VHF-DF Testing Methodology

Krysten Benjamin

Project Advisors: Professor K. Gross & LCDR T. Routhier

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ABSTRACT

The Coast Guard Headquarters Acquisition and National Distress division (G-AND) has tasked the Coast Guard Academy with developing a testing device for the modernized National Distress and Response System. The device will test the system built by General Dynamics, which began construction in 2002. The testing device consists of two mobile data radios transmitting information between a single base station. The position information obtained from the device will be compared to the General Dynamics results. The testing of the device will begin in Spring 2004 when the radios are delivered. The year has provided an opportunity to develop a knowledge base of Very High Frequency Direction Finding (VHF-DF) and Fast Frequency Shift Keying (FFSK), and Gaussian Minimum Shift Keying (GMSK), the various modulation methods. The project has gone through initial testing and will hopefully have the opportunity to continue into full testing next year.

INTRODUCTION

The Coast Guard's current National Distress and Response System is seriously outdated. The system consists of 300 VHF-FM antenna sites that provide coverage out to 20 nautical miles from the shore, in most areas. However, a position of a distressed vessel often cannot be obtained from the system unless stated by the caller. As a result, the Coast Guard responds to thousands of hoax distress calls and cannot receive others. Coast Guard resources are wasted trying to find these hoax vessels or find a distressed vessel when no position was obtained. There is always a high risk that lives may be lost because the Coast Guard cannot respond properly.

The Coast Guard Headquarters Acquisition and National Distress division (G-AND) has initiated Rescue 21 as the solution. The Rescue 21 project is the modernization and update of the National Distress and Response System. The Rescue 21 project will update the hardware of the current system by replacing most of the outdated technology on the 300 VHF-FM antenna sites. The update of the system will provide automation in areas where there is currently none. The update will also provide coverage in areas of the United States the previous system did not. The new system will link and network systems on the coasts, eliminating localized direction finding. This means that information received in the Boston area may be available in the New York area and vice versa.

The update of the system will provide the Coast Guard with a more accurate direction finding system, enabling the search and rescue teams to search smaller areas and locate missing boaters faster. It will also enable Coast Guard stations to distinguish between legitimate and false distress calls. This will make for a more responsive search and rescue team and fewer lives will be lost at sea.

The Coast Guard awarded General Dynamics the contract to build a system to meet these needs. Components of this system are currently undergoing installations and prototyping. The Rescue 21 group has asked the Coast Guard Academy to design and produce a device that will test the new VHF-DF system for its geolocation capabilities, accuracy and any technical issues. The testing device will allow the Coast Guard to observe the VHF-DF system in different locations along the United States coast, in different weather conditions, and different modes of transportation. The device will verify the ability of the VHF-DF system to pinpoint transmissions in real-world situations. The device must be able to assess the direction finding capability of a site, be easy to use, and portable.

OBJECTIVE

The goal of this project is to ensure the General Dynamics system is producing the results the Coast Guard desires. In order to reach this ultimate goal there

are several smaller goals that must be accomplished. The testing device must be constructed, and then must be tested using a known location as a test. Once it is confirmed that the device accurately transmits positions and bearings to positions, testing will commence on moving modes of transportation. General Dynamics submitted the Rescue 21 final design proposal in 2002. Construction to build the system is underway and nearing completion. The first site is up and testing in Atlantic City, NJ.

In order to make the project easily manageable and easy to understand, each element of the project is broken down into smaller steps to avoid the burden of having a broadly defined task. Enclosure 1 shows a break down of the expected work schedule. This tree breaks down the testing device into different aspects of the project process, including testing of the device and administration.

When the project is complete there are certain items that will be submitted to the Coast Guard Rescue 21 team. There are six deliverables as listed below:

1. Report analyzing VHF signal characteristics in various conditions
2. Test system description, block diagram, functional description of the blocks, and analysis done during the system design.
3. The following manufacturing related artwork and documentations
    a. Schematic diagrams and circuit descriptions
    b. Parts list, assembly drawings, and assembly instructions
    c. Bill of materials
4. Actual testing device
5. User's Manual
6. Results and Analysis of data received from testing device

SYSTEM DESIGN

There are actually two different system designs for the test beds. Due to the ordering of additional radios from California, there are now two sets of mobile data radios. This allows for more than one verification system.

