RF Chatter Box

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***Abstract* — College Campuses are among the densest areas when it comes to a need for individuals to be able to connect to various signals. The need for a device that can detect and analyze signal strength, as well as send it to a server to be processed for users is apparent. A cheap yet affective solution has yet to be established for college campuses. ISP's provides an expensive solution, but the cost is often too high to solve small network problems. The RF ChatterBox is intended to provide a cheaper alternative for hobbyist, and small-scale facilities to solve their network problems.**

***Index Terms* — Central Processing Unit, Embedded Software, Lithium Batteries, Serial Peripheral Interface, Receiving Antennas, Regulators, Transmitting Antennas.**

I. Introduction

The RF Chatterbox is a device that will scan a specified frequency range and collect a data set containing the frequency and a power level measure. Once the scanning and measuring period is over, the module will send the data set over a Wi-Fi network to be stored in a server. The data will be displayed on a heatmap of sorts, allowing the user to select a frequency and presenting the power levels for that frequency at the various locations of the devices. This network of devices will allow a user to observe frequency power levels in real-time and intuitive interface. 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. The goals defined in this section outline the intentions for this device and set forth a relatively broad baseline of requirements. In this section, the targeted frequencies, applications, and learning potential for this project will be identified. It's important to note that one of the main objectives of the RF Chatterbox is to minimize costs to widen applicability whilst also providing a user-friendly interface to display data effectively. 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 industrial, scientific, and medical frequency bands under 1 GHz, as well as the 2.4 GHz wireless internet channels. These frequencies are the most widely used by devices such as cellphones and laptops for wireless data transmission and reception. 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 spectrum analyzers, but they can be very costly and were not created with the purpose of mass visualization of frequency availability on a region. 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, RF 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.

II. System Components

This project is best represented as a combination of different systems. Each system has the goal of solving the different requirements for this project. Being able to integrate all the systems together into one package will be the hardest challenge for this project. Ensuring that the micro-controllers all have the required power, and that they have a proper channel to communicate effectively is vital to making the project work.

A. Micro-Controller

The heart of this project is the MSP432 Embedded chip. The MSP family was chosen because of the experience gained from the various classes taken at UCF. The MSP Family is made up ARM Cortex-M4F CPU micro-controllers. This style of micro-controller provides high performance with low power consumption. These processors can safely run on a 3.3V Power source. Multiple Regulators can support this voltage making integration easier overall. It can also support multiple different communication protocols including SPI, the main protocol to be utilized in communicating with the various RF integrated circuits.

B. Wireless Transceivers

There are going to be three total wireless transceivers that will be used in the design for this project. Split out in more general metrics, one will be needed to poll the strength for the ISM frequency bands, another for the strength of the Wi-Fi bands, and a third to transmit the data polled from the previous two chips to a server stored on a local network.

The goal of this project is to implement a basic spectrum analyzer at a relatively low cost whilst also including as many frequencies as possible. The combination of the RFM22B with the CC2500 covers the wide range of frequencies from 240 MHz to 960 MHz as well as the 2.4 GHz Wi-Fi channels at the cost of approximately $6.30. Due to the timing constraints we have opted for the slightly more expensive version of our Wi-Fi transmitter, the CC3100. The MOD version of the chip

C. Antennas

Antenna technology is a vital piece of this project. Data cannot be received or transmitted if the antenna is not properly selected. The selected antennas must be able to support the selected frequencies, whilst also being cost effective. Since the targeted frequencies are different for each transceiver, three separate antennas will be used.

The RFM22B has the widest frequency range and thus doesn't require a particularly specific antenna design. In order to save cost and time, a copper wire will be cut to a quarter wavelength of the median frequency in the 240 MHz to 960 MHz range and attached to the antenna pin of the module. It is known that this will create a peak around the center frequency; however, this will be compensated for in the actual display of the data. If more time and resources were allotted, an attempt would have been made to design multiple antennas with a switching circuit that would choose the ideal antenna for the particular frequency. The CC2500 and CC3100 both use the 2.4 GHz Wi-Fi channels and thus will be using chip antennas designed for that particular frequency operation. These antennas are very delicate in terms of their physical PCB layout and require 50 Ohm traces, bandpass filters, and supporting impedance matching circuitry. Moreover, the antenna must be placed on an edge of the PCB, no signals may be routed across the antenna elements on either layer of the PCB, and the ground must be cleared on all the layers near the antenna.

