

Geo-Location of RF Emitters

Final Proposal

Sponsor: Michigan State University ECE Department

Facilitator: Dr. Jian Ren

Executive Summary

The ability to accurately detect the location of radio signals provides a wide variety of uses ranging from determining the location of a distress signal from a party or individual in need of help to locating an interfering signal that is jamming communications. This project focuses on software defined radio technology to receive and process an RF signal to ultimately calculate position and angle of arrival of emitting radio signal. Using this method to sample from multiple locations we will be able to paint a picture of the location of the radio signal.

Design Team 2

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1. Introduction

The initial project was sponsored by the U.S. Air Force Research Laboratory. Due to time constraints and other unforeseen issues we unfortunately were unable to work with the Air Force to develop our design. Because of this our sponsor was changed to the Michigan State University ECE Department and the budget for our design was scaled back to accommodate a smaller project scope. While our end goal hasn't changed, we have had to make major alterations in our design to accommodate our new budget. One of the fundamental changes we needed to make was our hardware, without getting away from the main idea of this project.

The main idea behind this project is the ability to accurately detect the location of a radio signal. There are various techniques that may be used to discover radio signals. The design for this project uses two antennas hooked to a device called a Universal Software Radio Peripheral (USRP) and sweeping through an area looking for peaks in radio Received Signal Strength (RSS). While the antenna is swept through the area, all of the data collected from the USRP is sent via Wi-Fi to an embedded system running software which logs all of the data points. By using algorithms to process this information we can then paint a picture of the radio signal's location. Although useful in some circumstances, the unit has its limitations. For practical purposes, an individual is limited to testing from the ground. While it can be time consuming moving from point to point logging signal strength data points this design allows for flexibility. This system could be further implemented using multiple sub-systems as opposed to moving one sub-system around and then having to map the data to try and pin point the location. Though the multiple sub-system design would provide better accuracy and speed in locating the signal, using a single sub-system is the most economical and feasible approach with current resources.

2. Background

Software-defined radio (SDR) is a different approach to radio communications that implements components and functions through software rather than in hardware as with most other radio communications. The major advantage to using SDR is the capability to transmit/receive a wide range of radio protocols that are capable of changing during transmission and receiving.

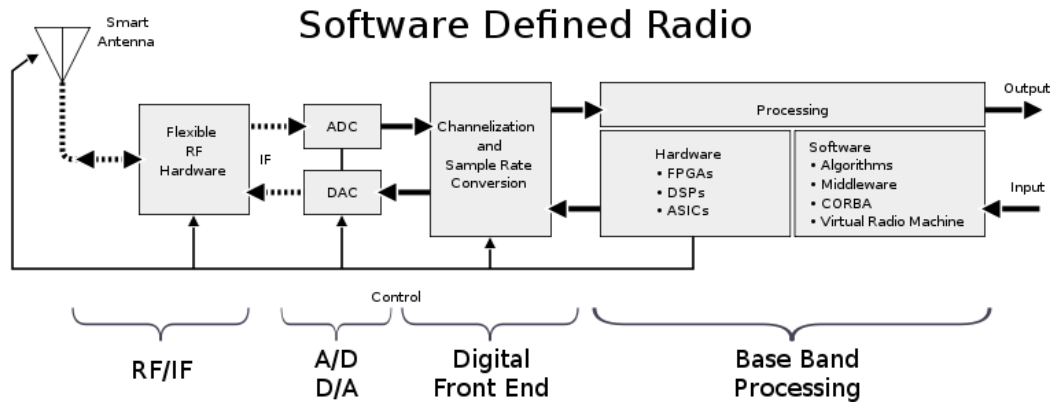


Figure 1 – Software Defined Radio Diagram

As shown above in Figure 1, SDR has the advantage of being flexible and allowing implementation of algorithms. This allows manipulation of the incoming data and processing as needed. With standard radio communication, hardware is designed and built for specific implementation and thus proves to be rigid in flexibility. Because of these advantages offered by SDR it was the obvious choice to use in this design. SDRs interface with software to provide methods for signal processing such as FFT analysis and low/high/band pass filtering. Furthermore, SDRs allow for interfacing to a computer and by doing so, all signal characteristics can be logged to data files and used to create visual graphics depicting signal properties as a function of signal strength, time, and position. Above in Figure 2 is shown an example of a visual graphic of signal properties.

