Directional Signal Strength Meter for DGPS

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Abstract

Using digital signal processing, and existing research completed in radio spectrum frequency sampling, the concept of designing and building a directional signal strength meter for Differential Global Positioning System beacons transmitters was explored. Although the actual meter has not been entirely completed, the system components are in place, and the concept has essentially been proven. Both the hardware and software pieces of the design have been tested and are working properly together. With further analysis of the gains of each antenna, beam forming and null steering calculations can achieve a higher level of accuracy. Furthermore, an algorithm to determine an absolute signal strength value must be designed and implemented into the existing software. After extensive field testing the signal strength meter will be ready for use in the DGPS field [1].

Introduction

The U. S. Coast Guard currently does not have the ability to validate propagation prediction models for Differential GPS beacon transmitters. This ability to validate a predicted coverage area is necessary in order to provide the coverage required by the Nationwide Differential Global Positioning System (NDGPS).

Currently, a method to easily make directional field measurements of the signal strength radiated by a DPGS beacon transmitter does not exist. This results in having to use more resource intensive measurement techniques. The ability to quickly measure the signal strength of a transmission antenna has many more applications than just those associated with DGPS. The development of this tool is being sponsored by both the Command and Control Engineering Center (C2CEN), and the Coast Guard Navigation Center (NAVCEN) [1].

Background

Using MATLAB®, initial software has been written to interface with Analog to Digital Converters and implement various DSP algorithms. 1/C Everette (2001) designed most of the software last year. 1/C Armstrong (2001) focused mainly on the system's hardware.

These algorithms read data in from an antenna array, process it, and when completed will display the strength of the signal of interest in the form of various graphical plots. A Graphical User Interface (GUI) has been designed to enter user input and display results.

The actual concept of directional signal strength detection was not proven last year. Most of the year was spent designing a GUI for the program and integrating the hardware and software.

New antennas and analog filters have been procured to improve upon last year's hardware design [1].

Objective

This year's objective was not only to prove the concept, but also to produce a directional signal strength meter and signal analysis package for differential GPS beacons. We planned to look at new ways to filter the data and increase processing speed. The algorithms already written needed to be verified and coupled with new code that would complete the signal analysis package. The capability to save data to the hard disk would also be added. Finally, we planned to include extensive testing and research to prove the product worked properly and was ready to be fielded.

The importance of this project to the navigation community is obvious. Therefore, it was important to let others know about the research being conducted at the Academy. This semester I had the opportunity to present the project, and a paper written by Dr. Keith Gross to the Institute of Navigation Conference in San Diego, California[2]. At this meeting, the importance of the work I was doing became more apparent to me. Keeping interested parties informed on the progress of this effort is an important project objective.

Technical Approach

Essentially, determining what needed to be accomplished and how to approach each task was determined using the system block diagram (Figure 1). All tasks up to and including the Antialiasing filter are hardware issues and drawn in blue, whereas each block after that is implemented in software and shown in black.

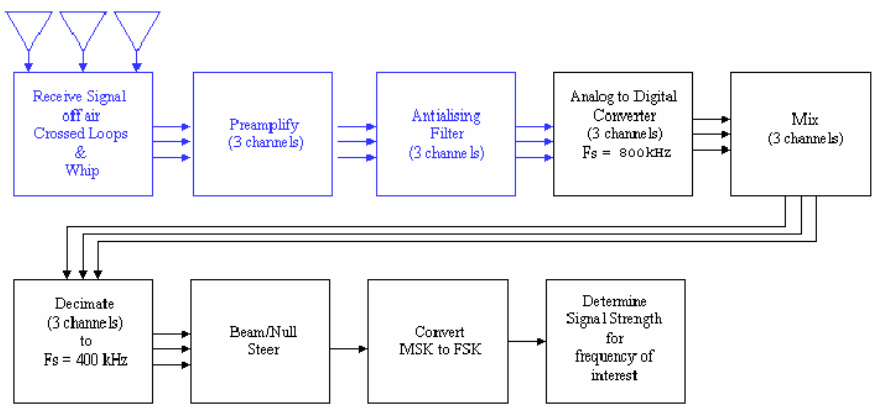


Figure 1 - Directional DGPS Signal Strength Meter System Block Diagram

Initially, I started by becoming familiar with the current system and verifying its operation. There is a lot of code that I was unfamiliar with. In order to make updates, I needed to have a much better grasp on the existing software and hardware.