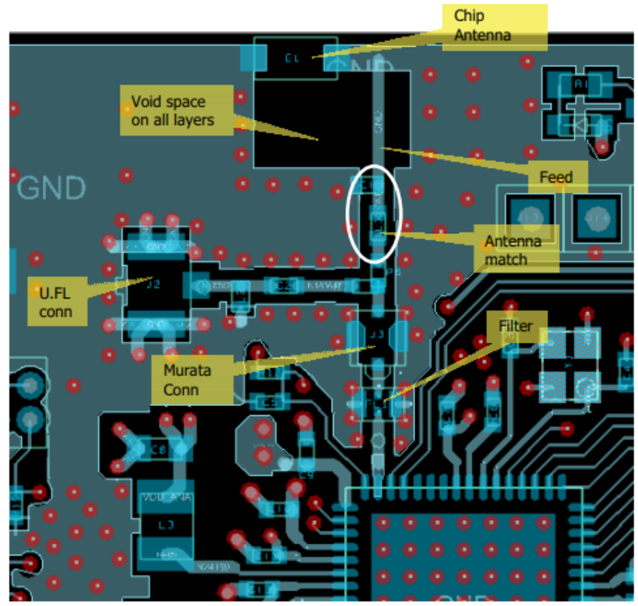

Fig. 1. RF PBC Example [1]

D. Power Supply

The most fundamental part of any project is how it is powered. There is no project without the proper power source. For this project a lithium ion battery was chosen as the main source of power. Lithium ion batteries require specific circuits to ensure safe charging. Being that standard lithium ion batteries are operated at 3.8V, a regulator circuit will be needed to step the voltage down to a level that all the IC's can handle. The TP4056A module was the starting point for a circuit that can safely charge and discharge. LED indicators will show when the battery is charging, and when charging is complete. The TPS630000 was chosen as a starting point for the regulator. The TPS630000 can regulate any voltage between 1.2V and 5V into a safe 3.3V.

The entire project is capable of being implemented onto one printed circuit board. The PCB has dual copper planes to ensure that the ground is large enough for all the current to return through. The PCB will have various test points that can be soldered to external components. This will help with trouble shooting any problems in the PCB.

III. System Concept

To be understood as a complete system, graphics such as flowcharts can be used.