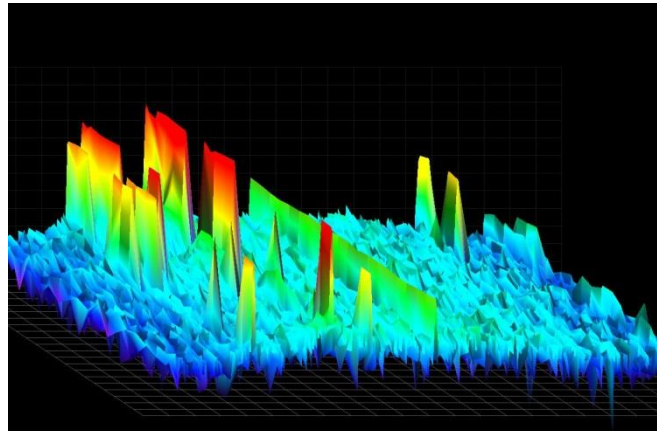


Figure 2 – Visual Graphic of Signal Properties

3. Design Specifications

A. Mission Statement

The purpose of this design project is to accurately calculate the location of a radio frequency. The final deliverable of this project will consist of a portable unit that can be used to acquire data from multiple locations and process this data to find the location of the emitter of the designated radio frequency. This unit will also be scalable such that it may be implemented into a system with multiple units.

B. Design Parameters

To accomplish goals of this project many factors need to be considered when both selecting hardware and also implementing software and hardware. Criteria that must be satisfied in the design include accurately measuring signal strength, calculating angle of arrival, and the ability of the system to be mobile. For this project to be feasible it must have a moderate level of ease of use, high angle of arrival accuracy, and also an adequate battery life. Each of these criteria has been rated from 1-5 on importance to the project with 5 being very important.

Must Be Satisfied:

1. Accurate Measurement of Signal Strength: (Criteria Rating - 5)
The ability to accurately measure the signal strength of the RF emitter is the foundation of this project. This is the initial data that will be received and processed to pinpoint the location of the RF emitter. This is the most crucial portion of the design.
2. Angle of Arrival: (Criteria Rating - 4)
Calculating the location with respect to the RF emitter is one of the most important aspects regarding this project. Angle of arrival will be the measurement used to determine from which direction the emitter is relative to the receiver.
3. Ability of Mobilization: (Criteria Rating - 4)
By sampling different locations for received signal strength and angle of arrival, moving the system becomes a factor. Obviously the more samples used to calculate the location of the RF emitter the more accurate the depiction will be. Based on this assumption the ability of the system to be moved plays an important part in the overall design of this project. A bulky fragile system would not only be difficult to move but could be susceptible to damage causing inaccurate reading.

Desirability Factors:

1. Ease of Use: (Criteria Rating - 3)
The application for a project such as this could be used by a wide variety of persons. Because of this, the ease of use of this application plays a semi-important role. For example, if military ground units were to use this system to detect the location of a radio jamming signal the ability to understand the functionality at a basic level would be critical. This reasoning obviously is dependent on the application of the system. For this reason this factor is categorized under desirability factor. Ease of use should be considered in the design but should not compromise accuracy or effectiveness of system.
2. Angle of Arrival Accuracy: (Criteria Rating - 4)

As discussed above in “Must be Satisfied”, angle of arrival is an important aspect of the design. The accuracy to which angle of arrival is calculated will directly play a role in the accuracy of the location of an RF emitter.

3. Adequate Battery Life / Power Consumption: (Criteria Rating - 2)

Adequate battery Life and or power consumption is similar in importance to ease of use. This factor is heavily dependent on the application of the system. If deployed on an Unmanned Aerial Vehicle (UAV), as was the original intent when sponsored by the U.S. Air Force, battery life and power consumption would be of low importance. If used in the scenario described under ease of use with a military ground unit battery life would increase in importance as it would affect the length of time the user would have to find the RF emitter. Because of the situational importance, battery life and power consumption are categorized as a desirability factor.

