

# **Bat Migration Monitor**

## **Final Report**

### **ECE 445**

#### **Team #35**

Hoguer Benitez[hoguereb2]

Lilian Rafferty[aidanr4]

Romin Patel[rominmp2]

TA: Tianxiang Zhang

Spring 2024

## **Abstract**

This paper presents the comprehensive design process and results of the Bat Migration Monitor, which is a wearable device tailored for bats specifically to understand their migration paths. Key features that are constructed for this device are a tracking device with VHF integration in order to retrieve the device back from the bat, a GNSS module to effectively collect precise longitude and latitude data, and a Battery supply module to make the device reusable for researchers. Throughout the development journey, significant portions of the design were proven to be successful with various subsystems operating in an effective manner on both development boards and printed circuit boards (PCB), and in this paper we'll detail those successes along with the challenges that were faced during the designing processes.

## Contents

<b>1. Introduction.....</b>	<b>1</b>
<b>1.1 Problem.....</b>	<b>1</b>
<b>1.2 Solution.....</b>	<b>1</b>
<b>1.3 Visual Diagram.....</b>	<b>1</b>
<b>1.4 High-Level Requirements.....</b>	<b>2</b>
<b>1.5 Block Diagram.....</b>	<b>2</b>
<b>1.6 Subsystem Overview.....</b>	<b>3</b>
<b>2. Design.....</b>	<b>5</b>
<b>2.1 Physical Design.....</b>	<b>5</b>
<b>2.2 Power Subsystem.....</b>	<b>6</b>
<b>2.3 Control &amp; GNSS Subsystem.....</b>	<b>7</b>
<b>2.4 VHF Subsystem.....</b>	<b>9</b>
<b>2.5 User Interface Subsystem.....</b>	<b>12</b>
<b>3. Requirement and Verifications.....</b>	<b>14</b>
<b>3.1 GNSS.....</b>	<b>14</b>
<b>3.2 EEPROM.....</b>	<b>14</b>
<b>4. Cost &amp; Schedule.....</b>	<b>17</b>
<b>4.1 Parts .....</b>	<b>17</b>
<b>4.2 Labor Costs.....</b>	<b>18</b>
<b>4.3 Schedule.....</b>	<b>18</b>
<b>5. Conclusion.....</b>	<b>19</b>
<b>5.1 Accomplishments.....</b>	<b>19</b>
<b>5.2 Challenges.....</b>	<b>19</b>
<b>5.3 Future Work.....</b>	<b>20</b>
<b>5.4 Ethics &amp; Safety.....</b>	<b>20</b>
<b>6. Reference.....</b>	<b>21</b>
<b>Appendix A: Schematics.....</b>	<b>22</b>
<b>Appendix B: Battery Testing Graphs.....</b>	<b>25</b>
<b>Appendix C: Requirement and Verification Tables.....</b>	<b>27</b>

# 1. Introduction

## 1.1 Problem

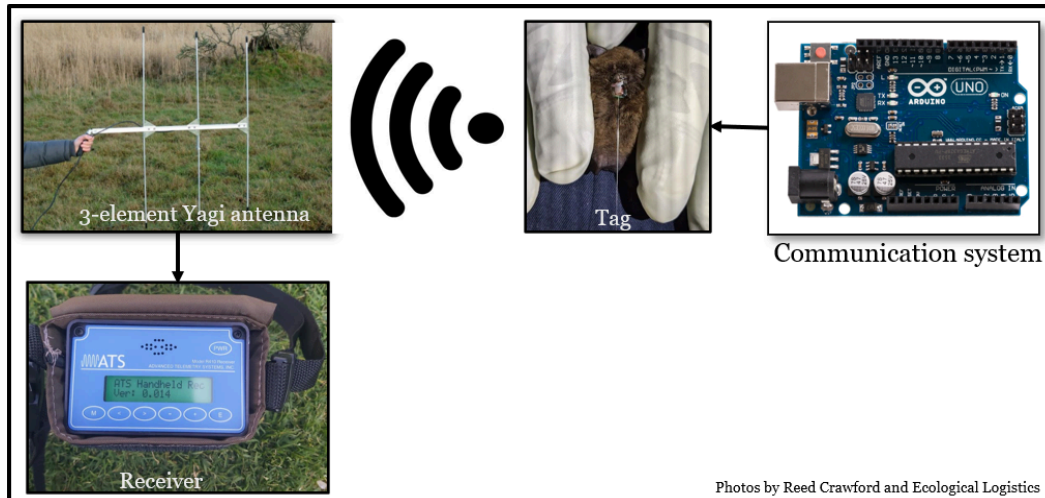
The population of bats, whose presence provides pest control, pollination, and seed dispersal has been on decline due to various reasons such as WNS, habitat destruction, and wind turbines (More than 400,00 hoary bats are killed by wind turbines annually) [1]. Due to the unawareness of their migratory path, minimum support has been provided in order to protect them. At the moment, there are VHF & Untraceable GNSS tags currently available in the market, however, they both have their own downsides. The VHF tags are very labor intensive and only are beneficial when the bat is stationary. Untraceable GNSS tags are unable to be retrieved which creates a lot of data loss of the paths. Additionally, both tags come with a substantial cost attached to them. To support bat conservation initiatives, it's imperative to understand bats' migration patterns. This necessitates the development of a new, affordable tracking product to enhance existing devices on the market, thereby safeguarding the current bat population.

## 1.2 Solution

The design is aimed to have low-cost VHF tracking & GNSS technology that can store the bat's movement as well as send a signal for recovering the device. This information will help us gather data for the bats' winter-summer migration paths, and use it to prevent the further increase in bats' casualties. For the design from a high level perspective, it is essential to construct a device that incorporates a GNSS tag integrated with VHF tracking capabilities to resolve issues that current devices have in the market. The construction of the device must ensure a weight below 1.6g and have an approximately 21x13x5 mm dimensions, such that the device would have no interference with the flight capabilities of bats. The creation of the device will be able to provide researchers with a cost-effective and user-friendly alternative compared to the existing devices that are available in the market.

## 1.3 Visual Diagram

Figure 1.1 shows the general visual representation of how the design will work. Firstly, the communication board will be utilized to program the behaviors of the VHF tracking system and the GNSS modules. Secondly, the device that is placed onto the bat will be tracked and retrieved with the help of a VHF receiver.



**Figure 1.1: Brief Visual Aid for Design**

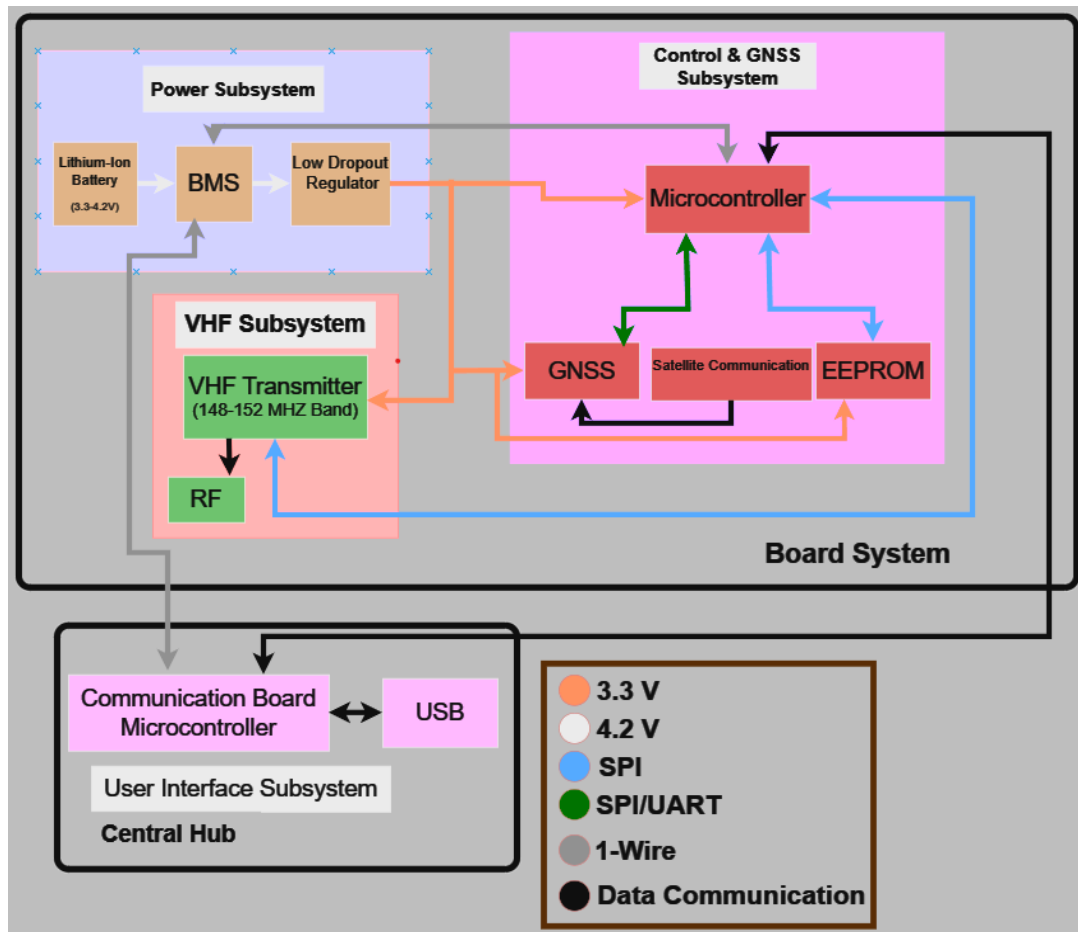
### 1.4 High-Level Requirements

In order to determine that the project is successful, the following objectives must be met:

- The design will need a GNSS module that will monitor the daily paths of a bat, which will provide insights of the movement patterns bat take throughout the day. The device should be able to collect data every 5-10 minute intervals over a span of 6 hours each day, over a period of 3 consecutive days.
- In order to retrieve the device that has been constructed, the design will require a tracking system such that it would be able to pinpoint the exact location of the device and be capable of collecting the data that was provided by the GNSS module. Thus, the device will utilize a VHF transmitter in the 148-152 MHz band, this band matches the receiver already in use by the lab. The transmitter should be able to be detected if it is within a 1 km range.
- The design must be able to integrate the GNSS and VHS modules such that it would not interfere with the bats normal functionalities. Therefore, the weight of the device should be approximately less than 1.6 grams and have a maximum dimension of 21x13x5 mm

### 1.5 Block Diagram

Figure 1.2 contains the subsystems: Power, Control & GNSS, VHF, and User Interface. The arrows that are represented in the diagram are color coded and are labeled with what type of voltage supply/communication that will be used accordingly. The microcontroller is being supplied power by the Power subsystem and it is in control of providing the functionality of the other subsystems that are a part of the design. The Central Hub is constructed to be separate from the board because it will be the stationary component for the researchers to examine the data found by the device with the help of a serial monitor in their labs.



**Figure 1.2: High-Level Block Diagram**

## 1.6 Subsystems Overview

### 1.6.1 Power Subsystem

The power subsystem consists of a portable voltage source that can constantly supply the different modules that are a part of the constructed device that will be attached to the bat. The LDO regulator has the primary function of regulating the voltage from the battery source to the GNSS and VHF systems. The design will require the reduction of voltage from the battery to the GNSS and VHF systems in order for them to properly function. Overall, The power subsystem will be connected to the VHF, GNSS, and the microcontroller subsystems so that the modules receive the necessary voltage to function properly.

### 1.6.2 Control & GNSS Subsystem

For the project it is essential to have a device that is able to provide accurate position data of the bat in the measurement of longitude and latitude in order to track the migration path that the bat takes throughout the day. The GNSS section will need to communicate with the microcontroller and EEPROM such that the data can be transferred and stored until the device is retrieved from the bat. In order to store the location data of the bats migration path, the EEPROM is essential.

Furthermore, for the design the size of the data that is being collected will not fit within the microcontroller, thus a EEPROM is required. The overall subsystem will need to be connected to the power subsystem in order to obtain the necessary power to function properly.

### **1.6.3 VHF Subsystem**

In order to access the data generated and stored by the constructed device, it is necessary to establish a tracking system that can find the device's location. For the tracking system for this project, a VHF transmitter system will be used. The system will be capable of transmitting frequency signals which will be captured by an external VHF receiver. This module may be provided initial programming by the microcontroller through SPI, as well as receiving power from the 3.3v supply.

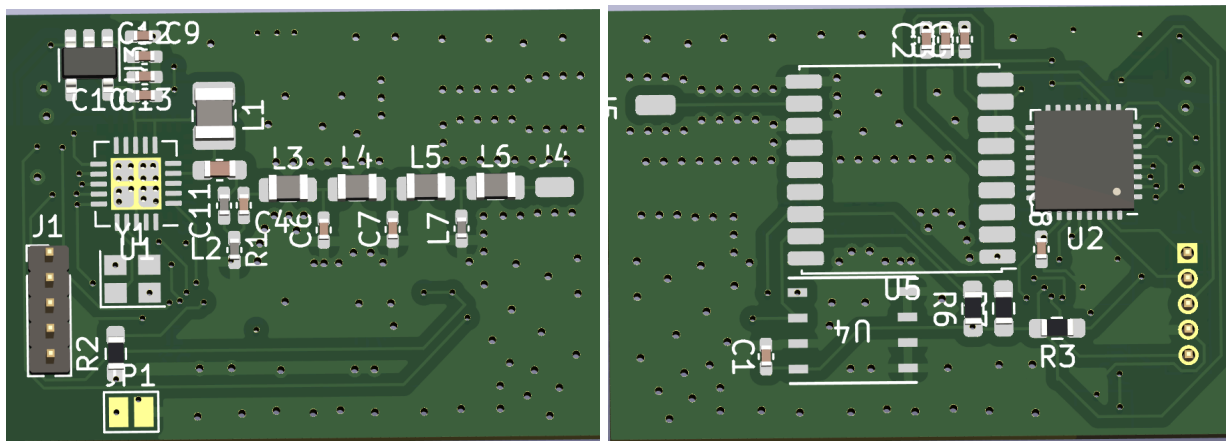
### **1.6.4 User Interface Subsystem**

This system is contained on a separate board and will not be placed on the bat. After retrieving the device off of the bat with the help of the VHF subsystem, the user interface subsystem will allow the user to obtain the location data off of the device to help determine the migration path that the bat followed throughout the day while charging the battery. The communication will be done using 1-wire protocol. The reason for this choice is simple, once complete the tag will be very small and encased in a water proof resin. Therefore we need minimal external connections that must handle unreliable signal integrity, as those connections will be used after being exposed to nature and water for long periods of time.

## 2. Design

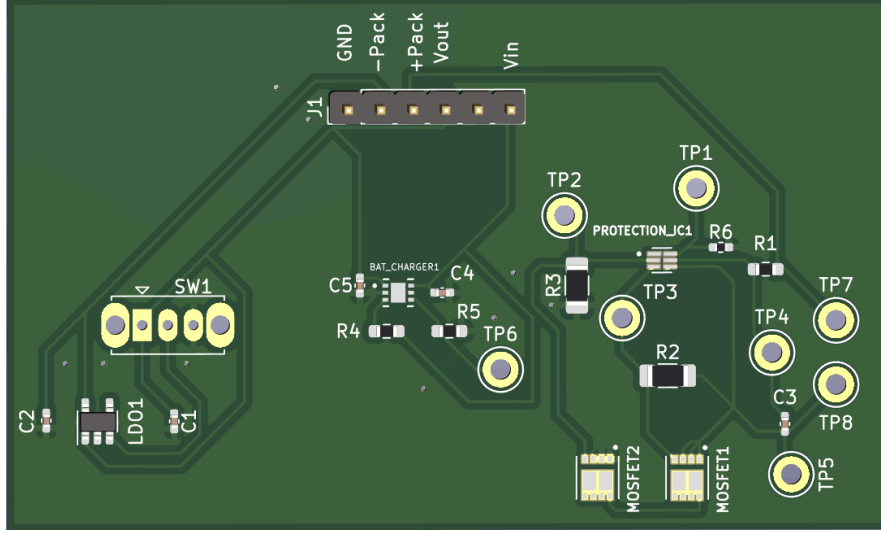
### 2.1 Physical Design

The physical design is a 2-layer PCB board that was chosen due to the complexity of the dimensions constraints that are a part of this project. Furthermore, one side of the PCB will have our VHF transmitter and the opposite side will have the GNSS module as shown in Figure 3. Proper grounding planes were scattered throughout the PCB and mainly surrounding the antennas in order to isolate and enhance the performance of the antenna without any interference of other components of the device. With the consideration of the dimensions it was decided that the power subsystem will be treated as a charging station in a separate PCB that is shown in Figure 4. Prior to the use of the device shown in Figure 3, the rechargeable battery will be soldered onto the device and placed onto the bat. After the device is later retrieved, the battery will be able to be unsoldered off of the device and resoldered onto the PCB shown in Figure 4 for proper recharging for the next trip. The final schematics are shown in Figure A.1 and Figure A.2 in Appendix A



**Figure 2.1: Physical Design Placed on Bat**





**Figure 2.2: Physical Design not placed on Bat**

## 2.2 Power Subsystem

The power subsystem requires a rechargeable battery able to supply a voltage of 4.2-3.7V. The Low Dropout Regulator was needed to bring the battery voltage down from 3.4V to 3.3V +/- 0.1 V as well as providing a max output current of 25mA +/- 1mA for the supply to the GNSS, VHF, EEPROM, and the Microcontroller. The BMS must manage a single cell battery in the 4.2-3.7V range.