I received new hardware that needed to be tested and calibrated before it could be implemented into the system. Specifically, I tested and calibrated both new antennas and new filters. An explanation of the testing conducted is given in the following section. All new hardware components added to the system needed to be interfaced with the existing software once calibration was complete. Testing also had to be done to determine whether or not the new equipment increases system performance.

Due to the problems encountered last year with the antenna array, a lot of the code written to perform directional signal strength measurements was not verified. Once a functional antenna array was obtained, I had to verify and test the software. In particular, the following functions needed to be addressed: beam steering and null forming equations, azimuth function, and overall compatibility of the software with the new hardware.

More functionality needed to be added to the MATLAB code. These changes included converting an MSK signal to FSK and logging both raw and processed data to the hard disk. Some errors were also noticed in the computation of bearing Furthermore, the list of available DGPS beacons had to be updated. Additional features that had to be coded and implemented were: the ability to scan all DGPS frequencies and all bearings and finding an estimate for the signal strength measurement.

Extensive testing in various locations around the U.S. needs to be completed to verify the capability of the meter.

Results

Hardware

Last year there were many problems with the operation of the antenna arrays. Therefore, we purchased 3 crossed loop antennas and 3 whip antennas. Furthermore, it was determined last year that conducting analog filtering before sampling might be useful. Three pairs of high and low pass filters were ordered to test this idea. A majority of first semester was spent testing and calibrating the new equipment.

The filter calibration process involved first making sure the equipment worked and then taking more intensive measurements to determine what cutoff frequencies would yield the best band pass filter. DGPS operates in the frequency band between 285 kHz and 325 kHz. Many different cutoff frequencies were analyzed to determine which set would provide both good pass band and stop band characteristics. The best results were achieved by setting the cutoffs of both filters to 285 kHz. The frequency response of the filters with these settings is plotted in Figure 2.

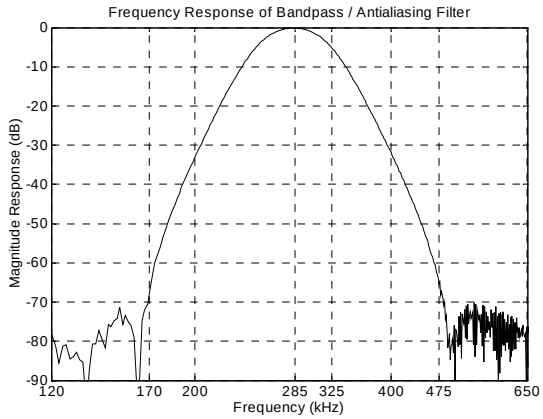


Figure 2 – Frequency Response of Analog Filters

A similar approach was followed to test the new Starlink loop antennas. Initially, I determined that all the new equipment was in fact behaving properly. However, results found during the following tests were not as conclusive. In the lab, a sine wave was generated by the HP89410 signal analyzer, and received by a loop antenna to examine the signal strength [3]. The results were similar to those found by the project team last year and are pictured below (Figure 3) [1].