4. FAST Diagram

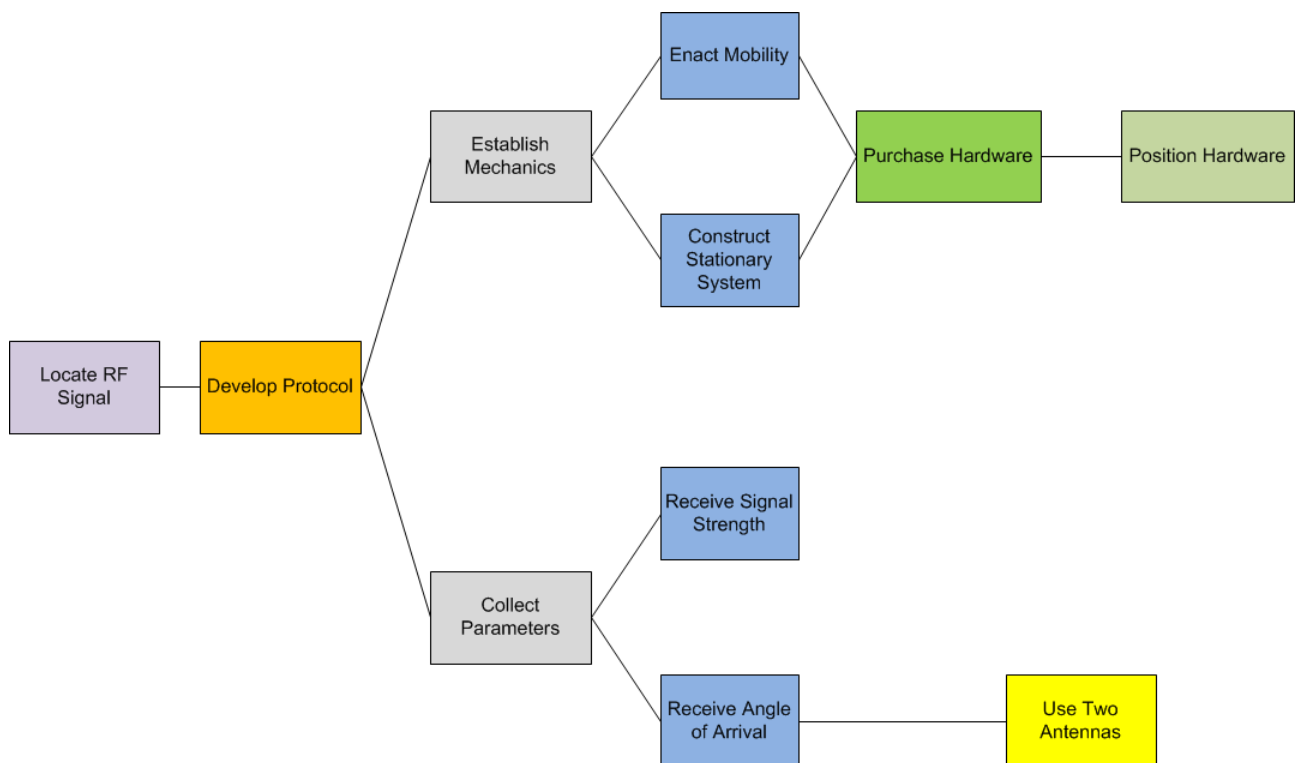


Figure 3 – FAST Diagram

5. Conceptual Design Descriptions

One of the biggest impacts on our design performance is the way we capture and locate

the incoming electromagnetic wave. There were three proposed ways of capturing and locating the incoming electromagnetic wave. Use two stationary dipole antennas, a single rotating dipole antenna, or two stationary monopole antennas.

A. Stationary Dipole Antennas

The two stationary dipole antennas design makes use of the three dimensional gain pattern of each dipole antenna. The caveat to this design is the symmetry it produces. It produces four lobes, two per dipole, and 2 RSS measurements, one per dipole. The AOA would be calculated comparing the 2 RSS measurements but because each dipole has part of its lobe in all 4 quadrants, 4 possible directions for the RF source will be given.