### 2.2.1 Design and Justification

Based on Equation (2.1),

$$Q_{batt} \geq i_{GPS, avg on} * (18 \text{ hours}) + i_{VHF, avg on} * (168 \text{ hours}) \quad (2.1)$$

where  $i_{GPS, avg on}$  is the current required to operate the GPS for a total of 18 hours, and  $i_{VHF, avg on}$  is the current required to operate the VHF for a total of 168 hours, the total required energy storage can be calculated as such:

$$i_{GPS, avg on} \leq \frac{1}{600 \text{ sec}} \left( \int_0^{30} (18 \text{ mA}) dt + \int_{30}^{600} (110 \mu\text{A}) dt \right) \leq 0.93876 \text{ mA} \quad (2.2)$$

$$i_{VHF, avg on} \leq \frac{1}{600 \text{ sec}} \left( \int_0^{.012} (30 \text{ mA}) dt + \int_{.012}^{600} (100 \text{ nA}) dt \right) \leq 36 \mu\text{A} \quad (2.3)$$

$$i_{GPS, avg off} \leq 100 \text{ nA} \quad (2.4)$$

$$Q_{tot} = \int_{T_{experiment}} i(t) dt \quad (2.5)$$

$$Q_{batt} \geq i_{GPS, avg\ on} * (18\ hours) + i_{GPS, avg\ off} * (150\ hours) + i_{VHF, avg\ on} * (168\ hours)$$

$$Q_{batt} \geq .93876\ mA * (18\ hours) + 100\ nA * (150\ hours) + 36\ uA * (168\ hours)$$

$$Q_{batt} \geq 22.9\ mAh$$

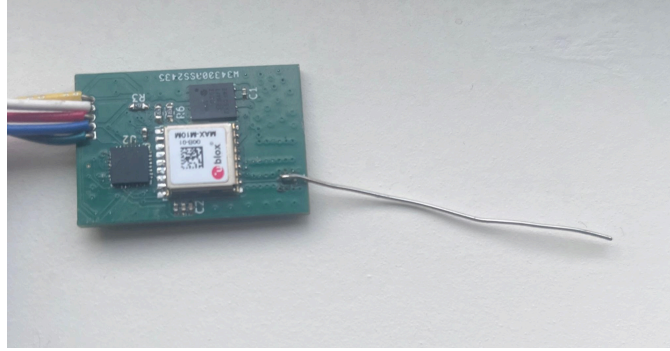
Given these calculations, we can estimate the battery to require an approximate 25mAh. Keeping in mind the weight requirement of the entire device, most of our time was spent finding a good balance between energy density and price of different battery materials. Our research led us to an ultra low weight Lithium-Ion battery, which weighs ~0.64g and is able to hold 25mAH. These numbers were calculated using the upper threshold of current draw (least efficient system) and the lower threshold for specifications. This analysis means that even if we had the worst implementation of our system, we were still on our way to meet our weight requirement.

### 2.2.2 Design Alternatives

In the current design, the power subsystem implements the charging unit and the LDO. One of the issues that arose while testing this circuit consisted in the output voltage from the LDO to shut itself. This would occur after the battery would undergo the charging state. In order to fix this, a sudden application of an external DC voltage onto the battery pack would allow the voltage to flow out of the LDO again. Another solution that we found for this blockage was to desolder and solder the battery from the PCB. The theory behind this error is that, due to our current circuit design, implementing a switch to go from a charging to a discharging state leads to the blocking of the battery voltage. For future devices, we recommend keeping the charging module separate from the complete bat tracker design. This would guarantee that the battery is able to flow again after it is recharged by the charging module, without having to apply an external DC voltage.

### 2.3 Control & GNSS Subsystem

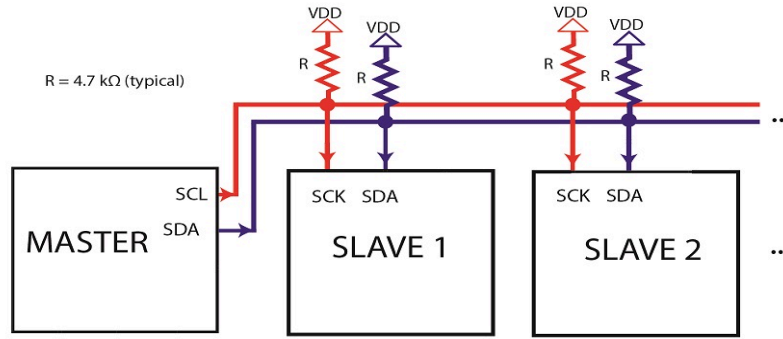
This subsystem is responsible for collecting the locational data from satellites that provide ~130 dBm signals with the GNSS module and is then assigned to transfer the data to the microcontroller. The microcontroller is responsible for transferring the data that consists of latitude and longitude points directly from the GNSS module to the EEPROM via I2C serial communication interface. The input voltage that is required to operate the subsystem is supplied by the power subsystem in order for the functionality of this system to be operating.



**Figure 2.3: Final Control & GNSS PCB Design**

### **2.3.1 Design and Justification**

For the design, a large amount of time was spent in order to consider the various chips that will be needed for our system and the compatibility of them. Furthermore, when determining the EEPROM, microcontroller, and the GNSS the following criterias were required to be met: low power consumption, no larger than 10 mm in length for each chip, be I2C compatible, weigh <0.6 grams, and user-friendly. With the following criterias, GNSS MAX M10M was chosen for the GNSS chip, 24FC512 I2C Serial chip for the EEPROM, and the AVesI128DR32 for the microcontroller. The GNSS MAX M10M operates with a 3.3 +/- 0.1 V supply, an accuracy range of at least 1.5m, 10x9mm in size, and weights ~0.6grams, and I2C compatible [2]. The AVR128DR32 is I2C compatible, 5x5 mm in size, and is I2C compatible. The 24FC512 chip is 3x3 mm, I2C compatible, and can store 512kb of memory. All of the components fit within the dimension constraints assigned for this device and function in the desired manner for this project. I2C serial communication was chosen to be used, due to the ability of accessing multiple devices to be connected to the same bus. The master device is then capable of controlling communication on the bus with multiple slaves and can respond to commands from the master device. The configuration of the setup is illustrated in Figure 2.4. Using I2C configuration and pin assignments based off of the datasheet from the individual chips, the schematic was able to be constructed as shown in Figure A.1.



**Figure 2.4: I2C Configuration**

Apart from the connections with the individual parts, the GNSS module will be connected to a resonant quarter-wavelength antenna of 4.76cm. This value was determined by running simulations in HFSS (High Frequency Simulation Software) as it provided very good radiation resistance of around 70 ohms, the inefficiency caused by the impedance mismatch is negligible. These values are found in Figure 2.5.

	Freq [GHz]	re(ActiveZ(1:1)) Setup1 : LastAdaptive	mag(ActiveZ(1:1)) Setup1 : LastAdaptive	im(ActiveZ(1:1)) Setup1 : LastAdaptive
1	1.575420	31.151052	76.581630	-69.959689

**Figure 2.5: Estimated Frequency Using HFSS**

### 2.3.2 Design Alternatives

Prior to choosing the AVR128DR32 for the final device, the ATTINY 1616 MCU was initially used. The compatibility is quite similar to the AVR128DR32, however, it was initially chosen due to the dimensions of the chip being 3x3 mm. During the test process, it was determined that the flash memory size of the ATTINY1616 MCU was far too small to fit our software.

## 2.4 VHF Subsystem

The VHF transmitter system will be in the 148-152MHz band and needs to have a range of at least 1 km. The receiver used by the lab has a minimal detectable limit of -150dBm and -133dBm with the DSP using a 3-pole Yagi antenna with a gain of 7.7 dBi. Given the Wavelength of 2-meters and the incredibly small form factor requirements and omnidirectional need the antenna will be electrically small giving a predicted gain around 1.76 dBi. This means the transmitter will need to output at atleast 13 dBm to be detected by the receiver and overcome

inefficiencies in the antenna. The modulation scheme is a simple pulse of width 12ms and fundamental frequency of 1.0 - 0.1 Hz. Table 3 summarizes our goals for our VHF system.

## 2.4.1 Design and Justification

### 2.4.1.1 Antenna:

The antenna is the one system on the device that may exceed the physical size dimensions given by the requirements, but must be discrete, low weight, and have low directivity given the use case. Given this the antenna type is essentially shoehorned into being an electrically small antenna. Decent antenna efficiency is possible however with impedance matching. The antenna design we are going with is a 4.76 cm antenna modeled 1 mm above the PCB ground plane (Figure 2.6 shows the antenna model, where the plane is 13x21x.035mm ). Given the physical orientation of the PCB plane to the antenna can loosely be approximated using small dipole calculations, but HFSS was used to simulate and get a better sense of antenna efficiency, radiation pattern, and input reactance. The results of calculations and HFSS simulations show a quite decent radiation efficiency and a large capacitive reactance, as predicted by calculations. This capacitive reactance can be mitigated by a 2.01uH inductor, which is combined with the last filter inductor, making it a 2.06uH inductor, bringing the load impedance to the desired impedance of 50 ohms.

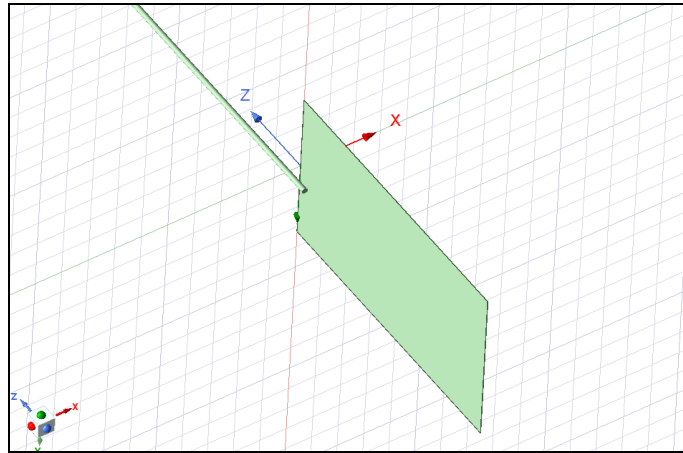


Figure 2.6 - HFSS antenna model

	Freq [MHz]	re(ActiveZ(2:1)) Setup1 : LastAdaptive	mag(ActiveZ(2:1)) Setup1 : LastAdaptive	im(ActiveZ(2:1)) Setup1 : LastAdaptive
1	150.000000	0.618404	1944.295398	-1944.295300

Figure 2.7 - VHF antenna impedance characteristics.

