data transfer between the MCU and the Bluetooth module. Pin A13 was connected to the Bluetooth chip select line. Pin A06 was connected to the Bluetooth SWDIO line. This allows for the developers to write Arduino code to send data using these lines. Once the Bluetooth module receives this data, it can send it to the user.

There are also plans to be able to monitor and transmit data via Bluetooth. To facilitate this, pin A07 is connected to a voltage divider network of two 100kΩ resistors. These resistors limit the current going into the input pin of the MCU. The battery level can be calculated using the specs listed on the Adafruit website. From there, battery is stated to output 4.2V at full capacity and 3.7V when empty. Therefore, the battery level can be found using the ADC pin by using this 3.7 to 4.2V range and dividing it by two to compensate for the voltage divider.

X. Discussion of Results

The objective of this project was to implement a wireless charging module and Bluetooth firmware to the previous iteration of the Smart Bottle. We were able to characterize a wireless charging module and with some mechanical improvements it could be implemented into the system. The current methodology of flashing the Bluetooth firmware through the JTAG was kept the same from the last iteration of the Smart Bottle, with some board design changes made to improve the testing process. We were able to manufacture a slightly modified version of the last Smart Bottle iteration, one that can be used for future Bluetooth testing capabilities.

While this version of the Smart Bottle is based off a working, preexisting model, there are still board design improvements that can be made to future iterations:

1. Wireless charger module: Soldering extension wires made it brittle at the point of connection, especially because it was necessary to bend it backwards below the PCB to fit it in the casing. A solution to this would be by adding epoxy on top of the solder joints to take some of the stress off the joint, making it more durable for vibrations and general handling. Additionally, adding epoxy to the contact points and pads of the board to prevent lifting due to thermal factors would be beneficial.
2. Component footprints: Using a TQFP package instead of a QFN one for the MCU would make it easier to ensure that all pads are connected to the board. The QFN package was difficult to solder by hand and posed a risk.
3. Redesigning the silkscreen layer: It was difficult to read the designators of some components on the board. It would be beneficial to scale the designators to be bigger, considering the radius of the board had increased from the previous iteration.

4. Charging improvements: Adding current protection on the charging circuit would be a beneficial safety mechanism for this circuit, as well as implementing a feature or indicator that reads charge status.
5. Current Sink Improvements: Shown below is an improved design of the current sink. This design uses an op amp to create a closed loop design that doesn't rely on the transistor's ohmic region. The load current is determined by Vin/Xl and is only limited by the supply voltage of the RRIO op amp. Riso, Cf, and Rfb are fine tuned for stability. Riso controls the switching speed of the transistor and in turn the oscillation of the transistor as well.

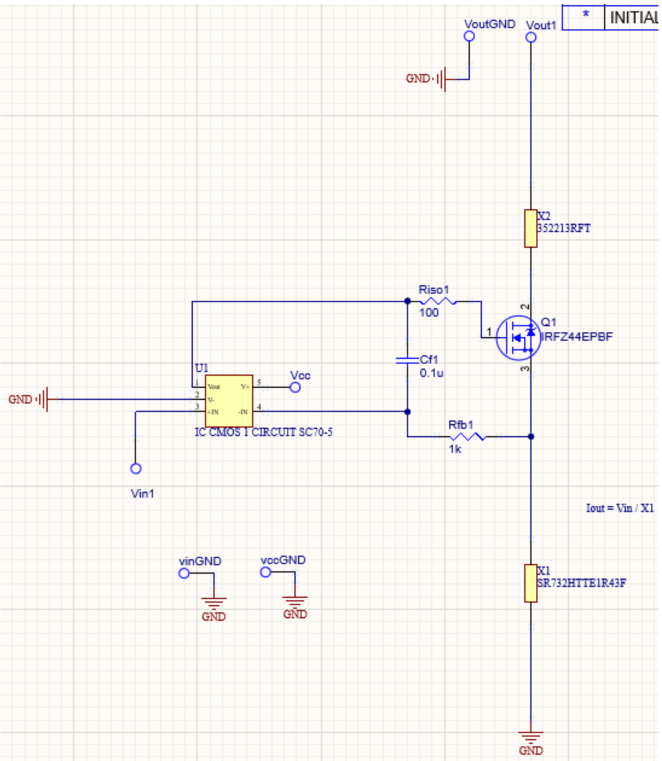

Figure 23: Improved LiPo Battery Current Sink Schematic

XI. References

[1] B. Watchmaker, B. Boyd, and L. R. Dugas, “Newborn feeding recommendations and practices increase the risk of development of overweight and obesity - BMC Pediatrics,” *BioMed Central*, 04-Mar-2020. [Online]. Available: https://bmcpediatr.biomedcentral.com/articles/10.1186/s12887-020-1982-9. [Accessed: 10-Feb-2023].