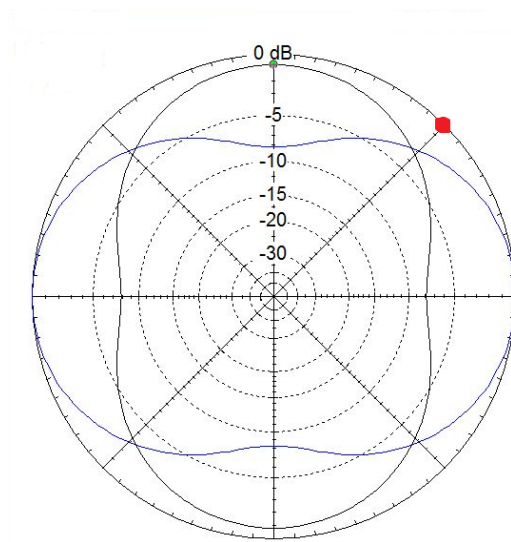


Figure 4 - Actual RF source location

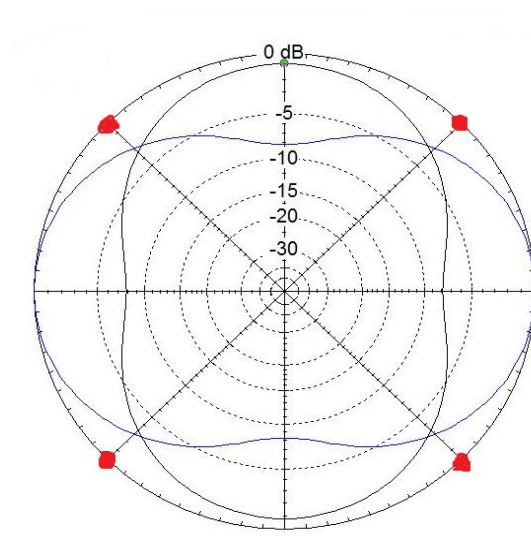


Figure 5 - Information on RF source location able to be retrieved from antenna setup

B. Single Rotating Dipole Antenna

A single rotating dipole antenna design makes use of the antennas orientation with respect to time. The caveat to this design is the amount of time for fabrication and reliability of an antenna that rotates and can output its rotation angle at any given time. This antenna would give us two possible directions because the dipole has two lobes.

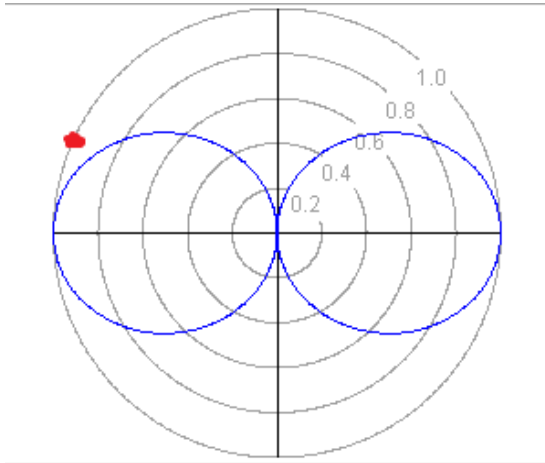


Figure 6 - Actual RF source location

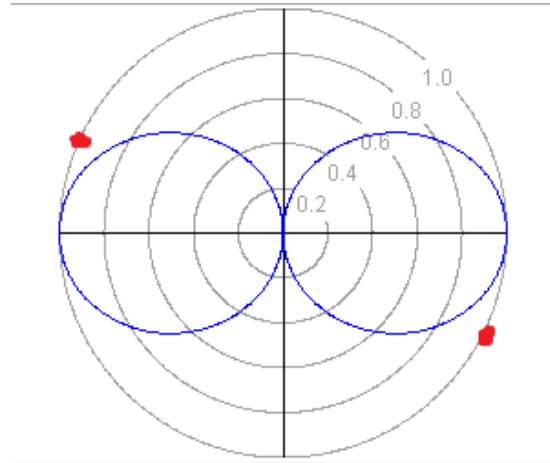


Figure 7 - Information on RF source location able to be retrieved from antenna setup

C. Two Stationary Monopole Antennas

The two stationary monopole antenna design makes use of the difference in phase of each signal each monopole antenna is receiving. Using the phase difference the AOA can be calculated and give two possible directions of the RF emitting source.