### 2.4.1.2 Antenna:

To achieve the transmitter requirements there were many different options to choose from, but the constraints are as given: Thermal stability given the unknown exposed environment; Low radiation resistance of the antenna due to physical requirements, high efficiency to meet power requirement; reconfigurability over frequency band of 148-152 MHz. These design variables

cause a class E amplifier being the best choice. A class E amplifier is a type of switching amplifier that uses a square wave driven resonant tank circuit filtered by a low pass filter to drive the antenna. This amplifier will be controlled by the on board microcontroller using the Si4063 rf transmitter chip. The power delivered by an ideal class E is given from the PA matching document as seen in Equation (2.1).

$$P_{out} = \pi \omega_0 C_{SHUNT} V_{DD}^2 \quad (2.6)$$

This is highly valuable, as the ideal power output has no dependence on load impedance. In practice for the Si4063 this is limited by mainly the electrical limitations of the transistors used in the amplifier. Using the PA matching guide for the Si4063, however given the desire 13dBm out for the transmitter, the circuit can be better matched as max VDD voltage at that power rating is only 4.12 volts, meaning the voltage spike across Voltage drain is far away from the ~6 volt recommended limit is a nonissue. A picture of the sample circuit is provided in Figure 2.8, as well as the simulation results from the calculated values using the HFSS modeled antenna values in Figure 2.9.

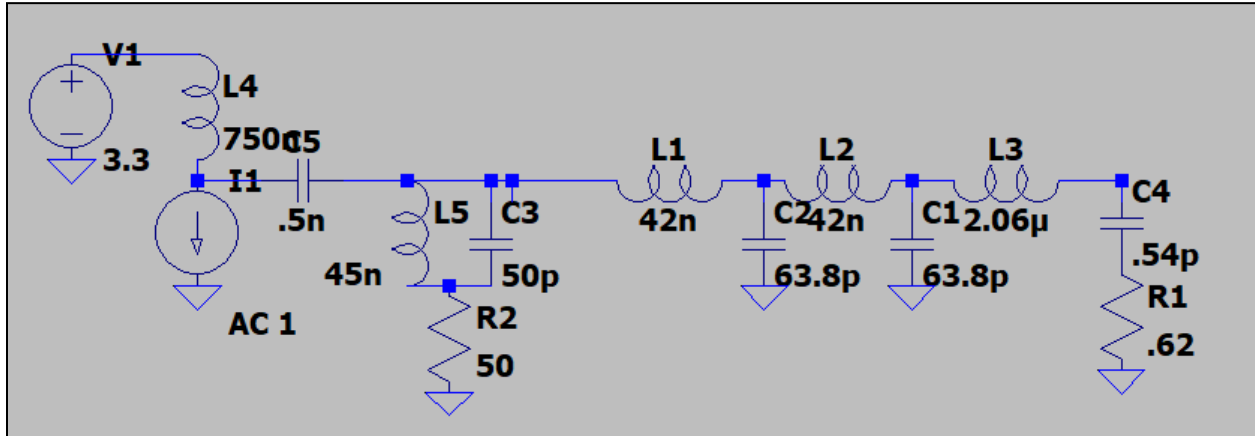
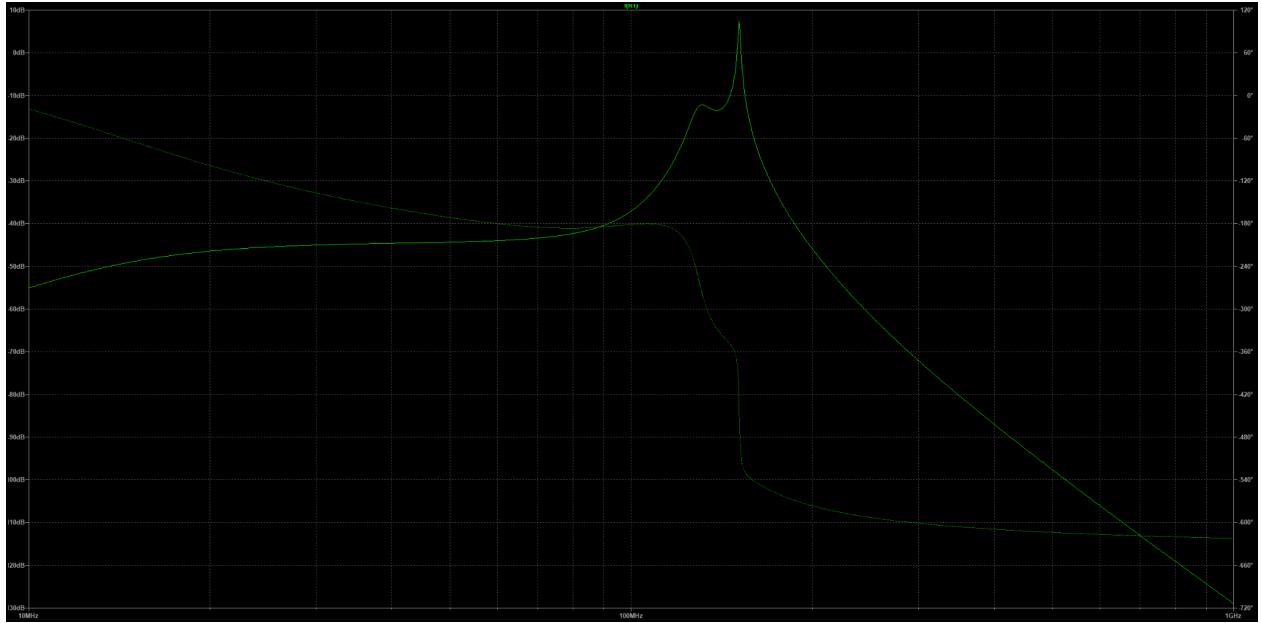


Figure 2.8 - Class E amplifier Matched load



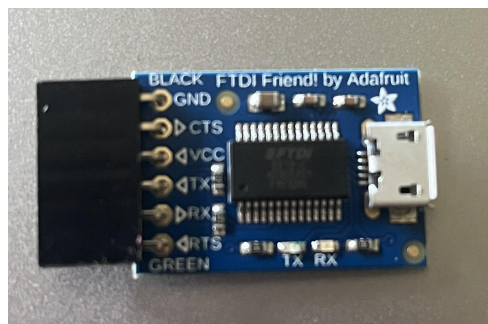
**Figure 2.9 - Class E amplifier matched load bode plot**

## 2.5 User Interface Subsystem

To retrieve the data off of the device, the user interface will communicate with the microcontroller utilized by the control and GNSS subsystem in order to properly transfer data from the device to a serial monitor.

### 2.5.1 Design and Justification

With the final PCB, there are pin connectors labeled RTX and TXD that will be utilized in the connection of the user interface subsystem in order to properly visualize the locational data that is stored within the EEPROM. In order for serial monitoring, the ADAFRUIT FTDI Friend was integrated with the project to have a proper connection with the serial monitor via Arduino IDE and the PCB [3]. The device is shown in Figure 2.10.



**Figure 2.10: ADAFRUIT FTDI Friend for Serial Monitoring**

### **2.5.2 Design Alternatives**

Prior to using the ADAFRUIT FTDI Friend for Serial Monitoring, the Arduino Uno's TXD and RXD pins were utilized. However, the Arduino Uno was not rendering the connections and resulting in errors when visualizing data for the serial monitor.



### 3. Requirements and Verification

In this section, critical portions of the project will be discussed along with the requirements and verifications that were conducted to ensure the proper functionality of the various portions of the project.

#### 3.1 GNSS

##### 3.1.1 GNSS Antenna Communication

After soldering the GNSS to the PCB and connecting it with the microcontroller, a test script was ran in order to verify whether or not the communication with the satellite and the antenna that is apart of the GNSS module is precise. Since the antenna was simply a 4.6 cm copper wire and the connectivity with the GPIO pins for the Arduino Uno caused compiling errors, the serial monitor was not able to successfully provide any sort of data that was expected. Writing the test script in order to verify successful communication is one of the verification procedures that was determined to be tested, which is labeled in Table C.1 in Appendix C.

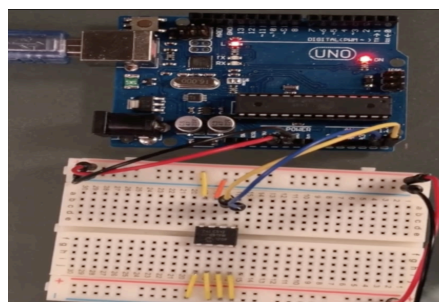
##### 3.1.2 Collecting Data from GNSS

The GNSS is required to properly provide data every 5-10 minute intervals for a span of 6 hours for 3 consecutive days. Therefore, to ensure that the antenna is inactive during the span of time when it should not be active, the voltage reading across the RF\_IN pin in the GNSS MAX M10M should be  $\sim 0$  V. This test was proven to be successful as the voltage reading when the antenna is Active Low was measured to be 0.024V.