A. Micro-Controller Concept.

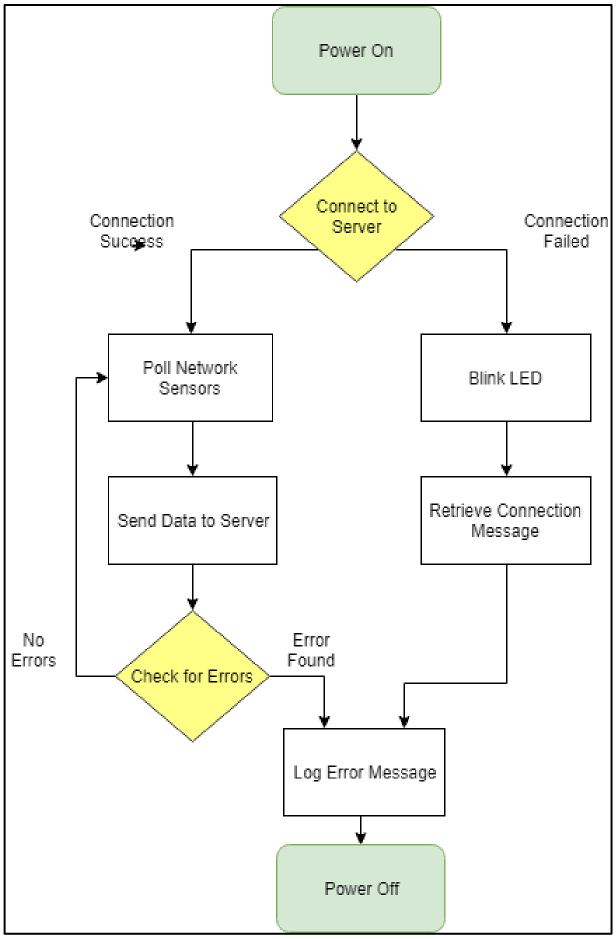

Fig. 2. Complete Micro-Controller Logic Diagram

As shown in the flowchart, the system is cyclical in nature. This code is meant to run indefinitely if a secure connection is established. If there is no connection, or errors are detected, the system will shut down. For this code to continue running, a network connection must always be present. If this device is taken into a place without a Wi-Fi connection, it will shut off. Over all the project in its current state will not be useful in areas without a proper Wi-Fi connection to use. This logic will be applied to all three of the used transceivers. If the code is working properly, at launch the device will attempt to connect to a Wi-Fi network. Once the connection is established. The Device will start to scan through all available frequencies. The code will read the Registers containing the RSSI value from each of the sensors. It will save all the received data in memory. After scanning, the device will send all the stored data to the server. This method of data transfer was chosen to reduce the overall amount of time spent in transmit mode considering that transmitting is the most power intensive task. After the data is sent, the server is responsible for conversion and display.

B. Server Concept

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. The combination of all these layers is called a stack.

As each stack offers a different set of characteristics, the software architecture for the project must be taken into consideration when choosing a stack. The 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.

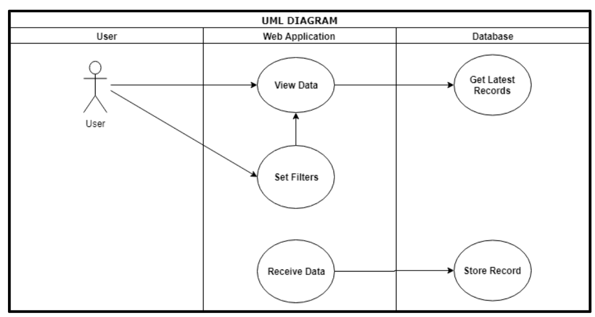

Fig. 3. Website UML Diagram

The decision the team took is to go with the LAMP (Linux, Apache, MySQL, PHP) 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.

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 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

Record Size = Header + Variable block +Fixed data + Variable data

Based on our record size 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.

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.

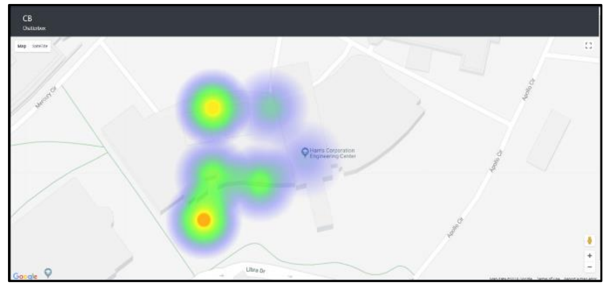

Fig. 4. Website Heatmap

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 [7]:

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

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 presents a different scenario. This due to each frequency having a different radius of coverage. 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 has a specific radius, indicating the limit at which the signal is no longer interpretable.

To calculate the ideal radius, the desired free space path loss is less 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 be created.

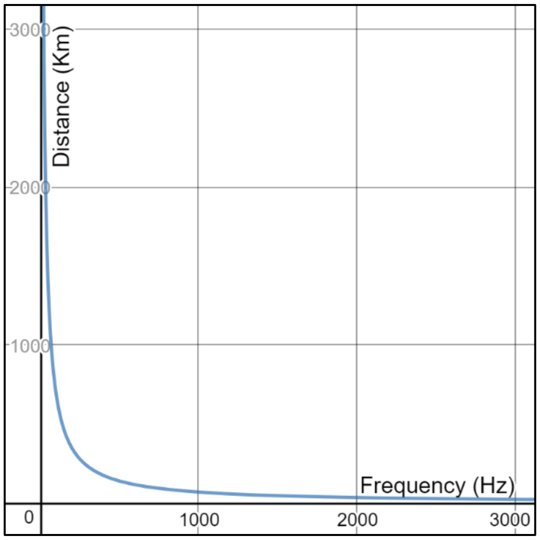

Fig. 5. Free Space Path Loss at 75 dB

C. Hardware Concept

Now that the micro-controller and server logic have been described, the hardware being used to realize this logic can be detailed. Each of the major components is presented in a block diagram format, with an emphasis on the I/O flow.