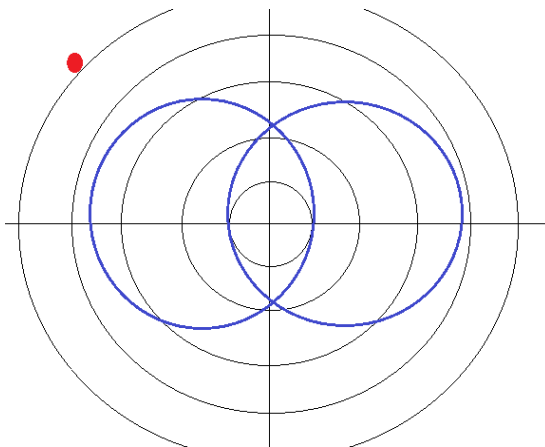


Figure 8 - Actual RF source location

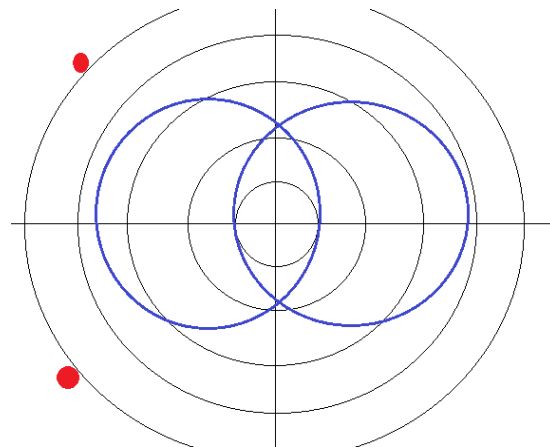


Figure 9 - Information on RF source location able to be retrieved from antenna setup

The term direction was used because an individual sensor will give accurate direction, not location, of an RF emitting source. To get location data we will move to multiple locations with a single unit to log multi-data points. This will be equivalent to having multiple sensors but won't process data efficiently as multiple sensors would.

6. Ranking of Conceptual Designs

Feasibility Matrix

	Stationary perpendicular dipole antennas	Single rotating dipole antenna	Two stationary monopole antennas
Functionality	Least accurate in detecting AOA. Easiest to implement into design with respect to designing the antenna and the programming required to determine AOA. Feasibility (4/10)	Greatly increases the complexity of our design. Our antenna criteria for this design to work requires an antenna not on the market, therefore it would need to be fabricated. Should give a very accurate AOA. Feasibility (5/10)	Given USRP1 can handle 2 antennas simultaneously receiving data, this design should be relatively easy to implement in regards to antenna design and programming required to determine AOA. Feasibility (8/10)
Cost	Two dipole antennas \$20 Feasibility (10/10)	Single rotating dipole antenna \$50 Feasibility (8/10)	Two monopole antenna \$20 Feasibility (10/10)
Time	2 days Feasibility (10/10)	9 days+ Feasibility (5/10)	5 days Feasibility (9/10)
Total Feasibility	(8/10)	(6/10)	(9/10)

Figure 10 - Feasibility Matrix

Selection Matrix

Selection Matrix	Importance	Stationary perpendicular dipole antennas	Single rotating dipole antenna	Two stationary monopole antennas
Cost	4	9	3	9
AOA Accuracy	4	1	3	9
Mobility	5	9	3	9
Scalable	5	9	3	9
User Friendly	2	9	3	9
Durability	3	9	1	9
		130	63	162

Figure 11 - Selection Matrix

7. Proposed Design Solution

The end result is specific and must include/be:

1. Based on Universal Software Radio Peripheral (USRP™)
2. Detection of received signal strength (RSS)
3. Protocol and analysis of signal's angle of arrival (AoA) with at least 30 degree accuracy
4. Real-time spectrum sensing of environment in the 1 – 250 MHz frequency band
5. Scalability
6. Reconfigurable
7. Capable of being mounted to an air or ground based mobile platform

With taking these specifications into consideration come several tasks that must be undertaken to successfully fulfill them; the first task being that of basing the design on the USRP university and industry standard. To do so, designers are constricted to ordering all software-based radios from Ettus Research. This is because Ettus is the sole company that not only created the USRP protocol, but they are also the only ones that design and sell USRP products.

Detection of signal strength is then the next most basic requirement of the project on the list. Received signal strength is defined as the measurement of power present in a received radio signal. What this means is that the antenna(s) used in unison with the USRP 1 will pick up a signal and use that signal power to determine whether the designed geolocator is getting closer or further from the selected signal being located. All-in-all, the only thing required to detect signal strength is to implement an antenna in the design with the USRP 1 that will pick up electromagnetic signals. Once the signal is picked up, the USRP 1 takes that data and scales it for us on a dBm based scale.