#### 3.2 EEPROM

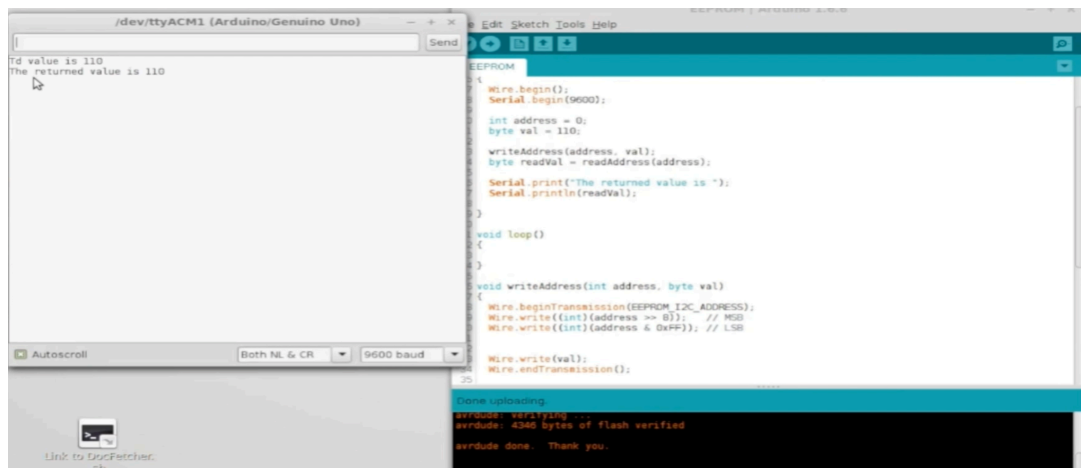
##### 3.2.1 Read & Write Operations

In order to separately check the EEPROM with the test script to verify that the EEPROM is capable of writing and reading, the EEPROM was separately connected to the Arduino Uno shown in Figure 3.1.



**Figure 3.1: EEPROM Individual Test with Arduino Uno**

It was determined that the read and write operations were properly functioning by writing into the EEPROM address with the .write function and it was able to be read with the assistance of the serial monitor. The visual representation of this successfully working is shown in Figure 3.2. Not only did this test script verify the operations we need from the EEPROM, but also confirms that the I2C interface is properly working.



**Figure 3.2: Read & Write Operation via EEPROM**

### 3.3 Battery

#### 3.3.1 LDO output voltage

In order to test the LDO's output voltage, we tested the circuit while the switch was set to make the current flow through the LDO. Then we connected a multimeter to the output pin coming from the 6-pin connector.

#### 3.3.2 Maximum Operating Current

To verify that the Power subsystem is able to supply the maximum possible current to the circuit, we needed to separately connect  $V_{out}$  to a resistive load that could draw about 25 mA. To calculate this resistive load, we can use Equation 3.1, the ideal output voltage of the LDO, 3.3V, and the maximum current that we want to draw from the battery, 25mAh. If there's no access to a current meter, we can use Equation 3.1 again, the voltage measured across the calculated load and the value of the load to calculate whether we're able to achieve our maximum current needs.

#### 3.3.1 Battery Discharge Protection

As a continuation from testing the maximum operating current, we can set up the same circuit and capture the data over time while measuring the voltage from the battery and the output voltage. To ensure that the protection IC is working, we'd see that the battery is disconnected

from the circuit when it goes under a voltage that is optimal for working conditions. See Figures B1-B3 in Appendix B for the testing data collected.

### **3.3.3 Battery Charging**

To recharge the battery, we needed to make sure that our switch in the power PCB is turned off, such that the LDO is turned off and the battery is able to charge. Then we connect an external DC supply to the input voltage pin located in the 6-pin connector. To verify that the correct input voltage is being supplied to the battery, we could measure the output voltage of the output pin from the charger IC, then record the data over time to make sure that the battery's voltage was in fact increasing with the charger. See Figures B4 and B5 in Appendix B for the testing data collected.

## 4. Costs & Schedule

### 4.1 Parts

Quantity	Component	ManufactureR	Total Cost	Link
1	GNSS	u-blox	\$21.00	<a href="#">LINK</a>
2	Microcontroller	Microchip	\$1.80	<a href="#">LINK</a>
1	EEPROM	Microchip	\$2.04	<a href="#">LINK</a>
1	RF Transmitter IC	Silicon Labs	\$6.87	<a href="#">LINK</a>
3	10uF Capacitor	Murata Electronics	\$0.10	<a href="#">LINK</a>
4	1uF Capacitor	Taiyo Yuden	\$0.10	<a href="#">LINK</a>
3	100nF Capacitor	Samsung Electro-Mechanics	\$0.10	<a href="#">LINK</a>
2	43nH inductor	Murata Electronics	\$0.10	<a href="#">LINK</a>
1	750nH inductor	Murata Electronics	\$0.23	<a href="#">LINK</a>
1	22nH inductor	Johanson Technology Inc.	\$0.10	<a href="#">LINK</a>
1	23nH inductor	Murata Electronics	\$0.15	<a href="#">LINK</a>
1	2uH inductor	Murata Electronics	\$1.48	<a href="#">LINK</a>
1	.5nH capacitor	YAGEO	\$0.11	<a href="#">LINK</a>
1	50pF capacitor	YAGEO	\$0.10	<a href="#">LINK</a>
2	62pF capacitor	KYOCERA AVX	\$0.14	<a href="#">LINK</a>
1	6 Pin connector	JST Sales America Inc.	\$0.30	<a href="#">LINK</a>

1	3 Pin connector	JST Sales America Inc.	\$0.19 \$0.10	<a href="#">LINK</a> <a href="#">LINK</a>
1	Charging IC	Torex Semiconductor Ltd	\$1.27	<a href="#">LINK</a>
1	3.3v LDO	Microchip Technology	\$0.18	<a href="#">LINK</a>
1	Stainless steel wire	Remington Industries	\$15.55	<a href="#">LINK</a>
1	Magnetic Wire	Remington Industries	\$11.20	<a href="#">LINK</a>
1	Crystal	EPSON	\$3.44	<a href="#">LINK</a>
1	FTDI Friend	Adafruit	\$14.75	<a href="#">LINK</a>

**Table 4.1 - Part List**

## 4.2 Labor Cost

The average salary for an electrical engineering graduate in Illinois is \$87.769 [6]. Since the project consisted of all electrical engineers, that salary is the only one that will be considered. It is assumed that there are 9 full working weeks and that an individual is working 15 hours per week at a rate of ~\$45/hour. With all this considered and assuming a multiple of 2.5 for miscellaneous expenses in the development process, the following value below was found in order to fund employees for this project.

$$45 \left[ \frac{\$}{hr} \right] \times 2.5 \times 135 = 15,187.50 \left[ \frac{\$}{person} \right] \times 3 = \$45,562.25 \text{ in labor cost for project}$$

## 4.3 Schedule

Please see Table C.5 in Appendix C to refer to the full schedule that the group made in the early parts of the project. The schedule provides the assigned roles for each individual for every given week until the duration of the semester, in order to remain on pace in an effective manner.

## 5. Conclusion

### 5.1 Accomplishments

Reflecting back on the achievements throughout this project, we found quite the satisfaction in our final results. Firstly, designing the PCBs within our dimension constraints was quite the task with beginner level computer aided design skills. Secondly, the ability to solder micro-level components onto the board by hand and the soldering oven was a challenge on its own. We were also proud to be able to successfully have operating functionalities with our soldered PCBs in terms of the power subsystem and the EEPROM read and write operations. Furthermore, we were pleased with the results that we found from the rechargeable battery system that we constructed onto the PCB as it ultimately allows researchers to reuse the product continuously for multiple travels for bats, which was not possible with the current VHF & GPS tags that are in the market. Additionally, being able to have the microcontroller successfully transfer data to the EEPROM in the PCB was quite the challenge as well due to the difficulties that were faced in order to properly connect the PCB with micro-components with a communication board.

### 5.2 Challenges

Although the power subsystem and the EEPROM were successful with our final PCBs, the entirety of the VHF subsystem and marginal parts of the GNSS module were not functionable with our final PCB. The main factors that lead to these results are the difficulties in the connection between the hardware and software components, soldering uncertainties, and the inability of constructing proper antennas for the VHF transmitter and the GNSS. Due to minimum resources/documentation that were available to properly setup the GNSS module to the microcontroller, there was minimal assistance that we were provided in order to troubleshoot the solution to properly connect the GNSS MAX M10M. Due to the fact that we had a 2-sided final PCB, the PCB came in with only the stencil for one side of the PCB causing us to recycle other stencils that were available to apply soldering paste to the other side. This resulted in the uncertainty of our connections when testing the GNSS module. Lastly, we were unable to construct proper antennas for the VHF transmitter and the GNSS module due to the member that was responsible for this task unfortunately having to withdraw from the project due to a medical

reason. Furthermore, due to this reason the entirety of the VHF subsystem was fully non-functioning along with the antenna of the GNSS module.

### **5.3 Future Work**

Due to the timeline and budget constraint, we were unable to successfully complete the VHF transmitter and the GNSS module without the accessibility of a proper antenna input. Therefore, if the system that requires antennas are constructed properly with the data that was obtained from the HFSS, then the functionality of the VHF transmitter and the GNSS module can be operating better compared to our final product. The final PCB we designed has the dimensions of 30.9 x 21.3 mm, which is quite larger than we hoped for. This PCB would only have the possibilities of being placed onto a female bat compared to a male bat due to the consideration that female bats tend to be larger in size. In order to allow the PCB to have the ability to be attached to both genders of bats, the shape of the PCB could be structured in a better manner in future work such that it can be seamlessly placed on both types of bats. If these two parts of the project were further studied and completed, then it would ultimately be possible to replace the current VHF and GNSS tags that are currently available.