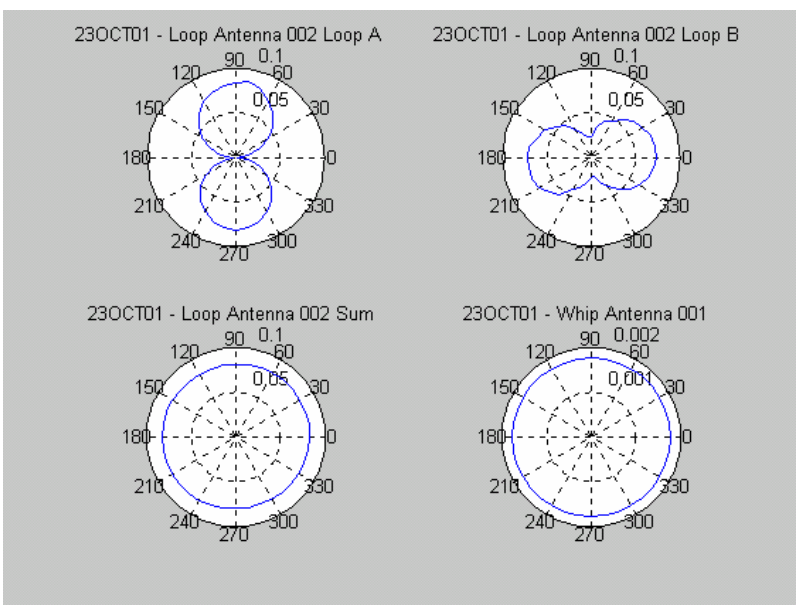


Figure 3 – Antenna Calibration Results (Mac 210)

Next the calibration process was moved outside. Initially, the testing was tried on the sidewalk outside Mac Hall. Using the same setup, I tried to measure the signal strength of the DGPS beacon at Moriches, which transmits at 293 kHz. The results seen were very inconsistent and led us to believe that there was too much interference to conduct the test in that location. Therefore, testing was moved to Avery Point where interference was essentially minimized. Unfortunately, the results were again much different from the values we expected. The deep nulls seen in the

lab were not seen outside. The differences can be seen by comparing the plots below (Figure 4) to the ones shown on the previous page (Figure 3).

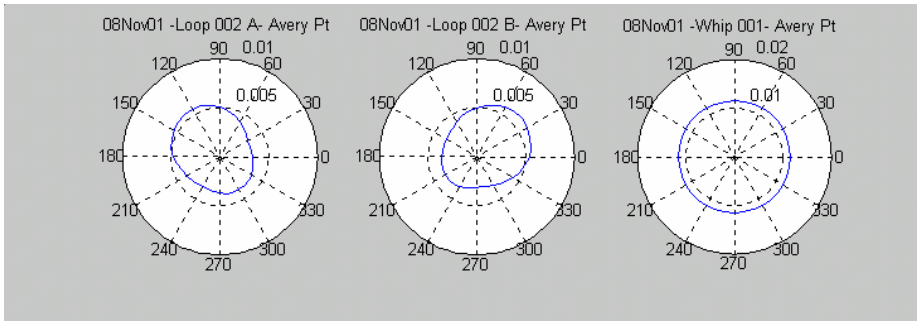


Figure 4 – Antenna Calibration Results (Avery Point)

In an attempt to narrow down the possible problems causing the strange antenna results, I conducted additional tests in the outdoor environment. The project's technical advisors suspected the problem might be occurring due to the interference between the 2 nulls in the new antenna package. Using a single loop antenna procured from an old project, I recorded the signal strength of Moriches, at 293 kHz, at 10-degree increments. The results are plotted in Figure 5.

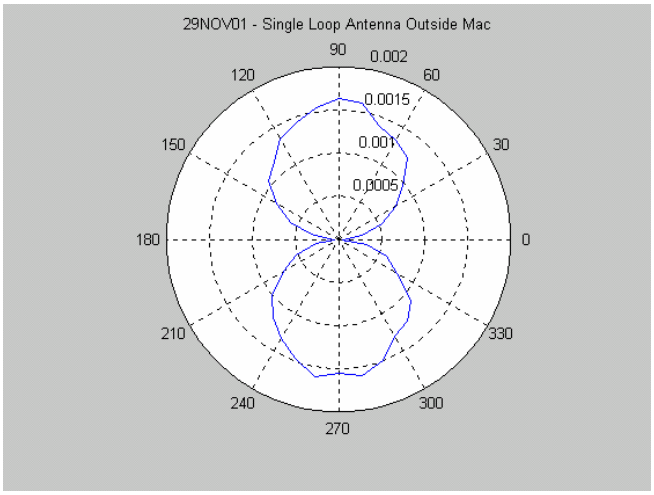


Figure 5 – Single Loop Antenna Pattern (Receiving Moriches DGPS Beacon)

As demonstrated by the test, a single loop antenna does, in fact, produce a figure eight antenna pattern, as expected. This test disproved our theory that the Moriches signal might be too weak to produce deep nulls.

