DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
UNIVERSITY OF CENTRAL FLORIDA

RF CHATTERBOX

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GROUP 6

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I. Executive Summary

Modern day society exists in the Information Age, with unparalleled access to most human archives, through a means of wireless communications. Current technology provides various resources for communication between individuals across the span of thousands of miles with no noticeable delay on either end. An integral component in this process of broadcasting endless streams of data is the ability to connect to a signal at a sufficient strength.

College campuses are among the densest areas when it comes to a need for individuals to be able to connect to various signals. Dr. Mainak Chatterjee has expressed the necessity for a device that is able to scan various frequency bands, sense signal strengths, and send the data to a server to display a real-time heat map of the signal strengths across the University of Central Florida. The implemented device is intended to provide a cheap alternative to using several overkill spectrum analyzers, whilst also displaying the data in real-time. The scope of this project entails the implementation of a device that scans and measures the signal strengths in a defined frequency band, along with the software realization that receives the data and displays it in an intuitive way to everyone, not just researchers.

To achieve these tasks, we will design a device incorporating a microcontroller, several sensors, wireless network connectivity, and mobile power distribution for the circuit. The microcontroller will control how the sensors change their frequency bands and poll signal strengths, whilst also controlling when and how data is sent from the wireless network module to the intended server. Additionally, LED indicators will be implemented to help troubleshoot any issues the modules may run into post deployment.

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V. Terms and Abbreviations

IEEE – The Institute of Electrical and Electronics
LAMP – An open source web service platform
PHP – Hyper Text Preprocessor
UML – Unified Modeling Language
RDBMS – Relational database management system
DB – Database
AWS – Amazon Web Services
HTML – Hypertext Markup Language
CSS – Cascading Style Sheets
JSON – JavaScript Object Notation
Li-Ion – Lithium Ion
Ni-Cad – Nickel Cadmium
DOD – Depth of Discharge
ESR – Equivalent Series Resistance
PCM – Protection Circuit Module
IC – Integrated Circuit

1 Introduction

1.1 Motivation

Our key motivation is to create something will not only help us learn, but will enable others to better understand the world, even if just a small bit. Throughout this project, the team learns about many engineering topics including integrated system development, PCB design, wireless communications, server infrastructure, and website development. With the outcome, researchers will gain the ability to make observations about how different environments affect wireless signals.

1.2 Project Goals

1.2.1 Targeted Frequencies

The goal of our project is to design a device that will read the signal strength of different frequency bands in common use. Our goal for this project is to poll the most popular cellular frequencies under 2 GHz, and both the 2.4 GHz and 5.0 GHz wireless internet bands. These frequencies are the most widely used by devices such as cellphones and laptops for wireless data transmission and reception.

1.2.2 Scalability

This design shall be easy to reproduce to create a large network of sensors for deployment throughout an area. A large-scale network of sensors will allow the collection of signal strength of frequency bands across an area. This data is then stored in a server which presents the data in a user-friendly webpage. Alternatives for this already exist, such as software-controlled radios, but they can be very costly and were not created with the purpose of mass visualization of frequency availability on a region.

1.2.3 Research

Currently, there is a lack of real time data for frequency reception over large areas. Reception data is limited to studies done by internet service providers when setting up wireless antennas for these areas. These studies are performed with very expensive equipment that does not consider changes in the environment throughout time. The results from these studies are not available to consumers or researchers. On the contrary, Chatterbox provides a solution by making data easily available - kickstarting new research on signal strength throughout college campuses and urban areas. Data will not only be easily visualized but obtained in a quantifiable way which subject matter experts can use to create reliable observations to support their studies.

2 Design Specifications and Constrains

2.1 Specifications

Electrical component housing	- The design will be no bigger than 10” wide x 6” long x 6” high - The design will have a watertight enclosure
Power source for electronics	- The design will operate on a battery - The battery will be rechargeable - The battery must hold a charge time of at least 12 hours
Temperature threshold for electronics	- The design will withstand temperatures up to 140°F
Frequencies being polled	- The design will poll the strength of most used cellular frequencies in NA - The design will poll the strength of the Wi-Fi frequencies (2.4 GHz) - The design will poll the signals with a step size of 1MHz
Data transmission	- The design will transmit data wirelessly through Wi-Fi - The design should transmit data at least once every 10 seconds
Software	- The design will have the server receive and store data from the devices - The design will include a user-friendly webpage to display the data - The design will have a database to store and retrieve the data - The webpage should display the latest data

2.2 Constraints

2.2.1 Economic Constraints

The cost of production is one of the biggest factors for RF Chatterbox. There are already products on the market that can read the strength of an incoming signal such as a spectrum analyzer. However, these products come with excess features and capabilities and can cost thousands of dollars. We are looking to limit our costs as much as possible so that it’s economically feasible to create multiple of these sensors down the road to create a signal map that encompasses areas of high foot traffic throughout much of the University of Central Florida. In addition, we are trying to minimize costs throughout the prototyping and development of this product for our client.

2.2.2 Environmental Constraints

The device will have no major negative consequences on the environment. However, we can make a positive impact by the choice of power source we choose to use. If we choose to use batteries to power the device then overtime the cumulation of used batteries will add up and will have to a harmful effect to the ecosystem. To being with the production and production process to create a battery requires the use of already depleting natural resources and many batteries are improperly disposed and wind up in landfills. Many batteries contain toxic and corrosive materials such as cadmium, mercury, lead, and lithium which can leak into groundwater posing health concerns not only for the surrounding ecosystem but for humans as well.

With the emergence of the renewable energy industry, we can explore the use of alternative forms of energy such as solar energy. Solar energy has been heavily researched and funded that it will not be too hard to find information to implement renewable energy technology into our product but also the cost is not as high as it once may have been in the earlier stages of solar panels. We will continue to research the feasibility of the use of a solar panel to power our product to further reduce the use of batteries in our society.

We plan on having our product to be able to be intended for not only indoor use but also outdoors as well. Therefore, another environmental constraint is for our product that will be mounted outdoors to be able to withstand Florida's harsh climate. The device must be able to handle temperatures above one hundred degrees Fahrenheit with the addition of internal heat that is produced by its components. It is also very typical to experience heavy rainfall almost daily in Florida especially during the summer, so the device must have a NEMA rated enclosure to ensure no damaging of any internal parts as well as a mount to withstand extreme winds.

2.2.3 Manufacturing Constraint

One of the ideas of designing the Chatterbox is having a product that is low in cost and easy to reproduce so that one can have full range of coverage to gather data of an area of interest. To do so consideration of material and components need to take place. Ideally, we would use components that do not need to be custom built or limited in numbers because that will create a big-time constraint on future devices and puts more stress on the current time constraint already in place which is discussed further in this paper. Also, we need to consider how established a manufacturer of parts is, because if the company goes out of business or cannot keep up with future manufacturing demands will likely cause us to redesign all aspects of the devices.

2.2.4 Sustainability Constraints

Another metric that we are trying to hit with this product is to make sure that this device can be long lasting and free standing on its own, even with potential outside interference such as students and animals. For example, if it is determined that the Chatterbox will have a wired connection for either power or data transmission, then we need to account for interference from faculty or students unplugging or tripping over the device and interfering or skewing with data collection for the heat map. Also, students may be tempted to tamper with the device and if the design calls for us to use a wired connection we may be limited in how to keep our device out of reach.

Another concern is damage caused from animals. The device needs to be able to keep small insects out to prevent damage on the inside of the device and withstand any tampering from small animals such as squirrels or birds.

2.2.5 Time Constraints

One of the biggest constraints for this RF Chatterbox is the amount of time allotted to design, create and demo a prototype. We will have only about nine weeks to come up with an initial design on paper and then a following fifteen weeks to create a prototype to be demoed by the end of the fall senior design 2 semester. This constraint does put a damper on the creativity and complexity of the project. With only about 24-26 weeks to work with, we may have to cut out some our stretch goals of the design to meet a deadline for senior design. For example, talks about using renewable energy such as solar power, or creating a PCB antenna to minimize size of the device and increase the ease of manufacturing and manufacture time of the chatterbox is discussed further in the paper, but the intricate design and troubleshooting process these features may prove not to be feasible with the given time constraints for the project.

Additionally, when given a time limit like the one we have, we need to be concerned about the lead time to acquire parts. During the prototyping phase it can be expected that our design may work out on paper but may require additional parts to make the components work or entirely new design with different components all together. For instance, some aspects of the device need to be custom built such as a PCB. A PCB may take a few weeks for creation and shipping, and then will need to be tested and odds are it will not work the first time, and we will need time for the troubleshooting and the redesign of the new PCB, and then wait again for the turnover time for a new PCB to be delivered. To help aid in this process there is a schedule that the team has planned to be the best plan of attack to design the chatterbox which can be found in the [header name] section here. The schedule has a couple of buffer days in case things do not go as planned but the team plans on sticking to the schedule for the prototyping to go as smoothly as possible.

2.2.6 Health and Safety Constraints

The Chatterbox is intended to be on one of the biggest universities in the United States and in areas where there is a high amount of foot traffic on its campus, because of this we need to make sure that the health and safety of the public is put on high priority. Since we are dealing with power and high heat, there’s a possibility for fire, electric shock, or even a small arc flash explosion from the power source. If one of these events were to happen we must strategically pick locations to where the damage caused by one of these events that it would not harm the public. This can be done by calculating the arc flash for the device. An arc flash calculation is the worst-case scenario if a fault does occur and will give the intensity of the blast and as well as the radius of it. We can take that information and make sure no person would be in harm's way if that event did occur. In addition, the enclosure of the device will also help minimize any harmful effects of a malfunction or short of the chatterbox. Also, the product should not be placed near any flammable objects to minimize the risk of starting a fire.

To further increase the safety of the project, our team during the prototyping phase will take all safety precautions even minor ones, such as also working in at least teams of two in the design lab. Also, the team will research all regulations and standards for our design and make sure to implement them in our work to ease concerns of harming individuals or the campus's property.

2.2.7 Ethical Constraints

The team plans on holding each other to highest ethical standards. The integrity of the product will not be compromised for that of lower manufacturing costs. The product will not intentionally damage or excessively pollute the environment for the benefit of ourselves or anyone else. The team will search for any feasible solutions that will help minimize our footprint and look for solutions to maintain the product's integrity. We will give credit where credit is due and not plagiarize or infringe on someone else's work or intellectual property.

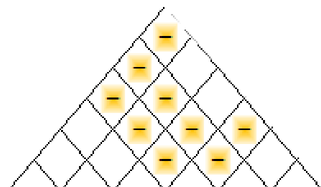
2.2.8 Testing and Implementing Constraints

A constraint that will hinder our product is the availability to implement it on campus. We need permission from administration to be able to place the chatterbox in various places on campus. Additionally, we would need to gain permission from UCF's information technology team for us to send information via the wireless internet to a server on campus. We already have access to use the HEC for testing and demoing but would like to have the sensor be able to survey a broader range on campus.

2.3 House of Quality Analysis

As the development of RF Chatterbox continues, it is important to make distinct tradeoffs between marketing and engineering requirements. This will facilitate the process of making appropriate decisions that path the way to a successful project. The house of quality table **(Table 1: House of Quality**) will be the tool used when orchestrating the development and construction of the project to maintain our highest priority goal: to provide a high-quality product to our client(s).

- Negative Correlation ↓
- Positive Correlation ↑
- Positive Polarity +
- Negative Polarity -



Direction of improvement	Functional Requirements / Customer Requirements	Frequency Range	Temperature Resistance	Install Time	Cost	Dimensions	Polling Rate
	Direction of Improvement	+	+	−	−	−	+
+	User Friendly Interface						
−	Low Cost	↓	↓	↓	↑	↓	
+	Installation Ease			↑	↓	↑	
+	Reproduction Ease				↓	↑	
−	Power Consumption	↓					↓
+	Quick Realtime Updates	↓	↓		↓	↓	↑
+	Broad Spectrum	↑	↓		↓	↓	
		200MHz - 3GHz	0 -145°F	1 hour	<$200	10"x6"x6"	30 Full Range Sweeps /Second

Table 1: House of Quality

2.4 Project Block Diagram

A quality focused project not only requires planning. It requires that each of its members can understand their portion of the work with a high degree of expertise. For this reason, the team has decided to split the product development into four portions as seen in our Project Block Diagram (**Figure 1: Project Block Diagram**). It is the responsibility of each of the members to make sure that each of their portions is compliant with this project's goals and specifications. However, this should not limit teamwork, as it is the responsibility of the entire team that the project is successful.

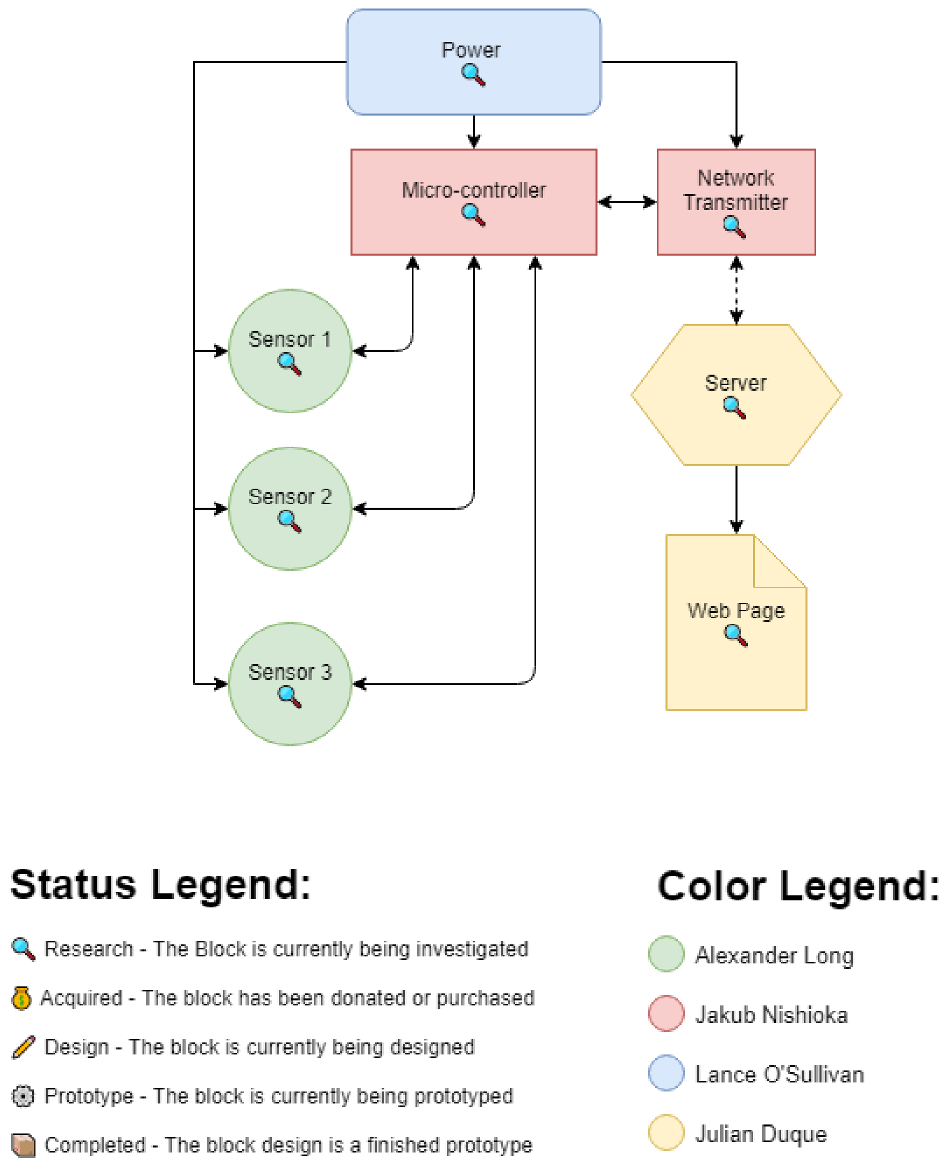


Figure 1: Project Block Diagram

2.5 Microcontroller Software Logic Diagram

With the implementation of a microcontroller, a logic diagram (**Figure 2: Microcontroller Logic Diagram**) needs to be followed. Microcontroller's operate based on logical statements that allow for multiple functionality depending on the environment and state of the system. Specifications for this project do not require a high level of logic complexity. However, things like logging errors for troubleshooting, blinking the LED for failed connections, and powering off in case an error occurs are still accounted for.

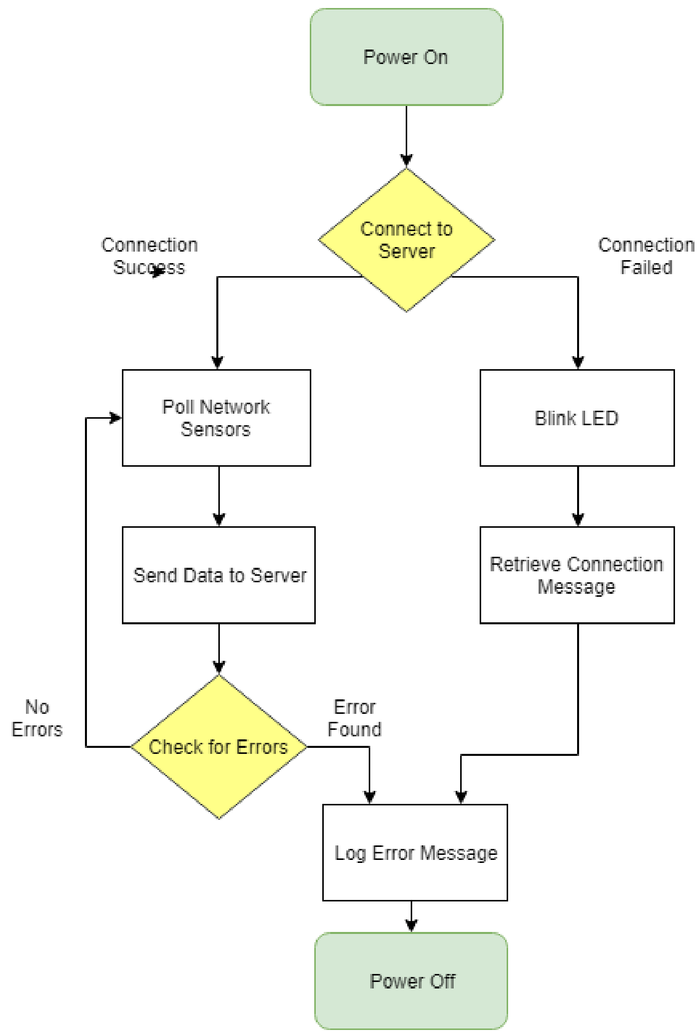


Figure 2: Microcontroller Logic Diagram

The device will need to send data every 5 seconds. Before sending data, the device needs to be deployed into an area in which Wi-Fi connectivity is available from which it will test a connection with the server. Allowing errors to be logged and notifying them when establishing a connection will allow troubleshooting during the testing phase. Displaying the presence of an error using a LED will notify the user that the device has failed to establish a connection with the server.

2.6 Website / Server Diagram

Thanks to the open source community and the World Wide Web foundation, web application development has been rapidly standardized throughout the past 20 years. Together, they have created a modern template **(Figure 3: Web Application General Template**) that most modern web applications follow.

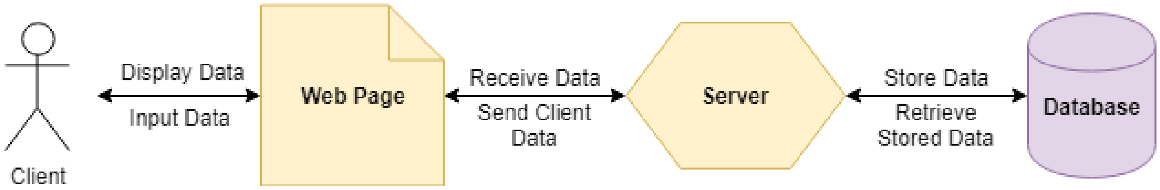


Figure 3: Web Application General Template

This general template helps developers guide the general architecture of any web application. The server is the mediator between the web page and the database. The server also handles all the complex layers of logic that are needed to format the data needed for the web page to function correctly. The database holds the records provided by the web page through the server with extra added security and logging features needed for an enterprise product. The web page is the visual representation of the entire application; it is what the users interact with to analyze or generate data.

This project's version of the template (**Figure 4: Web Application Project Template**) deviates a bit from the original. The main reason being that data is not being generated by a client from the webpage. The data for this project is generated from the devices being created. The webpage's main purpose is to display this data in a way that is intuitive to the user. The server simply manages the data given by the sensors and ensures that it is stored in the database. It also allows the webpage to access this data.

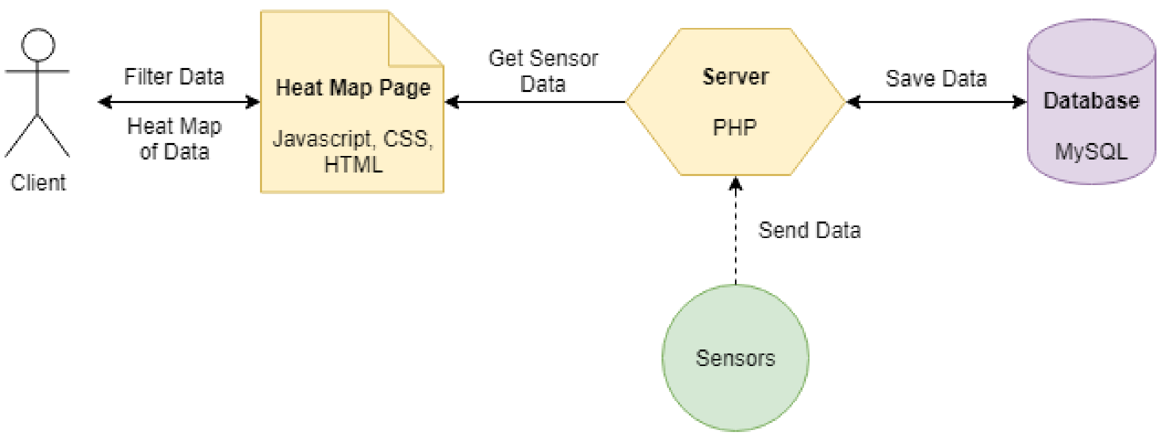


Figure 4: Web Application Project Template

3 Relevant Technologies

3.1 WLAN

A wireless local area network (WLAN) is defined as a wireless network that connects two or more devices using a specified wireless communication within a defined area. Modern day WLANs base their framework off the IEEE 802.11 standards and thus can be Wi-Fi certified. With more and more devices implementing some type of WLAN connection, it is significant to achieve accurate data regarding the most common Wi-Fi bands.

3.1.1 Wi-Fi

The term Wi-Fi refers to the Wi-Fi Alliance, which is a non-profit company that establishes Wi-Fi protocols and provides Wi-Fi certification. The Wi-Fi certification that products receive ensure that the device has passed the interoperability requirements set forth by the Wi-Fi Alliance. There is a variety of IEEE 802.11 standards that explain a diversity of applications for several frequency bands. In terms of Wi-Fi, the 2.4 GHz and 5 GHz ISM bands are most commonly used by everyday consumers. There are 14 total channels within the 2.4 GHz band, each with their own frequency boundaries.

Channel Number	Lower Frequency (MHz)	Center Frequency (MHz)	Upper Frequency (MHz)
1	2401	2412	2423
2	2406	2417	2428
3	2411	2422	2433
4	2416	2427	2428
5	2421	2432	2443
6	2426	2437	2448
7	2431	2442	2453
8	2436	2447	2458
9	2441	2452	2463
10	2446	2457	2468
11	2451	2462	2473
12	2456	2467	2478
13	2461	2472	2483
14	2473	2484	2495

Table 2: 2.4 GHz Wi-Fi channels and Respective Frequencies

Depending on the location, there are governing entities that regulate (for the United States it's the Federal Communications Commission) which channels are in use.

Channel Number	Europe (ETSI)	North America (FCC)	Japan
1	√	√	√
2	√	√	√
3	√	√	√
4	√	√	√
5	√	√	√
6	√	√	√
7	√	√	√
8	√	√	√
9	√	√	√
10	√	√	√
11	√	√	√
12	√	Low power conditions	√
13	√	Low power conditions	√
14	✗	✗	802.11b only

Table 3: 2.4 GHz Wi-Fi Channel Availability Per Region

If the channels are plotted on a frequency spectrum, it is easy to see that there are five sets of three no overlapping channels. Wi-Fi utilizing devices can hop between these channels to decrease interference with each transmitting/receiving device and improve overall performance of the network.

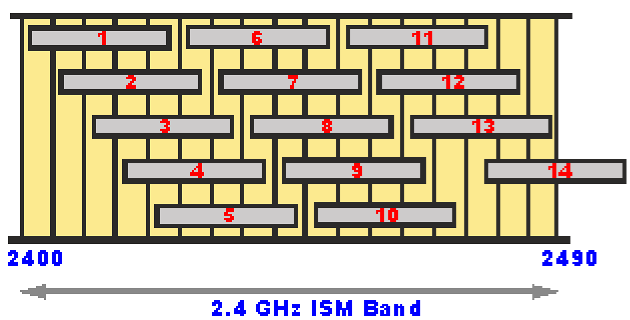


Figure 5: Wi-Fi Channel sets and Overlaps

In addition, there are the 5 GHz channels with their own frequencies and regulations. These channels provide more space on the frequency spectrum whilst also achieving higher data transfer speeds. Many channels within the 5 GHz spectrum fall outside of the accepted ISM unlicensed bands and thus some have varying restrictions.