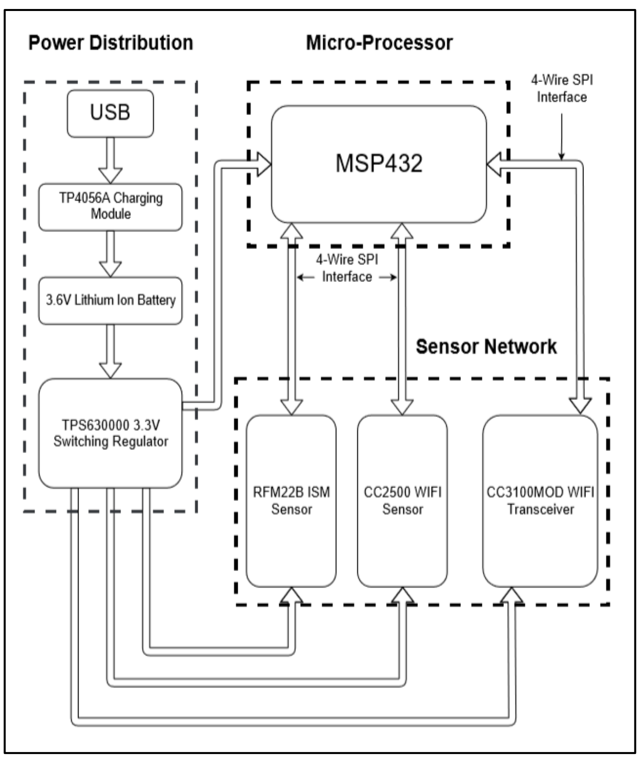

Fig. 6. Hardware Flow Chart with Data I/O Configuration

The main digital data lines present is the system are:

(1) 16-Bit SPI connection between MSP432 and RFM22B
(2) 16-Bit SPI connection between MSP432 and CC3100
(3) 16-Bit SPI connection between MSP432 and CC2500

IV. Hardware Detail

Each of the major subsystems outlined in section II will be explained in technical detail. Each subsection will explain what the requirements are, and how the specific hardware choice meets those requirements.

A. Battery Selection

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 have lost 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.

B. Charging Circuit

Because a lithium ion battery was selected as the power source., a circuit is required to control the charge and discharge rate. Lithium ion batteries need to be charged in a specific manner. The process is known as Constant-Current, Constant-Voltage. There are many different IC's capable of charging in this way. The IC chosen to control the battery charging is the TP4056. This IC alone will control the charge rate, but lithium ion batteries also need some form of discharge control. So, a circuit utilizing the DW01A and FS8205A is selected. 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. The combined circuit is presented below in a schematic diagram. It shows how the 3 main IC's are combined to form a compete charge and discharge protection circuit.

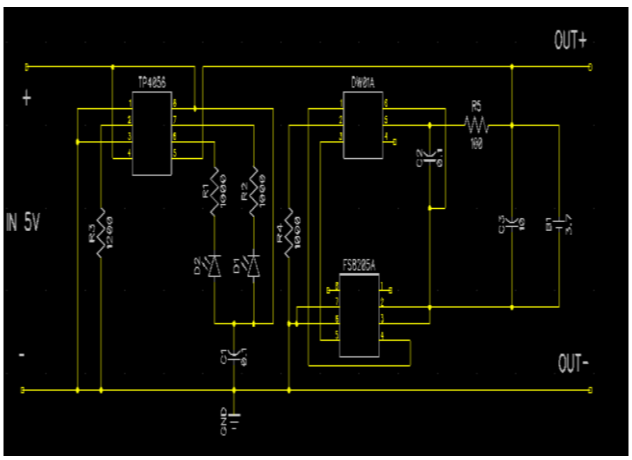

Fig. 7. Circuit Diagram presenting the complete charge protection module

C. Voltage Regulation

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. A switching regulator is the 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. After researching, the TPS630000 was found to be the best fit for this project. The TPS630000 can switch between buck and boost mode, this allows for it to adapt to a lithium ion battery changing voltage. They can be designed to output a wide range of voltages, from 1.2V to 5V. The base model will provide a constant 3.3V for any input within the correct range. 3.3V is the perfect voltage for all the sensors, and the microprocessor. So, another regulator won't be needed for this project. A complete circuit diagram will be illustrated below. The illustration will show how to correctly connect the pins of this device as well as the necessary external components needed.