[2] “Childhood obesity facts,” *Centers for Disease Control and Prevention*, 17-May-2022. [Online]. Available: https://www.cdc.gov/obesity/data/childhood.html#:~:text=Prevalence%20of%20Childhood%20Obesity%20in%20the%20United%20States&text=The%20prevalence%20of%20obesity%20was,14.7%20million%20children%20and%20adolescents. [Accessed: 10-Feb-2023].

[3] “How much and how often to feed infant formula,” *Centers for Disease Control and Prevention*, 16-May-2022. [Online]. Available: https://www.cdc.gov/nutrition/infantandtoddlernutrition/formula-feeding/how-much-how-often.html#:~:text=You%20can%20start%20by%20offering,12%20times%20in%2024%20hours. [Accessed: 10-Feb-2023].

[4] J. Guan, R. Brewster, J. De La Fuente, A. K. Ventura and B. G. Hawkins, "Artificial Neural Network for Identification of Infant Feeding Tracking Using the Smart Bottle System," 2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), Mexico, 2021, pp. 7539-7543, doi: 10.1109/EMBC46164.2021.9629536.

[5] A. Industries, “Universal Qi Wireless receiver module,” *adafruit industries blog RSS*. [Online]. Available: https://www.adafruit.com/product/1901?gclid=CjwKCAiA9NGfBhBvEiwAq5vSy8_Ir1Lsl3DEfdM0re+2bsojokz_ahyo4F8e1fgYvROSdiJr2dX5lyxoCLpwQAvD_BwE. [Accessed: 14-Mar-2023].

[6] “4430: Digi-Key Electronics,” *Digi*. [Online]. Available: https://www.digikey.com/en/products/detail/adafruit-industries-llc/4430/11569133?utm_adgroup=Educational+Kits&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Product_Maker%2FDIY%2C+Educational_NEW&utm_term=&utm_content=Educational+Kits&gclid=CjwKCAiA9NGfBhBvEiwAq5vSy-w69eILFO0rGGyr9Obc-pBzg3LM3YhxJEm9GssU84Llw7l6dm9_PBoC-ZgQAvD_BwE. [Accessed: 16-Mar-2023].

[7] S. built by: Salary.com, “Graduate Electrical Engineer Salary in California,” *Salary.com*. [Online]. Available: https://www.salary.com/research/salary/recruiting/graduate-electrical-engineer-salary/ca. [Accessed: 17-Mar-2023].

[8] Osh Park, “2 Layer Prototype Service,” *docs.oshpark.com*. [Online]. Available: https://docs.oshpark.com/services/two-layer/. [Accessed: 17-Mar-2023].

[9] G. Satterfield, Programmable low-side current sink circuit, https://www.ti.com/lit/an/slaa868/slaa868.pdf?ts=1694137529001&ref_url=https%253A%252F%252Fwww.google.com%252F#:~:text=The%20programmable%20low%2Dside%20current,ensure%20stability%20of%20the%20circuit. (Accessed Sep. 8, 2023).

[10] P. Horowitz and W. Hill, *The Art of Electronics*. New York: Cambridge University Press, 2022.

Appendix A: Impact Analysis

A. Functional Requirements

The Smart Bottle records real-time data on infant feeding patterns for parents and researchers to examine the correlation between infant feeding patterns and childhood obesity. The Smart Bottle module is attached to the bottom of a baby bottle and uses sensors to capture data on the amount of food consumed at the time of feeding, the time when the bottle is lifted, and the duration of the feeding time. The data collected is then recorded on an SD card that can be removed from the Smart Bottle module and accessed to analyze.

B. Primary Constraints

The major limiting factors that come with this project mainly revolve around the lack of board real estate, considering that the PCB itself has a 7cm diameter and the modules that are already implemented on it take up all the space. Implementing a wireless charging module to the previous iteration of the Smart Bottle is impossible, therefore PCB redesign is necessary. Additionally, the BLE implementation is associated with a learning curve, and taking over this implementation using a different software language causes miscommunication between past literature.