Channel Number	Frequency (MHz)	Europe (ETSI)	North America (FCC)	Japan
36	5180	Indoors	✓	✓
40	5200	Indoors	✓	✓
44	5220	Indoors	✓	✓
48	5240	Indoors	✓	✓
52	5260	Indoors/DFS/TPC	DFS	DFS / TPC
56	5280	Indoors/DFS/TPC	DFS	DFS / TPC
60	5300	Indoors/DFS/TPC	DFS	DFS / TPC
64	5320	Indoors/DFS/TPC	DFS	DFS / TPC
100	5500	DFS/TPC	DFS	DFS / TPC
104	5520	DFS/TPC	DFS	DFS / TPC
108	5540	DFS/TPC	DFS	DFS / TPC
112	5560	DFS/TPC	DFS	DFS / TPC
116	5580	DFS/TPC	DFS	DFS / TPC
120	5600	DFS/TPC	✗	DFS / TPC
124	5620	DFS/TPC	✗	DFS / TPC
128	5640	DFS/TPC	✗	DFS / TPC
132	5660	DFS/TPC	DFS	DFS / TPC
136	5680	DFS/TPC	DFS	DFS / TPC
140	5700	DFS/TPC	DFS	DFS / TPC
149	5745	SRD	✓	✗
153	5765	SRD	✓	✗
157	5785	SRD	✓	✗
161	5805	SRD	✓	✗
165	5825	SRD	✓	✗

Table 4: 5 GHz Wi-Fi Channel Frequencies and Uses

DFS refers to dynamic frequency selection, this requires that Wi-Fi networks operating in those designations implement a radar detection and avoidance capability. This goes hand in hand with TPC, or transmit power control, which ensures that the average power is less than a regulated maximum to reduce interference to satellites. A SRD is a short range device that is regulated by the radiated power, usually around 25 mW; which lacks the ability to cause harmful interference to other devices out of the range of said device.

3.2 Signal Metrics

Signal strength generally refers to the power output of a transmitting device as read by a receiving antenna. Since the focus of RF Chatterbox is to display a heat map of various frequency bands' signal strengths in locations across the university, a specific metric, or normalized set of metrics, will be utilized to provide a data set to be mapped.

Signal quality is also an important metric to consider due to the idea that a signal may be received but it may be too bogged down with interfering signals that the device receiving is unable to retrieve the intended signal. Due to the low-cost implementation of this project, a signal quality metric will not be incorporated; however, the idea is present for potential expansions of the project.

3.2.1 Power Detection

Radio frequency power detectors are primarily used to measure signal's strength and convert it to a DC output voltage proportional to the power received. This type of power detection is closely related to RSSI, which also relates a DC output voltage to a signal's average power. The main concern in the realm of power detection is finding sensors that are low cost that also have a low enough sensitivity for the desired application. Since the idea is to map frequencies from 200 MHz to 3 GHz, and many of the bands within that range are not necessarily strongly transmitted, it's imperative to have a power detector with a low enough sensitivity to determine if there is a signal being transmitted at all.

3.2.2 SNR

Signal-to-noise ratio (SNR) is defined as the ratio of signal power, or the desired signal, to the noise power, unwanted interference. SNR can be calculated through the following equation:

$$SNR = \frac{P_{signal}}{P_{noise}}$$

Where P represents the average power of the subscripted signal.

Often, SNR is expressed as a value in decibels, using the following equation:

$$SNR_{dB} = 10\log_{10}(SNR)$$

It's important to note that unlike voltage and current ratios, power ratios are multiplied by 10 instead of 20 when converting to decibels. Most often, this metric is used in wired analog communications applications, as it allows one to determine the quality of a signal in regards to the natural and ever present noise in a wire.

3.2.3 SINR

Signal-to-interference-plus-noise ratio (SINR) is defined as the ratio of the power of a specific signal of interest to the power of any other interfering signals, including noise. In wired communications the presence of the wired path between the transmitter and receiver determines the correct reception of data; however, in wireless communication other factors, mainly background noise and interfering power of simultaneous signal transmissions, require the SINR model to appropriately determine the quality of the signal. The following equations shows how to calculate SINR:

$$SINR = \frac{P}{I + N}$$

Where P is the power of the signal of interest, I is the power of any interfering signals, and N is the power of the noise present in the network.

Due to the nature of a wireless network, the mathematical model for calculating SINR accurately has to take into account path loss. Path loss is the reduction of power of a signal as it propagates through a medium, such as air. To display this relationship, the propagation model is applied to the equation above to show how the signal decays with respect to the distance traveled. For the purposes of this project, the SINR model considering the propagation of a signal through a medium will not be included.

3.2.4 RSSI

Received signal strength indication (RSSI) is the measurement of the total average power within a passband, normally relative to the vendor of the device, of a signal sent to a device, most commonly in a wireless environment. The RSSI output is a direct current (DC) analog level, which is sampled by an analog to digital converter (ADC). RSSI is a commonly used metric in the realms of radio frequency and wireless network communication. Although the units are not standardized across all devices (i.e. Cisco Systems utilize a zero to one hundred scale, whilst Atheros devices' RSSI ranges from zero to 127), one can expect a more positive value to represent a stronger signal. RSSI measures the power of what is highlighted in yellow within the figure below.

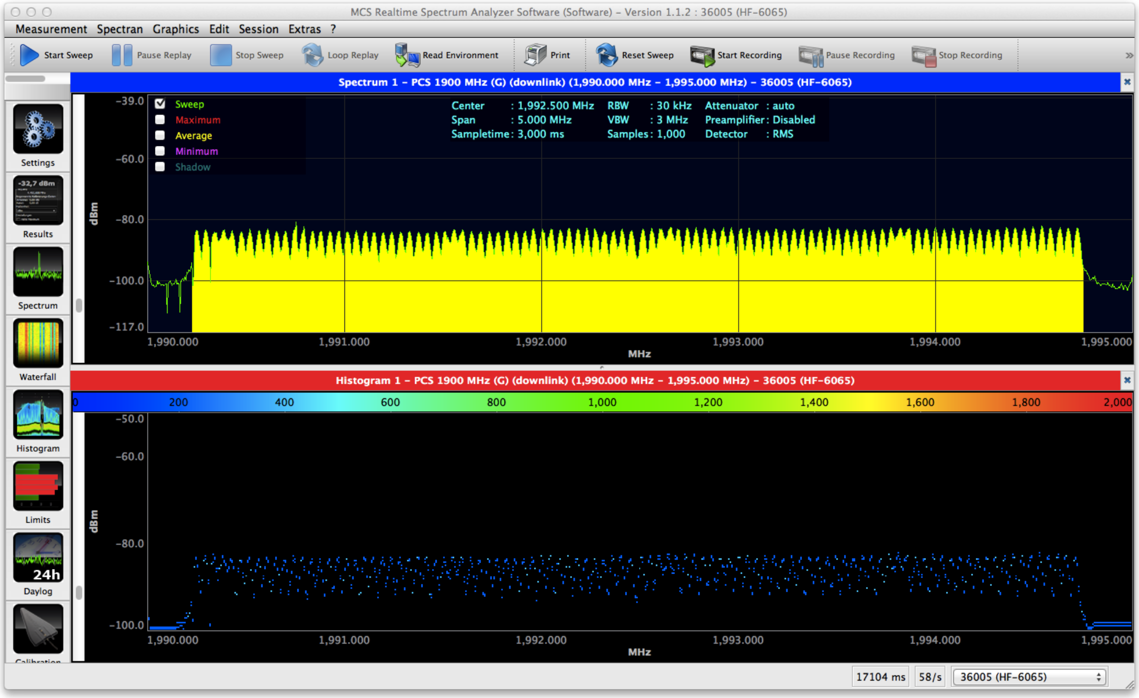


Figure 6: Visual Representation of RSSI Within a Passband Filter

RSSI can also be represented as a negative value, which is likely due to its relationship with decibels in respect to one milliwatt, or dBm. Chipset manufacturers tend to follow their own metrics in terms of precision, granularity, and range of the actual power of a signal, normally measured in milliwatts or dBm, and then assign respective RSSI values. Additionally, the RSSI measurement is only acquired during the preamble sequence of receiving a signal, meaning that RSSI is achieved during the stage where receiver synchronizes with transmitter to ensure that data is transmitted correctly.

In general, a signal with an RSSI value in the range of -35 dBm to -70 dBm is desirable for high speed data transfer. In some non-Wi-Fi applications, an RSSI value above -35 dBm can be too strong and oversaturate components that handle throughput and performance. Signals with values below -70 dBm are too weak to be used in any reasonable manner. Ideally, the detectors that are chosen will have a wide enough dynamic range to pick up the strength of the signals even if they are very weak.

3.2.5 RSRP

Reference signal received power (RSRP) is the metric used for most LTE bands that averages the radio frequency power in all reference signals in a passband. Although RSRP is like RSSI, the distinction is that RSRP averages the power of all the channels within the passband; whereas RSSI takes the average power of the entire passband. Taking this difference into account, RSRP tends to read about 20 dB lower than RSSI. RSRP measures the power of what is highlighted in red within the figure below.

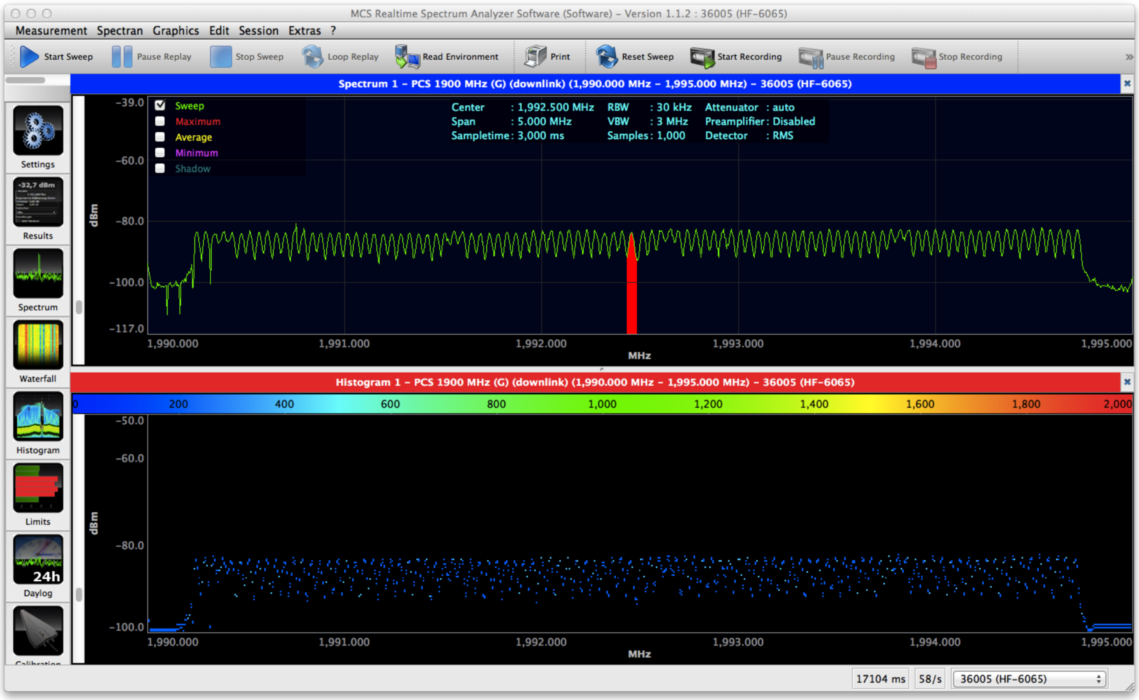


Figure 7: Visual Representation of RSRP Within a Passband Filter

This metric is generally used in LTE applications as there are many channels within a passband and different passbands have varying amounts of channels contained within. Assuming all other factors are equal, a 10 MHz bandwidth LTE band would measure 3 dB greater than a 5 MHz bandwidth LTE band when using RSSI as the metric. In the very same scenario, the RSRP would yield a more accurate measurement of the signal strength because it would only consider the properties of the used channel within each passband. In this thought experiment, the RSRP would be the same for each channel; again, if all other factors aside from the passband bandwidth are identical.

RSRP values are also normalized and have an integer value corresponding to its dBm value. The table following displays this relationship.

Integer RSRP	RSRP in dBm
0	RSRP < -140
1	$-140 \leq$ RSRP ≤ -139
…	…
N	N-141 $\leq$ RSRP $\leq$ N-140
…	…
96	$-45 \leq$ RSRP ≤ -44
97	$-44 \leq$ RSRP

Table 5: RSRP Values and Corresponding dBm

This is another reason as to why RSRP is applied to LTE bands as opposed to RSSI.

3.2.6 RSRQ

Reference signal received quality (RSRQ) is a signal quality metric used in LTE applications when RSRP is insufficient to make a cell reselection decision. RSRQ takes the ratio of the RSRP multiplied by the resource blocks (or channels) within a passband to the RSSI of that passband. The following equation models the calculation of RSRQ:

$$RSRQ = \frac{(N * RSRP)}{RSSI}$$

With N being the number of channels within the passband. Note that this must be measured across the same passband to achieve a proper RSRQ. Like RSRP, RSRQ is normalized as described by the following table:

Integer RSRP	**RSRQ in dB**
0	RSRQ < -19.5
1	-19.5 ≤ RSRQ ≤ -19
…	…
N	(N*0.5)-20 ≤ RSRQ ≤ (N*0.5)-19.5
…	…
33	-3.5 ≤ RSRQ ≤ -3
34	-3 ≤ RSRQ

Table 6: RSRQ Values and Corresponding dB

3.3 Federal Communication Commission

All wireless communication that takes place in the United States is regulated by a governing body called the Federal Communication Commission (FCC). This agency splits up the entire frequency spectrum into what are called frequency bands. Each band has a special purpose or reservation. Some bands are reserved for other agencies such as the military for underwater communication or reserved for if there is ever a time of war that takes place domestically, and some of the spectrum is auctioned off to private parties such as phone companies. To help give an idea of this, below is a table breaking down the frequency spectrum into ranges and what application those ranges have.

Band	Frequency range	Applications
L	1 to 2 GHz	Satellite, navigation (GPS, etc.), cellular phones
S	2 to 4 GHz	Satellite, SiriusXM radio, unlicensed (Wi-Fi, Bluetooth, etc.), cellular phones
C	4 to 8 GHz	Satellite, microwave relay, Wi-Fi, DSRC
X	8 to 12 GHz	Radar
K_u	12 to 18 GHz	Satellite TV, police radar
K	18 to 26.5 GHz	Microwave backhaul
K_a	26.5 to 40 GHz	Microwave backhaul, 5G cellular
Q	30 to 50 GHz	Microwave backhaul, 5G cellular
U	40 to 60 GHz	Experimental, radar
V	50 to 75 GHz	New WLAN, 802.11ad/WiGig
E	60 to 90 GHz	Microwave backhaul
W	75 to 110 GHz	Automotive radar
F	90 to 140 GHz	Experimental, radar
D	110 to 170 GHz	Experimental, radar

Table 7: Table of Microwave Bands, Ranges, and their Applications

3.4 Human Interface Design

The core aim of human interaction design is to reduce the negative experiences that users encounter while enhancing positive ones. Interaction design studies look at the differences between good and poor designs, emphasizing on how products can be more functional and enjoyable to use. In 1987 Ben Shneiderman, a researcher in Human Computer Interaction, created the **Eight Golden Rules of Interface Design**:

- Strive for consistency
- Enable frequent users to use shortcuts
- Offer informative feedback
- Design dialog to yield closure
- Offer simple error handling
- Permit easy reversal of actions
- Support internal locus of control
- Reduce short-term memory load

3.5 The LAMP Stack

The term stack is derived from the way in which each of the components of the system is derived off its base layer. Each component works together to make up a complete platform capable of supporting a web server application. The LAMP stack is an open-source platform solution that constitutes of:

- Linux – The operating system
- Apache – The web manager
- MySQL – The database manager
- PHP – The programming language

3.6 Technical Terminology for Batteries

The following table describes the terminal terms used in this paper regarding battery technologies.

Term	Definition
Li-Ion	Abbreviation of Lithium Ion - A type of rechargeable battery utilizing Lithium Ions in either a Carbon anode or Oxide cathode.
Ni-Cad	Abbreviation of Nickel Cadmium - A type of rechargeable battery utilizing a nickel oxide cation electrode and a cadmium anode.
DOD	Abbreviation for Depth Of Discharge - The percentage of a batteries total capacity that has been discharged.
Memory	Regarding battery cells, refers to the reduction of total capacity due to discharging to the same percentage.
ESR	Abbreviation for Equivalent Series Resistance - Batteries all have internal ESR causing loss and changing the charging characteristics.
PCM	Abbreviation for Protection Circuit Module - A circuit used for protection of delicate electrical equipment, most notably Lithium Ion batteries.
IC	Abbreviation for Integrated Circuit - A single complex component made up of multiple simple components in a circuit.

Table 8: Technical Terminology for Batteries

X.X.X Digital Circuit Design

All **circuits** need to be modeled on an appropriate software to ensure the values are working correctly. There is various types of different software available for testing a circuit before the physical model is manufactured. However, sometimes the choice of software is subjective. Some software are more user friendly, with a wide range of components to use. While some nicer software may usually be higher in cost, which is required in order to obtain a license. There is some software that provides plenty of features at no extra cost. Furthermore, some universities have licenses for the paid software which allows students to access expensive software that eases the design phase without having to pay for it. The main problem with the software offered by the university is that it is only available on campus, which could be an issue for students who live off campus and having to commute.

Overall, the goal is to choose a software that is easily accessible from anywhere while getting the best features for the money paid.

3.6.1 Multisim

Multisim is a popular simulation software for experienced designers. This software provides a multitude of design components to use for testing any scenario. Additionally, the user interface is easy to understand and use. Using Multisim is a polished experience offering smooth circuit design and interactive testing equipment, and output signals are easy to compare directly to the input. Components are generic with the option to design the internal parameters to tailor a specific component from an outside source. With all the pros in mind, the biggest drawback is having to use Multisim in university labs. This limits the available time for design to a single place. Furthermore, designing outside of the lab would often be a waste of time without a process to draw and test the new design. Additionally, school laboratories are not always available for use, because if the labs are full, or closed, design and simulation will be impossible. Ultimately, if the lab is unavailable for any reason, all the provided benefits are wasted.

3.6.2 LTSpice

LTSpice is the most popular circuit simulation system for inexperienced designers. It is offered for free by Linear Technology. This software provides plenty of features; however, since it is offered for free there will be some expected drawbacks. The main reason being is the lack of variety in the components. While Linear Technology offers this software, the components for simulation are all from Linear Technology. Thus limiting the ability to test a variety of components. To test foreign components, the spice model will need to be found. At this point, designing a spice model for complex integrated circuits will be unreasonable. The most significant pro for LTSpice is how it can be diverse by using it on any computer. Therefore, progress can be continually go forward even if the university lab is not available.

3.6.3 Digital Circuit Design Software Chosen

Given the positives and negatives of both multisim and LTSpice, the best choice to rely on is LTSpice. Being able to work on the design from anywhere is the most significant aspect needed for this project. Contradictory, being confined to one space limits the ability to design and test any new ideas. However, Multisim can be used as a secondary option while at school to provide access to the extra features.

4 Hardware Design

RF Chatterbox calls for an electronic hardware implementation using different components to perform the desired functions. This section covers the necessary hardware design to meet the required specifications keeping in mind constrains that this project has. Each decision is backed with an analysis, such as why a component was chosen over another one, or why the product calls for a specific type of design.

4.1 MSP432

The MSP432P401X family includes ARM Cortex-M4F CPU microcontrollers that deliver high-performance and operate at a relatively low power. These microcontrollers also include a SAR Precision ADC with 16-bit performance and have support for a variety of wireless connectivity options. Another benefit to these microcontrollers is that the TI Innovation Lab is available as a resource on campus and could lower overall cost for the project. This microcontroller also features a development kit, that implements features onto the board to make it easier for first time users; the development board is shown **in Figure 8: MSP432P401R Launchpad Development Board**.

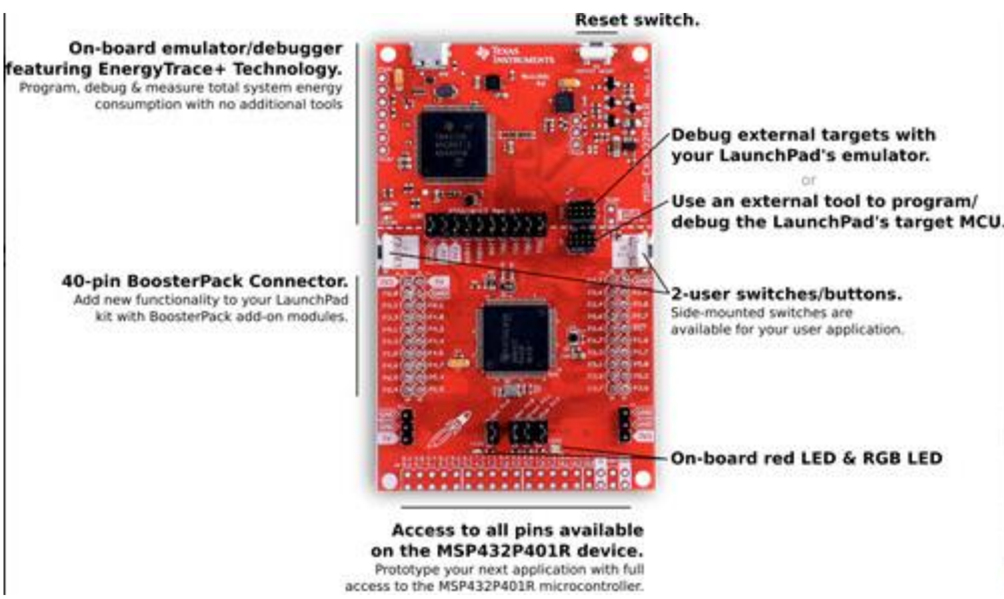


Figure 8: MSP432P401R Launchpad Development Board

This board is also known to be compatible with the CC2500 Wi-Fi transceiver that was chosen for this project and meshes well with the low-power functionality that the project is aiming towards. In addition, the pin configuration should be more than sufficient to accommodate the RFM22B and leave some additional room for any RF log power detectors that will be tested for functionality.

4.1.1 Low Power Modes

A key feature for this microcontroller is the power control manager (PCM), which dictates the operating mode of the microcontroller. Depending on the state of the device, it may be more efficient to implement a low-power mode that only uses the components which are absolutely necessary to carry out the task. The variation in low-power modes and ability to switch between the modes will hopefully allow us to save costs in battery hardware and power consumption. **Table 9: MSP432 Operating Modes** is a list of the various operating modes along with a short description as to what they allow.

Operating Mode	Description
AM_LDO_VCOREX	LDO based active mode, normal performance, core voltage level X.
LPM0_LDO_VCOREX	Same as above, but the CPU is off (no code execution).
AM_DCDC_VCOREX	DC-DC based active mode, normal performance, core voltage level X.
LPM0_DCDC_VCOREX	Same as above, but the CPU is off (no code execution).
AM_LF_VCOREX	LDO based low-frequency active mode, core voltage level X.
LPM0_LF_VCOREX	Same as above, but the CPU is off (no code execution).
LPM3_VCOREX	LDO based low-power mode with full state retention, core voltage level X, RTC and WDT can be active.
LPM4_VCOREX	LDO based low-power mode with full state retention, core voltage level X, all peripherals disabled.
LPM3.5	LDO based low-power mode, core voltage level 0, no retention of peripheral registers, RTC and WDT can be active.
LPM4.5	Core voltage turned off, wake-up only through pin reset or wake-up capable I/Os.

Table 9: MSP432 Operating Modes

Every X that is associated with a voltage level is either 0 or 1 which correspond to either a 1.2 or 1.4 voltage level, respectively. This chip also features a low-dropout (LDO) regulator based active mode, which allows the microcontroller to be active when the supply voltage is close to the active voltage, rather than there being a large difference between input and output voltage. The LDO options are used for ultra-low power modes of operation while the DC-DC switching regulator provides boost in power efficiency for high-current high-performance applications.

The **real-time clock (**RTC) is an integrated calendar that considers months with less than 31 days as well as leap year corrections, which is also available in low-power modes to minimize power consumption. Similarly, the **watchdog timer** (WDT) can perform a controlled system restart if necessary. In addition, this feature can be configured to generate interrupts at selected time intervals.

4.1.2 Memories

Another benefit of this particular microcontroller is the memory configuration; this device includes flash memory and SRAM for general purposes. The SRAM also contains a subset of memory that is reserved and retained in low-power operating modes. The flash memory in this microcontroller is optimized for high-endurance and low power consumption.

In terms of specifications, this flash memory is 128 bits wide (permitting high code execution performance with the capability of each fetch to return four 32-bit instructions) and supports a minimum of 20,000 write or erase cycles. To allow independent usage, the flash memory contains both main memory and information memory regions, that are equally divvied into two banks. With this type of configuration, one bank might be experiencing a read/execute operation whilst the other undergoes a program/erase operation. **Figure 9: Flash Memory Mapping** shows the mapping of the flash memory in MSP432P401x microcontrollers.