The project design performance, in its entirety, requires a specific parameter that trumps nearly all others by default; that parameter is the angle of arrival. The angle of arrival is a measurement method for determining the direction of propagation of a radio-frequency wave incident on an antenna array. Without AoA, even with the USRP and all its hardware totality, no sense of direction can be accomplished. This renders the entire design as useless because it makes the signal location nearly impossible to detect.

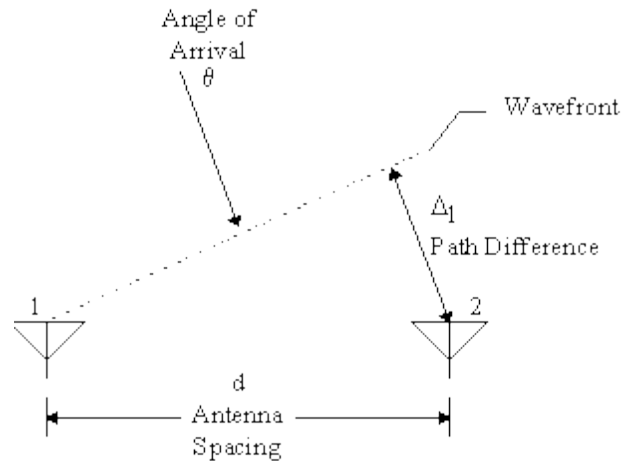


Figure 12 – Visual Graphic of Signal

The angle of arrival determines the direction of the RF emitter by measuring the Time Difference of Arrival (TDOA) at individual elements of an antenna array; it is from these delays that the AoA can be calculated. The TDOA is generally measured using the difference in received phase at each antenna element in the antenna array. It also must be taken into consideration that the design requires 30 degree accuracy on calculating the AoA. Refer to figure 12 for a visual example of AoA.

The next highlighted task requires real-time spectrum sensing of environment in the 1 – 250 MHz frequency band. This is going to be accomplished by using the antenna in unison with our purchased BasicRX Daughterboard. This daughterboard has the compatibility to detect signal anywhere within that frequency band through using the GNU provided for the USRP 1 unit. These connections are shown in detail in figure 13.

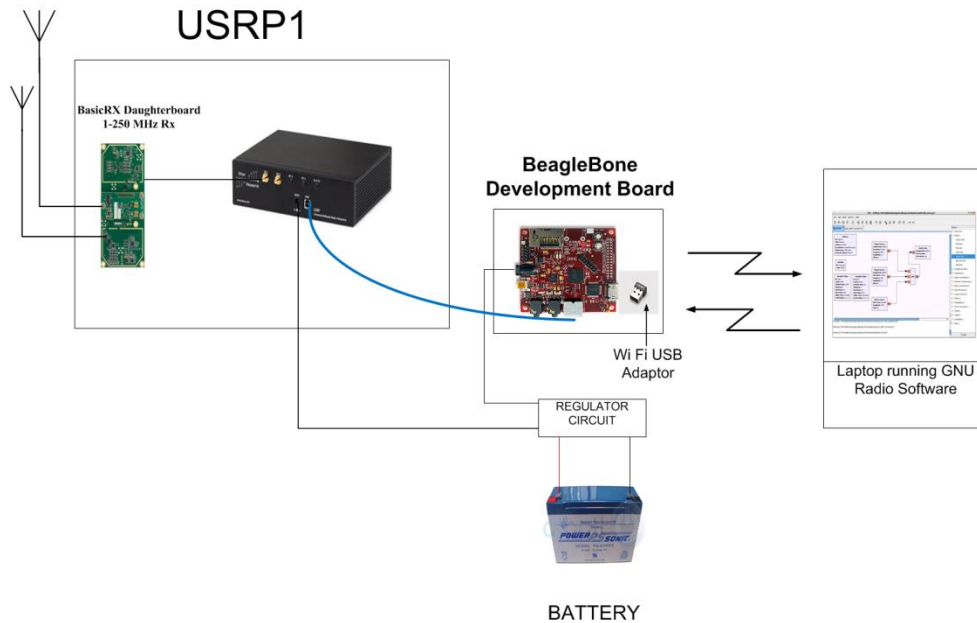


Figure 13 – Proposed Design

The next couple requirements are simple enough to where they can be briefly talked and understood. Firstly, scalability is going to be achieved through simply having the general coding not base calculations on sole distances being used in the test bed. Second, the project must be reconfigurable. This means that our code must be kept clean and neat so that errors can be found (if any) and the company receiving the unit can make modification if they are needed. Finally, the design must be kept light and small enough such that the model can be mounted to an air or ground based mobile platform. This is simple enough because the entire design can be fit into a backpack, as far as the signal detection materials are concerned. The only part that could really cause an issue with this is the mechanical platform that will be implemented to either keep the module mobile or stationary.