### **5.4 Ethics & Safety**

We recognize the importance, and commit ourselves, to the highest ethical and professional conduct that surrounds our profession. We understand the IEEE Code of Ethics [7] and recognize that the technology we create may impact our profession, our fellow teammates, and the communities we serve. The main major ethical concern our group faces is relating to the conflict between the desire of this course and the desires of the lab to whom the idea belongs. This conflict is due to the necessity of the weight limit imposed by the lab compared to the electrically focused nature of the course. To be blunt, there may be a point in which our group is faced with a decision to choose making a more useful product for the lab at the expense of our grade in the course due to not meeting a proposed electrical specification to instead hit the weight spec. The particular issue our team faces in this project is that we are making a tracking monitor for animal research, and unfortunately that type of device could also be used to track and monitor people. Given this is a pitched project and open source, there is very little we can do to combat potentially nefarious actors from reproducing this tag.

## 6. References

- [1]“State of the Bats | U.S. Fish & Wildlife Service,” *www.fws.gov*, 2023.  
<https://www.fws.gov/story/2023-04/state-bats#:~:text=Extinction%20Risk%20is%20Rising>
- [2]“Standard precision GNSS module Professional grade Data sheet.” Available:  
[https://content.u-blox.com/sites/default/files/MAX-M10S\\_DataSheet\\_UBX-20035208.pdf](https://content.u-blox.com/sites/default/files/MAX-M10S_DataSheet_UBX-20035208.pdf)
- [3]“FTDI Friend,” *Adafruit Learning System*. <https://learn.adafruit.com/ftdi-friend/overview> (accessed May 02, 2024).
- [4]“XC6808 Series.” Accessed: Feb. 23, 2024. [Online].  
<https://product.torexsemi.com/system/files/series/xc6808.pdf>
- [5]“What is I2C? | Protocol Guide,” *Microcontroller Tutorials*, Apr. 24, 2018.  
<https://www.teachmemicro.com/i2c-primer/>
- [6] G. E. O. of M. and Communications, “Salary Averages,” *ece.illinois.edu*.  
<https://ece.illinois.edu/admissions/why-ece/salary-averages>
- [7]IEEE, “IEEE Code of Ethics,” *ieee.org*, Jun. 2020.  
<https://www.ieee.org/about/corporate/governance/p7-8.html>
- [8]D. Johanneck, “Logic Level Shifting Basics,” *DigiKey*, Aug. 05, 2021.  
<https://www.digikey.com/en/blog/logic-level-shifting-basics>
- [8]“AN648 Si4X6 X AND EZR32 HIGH-POWER PA MATCHING.”  
[Online]. Available:  
<https://www.silabs.com/documents/public/application-notes/AN648.pdf>



## Appendix A: Schematics

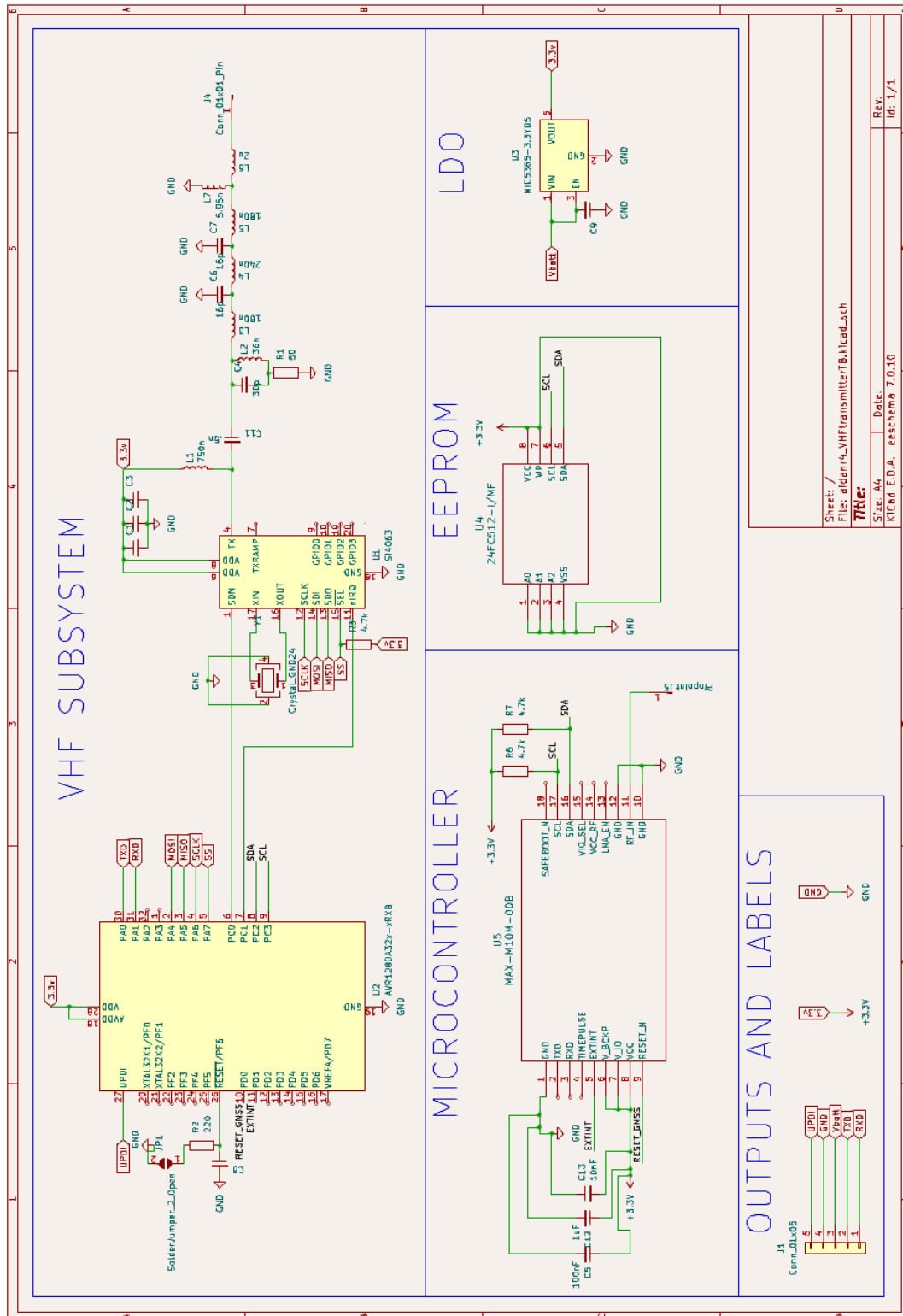


Figure A.1 Final Bat Tracker Schematic (W/O Battery)