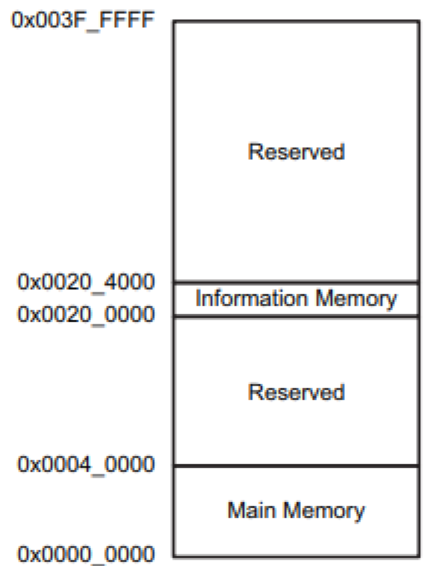


Figure 9: Flash Memory Mapping

The main memory allocation can be as large as 256 KB, whilst containing sixty-four 4 KB sectors. The main memory is evenly split into those two aforementioned banks, allowing for simultaneous read or execute directives with program or erase operations. The information memory region is 16 KB and contains four 4 KB sectors. These four sectors contain boot-override configurations, a unique device descriptor, and some bootstrap loading (BSL) features.

The CPU data busses are 32 bits wide, but the flash is capable of buffering 128-bit write data before commencing flash programming. This is done in order to achieve power efficiency. Additionally, the flash memory is able to operate in a burst write mode that decreases programming time in comparison to individual word programming. The main purpose of the main and information memory regions is to provide a means of write/erase protection control, achieved at a sector granularity which enables features such as mass erase while preserving specific regions in the flash.

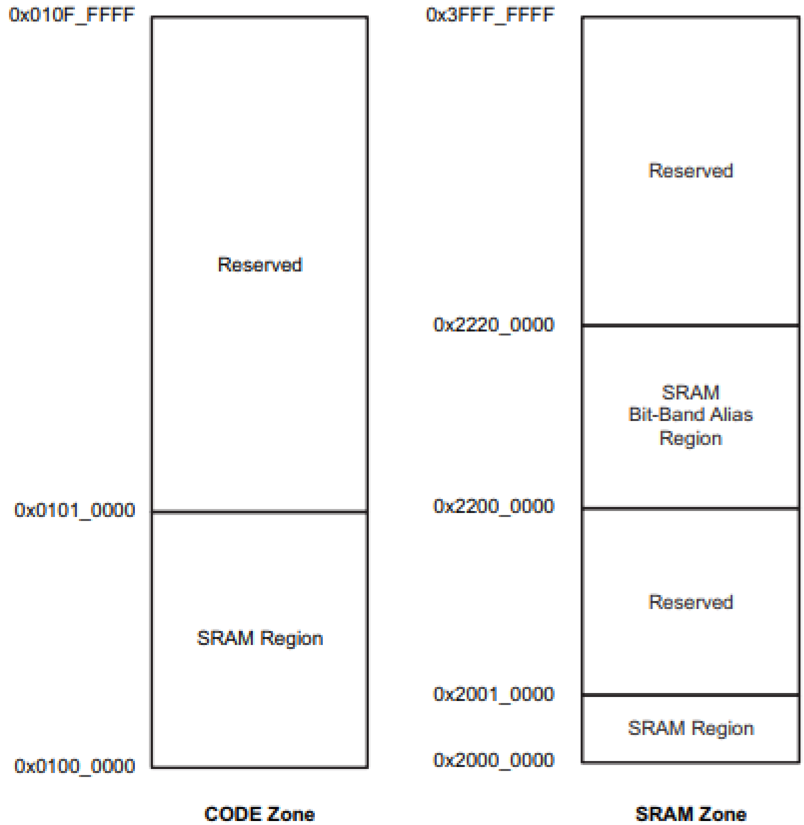


Figure 10: SRAM Mapping

This microcontroller can support up to 64 KB of static random-access memory (SRAM), **Figure 10: SRAM Mapping** shows how the SRAM is divided into two zones. The SRAM is divided into 8 KB banks which are individually configurable, so long as the memory map is contiguous. (e.g. 00000111 or 01111111 are allowable; while 00100111 would be changed to 00111111 automatically) Applications specific to the designated low power modes, LPM3 and LPM4, allow the SRAM to be individually configured for retention as well.

4.1.3 Analog-to-Digital Converter

The analog-to-digital converter (ADC) featured in this chip is capable of realizing up to 16-bit precision with software tweaks. The 14-bit successive approximation register (SAR) core-based converter can attain up to a 1-Msps sampling rate. The implemented conversion-and-control buffer permits 32 individual ADC samples to be processed and stored without need for CPU processing.

4.2 RFM22B

HopeRF's RFM22B is a low-cost ISM transceiver module with a low sensitivity floor and highly customizable frequency band selection. Although this transceiver is marketed for 433/470/868/915 MHz frequency band operation, the controller interface features a combination of frequency control registers that allow frequency band selection from 240 MHz to 960 MHz In addition to this, there are frequency hopping registers that allow for more precise incrementation of center frequency within the frequency bands. This module also contains RSSI dedicated functionality, with RSSI registers whose status can be routed to GPIO lines for microcontroller use.

4.2.1 Frequency Control

HopeRF also supports the RFM22B with an Excel spreadsheet to assist calculating necessary register values that may need to be programmed into the module depending on the desired application. For any receiving or transmitting applications, the channel frequency, $f_{carrier}$, must be programmed into the respective frequency band select register. Since the objective of this project is to map the signal strengths for various frequency bands, the frequency-hopping spread spectrum (FHSS) feature will be heavily utilized. In addition, this transceiver has a frequency hopping step size register that allows incrementation of the nominal frequency from intervals of 10 kHz up to 2.56 MHz.

$$F_{carrier} = F_{nom} + fhs[7:0] \times (fhch[7:0] \times 10 \text{ kHz})$$

The above equation shows the relationship between the frequency hopping step size register, frequency hopping channel select register, carrier frequency, and nominal frequency. The configuration of these registers, along with the algorithm implemented to increment through frequency bands will be a crucial factor to get an accurate data set.

4.2.2 RSSI and Clear Channel Assessment

This module supports a RSSI readout from an 8-bit register with a 0.5 dB resolution per bit. This RSSI value is available for reading at any time; but is reported to provide an erroneous reading if read during the update period. The datasheet details that the update period lasts about 10 ns every 4 Tb. For the data transfer rates used in this project, the probability to read an incorrect RSSI is very low and thus will be handled during the testing phase. If any issues related to this arise, majority polling or clear channel assessment can be implemented as a solution.

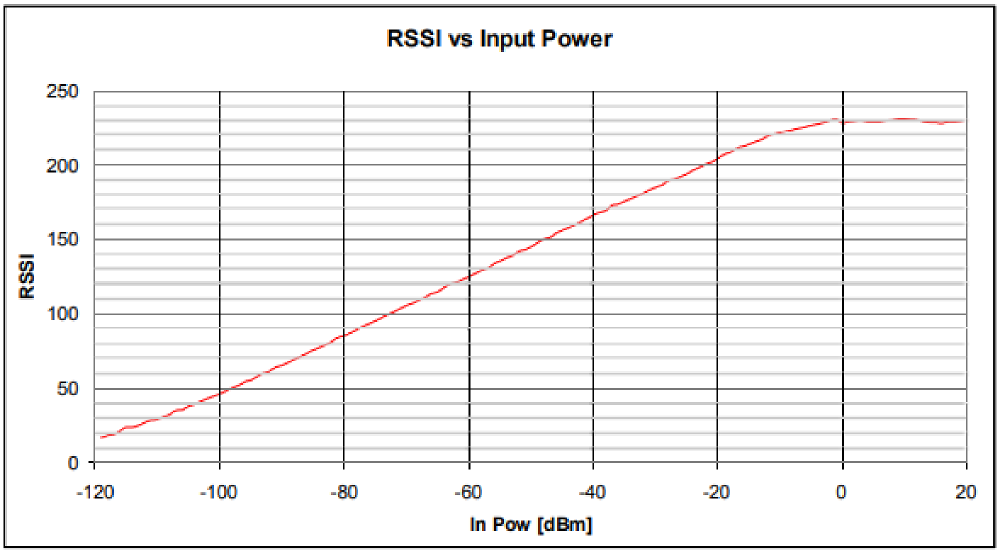


Figure 11: Input Power to RSSI Mapping for the RFM22B

This figure shows the relationship between RSSI and input power that the vendor has mapped within the module. In addition, from the dataset that the vendor shows, the RSSI values only truly range from approximately 15 to 230 as opposed to the full 0 to 255, 8-bit, range. One of the main reasons this module was chosen is due to its high range of sensitivity, the datasheet boasts of a -121 dBm sensitivity which should be more than sufficient to attain accurate data.

4.3 CC2500

TI's CC2500 is a low-cost Wi-Fi transceiver operating in the 2.4 GHz range optimized for very low-power applications. This module was designed for use in the 2400 MHz to 2483.5 MHz ISM and short-range device frequency range. This transceiver is also equipped with hardware to support packet handling, burst transmissions, and data buffer transferring. This device will be responsible for providing an RSSI signal from the 2.4 GHz band and will also transmit the data measured by the other sensors to the server to be displayed on a map.

As the sensor that measures the Wi-Fi signal strength, it is also important for this chip to feature a high sensitivity, which it does at -104 dBm. Additionally, this transceiver features a Wake on Radio (WOR) functionality that allows it to wake up from a low-power sleep mode and listen for incoming data packets without microcontroller interaction to decrease overall system power consumption.

4.3.1 Digital RSSI Output

One of the many reasons this Wi-Fi transceiver was chosen is that it features a digital RSSI output. This RSSI value estimates the signal strength in the chosen Wi-Fi channel. The RSSI value is continuously read from the RSSI status register while the chip is in its RX state. RSSI output is in dBm with a 0.5 dB resolution and is stored as a 2's complement number in the RSSI status register; in order to convert this to a power level the output needs to be converted to a decimal number, and then input into one of two equations depending on its decimal value. **Table 10: CC2500 RSSI Offset Values per Data Rate** provides a list of RSSI offset values per each data rate available to this module to be applied in the equations when converting from RSSI to power level.

Data Rate (kBaud)	RSSI_offset (dB)
2.4	71
10	69
250	72
500	72

Table 10: CC2500 RSSI Offset Values per Data Rate

In addition, **Figure 12: CC2500 Typical RSSI Output vs Input Power Level for Varying Data Rates** provides a typical plot of RSSI readings as a function of input power with differing lines for each data rate. This plot will be used as a control reference when testing the functionality of our prototypes and final product.

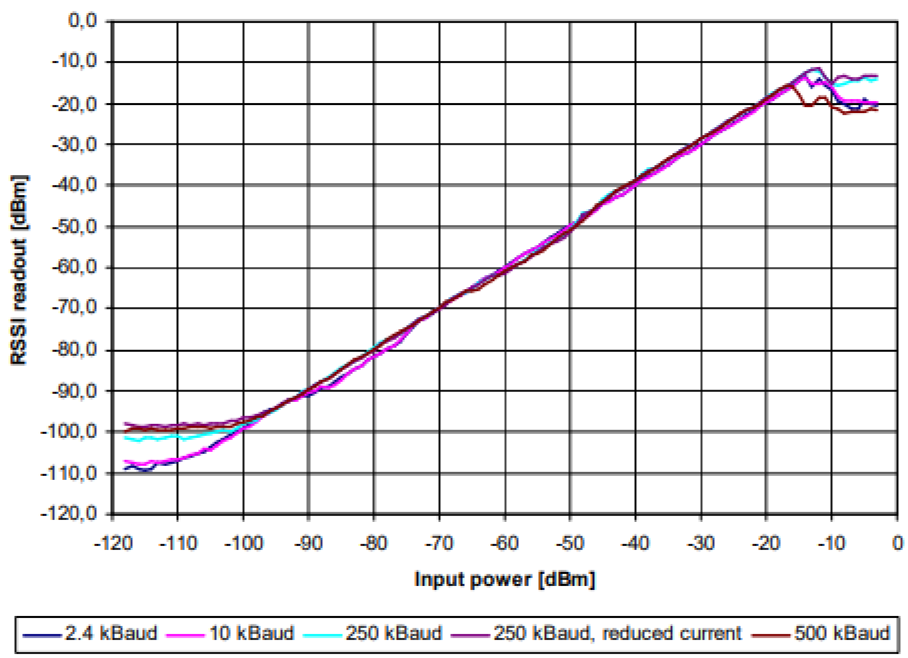


Figure 12: CC2500 Typical RSSI Output vs Input Power Level for Varying Data Rates

The RSSI output on this device can also be programmed to assert or de-assert specific flags that relate to network connectivity. The Carrier Sense (CS) flag for example, will use the RSSI output as a threshold for a sync word scan to occur. Seemingly little tweaks like this can work wonders on the ability to implement a low-power consumption device.

4.4 ADL5513

The ADL5513 is a logarithmic amplifier that maintains the ability to convert an RF input signal to a dB-scale output reading. The main selling point to this device is the price and frequency range it operates in. While preserving approximately 80 dB sensitivity, the ADL5513 operates from 1 MHz to 4 GHz. Currently, the main concern about this module is the configuration to get it to work in the application desired. **Figure 13: ADL5513 Functional Block diagram** shows the functional block diagram of this log detector, which is very similar to the block diagrams of most every other log detector.

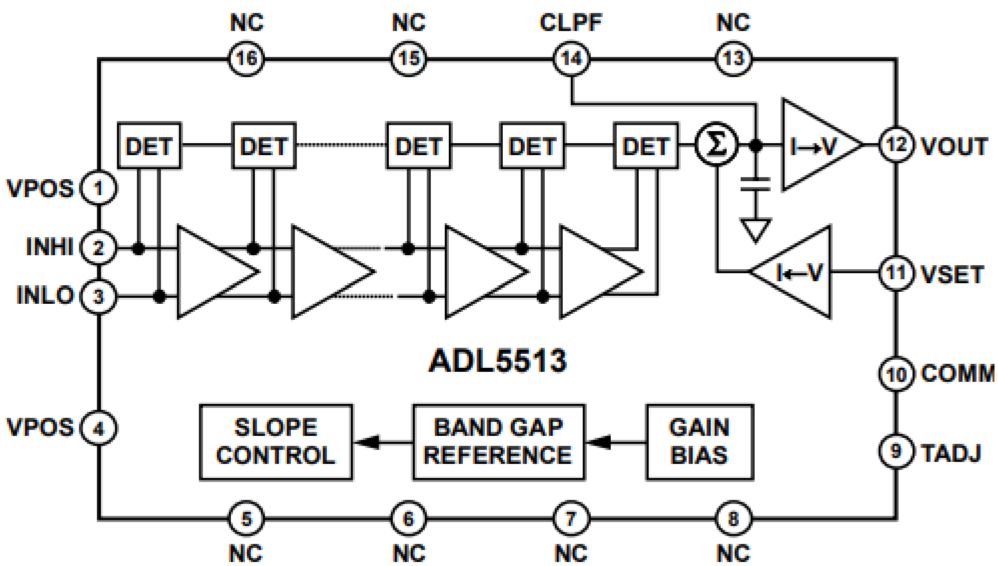


Figure 13: ADL5513 Functional Block diagram

This device also operates within a specific measurement mode that allows it to work as an RSSI module. The measurement mode displays a voltage output as a response to an input signal voltage. The main considerations regarding this module are the sensitivity and ease of use. This device is marketed to experience an 80-dB dynamic range; however, this dynamic range can be enhanced to 95-dB with the addition of a voltage gain amplifier (VGA) and a bandpass filter.

4.5 MAX2016

The MAX2016 is another logarithmic detector module that operates in the 100 MHz to 2.5 GHz range with an 80-dB dynamic range. The main difference, as shown in **Figure 14: MAX2016 in RSSI Detector Mode** which is specifically set up for RSSI measurement, is that this module utilizes two logarithmic detectors within the chip. This chip operates within a measuring power/RSSI detector mode which provides an output voltage proportional to input power.

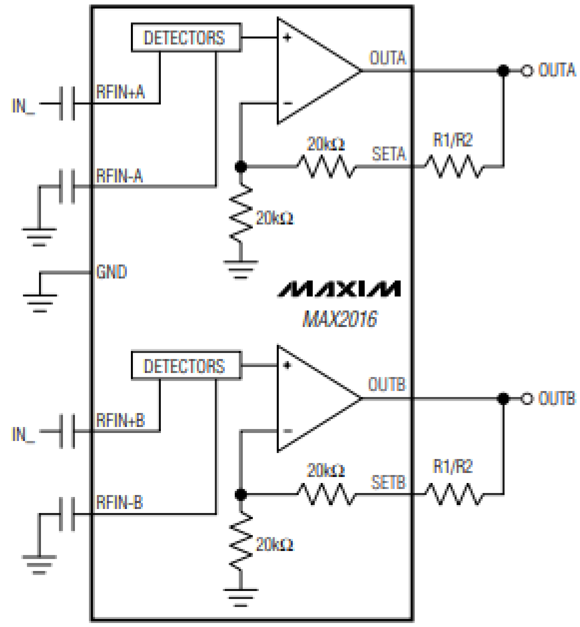


Figure 14: MAX2016 in RSSI Detector Mode

Again, the main contemplation is the ability to implement this device in a frequency sweeping application, whilst also maintaining reasonable cost and a sufficient dynamic range.

4.6 Antenna

The antenna is a very key feature in the Chatterbox, without it we will not be able to detect any signal. Also, just not any antenna can be selected for the device. There are multiple antennas, such as a monopole or dipole antenna. There are also chip antennas, PCB antennas, whip antennas and along with many others to consider. The size of the antenna that is needed also varies by the wavelength and frequency of the signal that is trying to be received or transmitted. Transmitting antennas transform electrical signals into electromagnetic waves by propagating them in free space as sine waves. Receiving antennas receive the electromagnetic waves and convert the energy into electric signals again.

The most important equation is shown below and shows the relationship between wavelength and frequency. As the frequency increases the wavelength gets shorter. In theory the length of the antenna needs to be the same length as the wavelength of the signal it is trying to radiate or receive. However, it is shown later that this is not the case and shorter antennas can be used.

$$\lambda = \frac{c}{f}$$

An important characteristic of electromagnetic waves is that longer the wavelength or smaller the frequency, the further a signal can travel and the better that signal is at traveling through objects in the way such as buildings that are in its path. This information lets know we should not expect many signals in a higher frequency range besides 2.4GHz and 5GHz Wi-Fi due to the many repeaters/boosters on campus.

Another special feature of wireless transmission is the ability of a signal being polarized. A sine wave can be produced to be horizontally polarized and vertically polarized. The reason for this is for multiple sine waves to be transmitted without interference. Also, when a horizontally polarized signal and vertically polarized signal combine they create circular polarization.

Furthermore, for maximum power transfer between a pure signal and the hardware we need to consider a concept called impedance matching. This happens when the source resistance equals the load resistance, and this is called the Moritz Von Jacobi's maximum power theory. If impedance is not matched between the antenna and the feeder there will be signal lost and cause signal reflection in line causing noise and possible damage to the equipment. Consider Z_S to be the source impedance (antenna's radiation resistance) and Z_L to be the load impedance (conductor impedance).

$$Z_S = Z_L^*$$

4.6.1 Dipole Antenna

One of the many commonly used antennas is a dipole antenna. The dipole antenna consists of two bilaterally symmetrical conductors. With each conductor having a length of one quarter of the wavelength which combines to a total length of one half of the wavelength. A dipole antenna uses half the wavelength because if a full wavelength is used both dipoles would radiate an equal and opposite peak and trough. The peak and trough would cancel each other out due to them being perpendicular waves therefore rendering the antenna useless. Therefore, one half of the wave length is used to receive or radiate a peak of a cycle. For example, a 900 MHz signal, a frequency commonly used in cellphones, would have a wavelength of about 13.1 inches. Cutting this into quarters the length of both dipoles will be 3.275 inches and combine for a total antenna size of 6.55 inches.

The advantage of using a dipole antenna is that you only need to use half of the wavelength instead of the full wavelength, reducing the size of the antenna and further reducing the bulkiness of the device itself. Also, the antenna does not require a ground plane due to the nature of the dipole antenna, which we will discuss later with monopole antennas. This reduces the number of features needed for the antenna and having one less feature to have to design and troubleshoot. Also, the dipole antenna is set up to be oriented towards horizontally polarization, which will make the antenna the better option than a monopole antenna when dealing with those class of signals.

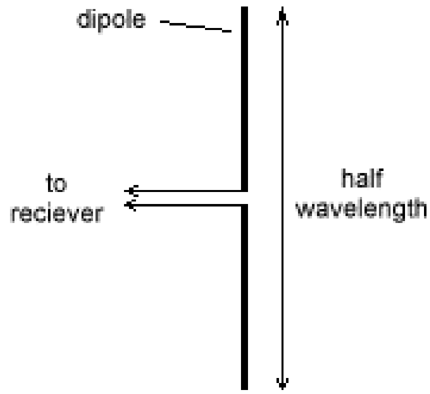


Figure 15: Dipole antenna

4.6.2 Monopole Antenna

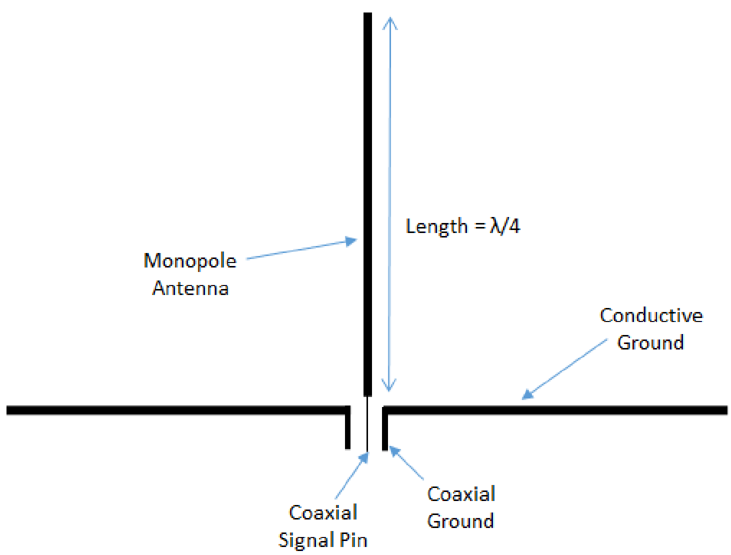


Figure 16: Basis of Monopole Antenna

Another type of antenna the team is taking into consideration is the monopole antenna. This antenna consists of one smaller conductor consisting of a length of one fourth the required wavelength. Just like how a monopole does not exist in nature or physics, a monopole antenna does not behave as a monopole either. For a monopole antenna to work, a ground plane is needed, which is used to create a replica image antenna directly underneath the actual monopole antenna. The electromagnetic waves reflect off the ground plane and create a reflected antenna with the same length as the current physical antenna above but underneath the ground plane. The physical monopole antenna and the reflected antenna simulate a two-element center-fed dipole antenna. The effect of reflected rays and the ground plate is illustrated in the figure below.

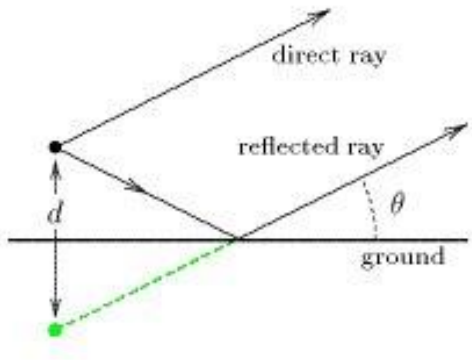


Figure 17: Reflected Rays from Ground Plane

A ground plane has must have a few characteristics to make it a "good" ground plate. To begin with, the ground plate must be a very good conductor to have almost all the electromagnetic wave to be perfectly reflected at a 180° angle. If a dielectric like surface is used, then a good chunk of the power will be absorbed, and the reflection angle will be different. However, at lower frequencies at about less than 30 MHz the conductive plane acts more like a dielectric plane no matter what the conductivity of the plane is. Moreover, the diameter of the plane shall be one fourth the wavelength, or the radius shall be one eight the wavelength. Touching back on the previous example, when using a 900MHz signal, the wavelength would be 13.1 inches. The total antenna length would be 3.275 inches and the surface area of the plate would be 8.42 in^2, which would be a lot of space on the device if using a traditional conductive ground plane. However, it is possible to conserve space by just using four equally space radials at one fourth the wavelength. These radials will be pushed down towards the earth typically to create a radiation resistance closer to 50 ohms which has to do with impedance matching, and 50 ohms is a typical impedance used because it matches better with a coaxial cable feeder.

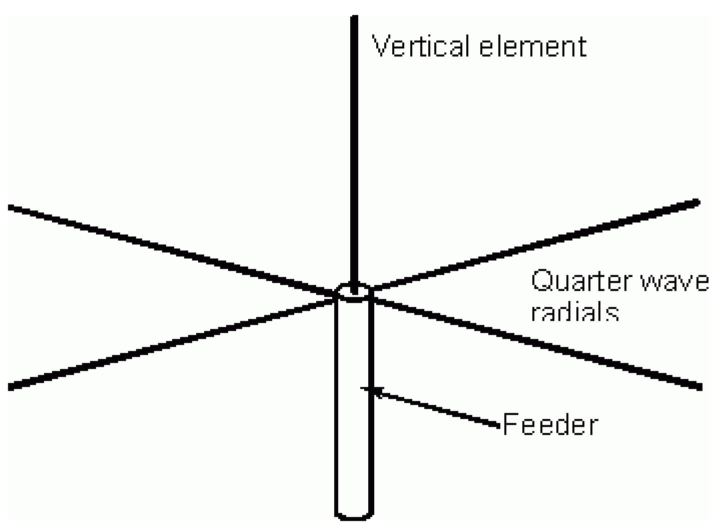


Figure 18: Radial Ground Plane Antenna

4.6.3 Whip Antenna

The most commonly seen antenna is the whip antenna. This antenna is commonly found on cars, FM/AM radios, Wi-Fi devices, walkie-talkies, and old cellular phones. The antenna is flexible in nature and gets its name from the motion it displays when disturbed. The antenna is designed to be durable and to withstand outside forces such as wind or other objects touching or hitting it. The antenna acts a monopole antenna and would require a grounding surface. A perfect ideal quarter wave whip antenna with a perfect ground will have a radiation resistance of 36.8 ohms and a gain of 5.19 dB but with alteration of the ground plane we can get the resistance to match the feeder line. The antenna also is an omnidirectionally vertically polarized antenna.