The first system, with the Key Radios has the following basic block diagram:

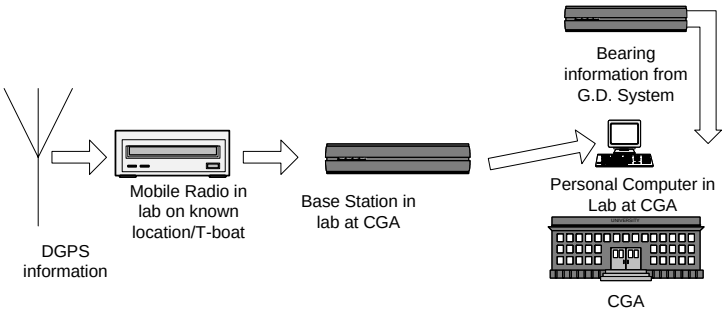

Figure 1. Block Diagram

The testing device consists of a mobile radio that transmits using Fast Frequency Shift Keying (FFSK). The first mobile radio is located on a moving mode of transportation (ultimately a Coast Guard cutter) transmitting to a base station located in a laboratory. The base station transfers the data to a computer located in lab where the information is deciphered and position information is used to calculate a bearing to the position. This calculated bearing is compared to the bearing information obtained from the General Dynamics system.

The second test bed consists of only two data modem radios. The only component that is different in the diagram above is the base station. There is no base station with the Teledesign radios, they transmit and receive between each other.

The other aspects of the project include the field-testing of the device, which is broken into two separate parts. The first part of the testing is the stationary testing, consisting of testing the device against a known position and adjusting or calibrating the testing device. The second part of the testing is the mobile testing, using different modes of transportation, ultimately ending up on a boat and comparing the results to the General Dynamics system and submitting the results.

RESULTS

Fall Semester

In the fall of 2003, I spent most of my time researching how direction finding worked. I spent a lot of time familiarizing myself with work of previous cadets. The first semester was focused on procurement and learning.

The fall semester I spent doing research on VHF-DF, learning about the projects completed in years previous. The project began in 1999 with the cadets tasked to

learn more about VHF-DF and if direction finding is accurate and possible using VHF. I learned how LTJG Shmihluk and LTJG Benin built a four dipole antenna array and used radios, that are no longer manufactured, to research VHF-DF. They provided the Rescue 21 team data on the verification, testing, and accuracy of VHF-DF. LTJG Shmihluk took the design on a Rigid Hull Inflatable boat (RHI) to help prove that direction finding can be used as an accurate way to determine position and bearing. They helped Rescue 21 know what they were looking for in a contracting company. I learned how ENS Courtade helped take a broad set of specifications given to General Dynamics by Rescue 21 and come up with very specific, detailed testing specifications. Through research ENS Courtade learned what each of the specifications meant and how they could be further defined and broken into more exact specifications. Through reading his research, I was able to better understand where his detailed testing specifications came from and why they were necessary.

ENS Courtade spent much of 2002-2003 researching different types of radios and which would be the most useful for this type of project. The radios used in previous years were no longer being maintained and the companies that manufactured them were no longer offering service on the radios. The search resulted in finding a modem radio that transmitted data packets using Fast Frequency Shift Keying modulation, or FFSK. The modem radios had a set of specifications that made them comparable to the voice transmissions of VHF. In order to figure out if the radios really did meet specifications, I had to learn about FFSK.

The radios that we are looking at modulate in FFSK, while the General Dynamics system operates in VHF-FM. The big challenge was making sure that FFSK was a valid way of looking at VHF-FM. FFSK and VHF-FM have similar power spectrum and frequency ranges. FFSK takes an input data sequence and differentially encodes it. Once the input data is encoded, the sequence follows the same process as Minimum Shift Keying (MSK), passing the information between two different frequencies with continuous phase.

In the figure below, the blue waveform represents a VHF-FM voice transmission; the red waveform represents the FFSK equivalent. Notice, the center frequency is where the axis meet, and the FFSK waveform looks like a sinc function cut in half. Notice the two waveforms follow similar paths. The nulls in the FFSK waveform occur at 4800 baud rate, which is the baud rate programmed in the radios. The baud rate is adjustable, however, if using another baud rate, the results would change and the comparison would not be comparable.