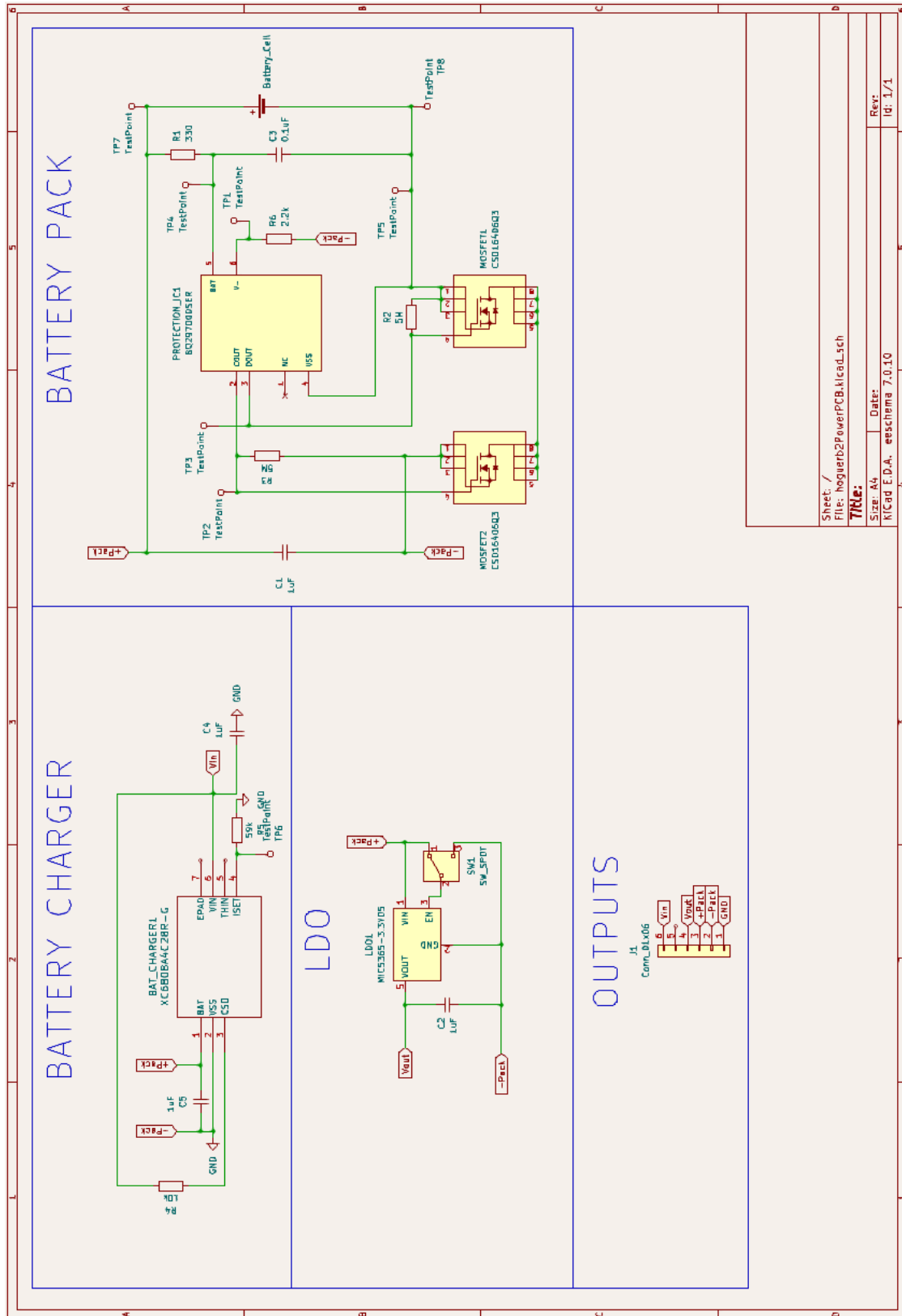


Figure A.2 Final Bat Tracker Power Source

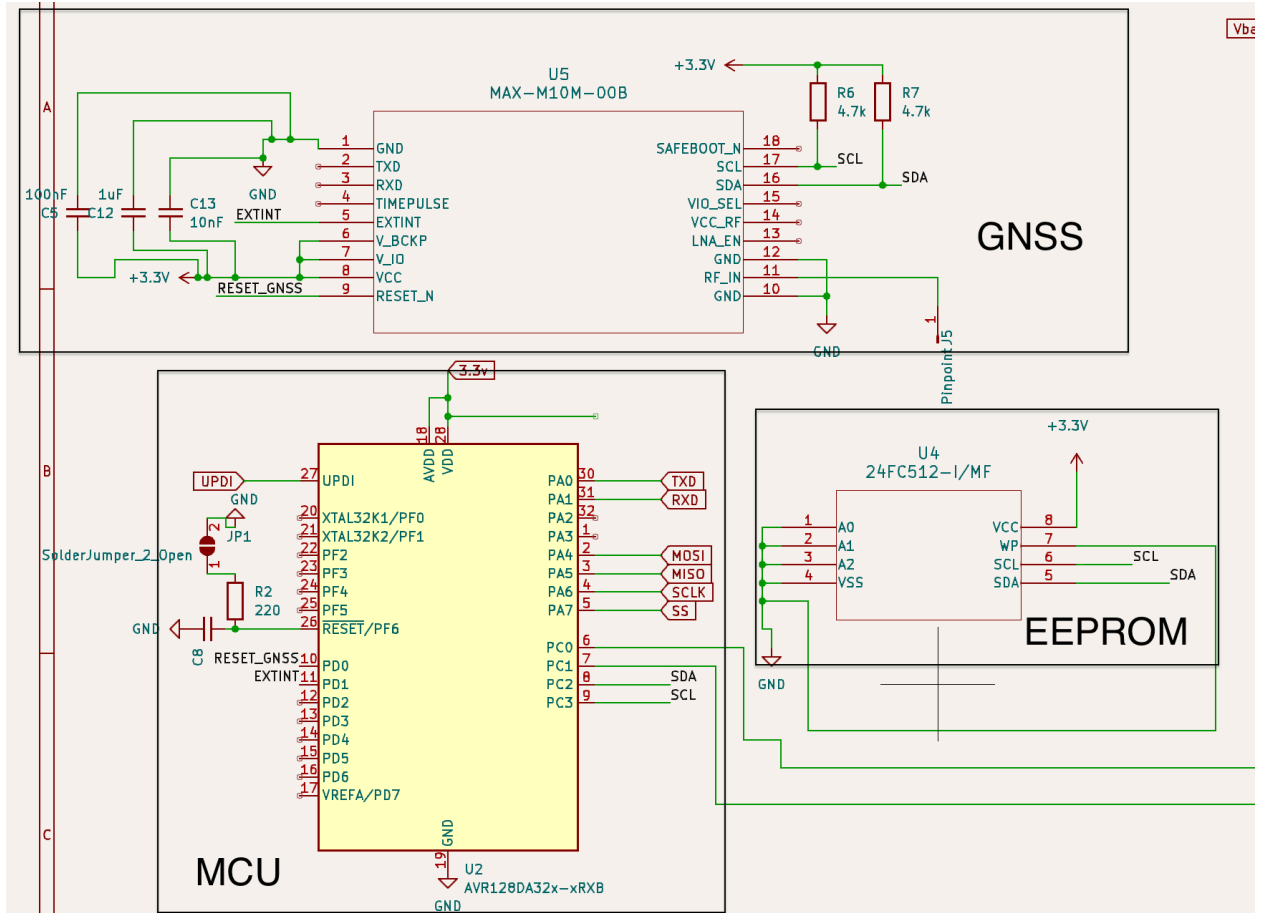


Figure A.3 Control & GNSS Circuit Schematic

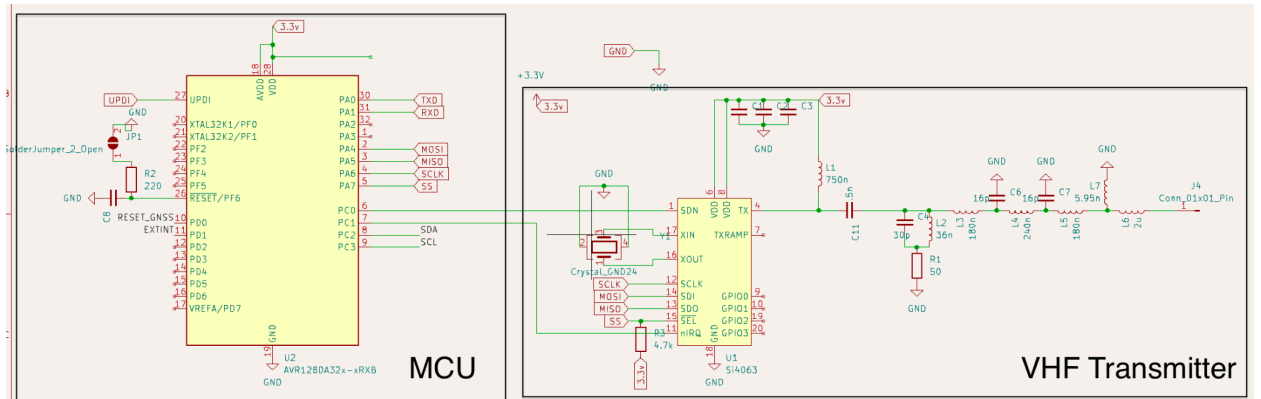


Figure A.4 VHF Transmitter Circuit Schematic

## Appendix B: Battery Testing Graphs

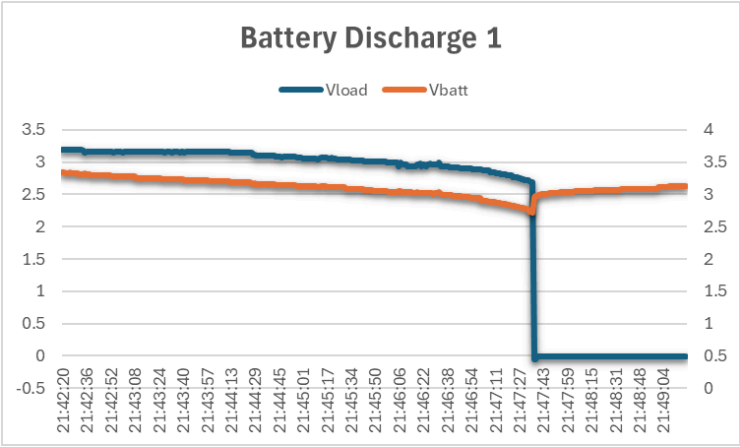


Figure B.1 Battery Discharge Test 1 with external Resistance Load

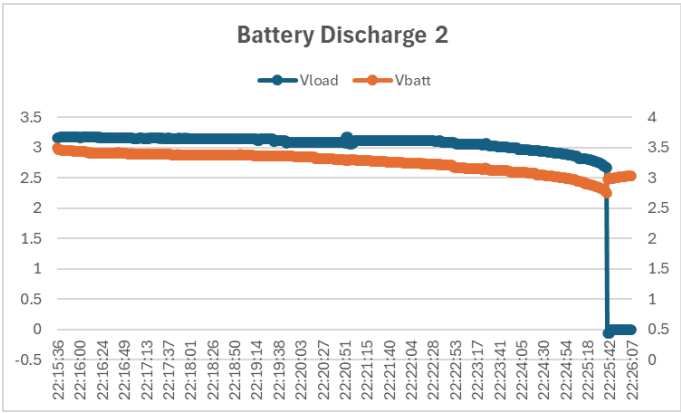


Figure B.2 Battery Discharge Test 2 with external Resistance Load

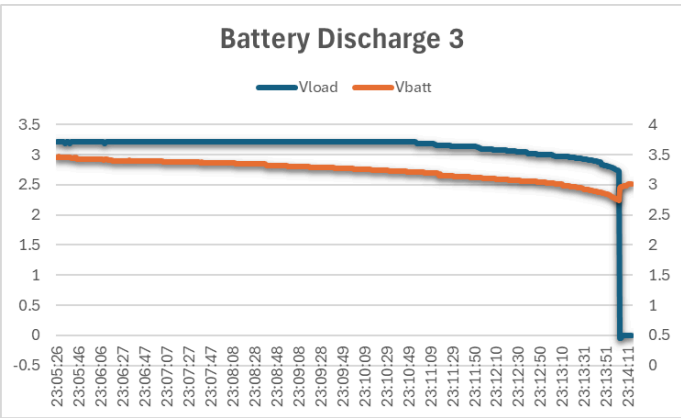


Figure B.3 Battery Discharge Test 3 with external Resistance Load

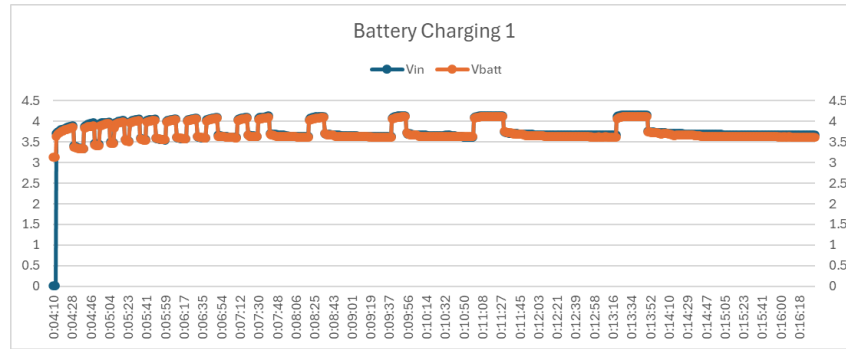


Figure B.4 Battery Charging Test 1

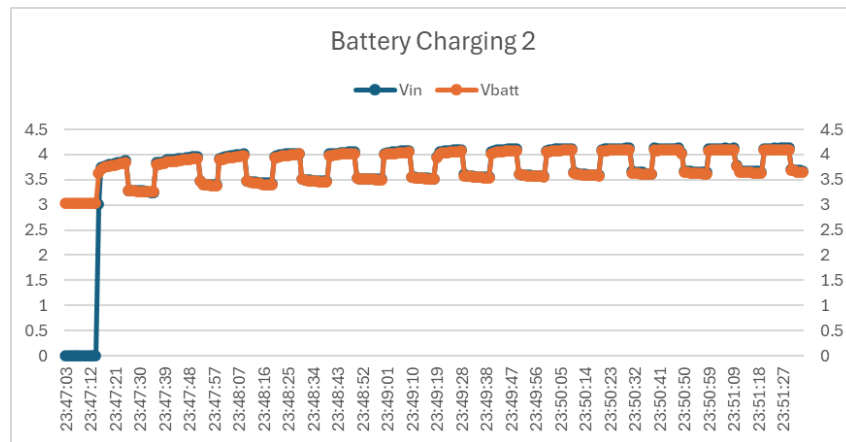


Figure B.5 Battery Charging Test 2

## Appendix C: Requirement and Verification Tables

Requirements	Verification	Verification Y/N
The GNSS, Microcontroller, and external EEPROM chips should be supplied by a 3.3 +/- 0.1 V voltage supply.	To ensure the correct amount of voltage is being supplied from the power subsystem, we can utilize an oscilloscope to confirm the voltage being supplied to the GNSS chip is approximately 3.3 +/- 0.1 V.	Y
The resonant quarter-wavelength antenna must accumulate precise location data by ensuring an effective connectivity with satellites. After the location data is collected, the GNSS chip must be able to transfer the data to the microcontroller via I2C.	In order to validate the connections between the GNSS, antenna, and the microcontroller, an oscilloscope could be used to monitor voltage readings during specific intervals where there should be an expectation of an alternation of the voltage. This ensures that certain connections between the chips and the antenna are connected in a proper manner. To verify that the I2C lines between the GNSS and microcontroller are properly connected, a test script can be programmed to the microcontroller to ensure that the necessary data is being received. Along with verifying the I2C connection, this verification procedure also ensures that the communication with the satellite and our antenna is accurate.	N
The GNSS unit should collect data every 5-10 minutes during a 6 hours interval for 3 consecutive days. This provides energy conservation and allows an efficient way to monitor a bats movement trends/patterns.	To ensure the GNSS chip is on standby mode when data is not needed to be collected, an oscilloscope could be used to measure the voltage readings of the connections with the GNSS chip.	Y
The external EEPROM must be able to store ~18 kbytes worth of data that is exported from the microcontroller via I2C.	A test script can be programmed to the microcontroller to transfer the locational data obtained by the GNSS chip to the external EEPROM.	Y

**Table C.1 - Control and GNSS Requirements**

Requirements	Verification	Verification Y/N
Input Voltage must be between 5+/- 0.25v	Hook up an oscilloscope to the output of the 5 volt LDO and	Y
Must be capable of communicating with other microcontroller	Setup test transactions and monitor using an oscilloscope to verify communication accuracy of one-wire.	Y

**Table C.2 - User Interface Requirements**

Requirement	Verification	Verification Y/N
The input voltage needs to be maintained at 3.3+/- .1 volt	This is handled by the Power subsystem and the verification of such will be covered in that section.	N/A
Peak Input current needs to be lower than 30 mA when operating at 13 dBm.	Connect a current probe to measure the input current to the chip and program the chip to 13dBm.	N/A
The Frequency Range needs to operate between 148-152 mHz	Connect Class E output match circuit to a vector analyzer to ensure correct filtering.	N/A
The Modulation type of OOK with a pulse length of 12 ms and a off time of 5-10 seconds	This can be verified using an oscilloscope E-field probe used around the antenna, or an oscilloscope at the Transmitter driver.	N/A