The whip antenna would be great for the Chatterbox because it will require a length of one quarter of wavelength, which would be half that of its dipole counterpart. The tradeoff is that it will need extra material to create a grounding plate or grounding radials to reflect the signals for the antenna to work. A whip antenna being vertically polarized will be beneficial when picking up Wi-Fi and cellphone signals due to them too being broadcasted vertically. This effect is seen when your phone is place parallel to earth and then brought to a vertically position and the received strength of the signal is greater than when it was at its horizontal state. Also, we are unaware where the broadcasting towers are and the would be most likely be broadcasting from all different directions causing directionally based antenna unnecessary for this project. So, an omnidirectionally antenna is a must, which the whip antenna is.

4.6.4 Chip Antenna

Chip antennas are a cheap lightweight solution to where space is limited for a design. These chips are common in cell phones, PDAs, tablet computers, portable televisions, satellite radio, headsets, USB dongles, GPS devices, and Wi-Fi and WLAN routers. Therefore, these chips have high commercial use and will be in stock and readily available at manufactures for us to purchase which will the time to market (TTM) for these antennas to be short. These chips will be very cheap in the $0.10 to $0.50 range. However, these devices usually need additional matching components and tweaking to create matching impedances. Also, the chip requires a correct ground plate to be placed on the PCB and requires additional parts for mounting.

Here are the common chip frequencies manufactured:

Wi-Fi	2.4 GHz
Bluetooth	2.4—2.48 MHz
WiMAX	2.5 GHz—3.5 GHz, as well as 5.8 GHz
UWB	3.1 GHz—10.6 GHz
GSM	380—1900 MHz
CDMA	1850—1995 MHz
GPS	1176.45 MHz; 1379.913 MHz; 1381.05 Mhz; 1227.6 Mhz; 1575.42 MHz;

Table 11: Commonly Manufactured Chip Antenna Frequencies

If these chips' prescribed frequencies can be altered with software to pick up a broader range of frequencies and paired the low cost and size, then they might be the best option even given the higher complexity of making them work compared to the previously mentioned antennas. Using these chips will also increase the ease of manufacturing of the Chatterbox.

4.6.5 PCB antenna

Another method of implementing an antenna is through PCB design. There are many different solutions and designs to going about implementing the antenna on the board, but every design achieves relatively the same result, which is a compact and cost-effective antenna. A PCB antenna uses copper traces in the PCB in such a way to emulate a dipole or monopole antenna. Once the design is perfected, the hardware would be easily manufacturable and as previously mentioned, cost effective. However, due to the time constraint and complexity of the design it may be best to look at other means of implementing an antenna in our design.

4.6.6 Wire antenna

A very simple and easy to create design is taking a conductor and wrapping it around the outside housing of the chatterbox. The wire would just need to be of correct length and would act as a cheap, easy to make antenna. This antenna would just need to be troubleshooted to get the best results for the device and would not need extraneous design that some of the other methods may require. The tradeoff is that this method is not easily manufacturable and could cause for varied results from device to device.

4.6.7 Antenna Materials

When selecting a wire for the antenna a few factors need to be considered such as the impedance of the conductor, the stretching of the material, insulation, if it's solid core or stranded, and the conductivity of the wire. For reference a chart of the conductivity of various possible conductors is shown below.

Metal	Conductivity
Silver	106
Copper (pure)	100
Copper (hard Drawn)	89.5
Aluminum	45
Steel	3-15

Table 12: Conductors and their Conductivity

Copper

Copper wire is one of the most typical conductors used for a wire antenna. Copper is anywhere from about 10 cents to 3 dollars per foot depending on the gauge size of the wire. For our purposes we would not need more than a foot to create 1-2 different antennas and because of the low strength of the signal we would not need a high ampacity that way we can use a smaller size wire. Even though copper is pricier than other metals other than precious metals such as silver or gold, cost should not be that big of concern because of how little of the material we would need for one prototype. Also referencing the chart above, the conductivity is much greater than that of aluminum and steel. This means that the conductor is much more efficient at sending signals through and having less of the signal's power being lost in the form of heat. Also, when connecting copper wire to terminals it is very easy to solder when compared to other metals such as aluminum.

There are different types of copper wires to consider, such as copper clad aluminum, hard drawn copper and stranded copper. Copper clad aluminum is a conductor with an aluminum core to provide support and then copper on the outside. This will work in an antenna application because of the high frequency of the signals. The signal will sit on the outside of the conductor due to the skin effect and will not enter the core. This will cause the conductor to be resistant to stretching, damage, and being moved out of place because of the aluminum core but still take advantage of the beneficial properties of copper. Additionally, the conductor will weigh less from the aluminum core. Furthermore, stranded copper wire would provide the same qualities of a single copper conductor but with more flexibility which allows for more adjustments and tweaks in the design. In contrast, hard drawn copper will provide tough rigid support for the antenna but will not be very pliable which could prove to be an issue for this application where we may need to bend the wire in the design.

There are a few negatives when using copper wire that needs to be taken into consideration. Copper tends to stretch over time and may need adjusts in the future to fix the antenna to the proper length. Additionally, copper may not be as durable and fatigue in the joints later in life cycle of the device, which effects the sustainability of the product.

Steel

Steel is usually not the preferred conductor due to the high resistivity, but it may serve a purpose for our design. Steel is typical in many every day products, such as a paper clip which can be used a conductor for an antenna. When we are testing different products a paper clip may prove to be effective for simply receiving signals and will be a lightweight, easily maneuverable, very readily available, and cost-effective design. However, it is recommended to not use steel in low impedance situations because it may make it hard to match the impedances of the antenna and the circuit.

Aluminum

Another material to consider being examined during the testing phase of antennas is aluminum. Aluminum is lighter, cheaper, stronger, and more durable than copper. However, the tradeoff is that the conductivity of aluminum is mediocre and is nowhere near as good as copper. This may not be an issue, because no signal is carrying large power and signals are not being transmitted and only received.

Antenna types	Pros	Cons
PCB antenna	• Very low cost • Good performance at > 868 MHz • Small size at high frequencies • Standard design antennas widely available	• Difficult to design small and efficient PCB antennas at < 433 MHz • Potentially large size at low frequencies
Chip antenna	• Small size • Short TTM since purchasing antenna solution	• Medium performance • Medium cost
Whip antenna	• Good performance • Short TTM since purchasing antenna solution	• High cost • Difficult to fit in many applications
Wire antenna	• Very cheap	• Mechanical manufacturing of antenna
IP based antenna	• Support from IP company	• High cost compared to standard free PCB antenna designs. • Similar cost to Chip antenna

Table 13: List of Pros and Cons of each Antenna Type

4.6.8 Smith Charts

Smith charts are the backbone of impedance matching circuit design and analysis. The smith chart is comprised of a series of concentric orthogonal circles which represents the real and imaginary part of a complex impedance. The chart is normalized to the system impedance which is typical 50 ohms. The horizontal line going through the center of the chart represents a load with a purely resistive load (no reactance). As seen in Figure X, at the exact center of the chart represents a perfect impedance match with the system, or characteristic, impedance. As you move further to the right, the resistance approaches infinity and represents an open circuit, and as you move further to the left the resistance approaches zero and represents a short circuit. The resistive component of the impedance is represented by the blue complete circles in figure X. While the green arcs represent the reactance circles. The curves above the horizontal base line are due to reactance from inductors and the curves below the horizontal are due to the reactance from capacitors. Additionally, any combination of reactance and resistance is able to be plotted on a smith chart due to that a smith chart using normalized values relative to the system impedance.

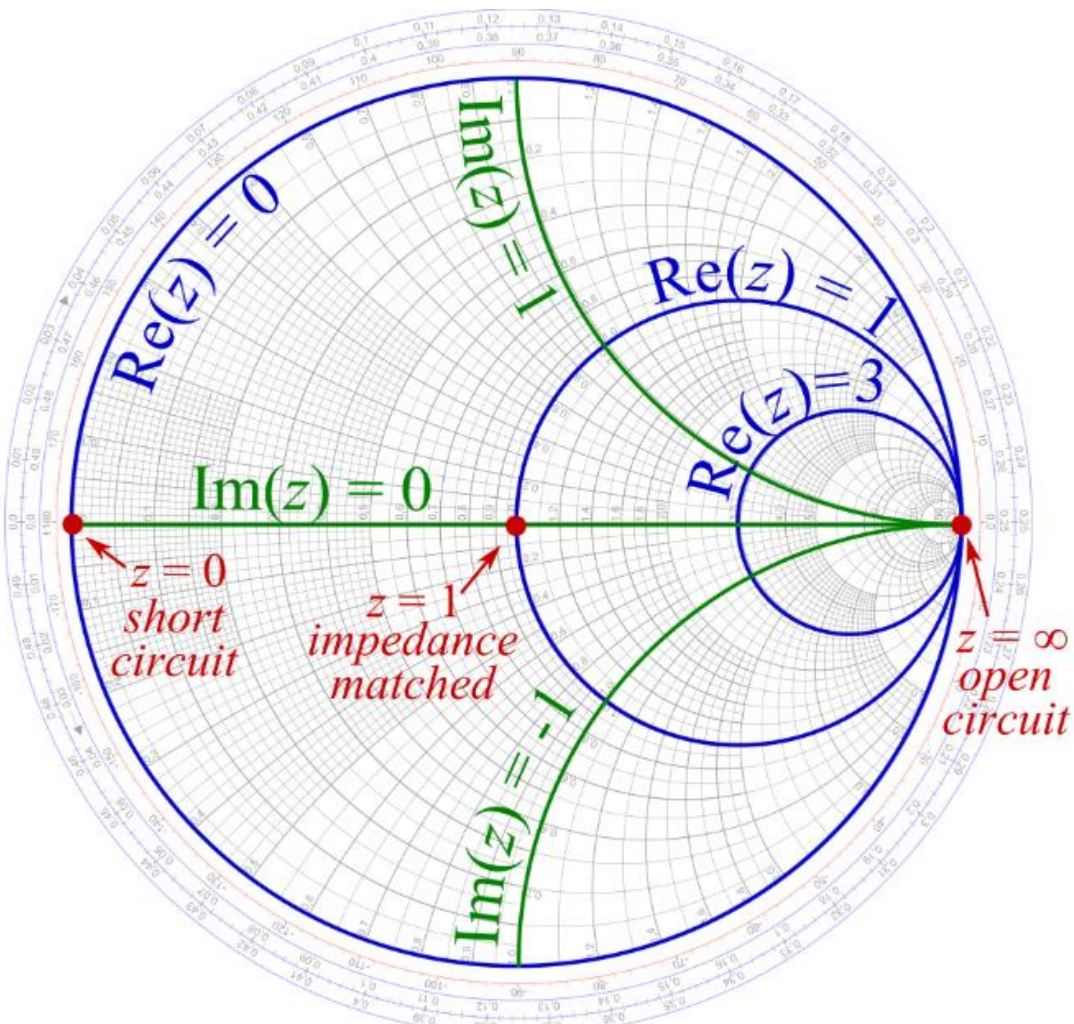


Figure 19: Smith Charts

With the brief background on smith charts, we can use a Vector Network Analyzer (VNA) to see the impedance of the antenna and where it lies on the smith chart. First a few basic formulas and variables need to be defined. Let Z_0 be the characteristic impedance of the line (which will typically be 50 ohms) and let Z_{Load} be any impedance. The normalized impedance, Z_N is given by the following equation.

$$Z_N = \frac{Z_{Load}}{Z_0}$$

To find the reactance of a capacitor is defined in this equation, where C is the capacitance and *f* is the frequency of the signal.

$$X_c = -j\frac{1}{2\pi f C}$$

To find the reactance of an inductor is defined in this equation, where L is the inductance.

$$X_L = j2\pi f L$$

Moreover, unless a signal has perfectly matched impedances part of the wave will be reflected at an angle when it hits a new medium. This value can be calculated with this equation and is important for further study of the signal loss as an electromagnetic wave enters the circuit.

$$\Gamma = \frac{Z_{Load} - Z_0}{Z_{Load} + Z_0}$$

The gamma is referred to as the reflection coefficient and is a parameter that describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium. With this new parameter we are able to numerically describe how well the antenna's impedance is matched to the receiver's or the transmission line's that it is connected to. Next, we can describe the power reflected from the antenna using what is called the Voltage Standing Wave Ratio (VSWR)

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

The perfect ideal VSWR to achieve is a 1.0 ratio and means that all power is fully transmitted and there is no reflection. This is hard to achieve and, in the design, will be shooting for a VSWR of less than 3 over a wide frequency range. Typically a VSWR of 2.0 is the cutoff for systems due to reflecting wave damaging equipment from transmission but we are only receiving, and antenna does not have any sensitive components that the team is concerned with. Once the VSWR is above 3 a different antenna will need be designed to operate in a new range of frequencies. Finally, with the

VSWR it is possible to quantitatively measure the return loss in a system with a relationship as display in the equation above.

$$Return\ Loss = 20Log_{10}(\frac{VSWR+1}{VSWR-1})$$

With these equations we are able to calculate for theoretical values and confirm using a smith chart for our antenna design. A table summarizing common VSWR and the reflected power from each value is shown in **Table 14: VSWR vs Reflected Power**. As you can see once you reach 3.0 VSWR half of the signal received is being reflected causing for 25% of the power to be lost.

VSWR	Γ (s11)	Reflected Power (%)	Reflected Power (dB)
1.0	0.000	0.00	-Infinity
1.5	0.200	4.0	-14.0
2.0	0.333	11.1	-9.55
2.5	0.429	18.4	-7.36
3.0	0.500	25.0	-6.00
3.5	0.556	30.9	-5.10
4.0	0.600	36.0	-4.44
5.0	0.667	44.0	-3.52

Table 14: VSWR vs Reflected Power

4.6.9 Impedance Matching Circuit

As mentioned earlier an impedance matching circuit will be needed in order to receive as much as the signal as possible. As depicted in figure X, this is done by measuring the impedance on the antenna and creating a circuit to cancel out the reactive components of the impedance.

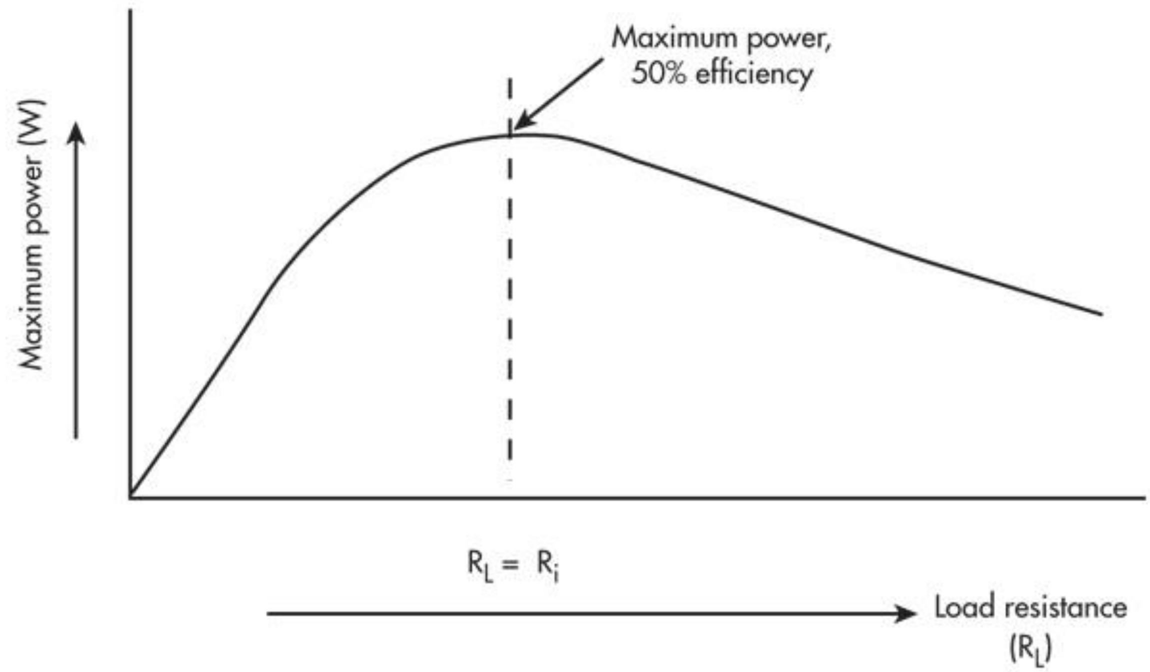


Figure X –

To create such a circuit, we will be using smith charts and frequency response diagrams to aid in the testing and design phase of the project. Below figure X shows the simplified design of the antenna circuit.

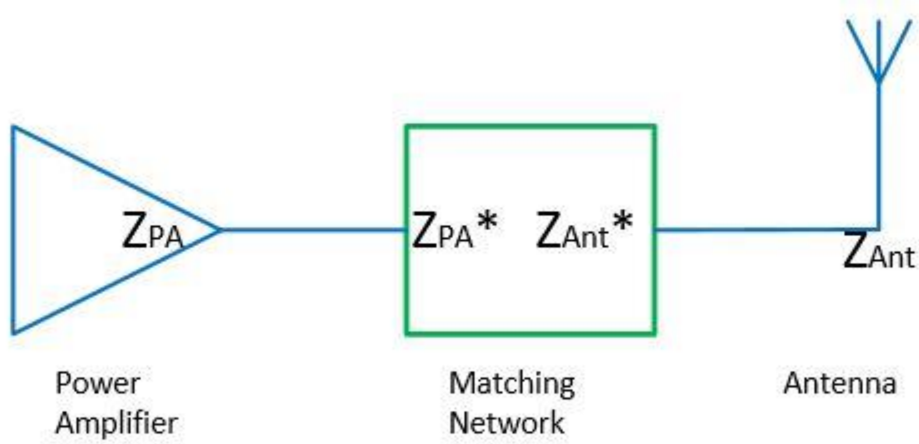


Figure X

Different reactive elements will have different effects on the load impedance from the antenna and will move the load to different points on the chart depending which component is used and how it is placed in a circuit. A capacitor or inductor in series with the load will rotate the load along the constant resistance circles. A capacitor or inductor in parallel with rotate our load along the constant conductance circles. Additionally an inductor will always rotate the load "up" along the real axis and a capacitor will rotate the load "down" along the real axis. All of this is illustrated in figure X.

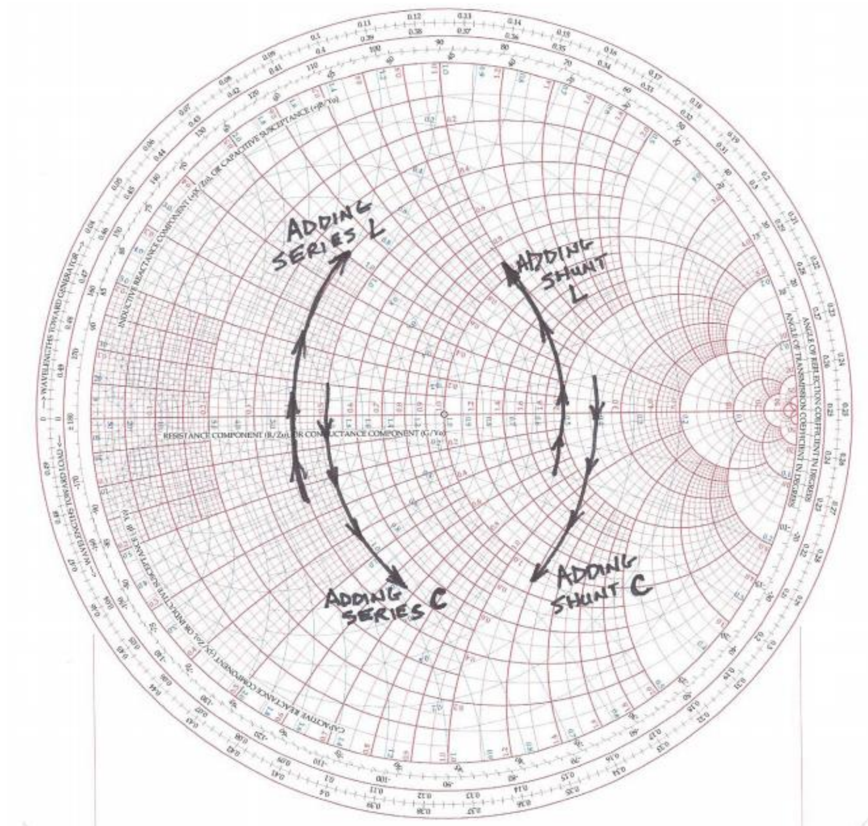


Figure X

With this knowledge it is possible to use any number of components to create a matching circuit, however all that is needed is a minimum of two reactive components to match any load to a target impedance. Furthermore, there are eight common matching network configurations that arrange two reactive components and different ways to achieve different results. Below these eight different circuits are shown including a shaded smith chart showing how these circuits all behave differently.

Circuit One – Circuit one is a series capacitor connected to an inductor that is parallel to the load. This circuit is a high pass filter and may be applied to filter out lower frequencies and harmonics. This circuit will be considered for our design depending on the desired frequency that is being used for the RF receiver chips. Also note that the amount of filtering this circuit can provide depends on the Z_{Load}'s impedance.

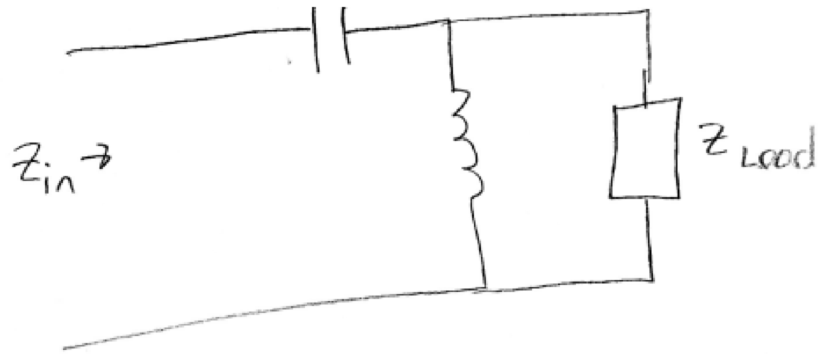


Figure X

Figure X is a representation of a smith chart that has been selectively shaded in. The unshaded potion represents the scope of the circuit. If a load falls in the unshaded area then it is possible to bring the load to the center unity point, which means the impedance has been successfully matched. For this circuit it's unshaded region encompasses the bottom region and the entire unity resistive circle.

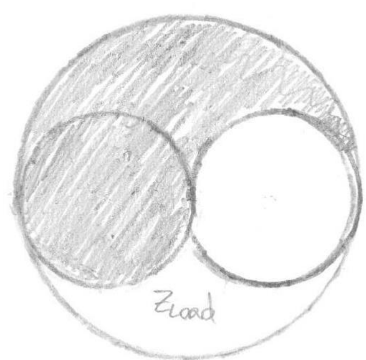


Figure X

Circuit Two – Circuit two is a series inductor connected to a capacitor that is parallel to the load. This circuit is a low pass filter as well and may be used to filter out higher order harmonics and higher unnecessary frequencies depending on what the design calls for.

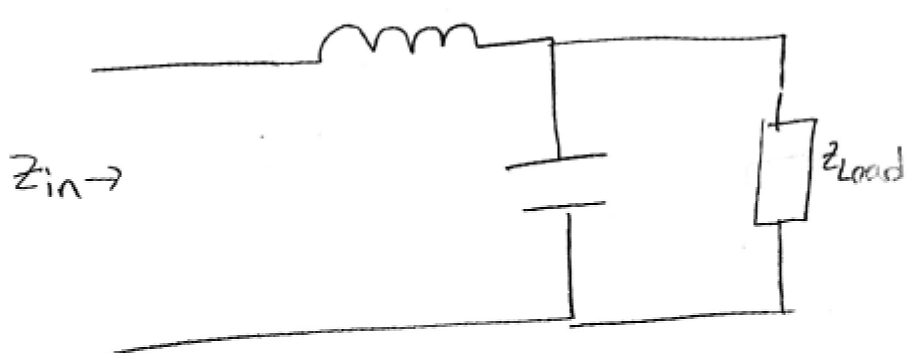


Figure X

Figure X shows that if the load is found in the upper region and unity conductance circle then the impedance can be successfully matched using circuit two.

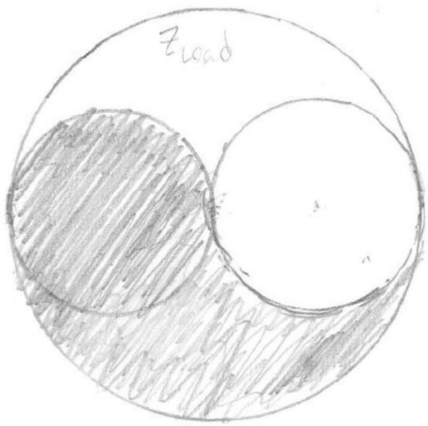


Figure X

Circuit Three – Circuit three is a parallel capacitor connected to an inductor that is in series with the load. This circuit is a low pass filter and may be used to filter out unwanted frequencies and harmonics depending on the scope of the design.

