87’ Coastal Patrol Boat Near Vertical Incident Skywave Antenna

Final Project Paper

Cadet First Class Nick Monacelli

Project Advisor: *Doctor Michael McKaughan*

Projects in Electrical & Computer Engineering
United States Coast Guard Academy
25 Apr 08

Abstract

The goal of this paper is to explain the design and testing of an antenna for the United States Coast Guard's 87' Coastal Patrol Boat (CPB) to determine if Near Vertical Incident Skywave (NVIS) technology will improve High Frequency (HF) communications. Every other white-hulled cutter in the Coast Guard can use NVIS technology, including the 110' WPB, whose antenna was the work of a previous cadet project. It has been proven that NVIS technology increases the effectiveness of HF communication on the other cutters. The Coast Guard Academy Antennas Team (CGAAT) has been tasked to provide a recommendation by May 2008 on whether the antenna should be implemented across the Coast Guard's fleet of 87' CPBs. The CGAAT has worked on several designs and are using Numerical Electromagnetics Code software to evaluate their performance. Due to time restraints and paperwork requirements, the project was unfinished. Testing is still needed to validate the design.

Introduction

The purpose of this senior design project is to design a viable Near Vertical Incident Skywave (NVIS) High Frequency (HF) antenna for the United States Coast Guard's 87' Coastal Patrol Boat (CPB) class of cutter. The Coast Guard has already outfitted large cutters with new HF antennas based on NVIS theory of wave propagation. Coast Guard's Telecommunications and Information Systems Command (TISCOM), who is sponsoring the project, has tasked the Coast Guard Academy (CGA) to propose and test a design for the antenna. The antenna should be available to implement on the other CPBs throughout the Coast Guard.

Other Coast Guard cutters have benefited from the use of NVIS antennas and have observed better HF communications all around the globe. Communications are more clear, are more consistently high quality, and HF communications are more readily available due to the

elimination of blind spots. Previously, TISCOM tasked CGA with designing an NVIS antenna for the 110’ Patrol Boat (WPB) class of cutter. Students tested and proposed a design that is currently in a prototype stage on 3 110’ WPBs in the fleet. HF communication is very important to the Coast Guard, as many cutters rely on it for long-range, over-the-horizon communications. Having this enhanced HF capability on the 87’ CPBs will increase their mission readiness and operational effectiveness [1].

The Coast Guard Academy’s Antenna Team’s (CGAAT) work on this project should complete the request from TISCOM and will produce a viable antenna design that is tested and fleet-ready. Because of the knowledge garnered from previous NVIS project on the 110’ WPB, the timetable for this project has been shortened. CGAAT knows a great deal more about NVIS technology on small cutters because of the hard work done by previous cadets. Where it took several years to complete the 110’ WPB NVIS project, the 87’ CPB NVIS project was designed to take one year to complete.

Thus far, the CGAAT completed documentation for the project according to the System Development Lifecycle (SDLC). At the very beginning of the process, the team drafted a Business Case which thoroughly discussed the need for the project and how it would benefit the Coast Guard. The business case is included as Appendix A. Following the Business Case, a Functional Requirements Document was drafted in order to outline all of the requirements that the project would have to meet. The Functional Requirements Document is attached as Appendix B. The CGAAT then produced a Support Plan, which outlined how the project would be supported in the time after implementation. The Support Plan is attached as Appendix D. After these documents were produced, the next step was to use Numerical Electromagnetics Code (NEC) software to model an NVIS antenna using a platform model developed by LT K.

Seals and Dr. Michael McKaughan as a CGA project. The team has come up with several viable designs and is nearing the prototype stage, using CGC CHINOOK, stationed in New London, CT, as a prototype platform. The team is also working with TISCOM, Headquarters, and Electronic Support Unit (ESU) Boston to complete the requisite documentation for a prototype antenna.

In order to test the prototype antenna on-board the CHINOOK, the CGAAT had to develop a Test Plan. The Test Plan is a comprehensive document which aims to describe how to test each requirement during the testing phase. This document is attached as Appendix E. Additionally, in order to facilitate constructing additional antennas, a Design Specifications document was created which outlines exactly how to build additional prototype antennas. This document is attached as Appendix F.

This paper will provide a more comprehensive background of the project, as well as the objectives of the project. Additionally, the paper will explain more details about some of the NVIS antenna designs that the team is working on. The paper will also explain some of the details of the test results and the final design proposal.