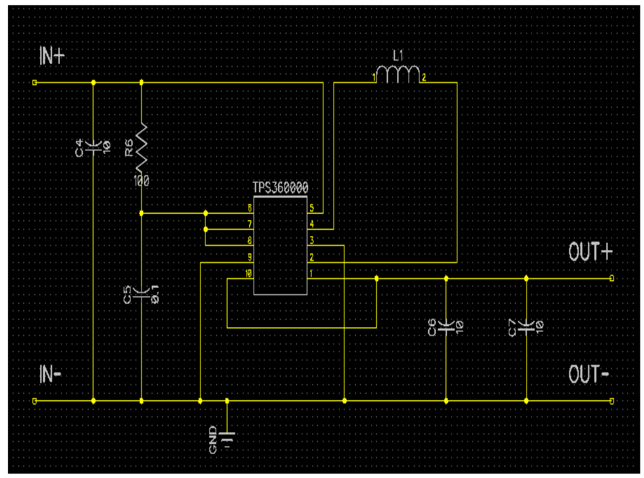

Fig. 8. Circuit Diagram presenting the complete Voltage regulation module

D. Frequency Strength Sensors

The RFM22B is a low-cost ISM transceiver module known for its wide frequency hopping capabilities. This module scans from 240 MHz to 960 MHz with as low as -121 dBm sensitivity. [2] This chip will be driven by the microcontroller to scan through available frequencies at a 1 MHz step size and poll the RSSI value at each frequency. The most significant bottleneck on this device is the settle time of the local oscillator; it takes about 10 milliseconds plus a few clock cycles in order to read a somewhat accurate RSSI value. In order to mitigate some of the delay, the strength measurements are sent every 15 or so measurements as opposed to the entire spectrum.

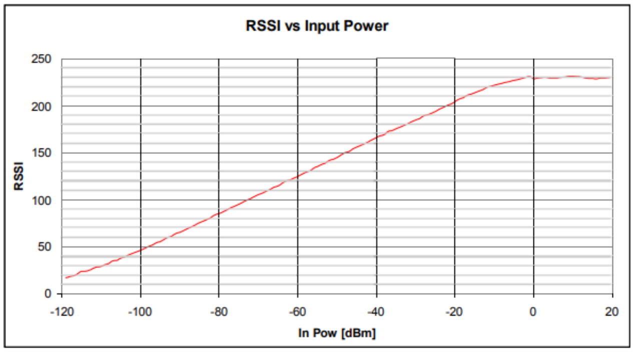

Fig. 1. RFM22B RSSI vs dBm Scale [2]

The CC2500 is a low-cost and power 2.4 GHz RF transceiver capable of polling each channel within the 2.4 GHz Wi-Fi frequency band. This chip also has a digital RSSI output which will be utilized in the same way as the RFM22B chip. Similarly, this chip will be driven by the microcontroller to scan through the 14 Wi-Fi channels. [3] These scans are going to have less latency than the ISM bands due to the fact that the 2.4 GHz Wi-Fi channels only go from 2,401 MHz to 2,495 MHz; 95 measurements averaged into the fourteen channels as opposed to 720 individual measurements.

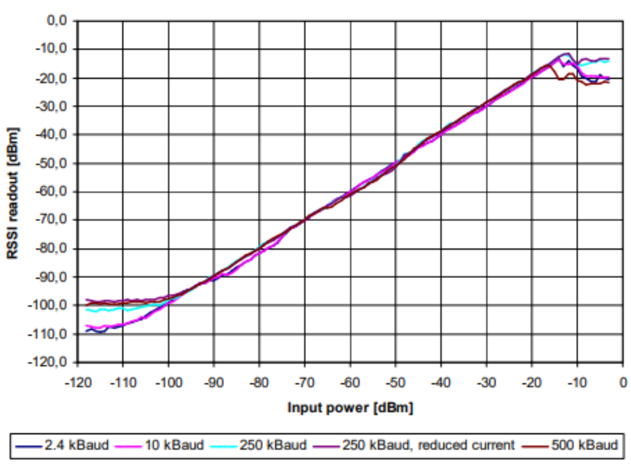

Fig. 2. CC2500 RSSI vs dBm Scale [3]

D. Wi-Fi Transmitter

The transceiver utilized to transmit the frequency strength data to the server is the CC3100. This module has an embedded Wi-Fi network processor with IEEE 802.11 b/g/n standard drivers preprogrammed onto the device. The first thought was to use the CC2500 transceiver to serve this purpose; however, that circuit doesn't come with a network processor and thus would prove too daunting of a task given the time and resources available. The most important aspect of this component is the surrounding antenna circuitry considering that's how the data will be transferred from the sensor to the server. In addition, there is a feature that allows us to attain an RSSI value each time we send a packet which will serve as a verification to check if the values the CC2500 polls are within family. [4]