It is likely that the difference in the antenna patterns is caused by some interference introduced when the loops are put into the same package. Another possibility suggests that the gain for the antennas was designed for the sum of the loops, and not the loops individually. The design specifications and any other manufacturer material for the antennas needs to be obtained from

Starlink to look at these possibilities. In the meantime, to facilitate progress, Dr. McKaughan modified a set of older, single loop antennas for the project's use.

Testing the modified single loop antennas began early in the second semester. Procedures used during earlier tests were again followed to obtain the antenna patterns shown below (Figure 6).

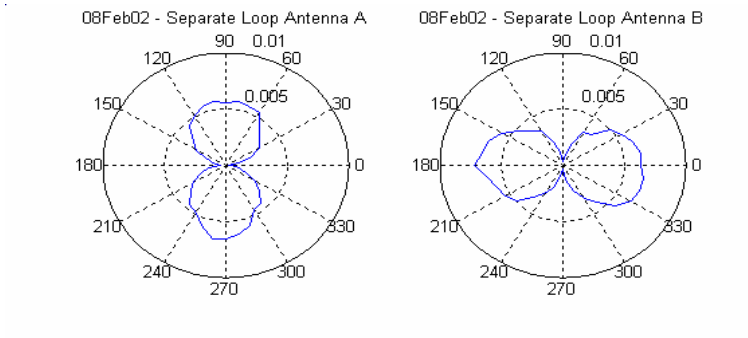


Figure 6 – Antenna Patterns of Modified Single Loops

Obviously, the ability to produce antenna patterns that resemble ideal patterns exists. After numerous obstacles, antennas that could be used for beam and null steering techniques had been obtained. Finally, it was time to mount the antennas on the roof of McAllister Hall and work the system with real DGPS signals. Pictured below is the antenna array on top of the building (Figure 7).

Figure 7 – Loops Mounted on Roof of McAllister Hall

Next I was able to test the operation of the filters with real DGPS signals. By observing the antenna signals before, and after filtering on the signal analyzer, it was easy to conclude that the filters were in fact eliminating unwanted data points. The bandpass and anti-aliasing filtering was working properly. With all the hardware in place, it was time to integrate hardware with software and bring the signal into the digital world. This work is addressed in the following section on software results.

Software

Advances in software development for the project were limited during the first semester due to the problems encountered with the hardware. My original plan had outlined that all software updates would be completed first semester, but this goal was not attained. During the first semester I was able to begin looking at converting an MSK signal to FSK and also logging data to the hard disk.

Due to the fact that the new hardware was not ready to implement in the system, I was initially unable to read real data from a DGPS beacon. Instead, I used a computer simulated MSK signal and looked at the effect the various parts of the code had on it. Specifically, I looked at the band pass filtering, mixing, and decimation of the signal. This helped me gain a much better understanding not only of these important steps in the block diagram, but also of how the program is coded and how the various functions written interact [1].

The majority of my effort regarding MSK and FSK signals was in research. I felt it was important to understand the reasoning behind the conversion before I implemented it. To convert an MSK signal to FSK you simply square the signal. The code to implement this step is therefore very simple and has been written into the software. The effect of this conversion is to produce discrete spectral components at

$$f_{lines} = 2 * f_{carrier} \pm \frac{DataRate}{2}$$

This operation is displayed in figure 8. The signal strength can be found by extracting these components and measuring them [4]. This will be an important consideration when writing the algorithm to calculate signal strength.