Background

The 87’ CPB oftentimes works close to land (50-500 NM), as a result of its missions, and may have to transmit and receive HF communications with the presence of a variety of topographical features that may interfere with HF signals. These topographical features include hills, mountains, and valleys [3]. Also, the 87’ CPBs have had trouble making HF contact with other units while in the “skip zone”- the area between the sky wave and ground wave of the HF transmission. They have been unable to pick up communications, which has hindered their operations.[2,3] Additionally, the communications that they have been able to establish have

been broken and un-intelligible at times. Since the main missions of the 87’ CPB are Search and Rescue and Law Enforcement, communication is paramount to mission success, and the Commanding Officers of 87’ CPBs should not have to worry about their communications capability being suddenly crippled because of improper equipment, when more suitable equipment is available. With a better HF system of communications, the 87’ CPB would be better equipped to perform its missions.

The 87’ CPB fleet needs a better antenna to communicate using HF communications. The new system needs to be easily accessible to operators in the field and should be easy to implement on the 87’ CPB platform. The new antenna should adapt to the current antenna wiring design with minimal modifications to keep the costs of implementing the system to a minimum. The new antenna should be similar to the NVIS antenna used on the 110’ WPB and should boost the overall effectiveness of HF communications.[1] The NVIS antenna should be similar to the towel bar antenna on the 110’ WPB because the design has been verified and engineers already have a sense of the technology that will make it easier to implement a similar antenna on a different platform.

HF propagation can depend significantly on topographical features in addition to ionospheric conditions.[3] It is not line-of-sight, and most transmitters send a ground wave and skywave simultaneously.[1,2] If the receiver does not pick up either of these signals, HF communication is lost. This situation most often will occur in the skip zone. Large topographical features can block ground waves, also causing a loss of communication.[2] Since HF waves can bounce off of the ionosphere, it can be very beneficial to use over long distances- when not blocked. NVIS is a solution to prevent the disruption of propagation because NVIS propagation sends the skywave of a signal nearly straight up into the air, versus sending it at a low takeoff

angle relative to the zenith.[3] The benefit of NVIS is that it can reach places that have not received very good reception before due to the unique nature of that particular environment, geography, etc. The hope is that by installing a new NVIS antenna that can pick up these different types of HF waves, the Coast Guard will be able to better utilize the 87’ CPB because they will have better communications.[1] It will allow the Coast Guard to use 87’ CPBs fully without having concerns that the platform may lose HF communication capabilities.

Objective

The first objective of the project is to design an antenna for the 87’ CPB that will increase the effectiveness of HF communications. The antenna will be designed using antenna modeling software and an electronic model of the 87’ CPB constructed by LT K. Seals.[1] The goal is to provide a design for the antenna that can easily be tested and will not interfere with other electronics on the cutter.

A second objective of the project is to test the new design on the 87’ CPB and to gather data for analysis of the antenna’s effectiveness. There will be comprehensive testing to determine if the new antenna increases the effectiveness of HF communications testing many factors that can quantitatively and qualitatively verify the advantages of NVIS. The factors that we will test will include the radiation hazard information, mid-range communications tests, and gather Link Quality Assessment (LQA) values.. By testing multiple variables with the antenna, the objective is to gather as much data as possible for analysis to make a recommendation for the antenna’s implementation.

The third objective of the project is to analyze all of the test results and synthesize them into a recommendation for or against fleet-wide implementation of the NVIS antenna. The

analysis of the antenna data will be very similar to the analysis done by 1/c Colin McKee and 1/c Chris Capule when they analyzed test data of the NVIS antenna on the 110' WPB. The CGAAT will gather signal strength data for different variables and aims to synthesize it into a recommendation for implementation of the NVIS antenna on every 87' CPB in the current fleet.

The plan was to have the recommendation ready to provide to TISCOM by May 2008. Due to several complications arising from the fact that the 87' CPB fleet is still in the Acquisition Phase, installation of a prototype antenna proved to be impossible. Because of time limitations imparted by the length of a standard semester, there was not enough time to gather all of the paperwork required and get it through the Coast Guard bureaucracy. In lieu of testing the prototype antenna onto the CHINOOK, testing of the antenna commenced from the top of MacAllister Hall at the Coast Guard Academy. The same data was collected in order to get some idea of how the antenna would perform onboard an 87' CPB. There are many factors that must be considered for the design of the project. These factors have been garnered from the project sponsor and are synthesized in the Functional Requirements Document supplied as an Appendix B to this paper.

Assumptions will play an important role in the development of the NVIS antenna for the 87' CPB. First, that the 87' CPBs will continue to use HF communications and not switch exclusively to satellite based systems for long range communications. Secondly, that the Coast Guard will continue to use NVIS transmitters for communications. A third assumption is that the addition of an antenna will not adversely affect ship stability.