E. Microcontroller

For the purposes of this project, the most contributing factors that led to the choice of the microcontroller were the cost and power consumption. The MSP432P401X family of microcontrollers from Texas Instruments meets these requirements and some. The chip itself costs around $6 if purchased individually and provides great value with 256KB of flash main memory, assortment of ultra-low-power operating modes, and multiple SPI modules. In addition, this chip in our configuration will have some room for modification if there is a need to implement additional frequency sensors. Furthermore, there is a development board for this specific microcontroller that will assist in developing the code for the project while the PCB is being manufactured. The JTAG interface will also be the method utilized to program the final product from the development board. [5]

V. Testing and Results

Once the parts were acquired and the PCB was sent out testing and implementation using the development boards began. Using the MSP432P401 development board helped realize that having an independent microcontroller for this project was overkill, as the ADC and several other features weren't even being utilized. In addition, sending the collected data to the separate CC3100 consumed more power and was more cumbersome to handle from a developer's viewpoint.

When confronted with these insights, it was determined that the two aforementioned components could be replaced with an all in one Wi-Fi wireless microcontroller, the CC3200. The CC3200 features the same capabilities as the CC3100 in terms of transmitting data across Wi-Fi, whilst also housing an ARM Cortex-M4 microcontroller which is more than sufficient in terms of controlling the two frequency sensors. [6] In terms of cost, the CC3200 is a few dollars cheaper than the CC3100 combined with the MSP432P401. In this case, it made sense to make an adjustment midway through the project as the first PCB design had some flaws such as a missing pulldown resistor, some JTAG pin locations shorting other traces, and incorrect antenna design.

Similar to the MSP432P401, the CC3200 is produced in a development board configuration to ease the development process. Using the development board, the RFM22B was successfully communicated with and commanded to scan the entire frequency spectrum available to the module. This data was then successfully sent to the server using the Wi-Fi capabilities of the CC3200. Additionally, all of the power circuitry worked on the failed PCBs and was incorporated into the testing procedures.

VI. Conclusion

A variety of aspects regarding the engineering design process were exposed over the two-semester experience with this project. Skills such as group corroboration, technical report etiquette, and distribution of work were developed and will continue to be used in professional engineering environments. Similarly, the slew of technical skills as well as general research relating to embedded systems, RF design, power electronics, and server development has enhanced our capability to contribute to future employers.

Each of us utilized the theory attained in our classes at UCF and were able to practically apply those concepts. It was also noticed that not everything was learned in the classrooms; whereas PCB design, antenna design, and acquisition of components was all learned on the fly. These holes being filled show why this course is in place at accredited universities and how crucial it is to the overall scope of an engineer's knowledge.

In terms of the overall success of this project, the research and physical product showed that there is a budget conscious solution to replace a spectrum analyzer. Of course, this particular solution is not as powerful as a fully-fledged spectrum analyzer; however, at a fraction of the cost it performs its task of gauging the power of sub 1 GHz and 2.4 GHz frequency bands. The GUI incorporated with this project has helped assist in determining the effectiveness of gauging the frequency spectrum power across an area.

VII. Acknowledgement

For this project, the group graciously appreciates the help of the following mentors for spending time with the group, clarifying the direction, and advising a path towards success. We greatly thank Dr. Mainak Chatterjee, Dr. Lei Wei, and Dr. Samuel Richie.

VII. References

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[2] HopeRF Electronic, "RFM22B/23B ISM Transceiver Module" RFM22B/23B datasheet, 2006.

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[7] The Scientific Papers of James Clerk Maxwell Volume 1 page 360; Courier Dover 2003, ISBN 0-486-49560-4

VIII. Engineers

Julian Duque, a 23-year old graduating Computer Engineer student that will be starting his career with Capital One in McClean, VA with an emphasis on computer software and development.

Alex Long, a 23-year old graduating Electrical Engineering student whom is looking to work in the defense industry with a focus in systems engineering and digital design.

Jakub Nishioka, a 21-year-old graduating Electrical Engineering student that will be starting his career with Lockheed Martin Missiles and Fire Control in Orlando, specializing in ASIC/FPGA firmware design for high performance military systems.

Lance O'Sullivan, a 21-year-old graduating Electrical Engineering student that will be starting his career with Harris Corporation in Melbourne Florida specializing in CCA and FPGA design.