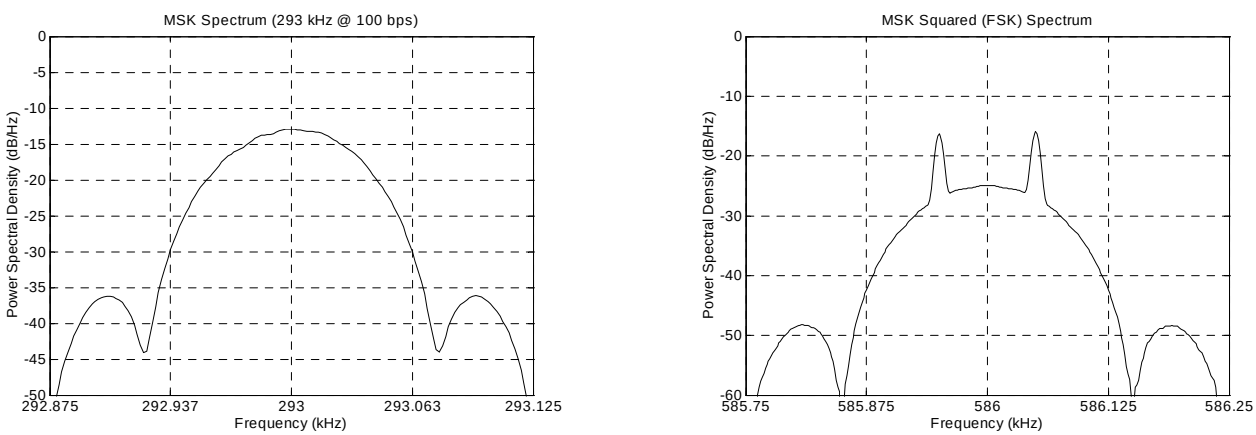


Figure 8 – ELF MSK Signal and the Same Signal Squared

Fortunately, second semester I was able to do a lot more work with the digital back end of the system. More importantly, I was able to conduct that work using actual data being received from the Moriches DGPS beacon. Initially, I had some difficulty using the NUDAQ analog-to-digital converter and the code that was written to drive it. After a great deal of troubleshooting, it was determined that the computer was missing a necessary file. By adding the required file and

working through some alterations in the code written last year, I was able to read in and plot the antenna signals in MATLAB.

Additionally, I finished writing and testing the code to save data to the hard disk. Currently, the user interface includes check boxes with the option to save either raw or processed data, as seen in the screen shot below (Figure 9)[1].

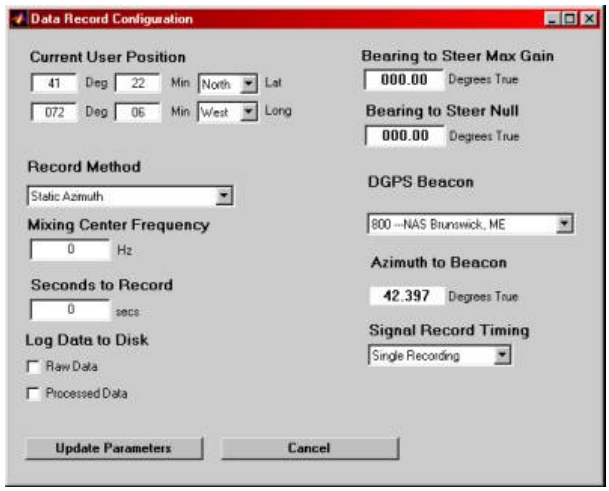


Figure 9 – Data Record Configuration Window

My initial design saved the data into a file I hard coded. The updated code written this semester automatically saves the data into a specified file according to the date and time the test was conducted.

Previously, updating the list of DGPS beacons was cumbersome and hard to follow. This semester I not only updated the list to reflect changes in DGPS beacon status, but I also improved the method used to complete that task in the future. Currently, the code is written to allow the programmer to update the list in either Excel or Notepad, copy the list to a specified text document, and run the program. The updated list will be available in the drop down menu of the "Date Record Configuration" window, as seen below (Figure 10), and all associated changes throughout the code are completed automatically.