At least 1km transmission range.	Put the antenna in Anechoic chamber with a known testing antenna, determine antenna realized gain. Use that realized gain to calculate max distance knowing -150 dBm reception limit. Cheaper option is to just walk 1km away from the receiver and see if it can pick up a signal from the tag.	N/A

**Table C.3: VHF Data**

Requirements	Verification	Verification Y/N
Provide 3.3V +/- 0.1V from a 3.7V source	Connect the subsystem output to a multimeter to ensure that the output voltage stays within 0.1V of 3.3V	Y
Operating current for standby and max operating current requirements, that is, 110uA and 24mA +/- 1 mA	Connect the LDO output to a variable load and measure the current and voltage using an oscilloscope to ensure the minimum current and the max current requirement is met while staying within 0.1V of 3.3V	Y
The battery charging circuit must be able recharge the battery at its specific current and voltage rates	The battery has a standard charge of 0.2C and a rapid charge of 0.5C. The battery should charge until current declines to $\leq 0.02C$ . We can verify this by setting up a separate circuit which draws a maximum of 1C. The charging circuit and the battery will be connected via banana wires and pins on different PCBs, this is to be able to use a current probe in such a small circuit. Once the circuit is tested, the final product will have the components in one PCB.	Y
Battery Protection for depletion. Discharge cutoff voltage of 3.0 +/- 10% V	To ensure the battery safety, we can discharge the battery by connecting the LDO output to a load, and let it discharge for around 2 hours(it'd require a load drawing a current of 0.5C). We need to continuously monitor the voltage on the battery using a multimeter or an oscilloscope to ensure the battery protection is doing its job. As an extra feature, we can connect a current probe to the load to measure the current and ensure the battery stopped providing power.	Y

**Table C.4 - Power Subsystem Requirement**



Week	Task
02/18-02/24	<p>Lily: Finalize VHF circuit</p> <p>Gary: Finalize the search for a battery</p> <p>Romin: Research and finalize on MCU, EEPROM, and GNSS chips. Start designing schematic for the Control &amp; GNSS subsystem.</p> <p>Everyone: Revise design proposal &amp; complete design document</p>
02/25-03/02	<p>Lily: PCB and components order</p> <p>Gary: Finalize the individual schematics</p> <p>Romin: Finalize circuit diagram of the Control &amp; GNSS subsystem.</p> <p>Everyone: Present design review &amp; attend peer review.</p>
03/03-03/09	<p>Lily: VHF Software package programming</p> <p>Gary: Have a Final Schematic with every component connected</p> <p>Romin: Construct circuit design with all subsystems</p> <p>Everyone: Complete teamwork evaluation &amp; first round of PCB orders</p>
03/10-03/16	SPRING BREAK
03/17-03/23	<p>Lily: VHF Software package programming and hardware debugging</p> <p>Gary: Solder pieces to PCB</p> <p>Romin: Assist with software programming MCU &amp; GNSS subsystem</p> <p>Everyone: second round of PCB orders</p>
03/24-03/30	<p>Lily: VHF Software package programming and hardware debugging</p> <p>Gary: Finalize hardware debugging</p> <p>Romin: Assist in software &amp; hardware debugging</p> <p>Everyone: third round of PCB orders &amp; complete individual progress report</p>

03/31-04/06	<p>Lily: Finalized VHF to be transferred to the combined PCB</p> <p>Gary: Finalize assembly for all individual components</p> <p>Romin: Testing compact final design</p> <p>Everyone: fourth round of PCB orders</p>
04/07-04/13	Everyone: Integrate
04/14-04/20	<p>Lily: Debugging</p> <p>Gary: Debugging</p> <p>Romin: Debugging</p> <p>Everyone: Mock demo &amp; complete team fulfillment contract</p>
04/21-04/27	Everyone: Final demo/mock presentation
04/28-05/04	Everyone: Final presentation, complete final paper, turn in lab notebooks

**Table C.5: Team Schedule**