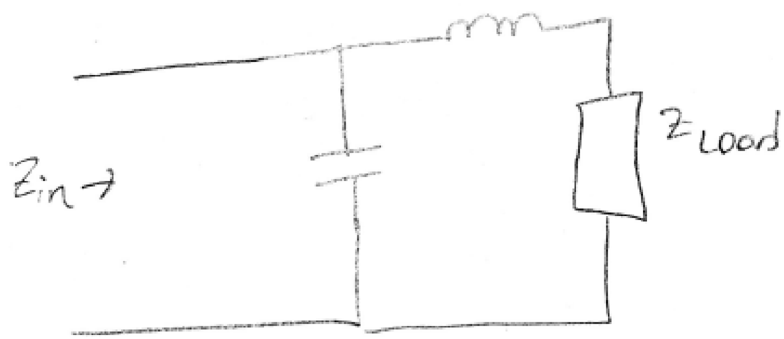


Figure X

Figure X illustrates that circuit three operates within the bottom half and unity resistance circle on the smith chart.

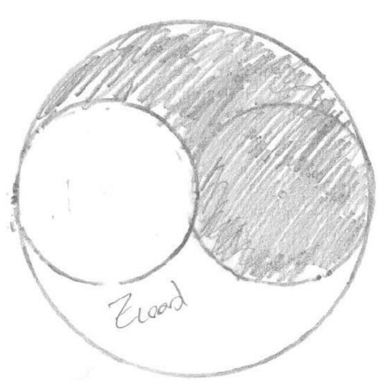


Figure X

Circuit Four – Circuit four is an inductor connected in parallel to the load and is connected to a capacitor that is in series with the load. This circuit is a high pass filter and may be applied to filter out lower unwanted frequencies.

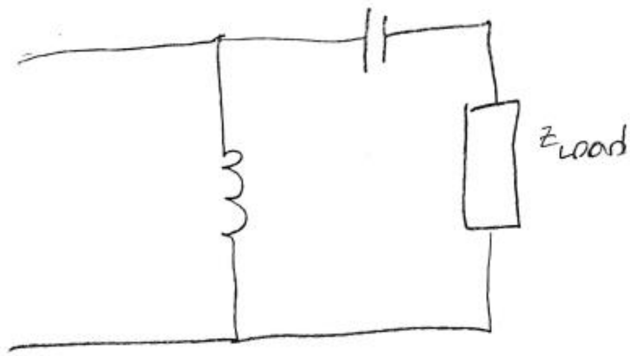


Figure X –

Figure X shows that the circuit is free to transform Z_{Load} across the upper region and unity resistance circle of the smith chart.

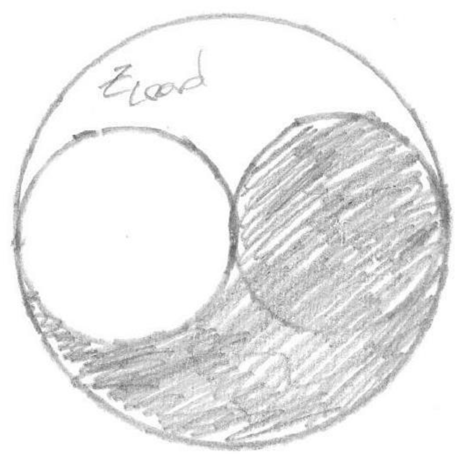


Figure X

Circuit Five and Six – Circuit five and six are a dual inductor system, where one is placed in series and another in parallel. The difference between the two circuits is whether the beginning element is a series inductor placed first or an inductor placed in parallel.

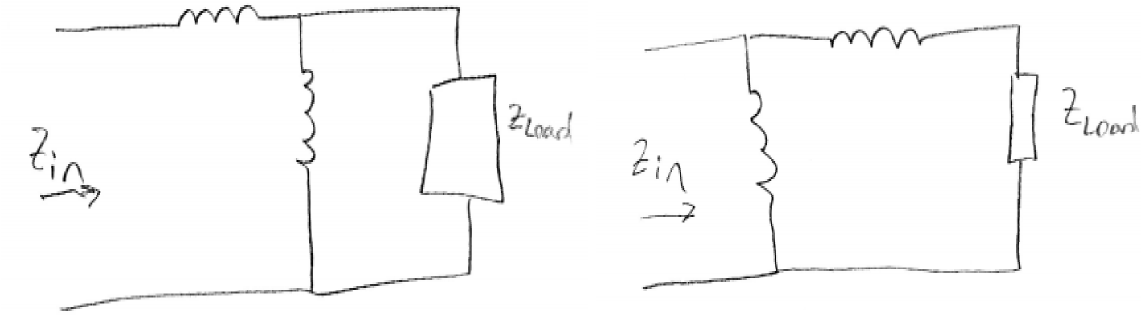


Figure X

Despite having different circuit set ups, both inductor systems have the same scope on the smith chart. In figure X, it is seen that the inductor only circuits cover only the lower region of the smith chart. This means that this circuit is very limited in scope but is a possibility to consider in design.

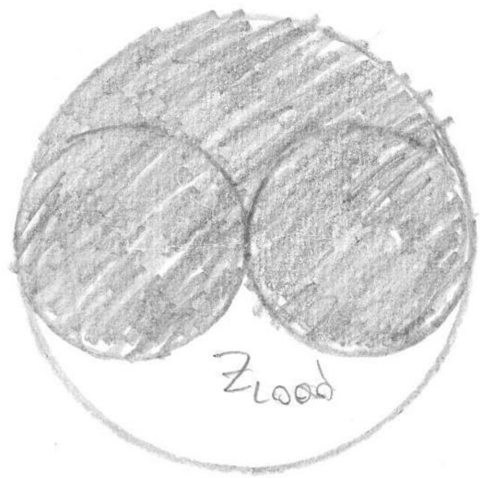


Figure X

Circuit Seven and Eight - Circuits seven and eight are a dual capacitor system, where one is placed in series and another in parallel. The difference between the two circuits is whether the beginning element is a series inductor placed first or an inductor placed in parallel.

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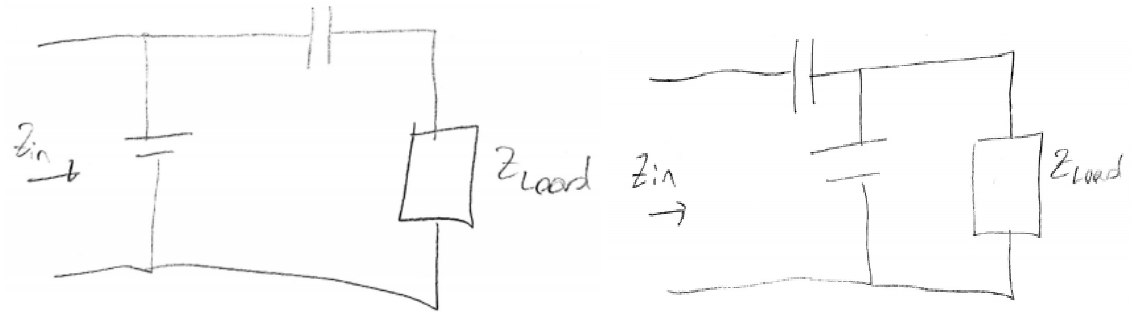
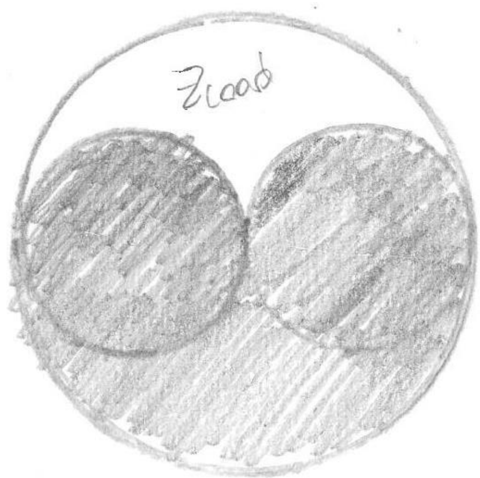


Figure X -

Just like in the inductor system the dual capacitor circuit is also limited in the region it encompasses. It still will be able to perfectly match a load that happens to fall its region and will still be considered if there is a load that is in the upper half of the smith chart.



Notice that many circuits overlap in unshaded areas, when this happens selecting a circuit comes down to preference. The team will investigate the cost and the practicality such as the size of the inductors and capacitors needed for the competing circuits. Also, the behavior of the circuits at different frequencies will be analyzed to help decide which circuit will be the best for the impedance matching circuit. Additionally, there is a general rule that also helps with selecting a circuit and that is if $Z_{Load} > Z_0$ then a series – parallel configuration should be used which is found in circuit one and circuit two. If $Z_{Load} < Z_0$ then it would be appropriate to use a parallel – series circuit which is found in circuit three and circuit four.

4.6.10 Antenna diversity

The RFM22B has an auxiliary feature that allows for the use of multiple antennas. This scheme is called antenna diversity in which two antennas are able to be used. The chip full supports this scheme and has its own integrated antenna diversity control algorithm. The antenna diversity algorithm is capable of automatically toggle back and forth between antennas. Here the chip is constantly evaluating the receive signal strength of each antenna and whichever antenna has the strongest received signal is the one that will be used. This is done by using an external SPDT RF switch, such as a PIN diode or a GaAs switch, and using the programmable GPIO pins found on the chip. This antenna diversity feature is interesting for this design, because it allows us to get a broader range of signals without sacrificing strength. This feature may not be necessary for the design and one antenna may suffice to get what we need out of the RFM22B. This will be determined in the testing phase and see if the excess cost is worth the possible added antenna efficiency made by using two antennas.

5 Power Systems

Every project has their own specific needs for power consumption. There are a multitude of different options to deliver the required power, such as battery power, solar, and a standard electrical outlet. This project will work considerably well with just battery technology. However, adding different sources of power could help this project work in a multitude of situations. For example, adding the ability for this project to work off a standard outlet would improve effectiveness when used inside buildings. Additionally, possible solar charging technologies would allow these devices to work without much interaction outside. This section is dedicated to the different means of powering this project.

5.1 Power Requirements

The first step in design, is to develop a complex power system that meets the power requirements for all the loads. Proper research needs to be done to determine the correct power source to be used and regulation system. Then, successfully designing the system to last a desirable amount of time. All the datasheets need to be examined to evaluate the proper size battery.

5.1.1 Microprocessor power requirements

The most important component to select is the microprocessor, with the nominal voltage of a li-ion cell being around 3.7 or 3.6. The differences in voltage arise from difference in manufacturers. It is important to check what the manufacturer states the nominal voltage of their battery is. Given this information, Li-Ion batteries can easily power a multitude of different microprocessors. Due to familiarity with the MSP family of processors, the processor chosen for this project will be the MSP-432. The MSP-432 is a low power option like the MSP-430 but has much better performance. Another reason this processor was picked was to gain experience in 32-bit arm embedded systems. **Table 15: MSP432 Nominal Power Values** will provide the nominal power required by this processor.

		Min	Nom	Max	UNIT
Vcc-Supply voltage range at all DVCC and AVCC pins	At power up	1.71		3.7	V
	Normal operation with internal Vcc monitoring	1.71		3.7	
	Normal operation without internal Vcc monitoring	1.62		3.7	
Vss-Supply Voltage on all DVSS and AVSS			0		V
I_{INRUSH}-Inrush Current into Vcc Pins				100	mA
F_{MCLK}-Frequency of the CPU and AHB Clock in the System		0		48	MHz
T_{a}-Operating Free-Air Temp		-40		85	C
T_{j}-Operating Junction Temp		-40		85	C

Table 15: MSP432 Nominal Power Values

From the table above, it is evident that the nominal battery voltage of 3.6V will be sufficient for this processor. Another important note from the data sheet is that the voltage difference between AV_{cc} pin and the DV_{cc} pin can only be 0.1V. With this in consideration, the correct battery must be chosen, as well as the correct power circuit to ensure the difference is not to large. Another important feature needed by this processor is to have multiple in/out ports. This sensor will need at least 3 different RF sensors to be constantly sending data because multiple ports are needed to send all the data. Additionally, having a clock signal output will also be useful when looking for sensors to be used. Acquiring key values to note regarding power consumption is the current this processor draws. provides the current consumption for different frequencies while using the MSP-432.

Parameter	Execution memory	V_{cc}	MCLK=16MHz		MCLK=32MHz		MCLK=48MHz		UNIT
			Typ	Max	Typ	Max	Typ	Max	
$I_{vcore\ (0),\ Flash}$	Flash	3.0V	2650	2950					µA
$I_{vcore\ (1),\ Flash}$	Flash	3.0V	2970	3300	5300	5800	7700	8400	µA
$I_{vcore\ (0),\ SRAM}$	SRAM	3.0V	1800	2010					µA
$I_{vcore\ (1),\ SRAM}$	SRAM	3.0V	1980	2250	3650	4020	5280	5760	µA

Table 16: MSP432 Typical Current Values

The values from this chart show the maximum current consumption. These values vary based on the frequency used. The current value used from this graph will the absolute max value of 8.4mA; however, it is likely that this won't be needed. Furthermore, good design is to plan the power to supply for the absolute max value, and then optimize the design to use as little power as possible. There are also charts for the various low power modes; however, those charts will be ignored for initial power requirement calculations. As the project develops the power requirements will be driven down.

5.1.2 Sensor Power Requirements

The next key component that requires significant power is the transceivers. These devices are needed to read the RF signals in the area; thus, they will require a majority of the power needed for this project. One of the transceivers will also be responsible for transmitting our data out to a server to be displayed. The transmitter will consume significantly more power than the normal receivers. Thus, all of this will be the components necessary to drive the choice of battery.

5.1.3 CC2500 Power Requirements

The CC2500 is a wireless transceiver responsible for receiving the RSSI values for the 2.4GHz Wi-Fi bands. This transceiver is also responsible for sending the data to an outside server. From the manufacturer data sheet, the RF Chatterbox's normal operating voltage will be between 1.8V and 3.6V. It would be best to use 3.0V so the voltage can match the requirements of the microprocessor. The operating temperature is also the same as the microprocessor. The maximum current needed when receiving is 17.0mA, and the maximum current during transmission is 21.5mA. These values will be avoidable if possible but planning for the absolute max possible situation is always the best course of action to take. This sensor will be the most demanding piece on the PCB.

5.1.4 RFM22B Power Requirements

After strenuous research, a good solution for detecting frequencies below 1GHz. This sensor should be able to be programmed from 240MHz all the way to 960MHz. These frequency bands will contain some cellular carriers. The RF Chatterbox will need comparable input current to the CC2500 requiring 18.5mA. It is capable of transmitting data as well, but that will not be necessary considering that all wireless transmission will be done via Wi-Fi connections. The RF Chatterbox can receive a RF signal and output a corresponding RSSI value for that frequency. Additionally, the device will also only require a 3V input. Thus, the RF Chatterbox will be able to match with many of the other devices on the PCB making power regulation easier.

5.2 Battery Technology Selection

A multitude of batteries are available for consideration. The first choice to make is whether rechargeable cells or single use batteries are the best option for this project. After choosing rechargeable or single use, the specific battery technology also needs to be selected. With all the devices used on the PCB requiring less than 3.6V, picking a single type of battery will much easier. Another key attribute to recognize is the current consumption. At this point in research, the maximum current this battery needs to deliver is around 50mA. So it is important to have a battery that can deliver that amount of current. Additionally, it may be required to wire two cells in parallel to achieve a higher output current depending on the type of battery used. Also, the power capacity is critical. For example, if the battery is too small, the user will not get enough useful information before needing to recharge or replace it. However, the battery size will need to be kept down in order save on space and cost. Therefore, finding the perfect value for this project will help in efficiency and overall cost. Additionally, it is also helpful to buy from a trusted manufacturer who also supplies a safety circuit they recommend for their battery. Thus, with all the required power specifications, it will be easier to search for the best battery technology to use.

5.2.1 Rechargeable V.S. Single Use Batteries

The final goal of this project is the ability to be implemented in a large network of sensors to be measured for industrial uses. This project needs to be cheap and easy to maintain over long period of time because many sensors is desired. Rechargeable batteries will be the more expensive option of the two, but they will not need to be replaced regularly. These batteries are expected to last many years before needing to be replaced. Thus making this battery type cheaper over time. However, one significant drawback of these batteries is that they require a charging circuit. These charging circuits can add to the complexity and price of the PCB. Also, many types of rechargeable batteries are also sensitive to outside conditions. Extra precautions must be taken to avoid damaging the batteries. On the other hand, single use batteries are cheap to use and easy to implement: they do not require an extra circuit for recharging, and their initial cost is much lower than typical rechargeable batteries. However, the problem with single use batteries is having to replace them indefinitely. This would be acceptable if the device did not consume much power. Additionally, the RF Chatterbox will have a wireless transmitter to transmit data, which a transmitter requires more power to operate. Also, single use batteries would need to be constantly charged if used in this design. This factor, combined with needing a large network of sensors, would significantly drive up the cost. Therefore, given the requirements of this project, a rechargeable battery will be the best choice.

5.2.2 Different Types of Rechargeable Batteries

The next piece of the design is the decision on what type of rechargeable battery to use. Although there are multiple battery types available, not all of them are exceptional choices for the RF Chatterbox; therefore, it is important to decide what kind battery to use. Some types of batteries do not work well for constant deep discharges. While others need specific temperature requirements to work efficiently.

5.2.2.1 Lead Acid Battery

The first possible choice would be a Lead Acid Battery; however, there is nothing about this technology that is useful for our project. This would be ludicrous and an obvious battery type to not be used. For example, these batteries are dangerous to be exposed to. Also they are way too large to be used in any kind of circuit. The only notable things of interest about these batteries are their low cost and high-power delivery. Lead acid batteries can deliver full power instantly, rather than over a long period of time.

5.2.2.2 Alkaline Type Batteries.

The next possibility is one of the many Alkaline Battery Types. For instance, one of the more known variants is Nickel Cadmium (NiCd) batteries. These batteries are a reasonable choice because they can be made into small packages. They also have decent power density compared to other types. Furthermore, their power density can range from 80-150 W/Kg. This number is comparable to most others in the alkaline battery family. Additionally, these batteries have a low self-discharge rate. This means they can be stored for long periods of time without the battery losing too much charge. This property is useful to have, but it is not necessary for the RF Chatterbox. These sensors are intended to be used constantly. In addition, NiCd batteries also have a high lifecycle. For example, with good conditions they can last for 50,000 cycles. A long-life time means they cost over time will decrease. Another good attribute about these batteries is that they are not very sensitive to overcharging, and they are capable of being overcharged with proper venting. However, this is not recommended. Not being sensitive to charging conditions ensures that the charging circuit is not complicated. The output voltage is very consistent, making these batteries reliable to use with sensitive electronics. Most digital circuitry requires that power sources have a stable output. A notable problem with these batteries is that they have memory. If these batteries are discharged to the same point multiple times in a row, they will begin to lose their capacity; however, this can easily be avoided by ensuring these batteries fully discharge often. Another critical issues with these batteries is their environmental impact. For example, these batteries contain cadmium; therefore, these batteries must be disposed of properly to avoid damaging the environment. The problem is that some of these sensors will need to be located outside, and if any of these sensors were to be broken while outside, they could release toxins into the environment. Also, these batteries have a relatively low cell voltage. At 1.2V per cell, multiple cells would be needed to achieve the voltage required by the sensors. This battery is a decent possible choice to use with this project because of the low cost, as well as it's relatively high capacity compared to its cost. However, they do also have some major drawbacks making them a concern to use for this project. Considering the voltage is low, at least 3 cells will be needed to have the correct voltage.

5.2.2.3 Lithium Ion Batteries

Lithium Ion (Li-Ion) batteries may be a better choice for this system. Lithium Ion batteries are made from light materials and have a high-power density. Most modern Li-Ion batteries can achieve around 200-1000 W/Kg. This is by far the highest of all batteries discussed at this point. Li-Ion batteries also have a high cell voltage of around 3.6V. Therefore, from these reasons these batteries are seen to be the best, but they do have some drawbacks with cost and feasibility. Lithium batteries generally cost more than other equivalent batteries. For instance, when buying in a large quantity this price can add up quickly. These types of batteries are also fragile. They are very sensitive to overheating, and overcharging; therefore, they need to be kept in safe conditions to remain safe. Also, they need very specific protection circuits to prevent overcharging. At best, their life cycle will be shortened if they are overworked; however, they can negatively impact one if they explode or burn users if not correctly handled. On the contrary, another prospect is that these batteries are not affected by memory and they don't need to be fully discharged to maintain their full capacity. These batteries prefer to not be discharged fully. Contrary to NiCd batteries, Lithium Ion batteries are best used when they are not fully discharged. It is interesting to acknowledge that while at 100% depth of discharge (DOD). Only 3000 cycles are to be expected from this battery. If the battery is used at 40% DOD, lithium ion batteries can reach 20,000 cycles. This property makes it useful to watch how often the battery charges and to ensure it is efficient. These cells are expected to have a nominal voltage of 3.6 V. With a much higher cell voltage than Nickel Cadmium batteries, Lithium Ion batteries can easily reach higher total voltages with series stacking. Based on the information researched thus far, Lithium Ion batteries will be the best option to be used for this project. They have nominal voltage of 3.6V, and they have some of the highest power capacities. With a proper battery selection, Li-Ion batteries are more than capable of power this PCB. The flaws of this technology are minute if proper steps are taken to ensure safe charging.

5.2.3 Selected Battery Technology

The choice of battery can be a hard choice to make. For example, Li-Ion cells have by far the best power specifications; however, these batteries are much more unstable. Adding a complicated charging circuit can create difficulties with the overall PCB. Complexity will often make the design phase last longer than originally intended, but the higher power density is hard to ignore. NiCad will not provide enough power for this project to reliably run without constant charging from the user. Considering this information, the optimal choice of battery is the Li-Ion battery, because it has a high cell voltage and a high-power density. Furthermore, the different types of Li-Ion batteries will also need to compare to ensure the proper fit for this project.

5.3 Different Li-Ion Batteries

Li-Ion batteries are the best technology to use for this project. There are multiple different types of Li-Ion battery types that could be used. Something to consider is the size of the battery, because its important when the device needs to be as small as possible. However, making the battery too small will reduce the capacity. Reducing the capacity will cause the RF Chatterbox to require additional maintenance to recharge the device. While some of the popular shapes are the flat cells and the cylindrical cells, the flat cells will often be thinner than any comparable cylindrical cell. However, they do require more space if they're in a wider area. Furthermore, the space saved in overall depth will be lost to the flat area. Also, most flat packs already have a charging circuit installed. This means flat batteries often need to be removed from the device to charge. Although this may be nice for general hobbyists, but for integrated design, it is more helpful to be able to fully design the charging and discharging circuit for the specific purpose. In this case it would be desired for the battery to remain inside the device instead of being removed for charging. For indoor uses, the RF Chatterbox is best used connected to a power outlet. However, for outdoor purposes, solar options would be a useful feature to add. Anything to make the RF Chatterbox last longer without user interaction would be desirable. Furthermore, a pre-made protection circuit could make these designs harder to implement. On the other hand, Cylindrical batteries are a good alternative. Some of these faults can be compensated by using a cylindrical Li-Ion cell. This type of battery is very cheap, and easy to implement. They are also easy to find without a prebuilt protection circuit. This allows for easy integrated design with a complex IC. Additionally, these batteries will have a high capacity for their size. These batteries are used often in consumer electronics making them relatively familiar to most users. Thus, increasing the ease of operation for the entire system. For this project, a cylindrical cell of interest is the 18650 sizes. The 18650 Is a Li-Ion cell with a familiar size because this battery is nearly identical to the common AA battery. The close match of size allows for a multitude of pre-made battery holders acceptable for use. Ensuring that the price isn't high, many of these batteries will already come with a manufacturer battery holder. This would decrease the total cost and increase the ease of manufacturing the end device. Furthermore, the next key step is to choose the proper battery. An acceptable flat and cylindrical battery will be compared to ensure the best battery is chosen.

5.4 Choices of batteries

It is important to choose the correct battery for this project. Something to consider is that not all Li-Ion cells are made the same. There are often cheap knock-offs that provide specifications they don't meet. These may look enticing to use because they are often priced much lower than trusted Li-Ion batteries. Therefore, it is important to order from trusted manufacturers to ensure a quality product is received. The most important thing to do when choosing a battery, is to make sure it will meet all the specification of each piece of equipment. For instance, the microprocessor will need 3V for operation. Thus, all the sensors should work with voltage lower than 3.6V. The two sensors found at this point are both suitable for use with a 3V input voltage. A single cell should be having the proper voltage to run all the components. The only drawback is the actual power density. The battery needs to be large enough to run the PCB for a reasonable amount of time. These sensors need to last long enough to record useful data. To leave the sensors out in the field for an extended amount of time, they will need to have charging circuit independent of the user. To maximize the operation time, the design will be made assuming the maximum current input required for each component. Then, a battery that will power them all for one hour will be selected. Hopefully upon further testing and optimization, the actual required current will be much lower than originally planned.

5.4.1 INR-18650-HG2

With all the requirements in mind, the INR-18650-HG2 from LG is a great candidate for use. This battery fits most of the requirements of this project while being cheap. **Table 17: INR-18650-HG2** will show the important values for this battery.