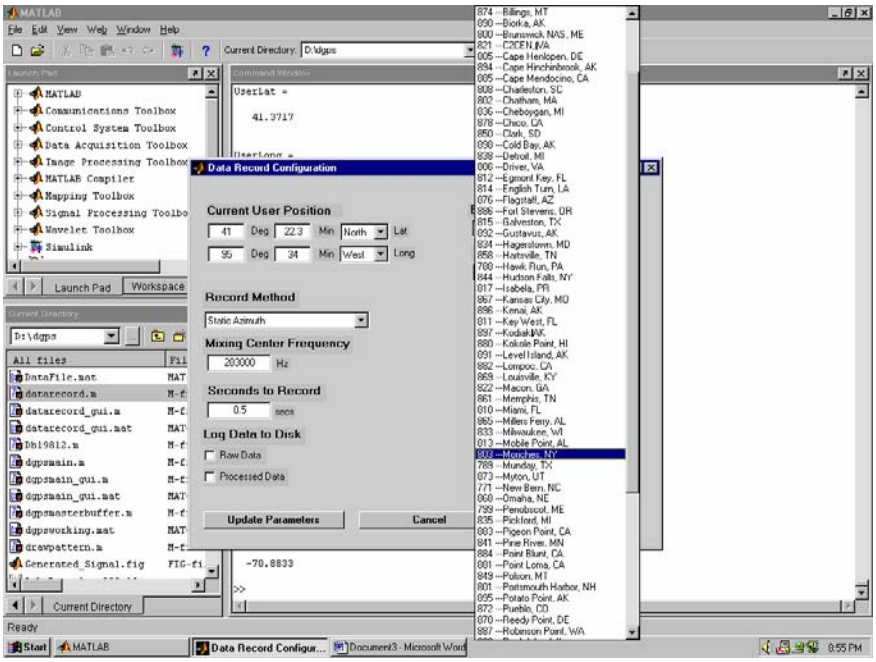


Figure 10 – Data Record Configuration Window – Beacon List

Also included in the "Record Parameters" window pictured above is the ability to enter your position, and read the bearing to a selected beacon. It was apparent that something was wrong with the code to perform this operation. Bearings obtained using charts did not concur with the program read-out. The necessary changes were made to fix the problem. Currently, charted bearings concur with results obtained in MATLAB.

To begin testing the capability to steer the antennas and analyze the signal strength in a certain direction, I used the Moriches beacon. Aware that the beacon is at a bearing of approximately 222 degrees true allowed me to steer in that direction and null 180 degrees relative to it. The processed signal that was plotted in MATLAB looked reasonable. However, when I altered the steering to form the beam away from Moriches, and the null towards it, the results were identical. This led us to believe that either the beam null steering equations were not being executed properly, or there were some changes in gain or phase that yielded steering errors. The first possibility was ruled out after examining the code and verifying that it was, in fact, correct. Therefore, I began testing to ensure there were no differences in phase or gain that might alter the signal strength measurements. Initially I setup the test using a generated sine wave. This proved not to be very useful and the decision was made to instead use the signal from one of the loops, split that signal, and run the same signal through the entire system. This test was successful and proved to us that there were no phase differences introduced by any of the 3 channels. However, a slight gain difference was noticed after the signal passed through the analog filters. This issue will have to be addressed further when determining a value for absolute signal strength.

In the process of testing the individual system components an error was found in the setup of the ADC. The antennas were connected in reverse order, which was assumed to be the primary

reason why the steering was not working properly. After fixing the problem, steering tests were conducted again. Unfortunately, the steering still was not producing expected results. At this point we decided to make sure the loops could actually produce a figure eight pattern that could be steered and later add the signal from the whip. Code was written that would step through 0-360 degrees and form the beam in the desired direction. Below are the results obtained by orienting the loops so that one was pointing at Moriches, and the other was oriented 90 degrees from it, and reading a null at 293 kHz (Figure 11).