C. Economic Impacts

The Smart Bottle is considered manufactured capital as it is made by myself, my partner, and those who have contributed to previous versions of it. The main costs accrue at the beginning of the product lifecycle, as the implementation contains most, if not all, transactions associated with this product. However, the costs accrued may also be considered nearing the end of the project as well in the case that new modules or PCBs must be purchased for troubleshooting. The version of this project that we are working on requires a material cost of less than $80, with the main costs being the newly designed PCB and the wireless charging modules that will be implemented.

The Smart Bottle was conceived as a research and data collection tool; therefore, the project intention is not to be profitable. The products emerge as PCBs are printed and meet engineering specifications as well as customer specifications, typically after testing and verification. The product exists for as long as research and data collection on infant feeding trends are needed, however, the product lifespan is to be determined. The previous iteration of the Smart Bottle is said to be about 732 days, but a wireless charging module and Bluetooth integration may degrade or elongate this estimate. After the project ends, we are optimistic that another team or individual will continue to make the Smart Bottle more efficient at data collection or improve the user interface of the data that is collected.

D. Commercial Manufacturing

The Smart Bottle is not intended to be manufactured commercially as of now. It has the sole purpose of being used as a data collection tool for Cal Poly researchers looking to analyze infant feeding patterns.

E. Environmental Impacts

The only environmental impact associated with the construction of the Smart Bottle is electricity. The Smart Bottle uses a coin cell battery to operate, and soon it will be able to utilize a wireless charging module to charge this coin cell battery. The project requires many electrical components (such as resistors, capacitors, transistors, etc.), therefore the resources needed to create those components are resources that this project uses directly. Copper, rosin, lead, and tin are just a few of those resources. The project seeks to improve the ecosystem as being able to collect data on infant feeding trends may show that infants require less formula or food, and in turn, this prevents the overconsumption of material per feed.

F. Manufacturability

The main issue with manufacturing the Smart Bottle would be soldering the surface mount components to the PCB as well as the ability to house the PCB in the 3D printed case. The Smart Bottle is intended to be light enough to attach to the bottom of an infant feeding bottle without obstructing the original act of feeding. Manufacturing the Smart Bottle requires human handling and precision.

G. Sustainability

Maintaining the completed Smart Bottle would require an efficient transfer of knowledge between the customer and the designers. Troubleshooting the Smart Bottle could be difficult as each iteration has had its own method of testing the device. In terms of physical maintenance, the Smart Bottle runs the risk of damaging the PCB once in contact with liquid. As mentioned before, the Smart Bottle could reduce the number of resources used in infant feeding if there are trends found linking infant feeding patterns and childhood obesity. The design of the project could be upgraded to create a completely waterproof housing to prevent any PCB damage. However, this waterproofing may come at an increased product cost or add to the weight of the Smart Bottle module.

H. Ethics

While the Smart Bottle is designed to monitor infant feeding in hopes of decreasing the rate of childhood obesity, it is possible that one can misuse this project and use it for infant weight loss. An additional ethical implication arises as the project can cause potential harm to the infant or the person feeding the infant in the case that the PCB malfunctions and produces an electric shock. This falls in line with the IEEE Code of Ethics I. “to hold paramount the safety, health, and welfare of the public,”.

I. Health and Safety

Infant safety is the number one risk associated with this design and it is possible that when exposed to liquid, the PCB could electrocute them. The safety risks associated with manufacturing include electrocution as well, however, the system runs at a very low current and a very low voltage so any severe safety risks should not be an issue.

J. Social and Political Implications

Childhood obesity is very prevalent, especially in the United States. However, there are those who do not see childhood obesity as a problem, arguing that it is good for the economy. The project will impact the public as it sheds light on the correlation between infant feeding and childhood obesity. With this new research backed by quantitative data, it may motivate those feeding infants to feed them to a degree where the infant is healthy, nourished and not overfed. The direct stakeholders of this project are Dr. Ventura, Dr. Hawkins, and the Cal Poly EE department for funding this project. The indirect stakeholders are those feeding infants and the infants themselves. The project benefits the stakeholders equally scientifically, as it is designed to be a research tool that quantifies infant feeding trends. The stakeholders receive all the data collected and are considered equal contributors to the project therefore there are no inequities. Dr. Ventura has access to different childcare agencies thus she can provide infants and adults with the Smart Bottle. Dr. Benjamin Hawkins has the lab space available for testing and verification of the actual Smart Bottle module.