ITEM	Condition/Note	Specification
2.1 Capacity	Std. Charge/Discharge	Nominal 3000mAh
2.2 Nominal Voltage	Average for Std. Discharge	3.60V
2.3.1 Standard Charge (Refer to 4.1.1)	Constant Current Constant Voltage End Condition (Cut off)	1500mA 4.2V 50mA
2.3.2 Fast Charge (Refer to 4.1.3)	Constant Current Constant Voltage End Condition (Cut off)	4000mA 4.2V 100mA
2.4 Max. Charge Voltage	-	4.2±0.05V
2.5 Max Charge Current	-	4000mA
2.6.1 Standard Discharge (Refer 4.1.2)	Constant Current End Current (Cut off)	600mA 2.5V
2.6.2 Fast Discharged (Refer to 4.1.3)	Constant Current End Current (Cut off)	10000mA,20000mA 2.5V
2.7 Max Discharge Current	For Continuous Discharge	20000mA
Dimensions	Diameter Height	18.5mm 65.2mm

Table 17: INR-18650-HG2

From the data sheet above, this battery should be able to deliver more than enough current to the final device. The maximum current the device should need is below 100mA and the recommended current is 600mA. If the required current stays below 125mA, the RF Chatterbox can be used for an entire day. Further optimization will continue to reduce this number, thus increasing the total time of operation. The longer the RF Chatterbox is active, it guarantees more useful data to be collected. This battery also provides some useful advantages that are not relevant to the battery specifications. For instance, these batteries are roughly the same size as standard AA batteries. This makes it easy to find a battery holder that this battery will fit without worrying about small connectors. This battery will be easy to implement using cheap existing technology. One of the goals is to keep the costs as low as possible. By using a battery that comes with a premade battery holder, it would continue to reduce the design cost and implementation cost. With proper design, this battery will lose long enough to get 24 hours’ worth of data without recharging. However this battery is unprotected, so charging and discharging protection will be required. This may be useful in designing a discharge controller that does not require the battery to be removed for charging. Furthermore, a circuit that allows for the battery to remain connected to the device will be preferable. Otherwise having to completely disconnect the battery to charge would make the user experience tedious. The manufacturer also provides a table of expected capacities at different operating temperatures. At a maximum temperature of 60 degrees Celsius, this battery should have 95% total capacity. This test gives an idea of how this battery would act while operating outside.

5.4.2 785060 Rechargeable Flat Cell

The next potential battery choice is from a company called Hunan Sounddon New Energy Co. The battery to consider is the 785060, which is a straight forward Li-Ion cell. This battery provides a lower capacity than the previously mentioned INR-18650-HG2. So this battery would not last if the battery from LG. The difference is only a couple of hours, so this battery should still last long enough to collect full day of data. Additionally, this battery also has an overall different shape. This battery would require more space on a flat surface, but has a thinner profile than the battery from LG. The 785060 also does cost more. At roughly $15 per cell, this battery is double the price of the 785060. Table X below will provide all the important information for this battery.

ITEM	**Condition/Note**	**Specification**
Nominal Capacity	Std. Charge/Discharge	Nominal 2500mAh
Nominal Voltage	Average for Std. Discharge	3.75V
Standard Charge	Constant Current Constant Voltage End Condition (Cut off)	500mA 4.2V 125mA
Max. Charge Voltage	-	4.2
Max Charge Current	-	2500mA
Standard Discharge	Constant Current End Current (Cut off)	1250mA 2.75V
Dimensions	Thickness x Width x Length	(7.9 x 50.5 x 60.5) mm^3

Table 18: Battery 785060

This table shows how the 785060 compares to the battery from LG. The dimensions are comparable for their length, but they differ in thickness and width. The 785060 is around 2.5 times wider than the LG battery. While the LG battery is around 2.4 times thicker than the 785060. The 785060 allows for a higher discharge current for standard discharging. Also, at 1250mA, this battery will provide more than enough current for the RF Chatterbox. Although that high discharge current will not be needed for this project, this battery will also charge slower than LG battery at only one fifth of the total capacity. This may not be a problem if these devices are only used one charge at a time. However, if these devices need to constantly be charged and redeployed, the slower charge rate could prove to be problematic. The 785060 also comes from a relatively unknown company compared to LG, which allows one to raise questions of how reliable the battery will be. Additionally, the working temperature is 25 degrees Celsius, but the manufacturers do not specify the temperature range for discharging. However, the manufacturers do specify that this battery can be charged anywhere from 0 to 40 degrees Celsius. Some of the potential deployment locations will be located outside making this a awful choice. Without any manufacturer guarantee, using the RF Chatterbox outside may not be advisable.

5.4.3 Final Choice of Battery

After careful consideration of the requirements of the device, cost needs to be as low as possible, while maximizing the total lifetime. The 785060 is a fine battery for most purposes. However it has a high cost without providing any clear benefit to LG's INR-1860-HG2. The INR-18650-HG2 provides more capacity at half the cost. Additionally, the overall shape and dimensions are preferable as well. The next action to take is to decide how to protect this battery without sacrificing overall functionality. The desired protection circuit should be able to remain connected to the battery and the device circuit.

5.5 Li-Ion battery Holder

Deciding on the right battery is only the first step. An often-overlooked aspect in power design is how the power will be kept within the device. If the batteries are loosely placed within the device, this may be acceptable if the environment doesn't knock the RF Chatterbox around or vibrate in a harsh manner. If the battery is loosely held in the container, the potential for unwanted shorts will arise. If the lead of the battery is not properly protected from the rest of the circuit, malfunctions should be expected. So wrapping the battery without professional help will likely make the device prone to faults. On the other hand, not many professionals will be around to help. With these devices meant to be easily used by any user, wrapping these batteries post purchase is not a viable option. The other option for this kind of battery is to purchase an ordinary battery holder that can hold the battery in place and protect it from any other possible dangers. These battery holders will greatly increase the ease of operation for the RF Chatterbox. If the battery were to ever die, replacing it would not be difficult. The only downside to using a battery holder, is the increase of space needed for the entire device. Battery holders by design need to be larger than the batter itself to encase it. The size can vary from manufacturer, so choosing a desirable shape will be essential. Furthermore, ensuring the case is not too bulky, while also providing good protection, is key to design. It would be desirable for this battery holder to provide some extra functionality as well. Therefore, cost effectiveness will be the most important constrain to worry about. The battery holders price should not be comparable in price to the final design. The holder must also be in stock without the danger of running out soon. **Figure 20: Single battery holder with wire leads (Replace with real photo)** below will illustrate the battery holder chosen for this project.

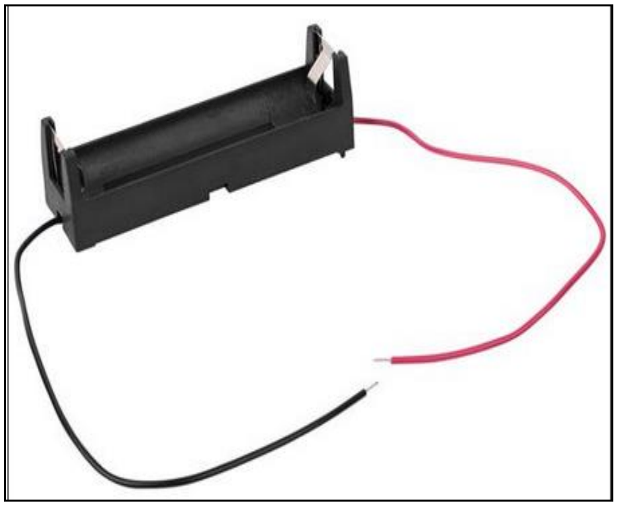


Figure 20: Single battery holder with wire leads (Replace with real photo)

This battery holder should provide enough of the desired benefits without extra costs. This example will also include a set of wire leads that can be easily attached to the final circuit. This battery holder should also be able to accommodate either flat top batteries or button top cells. This level of universality allows for future designs to incorporate different variations of the 18650 battery. This holder also only costs $2, thus making it a cheaper option. For the price, this holder still provides plenty of useful functions such as the wire leads, and it will not require too much extra space because it has a slim profile; therefore, making it easier to incorporate into the final product. Also, it will be easy to attach because two recessed screw holes are provided to make installation easy. This should be the ultimate choice for a battery holder for the RF Chatterbox.

5.6 Li-Ion Protection/Charging Circuit

Considering the charging fundamentals, it is important to control the voltage and current that the battery receives. The Circuit must be able to change between the constant current phase and the constant voltage phase. It would be useful if the Circuit can have a wide range of input voltages, while still charging at the correct voltage. This would make the circuit useable in multiple scenarios with different power sources. Another key feature desired is the ability to have the protection connected to both the load and the battery at the same time, thus making charging a less tedious task. The battery would not need to be removed from the load to charge. Additionally, the battery will not need to be disconnected from the charging circuit while in use. After researching the topic, 3 individual IC's can be used in conjunction to develop a circuit with all these features.

5.6.1 TP4056A

The TP4056 is a great option for charging a Li-Ion battery. Since the manufacturer provides a useful circuit, using this IC to produce a capable charging protection circuit. They also provide graphs showing the charging response over time. A detailed description of all the pins and how they respond to different conditions are listed below. This IC and circuit will be instrumental in designing a circuit capable of charging and discharging protection. By itself, this circuit still does not allow for the battery to be discharged safely. Extra components will need to achieve this effect. The technical data from the data sheet will be present below in **Table 19: TP4056 Data Sheet.**

Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Units**
Vcc	Input Supply Voltage		4.0	5	8.0	
Icc	Input Supply Current	Charge Mode, Rprog = 1.2k		150	500	µA
		Standby Mode (Charge Terminated)		55	100	µA
		Shutdown Mode (Rprog Not Connected, Vcc<Bbat, or Vcc<Vin		55	100	µA
Vfloat	Regulated Output (Float) Voltage		4.137	4.2	4.263	V
Ibat	BAT Pin Current Text Condition: Vbat=4.0V	Rprog=2.4K, Current mode	450	500	550	mA
		Rprog=1.2K, Current Mode	950	1000	1050	mA
		Standby Mode, Vbat=4.2V	0	-2.5	-6	µA

Table 19: TP4056 Data Sheet

According to the table, the charging current is programmable up to 1A. This value will be enough for the battery selected without over charging it. Also notable, the charge voltage is 4.2V, which will satisfy the charging voltage for the chosen battery. Most importantly, this circuit can work with a wide range of voltages. The typical value is 5V, meaning that a USB based power source will work for this circuit. In other words, the battery can be charged from anywhere a USB will work. Thusly, this greatly increases the universality of the project. Another key aspect from this datasheet is how the value of R_{PROG} can be changed to get different charging currents. Additionally, LED's can be added to this to indicate whether the battery is still charging or is ready to be used, and they provide a circuit best utilizing this IC. The provided circuit provides a clear example for how to use it effectively, and the manufactures provide a detailed list of what each pin is used for. Moreover, this information will help to understand how this circuit works. Understanding the circuit will help to add other IC's to expand upon the abilities of the entire circuit.

Pin Number	Pin Name	Description
Pin 1	Temperature Sense Input	By connecting the Thermistor's output to this pin, it will be able to sense if the temperature of the battery is too low or too high. If the Pin value is below 45% or above 80% of the supply voltage the temperature is either too high or low.
Pin 2	Constant Charge Current Setting and Charge Current Monitor	By connecting R_{PROG} to ground the charge current can be changed depending on the value of R_{PROG} using $I_{BAT} = V_{PROG}/R_{PROG}*1200$ **(**For $V_{PROG} = 1V$)
Pin 3	Ground	Ground Terminal
Pin 4	Positive Input Supply Voltage	Connect the supply voltage. If the Supply voltage falls within 30mA of the battery voltage, the circuit will go to sleep.
Pin 5	Battery Connection Pin	Connect the positive end of the battery.
Pin 6	Open Drain Charge Status Output	When battery charging is stopped, internal switch pulls this pin low. Otherwise this pin is high.
Pin 7	Open Drain Charge Status Output	When the battery is charging, this pin is pulled low. Otherwise this pin is high.
Pin 8	Chip Enable Input	A high input will put the device in normal operating mode.

Table 20: TP4056 Pin Description

5.6.2 DW01A

While the TP4056A is the device capable charging the battery in the correct manner, the DW01A is what ensures that the battery is not overcharged or over discharged. This product is key to utilizing Li-Ion batteries. Additionally, this device will prevent damage to the cell, and will prevent damage to the overall life span of these batteries. It also provides over current protection for one cell Li-Ion systems. The manufacturers also provide a description of the each of the pins uses. **Table 21: DW01A Pin Description** will provide all the pin names and what they are used for.

Pin Number	Pin Name	Description
Pin 1	OD	MOSFET Gate control for discharge control.
Pin 2	CS	Input pin for current sense, charger detect.
Pin 3	OC	MOSFET gate connection for charge control
Pin 4	TD	Test Pin to reduce delay time.
Pin 5	VCC	Power supply through resistor 1.
Pin 6	GND	Ground pin.

Table 21: DW01A Pin Description

They also provide a useful reference schematic on how this IC can be used. This circuit can provide overcharge protection, over discharge protection, and over current protection. For the reference circuit provided the DW01A is working in combination with 2 N-Channel MOSFETS to control the charging of the battery. The MOSFETS are used in determining the value used for over current detection. Therefore, choosing the right set of MOSFETS will help in producing a better circuit. The manufacturer recommends suppressing input voltage by adding R1 and C1 as shown below. This device is also prone to latching, so R2 is used to prevent latch-up conditions while charger is connected under over discharge conditions. There is still one more piece that will be needed to the TP4056 and the DW01A to make a great protection circuit. This circuit is relatively simple on its own and does not provide a lot of use for this project; therefore, when this piece is combined with others, a more useful circuit will be created.

5.6.3 XFS8205A

This device is a dual N-Channel enhancement mode power called MOSFET. This device is very simple and is used primarily in battery protection circuits. The manufacturer also provides a reference design, as well as the pin descriptions. The pin descriptions will be provided in **Table 22: FS8205A Pin Layout** below. The FS8205A is essentially two MOSFETS with their drains connected, and the pin description will be evident in how to wire this into a circuit.

Pin Number	Pin Name	Description
Pin 1	D12	Drain connection for 1 and 2
Pin 2	S1	Source 1
Pin 3	S1	Source 1
Pin 4	G1	Gate 1
Pin 5	G2	Gate 2
Pin 6	S2	Source 2
Pin 7	S2	Source 2
Pin 8	D12	Drain connection for 1 and 2

Table 22: FS8205A Pin Layout

This circuit is useful for power control and switching. Depending on the value of the gate voltages, current will flow between the two devices. Also, this makes it useful as a switch. In combination with the DW01A, this circuit will help switch a charger on or off.

5.6.4 Final Charging Circuit

These three components, when combined should create a useful charging and discharging protection circuit because all the necessary components are present. The TP4056 controls the actual charging of the battery and ensures that the constant current phase as well as the constant voltage phase are met. The DW01A Provides the protection against overcharging and over discharging. Additionally, it provides protection against over current conditions. This device will ensure the battery can be used safely always. The final piece is the FS8205A. This device is just a simple pair of MOSFETS. They provide the ability to have both charging detection and discharge detection. All the surrounding resistor and capacitor values will also help in choosing what value the charging current will be and will help in protection of the overall circuit. These three components can be combined in such a way will allow the circuit to charge the battery using the constant current/constant voltage method and have discharge protection. This combination grants all these benefits while allowing the battery to remain connected to the device. Below, Figure **21: TP4056A Module Circuit Diagram** will show the inner workings of this design.

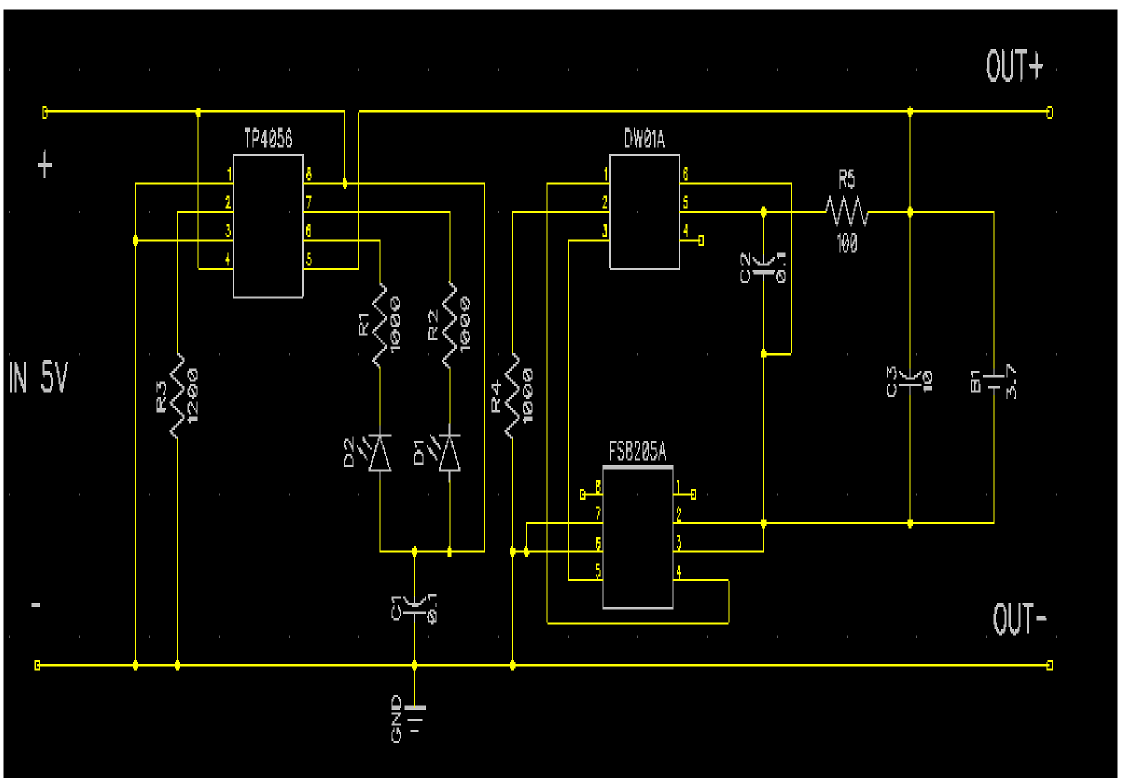


Figure 21: TP4056A Module Circuit Diagram

While this circuit requires some common resistors and capacitors, as well as two different color LED's, there is no programming needed for this circuit to operate. If the voltage across the battery does not pass the predetermined values, this circuit will operate normally. Also, all the components for this IC can be surface mounted. This will save space when the entire device is built. Thus, this circuit will combine the best part of all three components. The important specifications for the entire circuit will be displayed below in **Table 23: Charge / Discharge circuit**.

Parameter	Min	Typ	Max	Unit
Overcharge protection voltage	4.25	4.3	4.35	V
Over discharge Protection Voltage	2.3	2.4	2.5	V
Over Discharge Release Voltage	2.9	3.0	3.1	V
Constant Current Value	950	1000	1050	mA
Constant Voltage value	4.137	4.2	4.263	V

Table 23: Charge / Discharge circuit

Furthermore, these are the important values to consider when designing the rest of the power circuit. The charging circuit will release the battery once it dips below 3V. It also provides over discharge protection in the case that the circuit fails. Additionally, this circuit will require a 5V input to work. 5V is the easiest voltage to obtain. Also, USB connections all output 5V, so the 5V input can be connected to a common micro-USB. With the power input being USB, the RF Chatterbox can go anywhere. The battery leads can also be connected to a universal port for the battery to be connected to. The outputs can be connected to the load on the PCB, but the manufacturer doesn't recommend charging while the load is connected to the charger. This means a way to disconnect the load from the charging circuit during charging will be needed. There are various ways of disconnecting the load though. Thus, ensuring the safest switching method is key to developing a safer device.

5.7 On/Off Switch

Using the TP4056A protection module means that the load should not connect to the battery while the device is charging. It is still needed for the device to be able to charge without physically disconnecting the battery. Disconnecting the battery will complicate the operation of the device, so it is safest for general users to not handle Li-Ion batteries directly. The simplest way to achieve this effect is to use a simple mechanical switch in-between the charger and the load, because a switch would be able to electrically disconnect the load from the charger without physically removing the battery from the device. Furthermore, there are multiple different choices for switches. Button switches and rocker switches are some of the most popular options to use for this project. The switch to be used for this device will be a rocker switch, because a rocker switch would be better than a button switches for many reasons. A rocker switch will be clearer to determine whether the device is on or off, while a button may not be the easiest to determine for everyone. Additionally, it is important to consider that the finished device needs to easily fit into a case. Having the switch directly on the PCB, will result in installing the PCB into a case more difficult. So a way to connect wire leads for the switch would be desirable for implementation. There are many possible ways to approach connecting the switch to the load and the charger. The most effective way is to have wire ports that can easily accept direct wire leads from the switch. Therefore, this would ensure that port placement does not matter. If better cases are designed, with different switch placement, the entire PCB will not need to be changed.

5.8 Regulators

Once the Battery charging circuit is designed, regulation design can be started. The output from the battery can range from 4.2V to 2.9V. This project will need a constant supply voltage of at least 3V ideally. Since the voltage of the battery varies depending on the remaining charge, a regulator will be needed. The first option to consider, is a linear regulator.

5.8.1 Linear Regulator

A linear regulator is the most basic regulator. A linear regulator will supply the most constant DC voltage value, because a constant voltage is often needed for sensitive electronics. However, this should not matter for this project. None of the devices are sensitive enough to require this function. It works by introducing a voltage divider network into the system. This network is made up of two variable resistors that change according to the input power. Unfortunately, the resistors are the problem with this technology, because a linear regulator reduces the voltage through voltage loss. When the power difference between input and output is large, the amount of power lost becomes problematic. If all the power is lost in heat, linear regulators will need to be designed with some heat analysis. Also, bulky heat sinks are often necessary to ensure the regulators don't melt during use. Linear regulators need to be carefully designed to avoid wasting excess power, even if these heat concerns were properly addressed, most Linear regulators need a minimum voltage above the desired value. For example, a LM7805 will regulate the input to 5V, but this can only be done if the input is at least 7V. Any value below 7V will cause the output to be unpredictable. Therefore, a linear regulator might not be the best option for this project.

5.8.2 Switching regulators

A switching regulator is the next best option for this project. A switching regulator works by constantly switching the power supply to a RC circuit and an inductor is placed to hold store energy. The position of the inductor will decide whether the regulator is in a boost or buck configuration. If the inductor is placed before the switch, then the circuit is a boost converter. If the inductor is placed after the switch, the resulting circuit will be a buck converter. The switching regulator can regulate a wide range of voltages down to a single specific value, depending on the application. Additionally, they can come in various configurations: boost converter, buck converter, or both. A buck converter can step down the input voltage into a lower output voltage. These kinds of regulators are ideal for cases where the input voltage is too high to use. While a boost converter works in the opposite manner, a lower input voltage is stepped up to a higher output voltage. The buck regulators are helpful for this project, but they may not work properly always. To work, they will need a voltage higher than the desired regulated output. With a Li-Ion battery voltage varying over time, this will be hard to achieve. So a buck/boost regulator will be the best choice for this design. A buck/boost regulator combines both technologies to perform both operations. This type of regulator would be the most desirable because it can adapt to a Li-Ion's changing voltage. If the Li-Ion battery voltage falls below 3.3V, a buck/boost regulator will still be able to regulate back up to 3.3V. There are a variety of different buck/boost regulators that can be used for this project, so finding the correct one is key to further developing this project.

5.8.3 TPS630000

The TPS630000 was found using the Texas Instruments website. They provide a helpful tool for selecting the appropriate component. All the website needs is an input range and an output range. After inputting the desired values into their website, the TPS630000 is recommended. The TPS630000 is a high efficiency buck/boost converter and it requires a bulky inductor to be added to the design. This inductor will likely be the biggest single component on the entire PCB. Although any switching regulator will require an inductor, this downfall cannot be avoided. This product is specifically designed to be used with Li-Ion batteries, or other battery technologies that are comparable. They can be designed to output a wide range of voltages, from 1.2V to 5V. Also, the base model will provide a constant 3.3V for any input within the correct range. This component should automatically switch between step-down and boost mode. Additionally, power loss should not be a factor for this component. So considering temperature and bulky heat sinks are unneeded. Furthermore, an extra safety feature is over temperature protection. Even though the TPS630000 is efficient, placing it in outside environments can still be a risk. Having the protection element to shut the circuit off in the case of high heat will help protect the battery, the load, and the component itself. This product will also easily meet the required current output. At a max current of 1200mA, this component will easily deliver the power needed for this project. Another helpful feature the TPS630000 has, is the ability to disconnect the load during shutdown. This may not seem like much, for sensitive devices like the MSP432, ensuring complete isolation is vital for protecting the hardware. Texas instruments provides a full schematic for using this component. The schematic provided in **Figure 22: TPS630000 3.3V regulator** below shows the regulator with a regulated voltage of 3.3V.