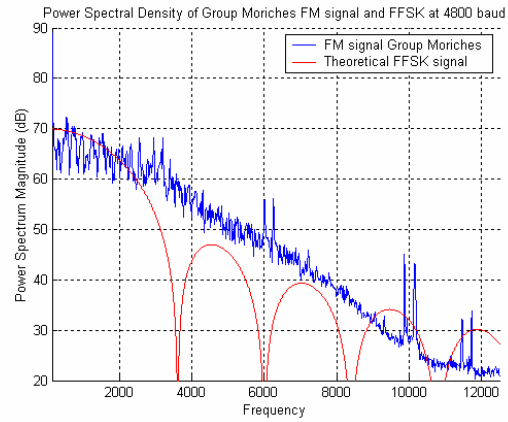

Figure 2. FFSK vs. VHF-FM @ 4800 Baud

This largest focus of the fall semester was trying to procure the radios from the United Kingdom. The United Kingdom is the only place that makes radios that have all the necessary specifications on them. The radios are required to be in the VHF-FM range (150.000 – 165.000 MHz), have embedded DGPS, and give latitude and longitude information using NMEA interfaces. The bulk of this semester has been spent doing the procurement process. I had initially filled out a sole source procurement form and attempted to purchase the radios from a single company. Key Radios Systems is the only manufacturer of the radios, however, they do not actually do the selling, and they use other companies to sell their products. The two companies that were finally used for competition were Radio Systems Limited and Radio Systems. The procurement finally went to Radio Systems Limited who had the lowest bid and were the only company to come back with a full quote.

Spring Semester

The spring semester started off with the disappointing news that the Key Radios would be delayed. It was determined that a second pair of radios would be ordered in order to speed up the results process. The second radios were ordered from a company in California called Teledesign Radios. The radios are simple data modem radios that transmit using Gaussian Minimum Shift Keying (GMSK), a modulation very similar to FFSK. The radios were within most specifications, lacking an imbedded DGPS receiver but having the ability to easily hook up to one.

The GMSK method of modulation is similar to FFSK, but it does not encode its input. Instead, GMSK takes an input string and passes it through a Gaussian filter, then it follows MSK as noted above. The two different methods are both comparable to VHF-FM voice transmissions. The only difference between the two is the baud rates at which each modulation method is comparable to VHF-FM. As shown in the Fall 2003, FFSK is comparable at a baud rate of 4800. However, GMSK at the same rate looks like the following:

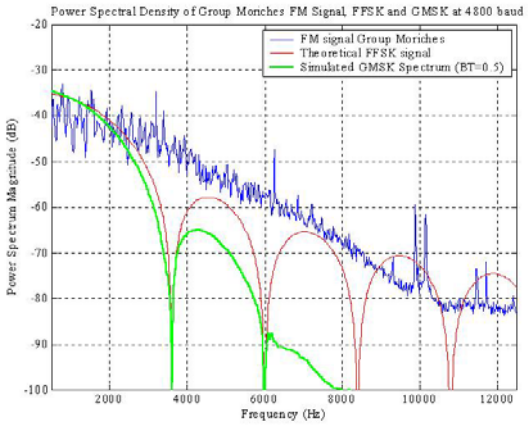

Figure 3. VHF-FM vs. FFSK vs. GMSK @ 4800 Baud

The figure is the same as before except the green curve is the GMSK modulation at a baud rate of 4800. It does not appear to follow the VHF-FM transmission very well at all. However, if the baud rate is increased, to 9600, the GMSK looks like this:

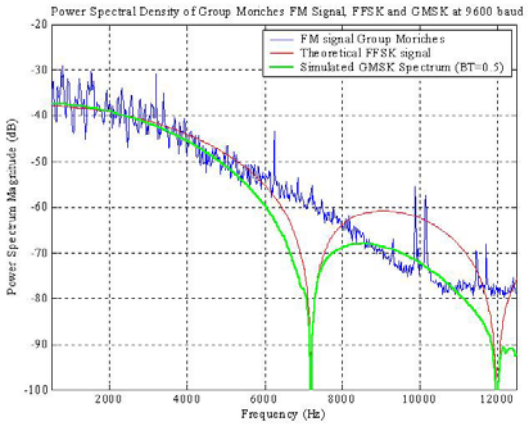

Figure 4. VHF-FM vs. GMSK @ 9600 Baud

In this figure, the GMSK modulation is much more comparable to the VHF-FM than at 4800. The FFSK still follows closely at 9600 but seems to fall off track towards the end.