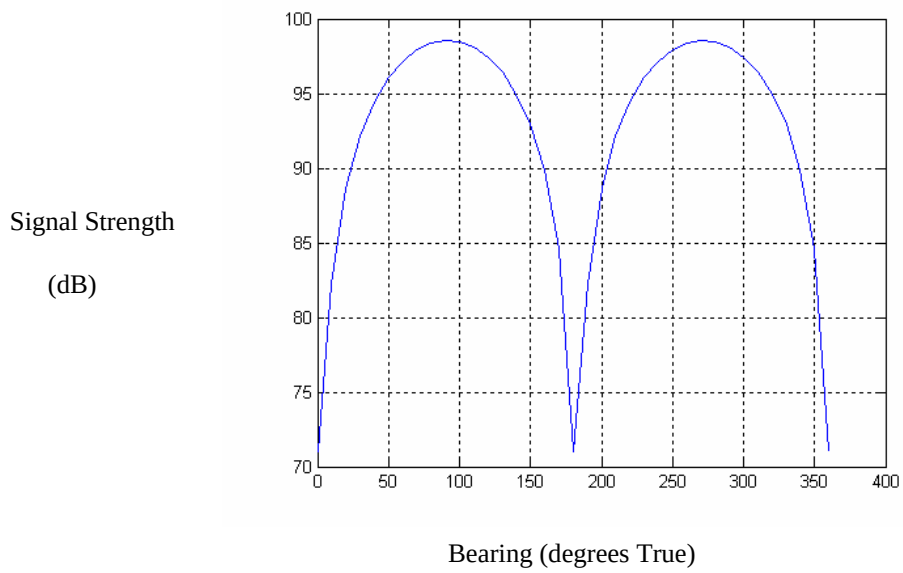


Figure 11 – Loop Steering Results (Oriented to point at Moriches beacon)

These results proved that steering the loops was possible. The antennas patterns display deep nulls and maximum values that are approximately 23 dB above the null values. Next we re-oriented the antennas in a North-South, East-West configuration. Again, we conducted a test that would steer the beam through 360 degrees. The results from this test are shown below in figure 12.

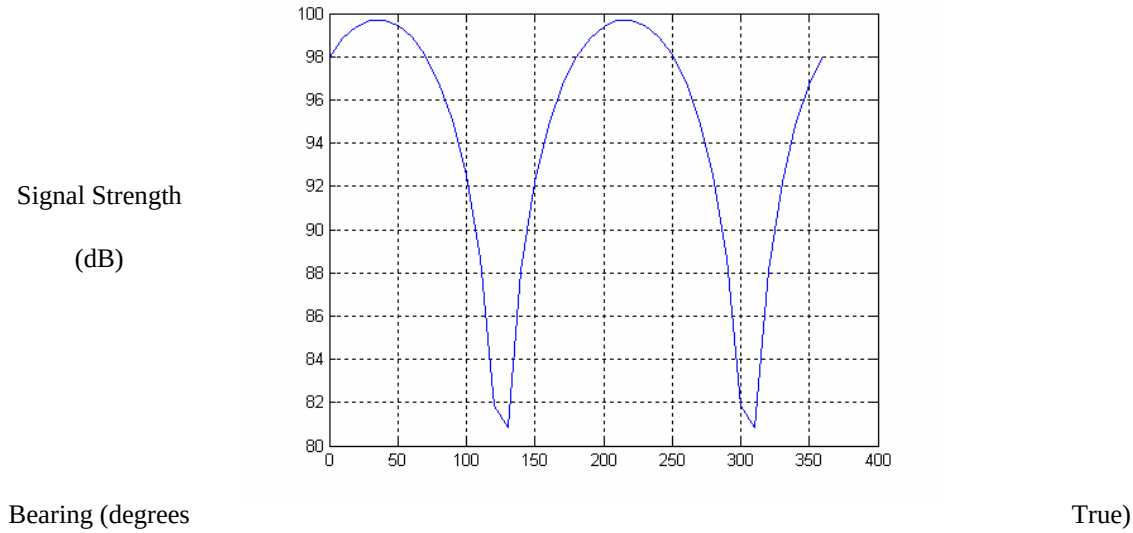
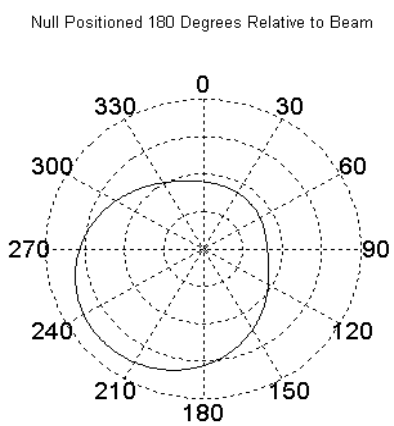