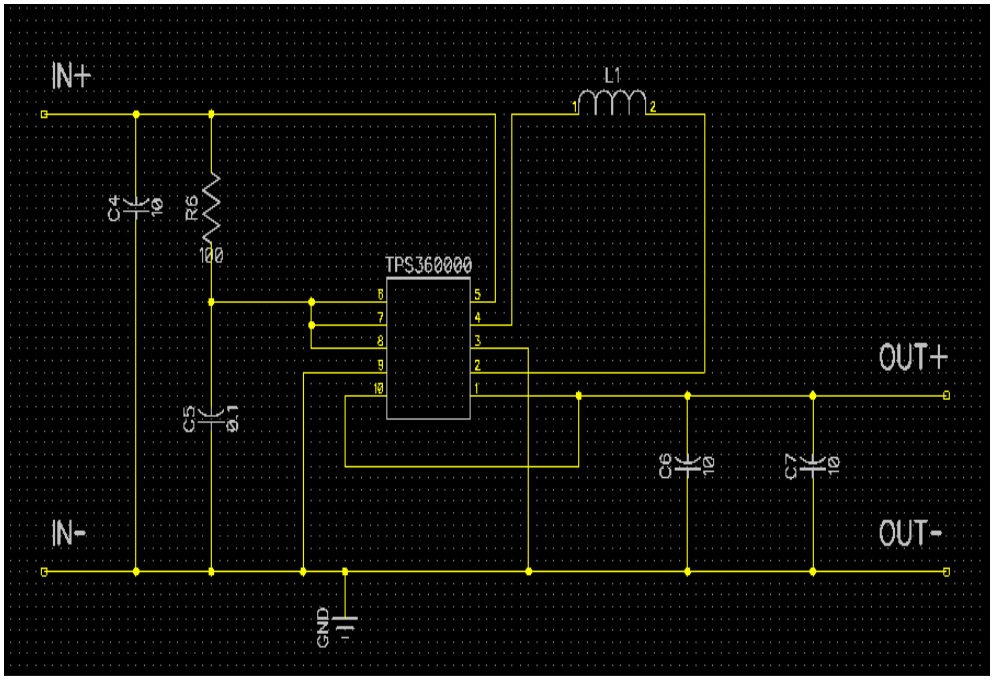


Figure 22: TPS630000 3.3V regulator

The schematic above will be used as the regulator for the RF Chatterbox. While very few external components are needed to achieve this design, every resistor or capacitor can be a simple surface mount component to save space. The inductor, on the other hand, will be the largest part of this design. A correct inductor will be needed to achieve the exact inductance while also remaining small enough to implement. The Pin Description will also be provided in **Table 24: TPS630000 Pin Layout** below to help understand how this component will work in real world scenarios.

Pin Number	Name	Description
1	VOUT	Buck-Boost Converter Output
2	L2	Connection for Inductor
3	PGND	Power Ground
4	L1	Connection for Inductor
5	VIN	Supply Voltage for Power Stage
6	EN	Enable Input (1 Enabled, 0 Disable)
7	PS/SYNC	Enable/disable power-save mode (1 disabled, 0 enabled, clock signal for synchronization)
8	VINA	Supply Voltage for Control Stage
9	GND	Control/Logic Ground
10	FB	Voltage Feedback of adjustable Version Must be connected to VOUT on Fixed Output Voltage Version

Table 24: TPS630000 Pin Layout

The TPS36000 will be able to provide all the regulating needs for the RF Chatterbox. Being purposely designed for use with Li-Ion batteries, this is the best option on the market. It will be easy to implement onto a larger PCB. With all the load accepting 3.3V, no other regulating device will be needed for this project. The power supply can be connected to the TPS360000, while the output is also directly connected. With all the major circuit design done, the next step is to determine the type of resistive components to be used for the RF Chatterbox.

5.9 Final Circuit Design

The goal of the power system is to use a single Li-Ion battery to supply power to various sensor, and a microprocessor. There are multiple steps in-between the input and the output, such as the battery needs to be capable of charging safely, as well as discharging without any deformation. Then, the charger is taken care of a switch is needed in between the charger and regulator. The switch should be capable of electrically disconnecting the circuit while the battery is still physically connected. The final step is to regulate the battery output into a usable voltage for all the major components. The final design will be a combination of all of the previously mentioned components. It will start with the INR-18650-HG2 Li-Ion battery. Next, the battery will be connected to the TP4056A charging/discharging module to ensure the battery is safe to use. Then, a rocker switch will be used to separate the load and charger. Finally, the TPS630000 will be used to regulate the 3.7V from the battery to 3.3V which is usable for all the major sensors and the microprocessor. The resulting combination will be displayed in Figure 23: Final Power System Design below.

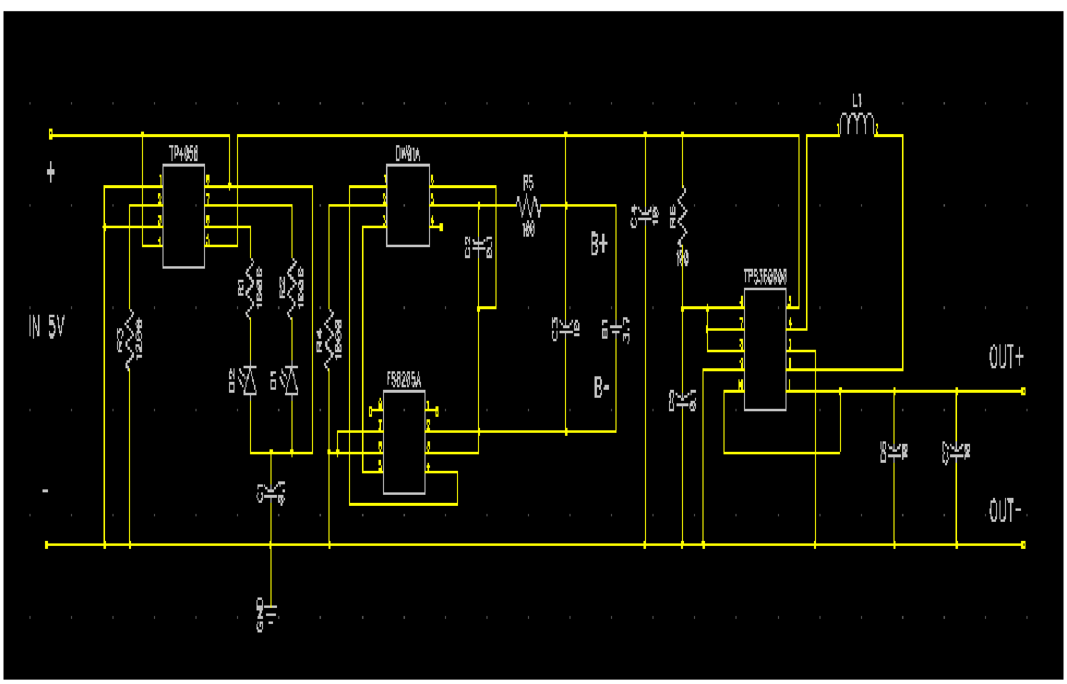


Figure 23: Final Power System Design

The circuit above incorporates all the major power system components. All these components should be capable of being directly connected to each other. This is the initial design to be used in the testing phase. After testing, if there are no problems, this will be the design used in the final device. If there are flaws found in testing, further improvements will be made to ensure it is acceptable in the final design. The next step is to formulate a test plan to verify this circuit works.

5.9.1 Minor Components Used

Once all the major components are picked, the relative size of the PCB can be roughly estimated. At this point, the type of resistors and capacitors can be determined. Using thorough hole components would be unreasonable because they would be too large for this purpose. To ensure the smallest possible design, surface mount components will be used. So, the intended component size will be 1206. This size could change depending how the circuit performs during testing. Furthermore, inductors will also be needed for the RF Chatterbox. Inductors will be the bulkiest component needed so picking the right style will be imperative for saving space.

5.10 Design Cost analysis

For this project, it is ideal to keep the cost as low as possible. While the initial cost of designing a single sensor will be expensive, the goal is to stream line to the final design to ensure that the final price is inexpensive. To achieve this goal, every component will be tested to determine the value it provides to the project compared to the cost addition. **Table 25: Cost Analysis** below will provide the cost of all the major components for this project.

Component	Price
INR-18650-HG2	$7.50
Single 18650 Battery Holder with Leads	$1.99
TP4056A charge/Discharge module	$3.94
Rocker Switch - SPST (Round)	$0.50
TPS630000	$1.80

Table 25: Cost Analysis

For each component, 3 purchases will be made. Design usually requires testing and verification to ensure the parts will work as intended. Purchasing 3 of each component will allow for design changes to be made in the case that the initial design is not sufficient.

6 Software Design

An onion has different layers from which the outer portions grow upon. Modern web platforms are constructed in a very similar way. At the inner-most level, the operating system (OS) acts as the interface between hardware and software. A web daemon operates on top of the OS allowing the server to become a host of digital information available to the world-wide-web. Said information is stored in a database which is managed by a backend application which oversees handling of all the logic needed for the application to function correctly.

6.1 Stack Analysis

The combination of these four "tiers" is called a stack. It is very important that the right stack is chosen for this project as there exists tradeoffs between different aspects of each one of them. These are some of the things to consider when choosing the right stack:

- Scalability – How much data and computing power does the application need?
- Cost – Is there a need to use a licensed software bundle?
- Experience – What are the developers' strengths?
- Efficiency – Is this technology good enough for the project's purposes?

These stacks were chosen to be compared (**Table 26: Stacks Comparison**) because they are amongst the most popular within the development community. LAMP is the most popular stack worldwide. It is open-source, well documented, secure, and flexible. Within LAMP it is very easy interchange any of its components for a better suited option, depending on the environment. It operates using both Linux and Apache which are offered by most hosting services available. The infrastructure can be controlled by PHP (Hyper Text Preprocessor), a server-side scripting language. Because PHP is a low-level language, it requires more lines of code and experience to set up a web application when compared to both the MEAN and the WISA stacks.

Stack	Free	Previous Experience	Code Efficient
LAMP	X	X	
MEAN	X		X
WISA		X	X

Table 26: Stacks Comparison

MEAN is an up and coming framework that challenges LAMP. It is also open-source and flexible as it can operate in a great variety of platforms without being OS dependent. The main benefit of the MEAN stack is that it's main scripting language is JavaScript. This means that there is language uniformity between the back and front end. Because JavaScript is interpreted and not compiled, it is said to be less efficient than both other frameworks.

Windows' alternative is WISA, a licensed web development platform using the .NET framework. Unfortunately, this software bundle is not open-source and can only be implemented using a Windows server which requires a licensing fee from most host service providers. However, WISA is very well supported by both Windows and its users. The .NET environment is also very easy to work with, as it requires minimal code to create a web application.

As each stack offers a different set of characteristics, the software architecture for the project must also be taken into consideration when choosing a stack. The UML diagram (**Figure 24: Website UML Diagram**) for this project shows the general software layout needed to complete this project. The Web Application has two endpoints with the only intent to store and retrieve records from the database. The application back-end does not call for any sort of heavy computation needed as it is only storing and displaying records. Most of the filtering done, will be performed at the frontend, were it will be done in real-time with the dataset provided. Because the information is only flowing one way (from the server to the client) and it is made to be available to everyone, there is no need to create a security function such as sign-in or sign-up.

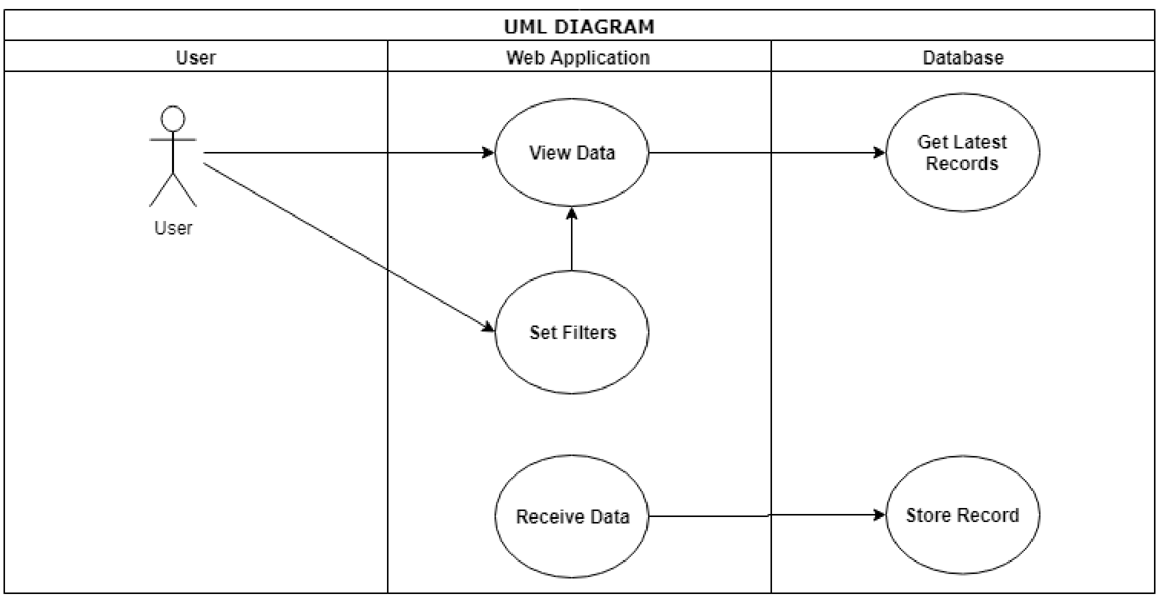


Figure 24: Website UML Diagram

The decision the team took is to go with the LAMP stack. The application does not have a high level of server-side complexity, so the longer amount of code needed to implement a LAMP stack is leveraged. Also, our team has more experience working with the open-source alternative, which is also free of any software licensing fees such as those found in the WISA stack. It is the team's opinion that LAMP also offers a more robust and secure number of libraries that are proven at the enterprise level over a longer period than the MEAN stack. The LAMP stack will ensure that our product is scalable, easy to implement, and will have no cost during the development stages.

6.2 Database

The LAMP stack offers the ability to work with many relational database systems (RDBMS), with the primary one being MySQL. Based on the relational model of databases, our project will have the ability to store data using logical and language-based management. MySQL offers the ability to work with the Structured Query Language to write the scripts that will allow this project to manage data automatically. The syntax used throughout the software development is described in the ISO/IEC 9075-1:2016 SQL standard for Database languages in Information Systems.

The design of the database (**Figure 25: Database Relationship**) takes into consideration the primary relationship in the data provided by all devices. Each device will be assigned a unique device ID that it will to provide to the server when transmitting data. Also unique to each device, is its location stored as a character array which will be needed to display each device on the correct location in the webpage map. Each device has a one-to-many relationship with each of the records it provides. Every record uses the device ID from which the record is created, as well as two numbers that indicate the frequency being measured and the frequency strength measured for that value. We use the timestamp as a secondary key to filter out old data whenever the endpoint is used.

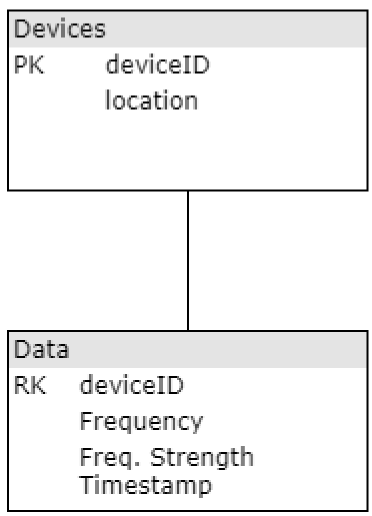


Figure 25: Database Relationship

6.2.1 Amazon Web Services

Due to the limited and expensive storage options within a hosting server space, the instance of the database is separated from the code hosting server in a separate system. The project uses the Amazon Web Services (AWS) free tier Relational Database System for MySQL. Amazon provides a free tier category for customer’s still in the development phase of a project. The following are the features given by the free tier of Amazon’s free RDS tier:

- 750 hours of Amazon RDS Instance usage running MySQL
- 20 GB of General Purpose (SSD) DB Storage

- 20 GB of backup storage for your automated database backups and any user-initiated DB Snapshots

The Chatterbox group decided to go with an RDS cloud provider due to the complex and time-consuming activities that involve manually deploying and maintaining a database. AWS RDS removes much of the complexity by automating most of the administrative processes that include hardware provisioning, software management, physical storage management, and backups in case of disasters. AWS is also one of the few data management providers that have a free tier and allow scalability of the database instance to larger storage sizes. Development advantages of using this service (**Table 27: AWS Development Advantages)** are also important as they lower the associated development time and cost of running a self-managed system.

	Self-Managed	**Amazon RDS**
Easy deployment by using web-interface		x
Scale compute resources with a single API call		x
Automated backups and disaster recovery		x
Managed database snapshots for merging		x
Automatic software updates		x
Compatibility with existing applications	x	x

Table 27: AWS Development Advantages

6.2.2 Data Storage Analysis

To validate that the 20 GB provided by the Amazon Web Services RDS free service are enough to support RF Chatterbox, a Data Storage Analysis is performed. Before performing an analysis, the basic elements of a relational database must be defined. Each database contains multiple ***tables***. A table is a collection of ***records*** in a structured format consisting of ***rows*** and ***columns***. Each row represents a record, and each column represents a value pertaining to the records.

When talking about the total storage required to host a database, there is a need to consider other factors like index and the table schema information. However, our main interest is in the size of each record within the ***Data*** table of RF Chatterbox. Within the Data table all the data generated by each of the Chatterboxes will be stored, meaning that it is where most of the storage space will be used. The schema for the ***Data*** table (**Table 28: Data Table Schema)** gives a description of each of the values that are found within each record of the table.

Value	**Type**	**Description**
DeviceID	VARCHAR	Relates record to device that sent data
Frequency	FLOAT	Frequency for this record

FreqStrength	FLOAT	Frequency strength measured by device
TimeStamp	TIMESTAMP	Time at which measurement was done

Table 28: Data Table Schema

The storage space used by each variable is directly related to the data type of that specific field. Each data type takes up a calculated amount of space. The nature of each data type can be segmented into fixed or variable; a fixed data type is always a specific size and a variable data type always occupies space according to the amount of data in the field. Fixed data size is defined by the operating system at the compiler level, from which it is derived by our database software. MySQL defines each of the variables used in RF Chatterbox as in **Table 29: MySQL Data Types Sizes**. Additionally, each row contains a header which oversees indexing the row within the table and keeping track of each field within the row. Each header is of size 4 bytes.

Data Type	**Size**	**Description**
VARCHAR (*size*)	Maximum size of 255 characters.	Where ***size*** is the number of characters to store. Variable-length string.
FLOAT(*p*)	4 Bytes	Where ***p*** is the precision
TIMESTAMP	4 Bytes	Values range from '1970-01-01 00:00:01' UTC to '2038-01-19 03:14:07' UTC.

Table 29: MySQL Data Types Sizes

Variable data within MySQL is defined as a data type that holds a variable length with a defined maximum sized limit. For this project, the data type for our DeviceID is a varchar specifying the key given to a specific device. The maximum length for each of DeviceID will be set to 10 characters. Each record holds a variable block with a size of:

$$Block\ Size\ (in\ Bytes) = 2 + (\ 2 * Number\ of\ Variable\ Fields\ in\ Record)$$

Along with the variable block, each record also contains variable data from which each character represents a Byte. To calculate the total size of each record, we must sum all the individual field sizes and blocks pertaining to each record. The equation for each record is as follows:

$$Size\ (in\ Bytes) = Header\ + Variable\ block + Fixed\ data + Variable\ data$$

Where the header size is 4 bytes, the calculated variable block pertaining to only one field is 4, fixed data of a single precision float is 4 bytes, the timestamp is also 4 bytes, and the variable data 10 bytes long.

$$Record\ Size =\ 4 + 4 + 8 + 10 = 26\ Bytes$$

Estimating the total storage provided by Amazon Web Services it can assumed that in a worst-case scenario, of the total 20 GB of storage, 10% is taken up by different files pertaining to the database itself. With our record size set to 26 Bytes, the remaining 18 GB of storage space can occupy at least 6 million records.

The test plan for RF Chatterbox is to use six devices which generate records on four different frequencies every 10 seconds. That is less than 210,000 records on a day. The free storage from Amazon guarantees that our test devices can operate for 28 days straight without any delays or having to sweep the database, meeting the requirement specification.

6.3 Human Computer Interaction

Due to the large amount of data being displayed to the user, the website will use the principles of Human Interface Design related to software. A lot of studies have been done; what stands out the most to the group as developers is a set of rules written by Ben Shneiderman from the book ***Designing the User Interface: Strategies for Effective Human-Computer Interaction***. These eight set of rules are applicable to most interactive systems. The following is our plan to ensure that this design meets these rules:

- Our website uses a ***consistent*** design throughout its entirety. Although our layout is simple, the colors pertaining to each of the frequencies stay consistent regardless of device or frequency.
- ***Shortcuts*** are enabled to ensure that customers can perform their tasks easily. The website allows the user to zoom in and out of the map with the mouse wheel. The site allows the users to move the frequency slider using the keyboard arrows.
- Every time the user performs an action related to the data, a message box ensures that the user receives ***feedback*** stating the action. A status label also ensures that the user understands which frequency they are looking at, and at what time the data was last updated.
- Throughout some of the action sequences, dialogs will be displayed. However, each dialog allows the user to stop the action and bring the sequence to ***closure***.
- There are many types of errors that can happen throughout the entire interface, it is important that we handle them as to not expect ***unwanted behavior***. Critical errors such as a failure to load the data, or a programming error, are displayed to the user within a dialog box. Small errors, such as a failure to load a payload of data are omitted and not displayed to the user but are logged to the server.
- Users can perform ***reversal of actions*** by simply sliding back to their desired frequency using the slider, zooming back using the google map buttons or the mouse wheel, or going back to the original position with a button.
- To allow for ***full control*** of the site, the user can filter through the data using simple sliders. For added control of data over a long period of time, the user will be able to download the data into a CSV format.
- To ***reduce short-term memory load*** the site opts to keep multiple status tags and dialogs that allow the user which was the last action performed, the current frequency the map is displaying, and the last time the map was updated.

6.3.1 Heat Map Interfaces

Throughout web development, heat-maps are used very commonly in various situations including displaying data, making visually appealing sites, and gathering information of what features are being used more. Heat-maps help visualize data when used correctly. For example, they show very large datasets regarding predicted rain over an area without taxing the screen without having to display the raw data.

During development, interface designers tend to make assumptions regarding how a client interacts with each screen. It is assumed that each decision made by a user is meditated, which is reasonable. But research shows that clients will pick the first reasonable action available they come across. This process is called **satisficing** and it is due because it is in our nature to be lazy. Heatmaps alleviate this issue by displaying all the data in an advanced user-friendly area which allows the user to see all options at once with no significant difference between them.

Although heatmaps are great for displaying large amounts of data they have various issues:

- ***Lack of detail*** occurs for many reasons. One, the user is only seeing the average data on a point, and not all the data pertaining to it. It is also shown as a color that is created based on a scale, and not a number.
- ***Implementation can be hard*** when compared to simply displaying the data on a spreadsheet or plotting it in charts. Using a heatmap requires knowledge of how to manipulate the data accordingly and how to work with the heatmap tools available.
- ***They can be computationally taxing*** when compared to traditional plotting methods. Not only is there a lot of filtering needed to display a great heatmap, but there is a lot of graphical drawing onto the physical layers of the map themselves.

For these reasons, the website has additional functionality. The lack of detail is mitigated by allowing the user to download the data in a raw format. This allows the user to see the entire data set pertaining to a specific set and be able to perform a more distinct analysis for their studies. It also allows the user to look at patterns over time, since the heatmap displayed on the website only shows the latest data.

The complexity of building an online heatmap deals with many factors. Most importantly, the user must understand what region of the world they are looking at hence the developers need to interact with a mapping interface. Added to this, developers need to draw the heatmap itself on top of the mapping container. All the information pertaining to the implementation of the heatmap can be found on section **6.4Webpage.**

There exists a relationship between user satisfaction and the load time of a website. Because the RF Chatterbox website updates to the latest data provided by the devices, it is necessary that load times are kept low. For this reason, the heatmap only loads the latest data, and not all previous datasets. Loading the entire frequency history causes the website load times to go higher.

6.4 Webpage

The design for the webpage has the major task of having to display multiple records from various devices in an intuitive way. Because each device can measure multiple different frequency ranges, the user must have the ability to select which frequency to visualize at once. Since all the devices work together to create a spectrum of the strength of frequencies around an area, the user must be able to visualize all the data related to one frequency from multiple devices at once.

The first design iteration of this project (**Figure 26: Website Prototype**) works in only one frequency, as it is just a proof of concept. It portrays the information using a heat-map which showcases the physical range in which that frequency has the measured strength. This demo showcases sample data around the Harris Engineering Corporation building in the UCF campus.

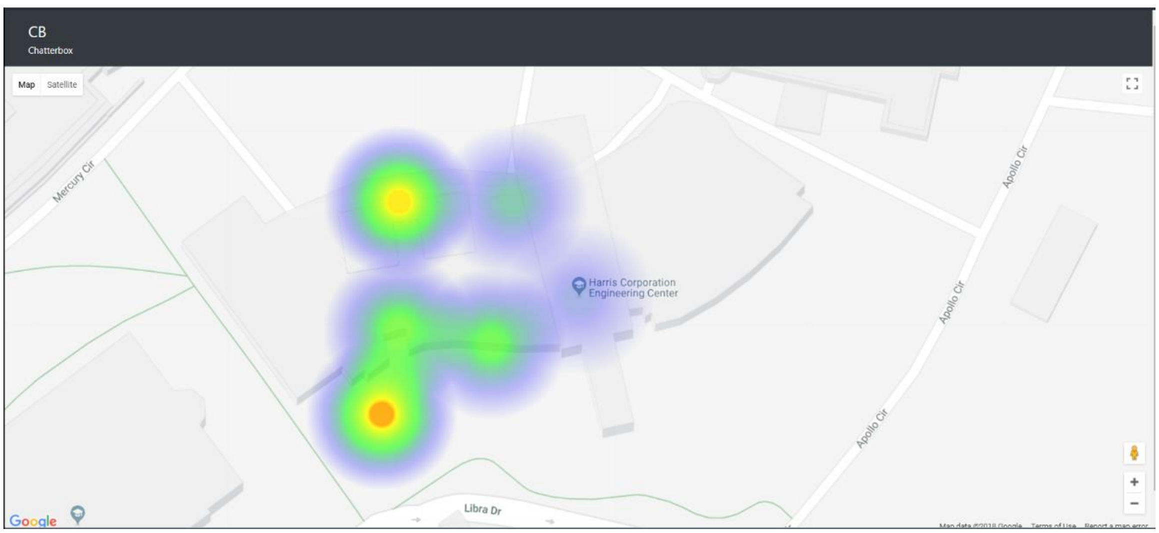


Figure 26: Website Prototype

The frontend website is constructed using a combination of the HTML, CSS and JavaScript languages. HTML is the markup language; the creator for the containers where each of the webpage elements exists. In HTML, each container is called a block and it is designated a definition such as an image, headings, or paragraph. HTML designates the general structure for the entire website. JavaScript is the programming language from which the website gains added functionality, dynamic behavior, and access to the data itself. CSS is a language used to describe how each element in a document is be presented. It allows developers to change the visualization of different blocks and elements created in the HTML structure. Together, these three languages are the triad of modern technologies that form the World Wide Web programmatically.