8. Risk Analysis

The issue with the most risk is picking an antenna design to capture the electromagnetic wave. Choosing the wrong one will cost the most time of any other trial and error experiment in this project design. This is due to the fact that the entire process of gathering data starts with our antenna. Without this information, virtually nothing can be done with this design or project in general. It is still unclear whether phase difference can be computed by a single USRP 1 unit. Ettus Research claims that there are two outputs that can both use an antenna but it is unclear whether these outputs can gather data simultaneously. Another risk is the microcontroller chosen is not readily available because it is out of stock for every vender giving us less time to implement the software of this project.

9. Project Management Plan

Team Member Non-Technical Responsibilities

Joe Godby	Document Preparation
Justin Mascotto	Lab Coordinator
Matthew Roach	Presentation Preparation
Viktor Simovski	Manager
Kenneth Wilkins	Web Design

Design Team Schedule

Below schedule includes required work, all reports, presentations, and demonstrations. For reference, facilitator meetings are every week on Mondays.

<u>Task:</u>	<u>Duration</u>	<u>Start</u>	<u>Finish</u>	<u>Project Work (PW) / Class Deliverable (CD)</u>	<u>Resource(s) / Person(s)</u>	<u>Deadline</u>
Pre-Proposal	5 Days	1/21/14	1/27/14	CD	All	1/27/14
Webpage Started	3 Days	1/23/14	1/27/14	CD	Kenneth	1/27/14
GANTT Chart	3 Days	1/23/14	1/27/14	CD	All	1/27/14
Voice of Customer	3 Days	2/5/14	2/7/14	CD	Joe	2/7/14
Oral Presentation	5 Days	2/6/14	2/12/14	CD	All	2/12/14
FAST Diagram	2 Days	2/13/14	2/14/14	CD	All	2/14/14
Order Parts	2 Days	2/14/14	2/17/14	PW	All	2/17/14
Design Day Program	2 Days	2/19/14	2/20/14	CD	Joe, Viktor	2/20/14
Build GNU Radio Companion	10 Days	2/10/14	2/21/14	PW	All	2/21/14
Final Proposal	10 Days	2/10/14	2/21/14	CD	All	2/21/14
Wi-Fi Network w/ Beagle	4 Days	2/25/14	2/28/14	PW	All	2/28/14
Build Network	2 Days	2/27/14	2/28/14	PW	All	2/28/14
Code User Interface	5 Days	2/27/14	3/5/14	PW	Ken, Matt, Justin	3/5/14
Progress Report #1	3 Days	3/6/14	3/10/14	CD	All	3/10/14
Photocopy of Engineering Notebook	2 Days	3/7/14	3/10/14	CD	All – Individual	3/10/14
Business Canvas Assignment	4 Days	TBA	TBA	CD	All	TBA
Prototype Demo	1 Day	3/17/14	3/17/14	CD	All	3/17/14
Field Testing	3 Days	3/19/14	3/21/14	PW	All	3/21/14
Technical Presentation	10 Days	3/10/14	3/21/14	CD	All	3/21/14
Individual Application Notes	5 Days	3/18/14	3/24/14	CD	All - Individual	3/24/14

Algorithms for Data	4 Days	3/24/14	3/27/14	PW	Joe, Ken	3/27/14
Project Demonstration	1 Days	4/7/14	4/7/14	CD	All	4/7/14
Progress Report #2	5 Days	4/1/14	4/7/14	CD	All	4/7/14
Design Issues Paper	15 Days	3/24/14	4/11/14	CD	All	4/11/14
Demonstration of Working Last-Generation Prototype	1 Day	4/14/14	4/14/14	CD	All	4/14/14
Professional Self-Assessment Paper	5 Days	4/10/14	4/16/14	CD	All - Individual	4/16/14
Final Report	15 Days	4/3/14	4/23/14	CD	All	4/23/14
Final Updates to Web Page	15 Days	4/3/14	4/23/14	CD	Ken	4/23/14
Design Day	1 Day	4/25/14	4/25/14	CD	All	4/25/14
Evaluation of The Contributions of Team Members	2 Days	2/24/14	4/25/14	CD	All - Individual	4/25/14