The Teledesign radios and the Key Radios arrived at the same time in early March. It was then my decision to begin testing using the Teledesign radios because of the easy to understand manual. The Teledesign radios are compact and easily transportable. The Key Radio base station is large and not as compact. In addition the manual is confusing and hard to understand.

I spent the first few days of testing getting to know the radios. With the help of all the technicians in the lab, I hooked the radios up to a Trimble DGPS beacon. The radios transmit and receive well, with the receiver connected to a labtop via cable modem. I developed a MATLAB program that reads in the position of the mobile radio and computes the bearing to the location based on the position of the stationary antenna on the roof of Macallister Hall.

Once I had the radios performing the basic functions of transmitting and receiving, I found the positions of three arbitrary DGPS stations in order to test the bearing accuracy of the radios. I chose the station in Sandy Hook, New Jersey, the station in Kansas City, Missouri, and the station in Chatam, Massachusetts. Each station became the stationary position and the job of the MATLAB program was to compute the bearing from each of the stations to the Academy. The bearings calculated were fairly accurate and made it capable to move to the next level.

The next challenge was to test the ability of the radio to find a bearing while the transmitter was mobile. I took a Trimble transmitter and mounted it to the roof of my car and drove around New London, stopping at places and allowing the radio to log a few minutes of bearings to those places. I stopped at places such as Eagle Pier, the Chapel on the Academy, Ocean Beach, L&M hospital, the train station, Dunkin' Donuts, and Wendy's on Coleman street.

I ran into some technical issues during my mobile testing and realized that I would need more than one person to help me conduct tests. I enlisted the help of George Sanders, who drove his truck around with my antenna on it, so that I could determine my maximum area of transmission. I was also able to find the bearings to several different places in Groton. I found the maximum area of transmission for the Teledesign radios at 5 watts transmission and receiving power, is out to Mitchell College. The important thing to remember about the transmission area is that VHF is based on line-of-sight transmission, of which New London is not conducive. The more the VHF is used in areas where line-of-sight is prevelant, it will be easier to transmit farther.

CONCLUSIONS

The biggest challenge of the year was to integrate the pieces of the testing system. Getting the DGPS receivers, the Key radios, and the computer to talk to each other will be a challenge. The radios use a proprietary format, meaning once they read in a string of information, they encode it and talk to each other using that specific format. The only way to read the information being outputted is to buy and use the software from the company, which is being sent. The second challenge of next semester is to develop a method and computer program to convert the received strings to longitude and latitude and establish a bearing in order to compare it to the General Dynamics system.

It was for this reason that is was decided to concentrate efforts on the Teledesign radios. The radios arrived in early March and testing began immediately. The first week was spent getting the test bed set up and verifying accuracy of the system. The second week and third weeks were spent finding the maximum range of the signal for the radios. The final week was spent testing the device against a commercial direction finding system in order to verify the accuracy of the test bed even further.

There is still much to be done. The Rescue 21 system is not ready to be tested in any location from what I understand. I believe it would be in the best interest of the Coast Guard to continue this project and allow a student to continue developing these test beds for the Rescue 21 system.

The project can continue in a couple of directions. Next year, the testing can begin with the Teledesign test bed right away. It should be ready to test the Rescue 21 system at the beginning of the project next year. The second direction is getting the Key Radio test bed up and running and able to do the same measurements and calculations as the Teledesign test bed. These two systems, once up and running should be tested against a commercial direction finder to verify locally the capabilities of the test beds. The Key Radios, I predict, will have a larger maximum area of transmission.

The testing methodology developed by ENS Courtade last year needs to be revised and revisited. The methodology had many good ideas but is only tailored to one system currently. The methodology only needs to be added to and built upon to include a comprehensive plan for testing next year. Once the plan is set, the testing of the Rescue 21 system in Atlantic City, NJ can begin.

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