One key functionality of the JavaScript language is the ability to operate using other modules that contain sections of code that are useful to our application. This project builds upon these libraries to create a final product. The team ensured that all the software components in use operate under an open-source license or they operated at free cost for the purposes of this project. The following are the libraries and APIs used in this project.

6.4.1 The Google Maps API

When talking about maps on the web, without doubt the best-known reference is Google Maps. At the time it was introduced it revolutionized the way in which maps could be seen on the internet. Today it maintains its leadership in many issues, such as geolocation services, traffic data, and route calculation. The Google Maps JavaScript API allows its users to visualize and publish maps on a website.

The Google Maps API is simple and has very good documentation. It has a gallery of examples, guides for learning and a complete description of the API endpoints. The main disadvantage of Google is its own nature. It is a commercial company and therefore its products are subject to its rules and prices. This project is therefore subject to their conditions of use.

The alternative that arises is the use of Open-Source libraries, the most popular being Leaflet. It is a good alternative, with the advantage that it is free and therefore has no restrictions on use. The Leaflet library offers the same functionality and it could be argued that its documentation is more complete than that of Google Maps. Leaflet also has a very large developer community which creates plugins which allows developers to incorporate other functions easily.

The Google Maps API is the biggest provider in the world for online mapping services. There is no fee at low usage levels, which changes once you reach 25,000 webpage loads in a day. Considering the cost, there are little to no advantages of using the Google Maps API or Leaflet as they are both very similar. This project uses the Google Maps API because of its greater developer support and the developer's known usability with the Heatmap.JS library.

6.4.2 Heatmap.JS Version 2.0

Heatmap.JS is an open-source JavaScript library used to draw heatmaps. It is mainly designed to track mouse activity within a website, but it is also useful for mapping. It works with a variety of mapping APIs by using plugins which support both Leaflet and the Google Maps API. On their official website, Heatmap.JS is said to support more than 40,000 data points, as well as working with most modern web browsers including Internet Explorer 9+, Firefox 3.6+, Google Chrome 11+, Opera, and Safari.

The library works by being fed a list of objects, each with coordinates in format containing X (latitude), Y (longitude), and. a weight. To make a real-time heatmap with measurement data from RF Chatterbox, the data must be re-drawn over the physical map layer repeatedly. The workflow is as follows:

1. Receive frequency measurement data from the server
2. Calculate the maximum and minimum to create a scale for the weights
3. Delete the current data list from the map
4. Draw the updated data received from the server

This process allows the logic to be mostly implemented in the backend. Keeping heavy operations such as calculating which data to send to the heatmap, finding outliers, and normalizing the data, allow the website to be more responsive to the user. It is also a good practice as described per the principles of human design interaction.

6.4.3 Estimating Cell Radius for RF Signals

A **signal** is a series of electrical patterns that is transmitted from a device connected to another. These patterns represent digital bits that are transported through the media as an electromagnetic wave. When the signals arrive at their destination, they become converted into digital information. The signals arriving at the other end should have a great resemblance to those that were sent. If something happens to the signal in the way to reduce its strength or alter its shape, the received signal can be incomprehensible. This degradation of a signal can occur by several reasons:

- ***Attenuation*** is a general term that refers to any reduction in the strength of a signal. It affects radio waves as they are absorbed and scattered in the atmosphere. This effect is commonly referred to as dispersion.
- ***Noise*** consists of electrical, electromagnetic or unwanted radio frequency energy that can degrade and distort the quality of signals. Wireless signal interference mostly originates from radio, radar, or microwave sources. These sources produce signals that can negate each other depending on their respective phases.
- ***Diffraction*** loss happen when there are obstacles in the signal's path. Diffraction occurs when the signal makes it through the object with some loss. This effect is mostly caused by things like terrain, buildings, and vegetation.

Research on signal decay over a free space scenario tells us that the decay of an electromagnetic signal in an open field is predicted as an inverse square law of 20 dB per decade increase in range. But in a terrestrial environment there are many outside factors that need to be considered with RF signal loss. The free space path loss formula considers things such as the curvature of the earth, and the obstacles that cause signal loss:

$$Free\ Space\ Path\ Loss\ (ratio) = \left(\frac{4\pi df}{c}\right)^2$$

$$d\ (kM) = \frac{C\ x\ \sqrt{Free\ Space\ Path\ Loss\ Ratio}}{4\pi f}$$

Where **d** is the distance of the receiver from the transmitter, **f** is the signal frequency, and **C** is the speed of light constant.

Signal loss is important when displaying the data produced by RF Chatterbox. Each frequency being displayed present a different scenario as each frequency has different radius of coverage before the signal cannot be interpreted by a receiver. The free space path loss ratio tells us that lower frequencies usually have a longer range of coverage when compared to larger frequencies. Visually, each device on the map must have a smaller radius when showing larger frequencies.

To calculate the ideal radius, the desired free space path loss should be around 75 dB given that this is the threshold for mobile device antennas such as the ones found in RF Chatterbox. Given this information, a clear relationship between distance and frequency from which we can calculate the desired radius (**Figure 27: Free Space Path Loss at 75 dB)** can be created**.**

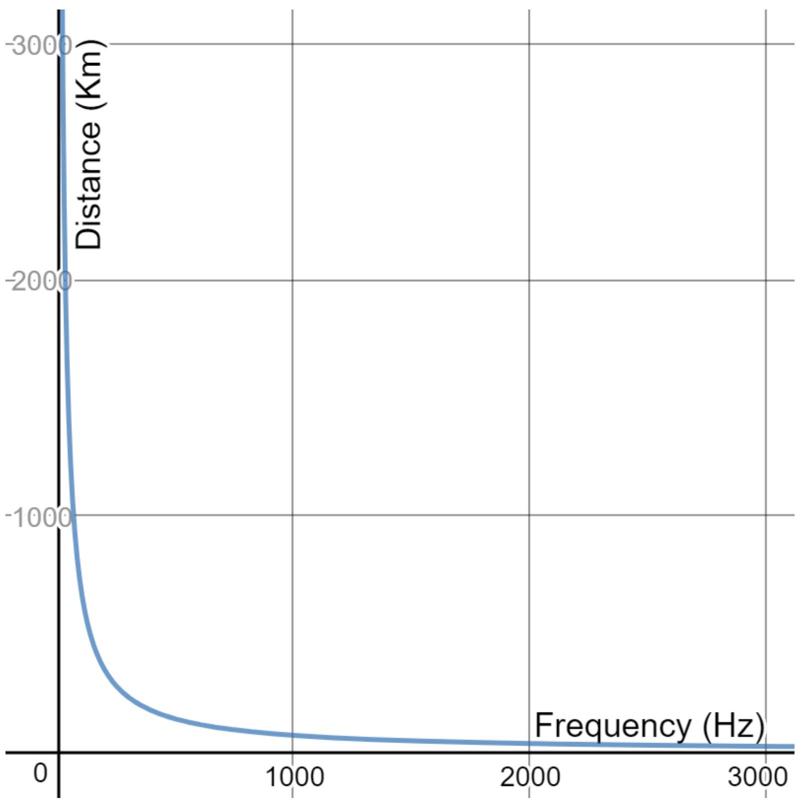


Figure 27: Free Space Path Loss at 75 dB

7 Standards

Throughout the design phase of any project, it is very important to keep in mind that development should not seek to reinvent the wheel. Nowadays, infrastructure exists for the general development of products that follow certain tendencies, such as storing and transmitting data. For this purpose, we analyze existing modern relevant technologies that make RF Chatterbox possible.

7.1 IEEE 1149.1-2013 Test Access Port and Boundary-Scan Architecture

IEEE Standards Association Description: Circuitry that may be built into an integrated circuit to assist in the test, maintenance and support of assembled printed circuit boards and the test of internal circuits is defined. The circuitry includes a standard interface through which instructions and test data are communicated. A set of test features is defined, including a boundary-scan register, such that the component is able Circuitry that may be built into an integrated circuit to assist in the test, maintenance and support of assembled printed circuit boards and the test of internal circuits is defined. The circuitry includes a standard interface through which instructions and test data are communicated. A set of test features is defined, including a boundary-scan register, such that the component is able to respond to a minimum set of instructions designed to assist with testing of assembled printed circuit boards. Also, a language is defined that allows rigorous structural description of the component-specific aspects of such testability features, and a second language is defined that allows rigorous procedural description of how the testability features may be used.

The Joint Test Action Group is known for developing the moniker JTAG for an industry standard for design verification and PCB testing post-manufacture. The MSP432 microcontroller utilized in this project is compliant with this standard, providing JTAG protocol support as well as implementing an IDCODE register within the JTAG chain.

7.2 IEEE 754-2008 Floating-Point Arithmetic

IEEE Standards Association Description: This standard specifies formats and methods for floating-point arithmetic in computer systems: standard and extended functions with single, double, extended, and extendable precision, and recommends formats for data interchange. Exception conditions are defined, and standard handling of these conditions is specified.

This is a technical standard which is widely used for floating-point computations in a variety of devices flooding today's market. The MSP432 microcontroller unit used in this project features an IEEE 754 compliant single precision floating point module; supporting add, subtract, multiply, divide, accumulate, and square-foot operations. The official standard documentation also defines arithmetic formats, interchange formats, rounding rules, further operations, as well as exception handling.

7.3 IEEE 802.11 Standards

The IEEE 802.11 standards are a set of specifications to follow when implementing WLAN communication devices, specifically in the 900 MHz, 2.4 GHz, 3.6 GHz, 5 GHz, and 60 GHz frequency range. The IEEE 802 committee dictates the medium access control (MAC) and physical layer (PHY) specifications such that commercial WLAN devices can communicate with one another. In the market, its common to see vendors designating a specific revision of the 802.11 standard as it provides an easy way to succinctly denote the wireless communication features of their products.

7.3.1 802.11-2016 Wireless LAN MAC and PHY Specifications

IEEE Standards Association Description: Technical corrections and clarifications to IEEE Std. 802.11 for wireless local area networks (WLANs) as well as enhancements to the existing medium access control (MAC) and physical layer (PHY) functions are specified in this revision. Amendments 1 to 5 published in 2012 and 2013 have also been incorporated into this revision.

Original 802.11-1997 Standard: The medium access control and physical characteristics for wireless local area networks are specified in this standard, part of a series of standards for local and metropolitan area networks. The medium access control unit in this standard is designed to support physical layer units as they may be adopted dependent on the availability of spectrum. This standard contains three physical layer units: two radio units, both operating in the 2400-2500 MHz band, and one baseband infrared unit. One radio unit employs the frequency-hopping spread spectrum technique, and the other employs the direct sequence spread spectrum technique.

7.3.2 802.11a

IEEE Standards Association Description: Changes and additions to IEEE Std. 802.11-1999 are provided to support the new high rate physical layer (PHY) for operation in the 5 GHz band.

This standard came out around the same time as the 802.11b standard but was not utilized in the market as widely. This was largely since it operated in the 5 GHz range and required more expensive chipsets for implementation. The 802.11a standard also featured transmission and reception of data at rates of up to 54 Mbps.

7.3.3 802.11b

IEEE Standards Association Description: Changes and additions are provided for IEEE Std 802.11b-1999 to support the higher rate Physical Layer for operation in the 2.4 GHz band.

The 802.11b standard was the first WLAN standard to be applied in a wide variety of commercial devices. This standard also led to businesses setting up Wi-Fi hotspots such that travelling individuals could access the internet. Even though this standard permitted much lower data transfer rates (11Mbps) than its 5 GHz counterpart, the ability to accommodate the 2.4 GHz frequency band more cheaply led to its widespread application.

7.3.4 802.11g

IEEE Standards Association Description: Changes and additions to IEEE Std 802.11, 1999 Edition, as amended by IEEE standards 802.11a-1999, 802.11b-1999, 802.11b-1999/Cor 1-2001, and 802.11d-2001, are provided to support the further higher data rate extension for operation in the 2.4 GHz band.

This iteration of the standard brought forth the ability to achieve the high data transfer rates of the 802.11a standard within the 2.4 GHz frequency band. This standard was gladly adopted in the marked even before the standard was officially ratified. Soon thereafter this standard was dominant in the Wi-Fi market.

7.3.5 802.11n

IEEE Standards Association Description: This amendment defines modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC) so that modes of operation can be enabled that are capable of much higher throughputs, with a maximum throughput of at least 100Mb/s, as measured at the MAC data service access point (SAP).

The 802.11n iteration of the standard brought forth even higher data transfer rates, peaking at a maximum of 600 Mbps. This standard applied to both the 2.4 GHz and the 5 GHz frequency bands and was quickly adopted into the market. It’s important to note that this standard was required to be backwards compatible with the 802.11b and 802.11g standards as many of the devices that users owned were not necessarily new.

7.3.6 802.11ac

IEEE Standards Association Description: The purpose of this amendment is to improve the IEEE 802.11 wireless local area network (WLAN) user experience by providing significantly higher basic service set (BSS) throughput for existing WLAN application areas and to enable new market segments for operation below 6 GHz including distribution of multiple multimedia/data streams.

As a relatively easy trend to spot, each subsequent iteration of the 802.11 standard focused on increasing throughput and data transfer rates. The max data transfer rate in this standard is just under 7 Gbps, which is a massive jump from the previous 600 Mbps.

7.3.7 802.11af

IEEE Standards Association Description: Enhancements to the IEEE 802.11 physical layers (PHYs) and medium access control (MAC) sublayer to support operation in the white spaces in television bands are defined.

This standard takes advantage of the unused TV allocated frequency bands from 470 MHz to 710 MHz. With processing technology advancing, the White-Fi technology arose. White-Fi introduces the concept that broadcast TV coverage is required to be spread out such that interference does not occur. Wi-Fi applications required very low power to operate and thus were possible to be used in the unused spectrum between the broadcast areas without fear of the potential for interference.

7.3.8 802.11ah

IEEE Standards Association Description: Modifications to both the IEEE 802.11(TM) physical layer (PHY) and the medium access control (MAC) sublayer to enable operation of license-exempt IEEE 802.11 wireless networks in frequency bands below 1 GHz, excluding the television (TV) White Space bands, with a transmission range up to 1 km and a minimum data rate of at least 100 Kb/s are defined in this amendment.

The 802.11ah standard aims to provide a global WLAN that would operate in unused ISM frequency bands sub 1 GHz. These frequency bands are not nearly as congested and allow Wi-Fi offloading as well as improved coverage range.

7.4 ISO/IEC 9075-1:2016 DATABASE LANGUAGES - SQL

The ISO/IEC 9075 standard describes the syntax followed by the Structured Query Language (SQL) framework and the results of processing its statements. This standard allows for portability within SQL applications as well as added functionality to the original SQL syntax. The 2016 revision of this standard has added functionality to operate with JavaScript Object Notation (JSON) files. The standard is divided into nine portions from which the following are applicable to RF Chatterbox:

- Part 1: The SQL Logical Concepts
- Part 2: The Mandatory Central Elements of the Language
- Part 3: The Call Level Interface
- Part 4: Persistent Stored Modules
- Part 11: Information and Definition Schemas

7.5 ISO 9241-11:2018 Ergonomics of human-system interaction

ISO 9241-11:2018 provides a framework for understanding the concept of usability and applying it to situations where people use interactive systems, and other types of systems (including built environments), and products (including industrial and consumer products) and services (including technical and personal services).

7.6 RFC 7540 Hypertext Transfer Protocol Version

The Hypertext Transfer Protocol (HTTP) is an application-level protocol for distributed, collaborative, hypermedia information systems. It is a generic, stateless, protocol which can be used for many tasks beyond its use for hypertext, such as name servers and distributed object management systems, through extension of its request methods, error codes and headers. A feature of HTTP is the typing and negotiation of data representation, allowing systems to be built independently of the data being transferred.

7.7 RFC 8259 The JavaScript Object Notation (JSON) Data Interchange Format

JavaScript Object Notation (JSON) is a lightweight, text-based, language-independent data interchange format. It was derived from the ECMAScript Programming Language Standard. JSON defines a small set of formatting rules for the portable representation of structured data.

7.8 ECMA-262 ECMAScript 2018 Language Specification

This Ecma Standard defines the ECMAScript 2018 Language. It is the tenth edition of the ECMAScript Language Specification. Since publication of the first edition in 1997, ECMAScript has grown to be one of the most widely used general-purpose programming languages. It is best known as the language embedded in web browsers but has also been widely adopted for server and embedded applications.

ECMAScript is based on several originating technologies, the most well-known being JavaScript (Netscape) and JScript (Microsoft). The language was invented by Brendan Eich at Netscape and first appeared in that company's Navigator 2.0 browser. It has appeared in all subsequent browsers from Netscape and in all browsers from Microsoft starting with Internet Explorer 3.0.

7.9 Standards For Li-Ion Batteries

There are two main standards when working with Li-Ion batteries. These standards will deal with the transportation, household use, and portable use of Li-Ion batteries. Having standards for Li-Ion batteries is especially important because of how violently they can react when not handled correctly. Additionally, these devices need to be safe wherever they are taken. For example, batteries should not explode or burn when on any kind of transit, and they should not explode during everyday use. Below is a list of common standards Li-Ion batteries must pass for safe use.

7.9.1 US/DOT 38.3

This standard is used for the testing of Li-Ion batteries to ensure they are safe for transportation over land, sea, and air. Li-Ion batteries are a hazardous material to be transported, so they need to be properly tested to ensure they do not violently react during transportation. For instance, if a single Li-Ion battery were to catch on fire, all the surrounding batteries will be at risk as well. This standard is made up of 8 tests to be passed. Tests 1 - 5 must all be done on the same cell in order, while Tests 6 - 8 are more limited in their applicability. Below in **Table 30: UN/DOT 38.3 Tests**, the 8 tests will be presented in order.

Test 1	Altitude Simulation	Batteries are stored at low pressure(11.6KPa) to simulate high altitude flight.
Test 2	Thermal Test	Batteries are stored at -40 degrees C and stored at 75 degrees C for 6 hours.
Test 3	Vibration	This test simulates vibration during transport using a sine wave sweep.
Test 4	Shock	This test also tests vibration during transport using various half-sine pulses.
Test 5	External Short Circuit	The terminals are short circuited. The use of protection mechanisms are allowed.
Test 6	Impact	Simulates impact to case of cell.
Test 7	Overcharge	Simulates overcharge conditions by charging at 2 time the recommended current.
Test 8	Forced Discharge	Simulated a forced discharge condition.

Table 30: UN/DOT 38.3 Tests

These tests listed above are the standard for testing Li-Ion batteries. All of the tests must meet the same pass criteria after testing. After the test, the battery should have no mass loss, leaking, venting, disassembly, rupture, or fire. The voltage must also be within 10% of the test voltage. If all these criteria are met, the battery will be deemed safe for transport.

7.9.2 IEEE 1625/1725

These two IEEE standards are used to test the safety of Li-Ion batteries used in portable devices. Ultimately, because of past incidents involving laptops powered by Li-Ion batteries, a slew of standards have been made to ensure the safety of these portable devices. Therefore, batteries need to have a method of failure protection. These standards looks at system integration, cell, pack, host device, and total system reliability. Every piece of a device is looked at to ensure it will remain safe even if failure events occur.

7.10 Antenna Standards

The IEEE Std 145-2013 standard establishes definitions for antennas and for systems that incorporate an antenna as a component of the system. This standard calls for uniform terminology when referencing antenna design so that there is no confusion from design to design. The team will reference the article when using technical terms to be sure that they are being used properly and correctly.

The IEEE Std 187-2018 pertains to spurious radiation from receivers in the 9kHz to 40 GHz range. This unwanted radiation can be a potential source of interference with other radio services. The team will reference this paper and make sure to prevent any unintentional interference with other services.

8 Test Protocols

A proper test plan needs to be implemented to verify that this design will suffice for its intended purpose. It is important to test all the major aspects of use for RF Chatterbox, because each component needs to be verified to work properly for the product to work. All the proper tests will be expanded upon to set a clear plan. The components will be tested in order, starting with the hardware components.

8.1 Battery charging Tests

The first and most important step in the power network is ensuring that the battery is charging and discharging correctly. If the battery does not charge or discharge properly, the entire device is at risk. This phase of testing will check to see if the charging circuit charges the battery without the battery failing. Also, it will verify that the battery can discharge without causing damage. There will be two main tests done: the first set of tests will be performed at room temperature to simulate indoor use, while the second set of tests will be done outside to simulate outside use. Each set of tests will be conducted the same except for the change in temperature. To link the test with the real-world use, a 37KΩ resistor will be used to simulate a current of 100mA. The battery will go through a series of full discharges and full charges. The charged and discharged voltages will be measured and compared to the theoretical values from the research. This will be done 3 times to ensure the results are consistent. The total time for full discharged will also be average across the three tests to compare to the expected lifetime. The condition of the battery will also be observed at each step. For example, the battery will be checked for any overheating, venting, or cracks in frame. After the charging circuit is guaranteed to work, the regulator will be added and the whole circuit will be retested.

8.2 Regulator Test

To test that the regulator is working properly, it will be tested by itself. This will help isolate any problems to the regulator. A wide range of voltage inputs will be used to test the output remains 3.3V for a varying voltage source like a battery. Values between 1.8V and 5V will be tested. This will test if the regulator switches between buck and boost configuration depending on the input. Once the regulator is verified to work on its own, it will be added to the battery and charging circuit. Thus, the same test will be performed on the charging circuit and will perform on the new combination circuit. To maintain the same 100mA output voltage, a 33KΩ resistor will be used. The battery will be charged and discharged full 3 times, with the output voltage constantly being checked. Also, the average time the battery lasts will be recorded again. If the entire circuit performs as expected, no changes will be made. If there are problems with the combined circuit, the circuit will be redesigned and retested until it works as intended.

9 Logistics

9.1 Cost Analysis

The aimed project budget is approximately $200 per unit. This budget is broken down into each of the individual components needed to build each individual device (**Table 31: Cost Analysis**). Our current cost analysis aims for higher than normal prices to allow plenty of room for unexpected price increases, costs of damaged products, and other fees such as shipping and tax. These values are subject to change due to possible design changes that may arise throughout the design and research phase. We hope to streamline our design to be able to build multiple sensors in a cost-efficient way.

Part	Price
Wireless Transmitter	$40
Sensors	$20
PCB Design	$20
Microcontroller	$20
Batteries	$10
Antennas	$60
Total	$170

Table 31: Cost Analysis

9.2 Project Timeline

The timeline for this project is divided into two sections in which the team will be available to work, Summer (**Table 32: Summer 2018 Timeline**) and fall (**Table 33: Fall 2018 Timeline**). Due to the time constrain of having less time during the summer, the team will work during the break between both semesters to complete the first prototype of the project. Having this extra time will ensure that we can build and order a test PCB as soon as the fall semester starts.

Description	Duration	Dates
Idea's research	2 Weeks	5/16/18 - 5/30/18
Project selection	1 Weeks	5/30/18 - 6/6/18
Divide and Conquer	2 Days	6/6/18 - 6/8/18
Divide and Conquer Revision	1 Week	6/8/18 - 6/15/18
Research and Documentation	3 Weeks	6/15/18 - 7/6/18
60 Page Draft	1 Day	7/6/18
Research and Design	2 Weeks	7/6/18 - 7/20/18

Final Document	1 Day	7/20/18
Proof of Concept	3 Weeks	7/30/18 - 8/20/18

Table 32: Summer 2018 Timeline

Description	Duration	Dates
Build Prototype	4 Weeks	8/20/2018-9/17/18
Testing	2 Weeks	9/17/18-10/8/18
Redesign	2 Weeks	10/8/18-10/22/18
Finalize Design	1 Week	10/22/18-10/29/18
Peer Presentation	TBA	TBA
Final Report	TBA	TBA
Final Presentation	TBA	TBA

Table 33: Fall 2018 Timeline

10 Sponsors

Our project will be sponsored by Dr. Mainak Chatterjee. Dr. Chatterjee is a researcher who mainly focuses in computer networking. He studies the economic issues of wireless networks, cognitive radio networks, dynamic spectrum access, and network science among other topics.

11 Outcome

With the completion of this project the desired outcome is to have a system that consists of self-sustaining, low cost, and reliable devices that works with a remote server to allow the collection different radio frequency signal strengths. This collection system will allow researchers to further study the relationship between environments such as urban and university areas and their effects on common radio frequencies used for things such as mobile devices, TV broadcasting, and navigation.

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