GANTT Chart

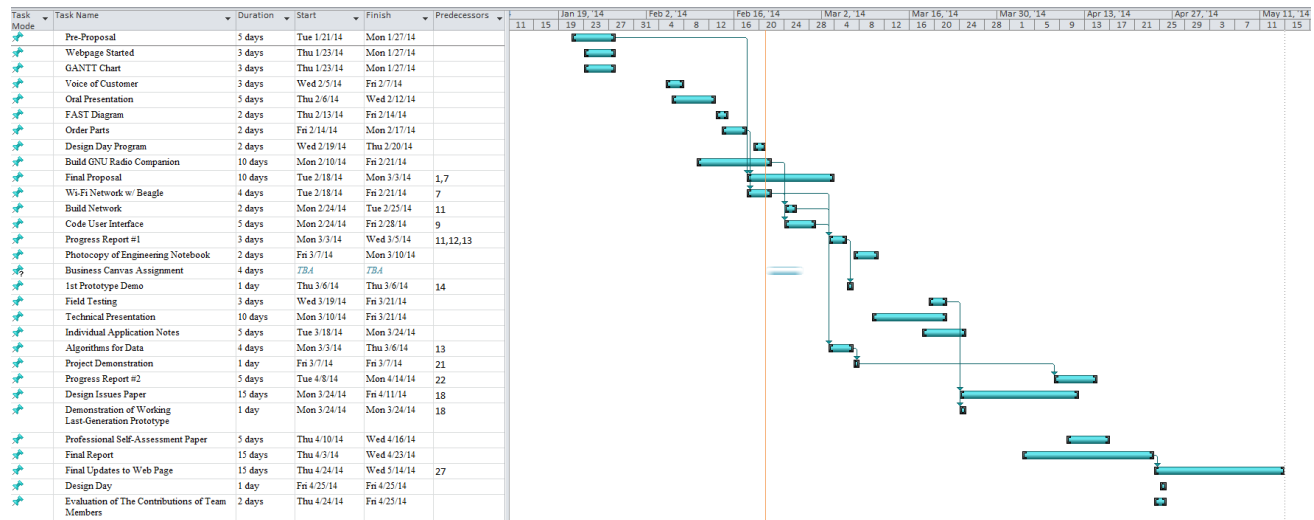


Figure 14 – GANTT Chart

10. Budget

<u>Components:</u>	<u>Price:</u>
USRP1	\$700.00
BasicRX Daughterboard	\$75.00
BeagleBone Board	\$88.95
Wi-Fi Adaptor	\$11.95
6V Battery	\$16.19
Antenna(s)	\$170.00
GPS	\$100.00
TOTAL: \$1,192.09	

Due to the high cost associated with the critical hardware (USRP1 & BasicRX Daughterboard) of the project a secondary budget analysis has been excluded. The cost associated with manufacturing multiple prototypes will be zero due to the prototype using our final hardware.

Component Justification:

1. USRP1: Software-Defined Radio
2. BasicRX Daughterboard: Mandatory hardware associated USRP
3. BeagleBone Board: Allows for mobility of antenna/USRP system by providing a Wi-Fi interface. Also need for GPS interface
4. Wi-Fi Adaptor: Provide Mobility
5. Battery: Provide Mobility
6. GPS: Enables a position element to be added to collected data

11. References

USRP1:

<https://www.ettus.com/product/details/USRP1>

BeagleBone Board:

<http://beagleboard.org/Products/BeagleBone>

Figure 1:

http://upload.wikimedia.org/wikipedia/commons/2/22/SDR_et_WF.svg

Figure 2:

http://alumni.media.mit.edu/~jcooley/gr_experiments/experiments/fft_3d_time/gr_3d_fft_time.htm

Figure 12:

<http://www3.telus.net/public/tnhaynes/electronics/beamforming/>