Figure 12 – Loop Steering Results (Oriented to point N/S, E/W)

The patterns seen above were very promising. As expected, a maximum value is seen around 220 degrees true, the bearing to Moriches from the lab. Deep nulls are observed 90 degrees to either side of the maximum values. Once it was determined that the loops could in fact be used to steer a beam properly, it was time to add the whip, and verify that a null could also be pointed directionally. In order to achieve accurate results, gain differences between the 3 antennas were needed. These values were obtained by manually rotating the antennas on the roof and recording the maximum values for 293 kHz, the Moriches beacon. These gain factors were adjusted in the code and again steering tests were conducted. Below, on the left, are the results obtained by steering at the beacon, and nulling 180 degrees relative to it (Figure 13). On the right, figure 14 shows the theoretical pattern that is expected for a similar case.



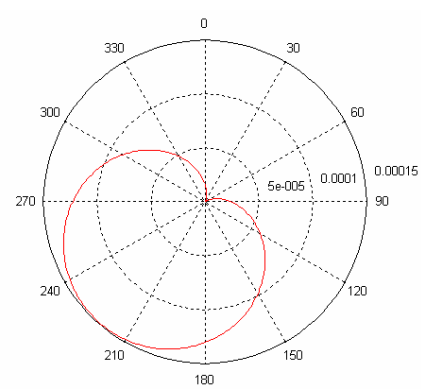
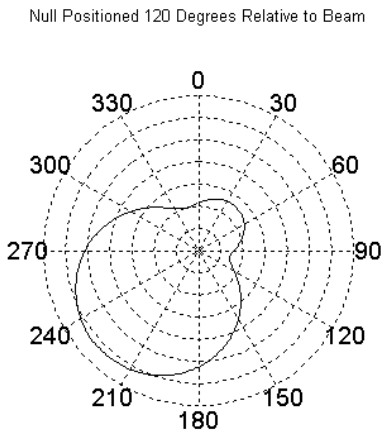


Figure 13 – Loop Steering Results (Null 180 degrees relative to beam)

Figure 14 – Theoretical Results

The plots displayed below are the results of similar tests using a beam steered at 222 degrees, and the null pointed 120 degrees relative to it (Figure 15,16). Again, the results are sub optimal, but with some adjustments of the relative gains of the antennas it is likely we can achieve better results.



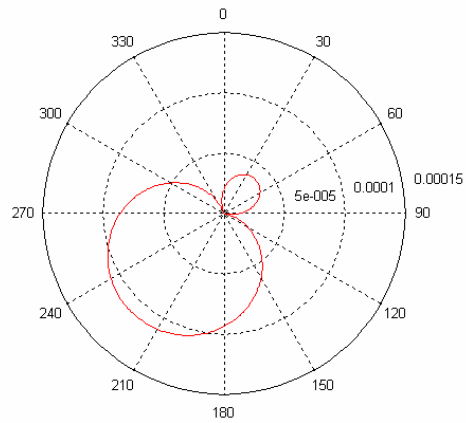


Figure 15 – Loop Steering Results (Null 120 degrees relative to beam)

Figure 16– Theoretical Results

While the results shown are not ideal, they do prove the concept of directional signal strength measuring techniques. The differences between the ideal and our results are likely due to small inaccuracies between the gain factors we used in the steering equations. Producing a deep null can only be accomplished if the gain of the channels is equal. Further testing may need to be conducted to obtain more precise gain measurements.

Conclusions

Originally, my plan called for the completion of the meter and associated testing this year. However, numerous obstacles throughout the engineering process held me back from reaching this end. Fortunately, I have made great strides in the project. My test results prove the concept of antenna beam forming and null steering techniques. Furthermore, I have assembled a complete set of equipment for the system and integrated many new, and old components to function together. The end goal of a working signal strength meter is very close. Further testing will need to be completed to obtain all the gains introduced throughout the system. These gains will be essential to determining an absolute value for signal strength. Furthermore, precise antenna gains will be needed to perfect the steering computations. Once final tests are completed and the algorithm to calculate signal strength is written, the testing phase can commence. This project has come a long way in the past year, and I believe a completed product is close at hand.

References

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