In addition to some assumptions, there were also some constraints placed on the project from the beginning. These restraints were outside of the control of the CGAAT and were a function of the equipment and test platform. One of the constraints for the project is the available

space to mount an antenna onto the 87’ CPB. Another constraint is the safety requirements for antenna radiation energy and how much energy the antenna will be allowed to emit in such close proximity of people. A final constraint is that the testing phase of the project will not be able to completely test every application of the antenna in every place that it may be used, which could mean that analysis will have to interpolate some data. Additional information about these constraints is included in Appendix B.

The sponsor of the project, TISCOM, needs an NVIS antenna that is compatible with existing hardware on the 87’ CPB and will function as well as the current whip antenna. Also, the antenna needs to be safe for crew members aboard the cutter. The radiation emitted from the new NVIS antenna must be equal to, or less than, the current amount of energy emitted by the installed whip antenna. The sponsor has asked that the antenna be easy to test for efficiency and performance, and that the design is such that it can be implemented on all 87’ CPBs if successful. This means that the antenna should connect directly to either the couplers or transceiver already installed on the 87’ CPB. If the antenna can meet these specifications, it will be much easier to test as a prototype and easier to install as a permanent replacement for both whip antennas currently used.

Lastly, the new NVIS antenna should not adversely affect the performance of any other electronic equipment onboard the 87’ CPB including the RADAR, VHF communications equipment, and GPS navigation equipment. The current whip antennas do not adversely affect any of this equipment, though the new antenna may be positioned closer to the equipment and tests will need to be conducted to ensure no interference occurs.

System Design

The NVIS team is developing a horizontally polarized antenna to be mounted on top of the 87' CPB pilothouse. The main design that the CGAAT is working on requires using 3" diameter n To Coupler e CGAAT used knowledge learned by the 110' WPB project to influence designs. The layout of the 87' CPB also played a significant role in how we came up with the design.

The CGAAT knew that 3" diameter tubing worked well on the 110' WPB NVIS antenna, and there was some material left over from the previous project. Since the material worked well, and because of the availability, we decided that the 3" tubing was a good solution. Secondly, the 110' WPB NVIS antenna was horizontally polarized and mounted topside, immediately below the bridge. Because of the smaller size of the 87' CPB, that same position was unavailable because of RF energy emissions and the team was limited by the size of that area.

Instead, we decided that the best place to mount the antenna would be on top of the pilot house. Here, there would be minimal RF energy exposure as few individuals venture to the top of the pilot house. This is especially true while the cutter is underway due to the radar antenna. The concern with placing it on top of the pilot house was that other electronics, namely the radar, might interfere with the effectiveness of the antenna. This interference has been modeled using the NEC software; however, more tests are necessary to determine the full effect.

Another benefit from placing the antenna on top of the pilot house is that there are already some "kickpipes" (wire channels) running from the bridge to the top of the pilothouse. Figure 1 is a sketch of the design. This would make connecting the NVIS antenna very easy because the CGAAT will not have to drill any additional holes into the superstructure of the ship to route wires. Further, by placing the antenna on the pilot house, we will be minimizing the

possibility of damage due to individuals grabbing onto the antenna, dropping items on it, or otherwise tampering with it.

Regarding the shape of the antenna, we relied on antenna theory and knowledge of propagation, knowing that the signals would be HF. We knew that we wanted to keep the antenna only 6”-8” above the deck because of fear of interference from the radar antenna, which

Figure 2: Photograph of Forward Pilot House

sits at a height of 2’ above the deck. Additionally, propagation theory dictates that the performance for this type of antenna will increase with the length. Because it resulted in the longest antenna, we decided that a “U” shaped antenna would perform the best.

Because of the characteristics of NVIS, we also knew that the antenna must be horizontally polarized in order to most effective transmit and receive HF NVIS. Some additional shapes that are possible solutions to the design are modifications of the “U” shape in Figure 1.

These include an “L” shape, a “U” shape oriented in the reverse manner, or a simple towel bar across the fore of the pilot house. Figure 2 is a picture of the forward part of the pilot house and depicts the radar antenna discussed previously.

Our designs are being modeled and tested using NEC software in the laboratory. Figure 3 is the “U” shaped antenna as modeled in NEC. It is clear from the model that there are many pieces of electronic equipment on the top of the pilot house. Because of the strong radiation of the radar antenna, that remains to be the main focus of concern for interference.

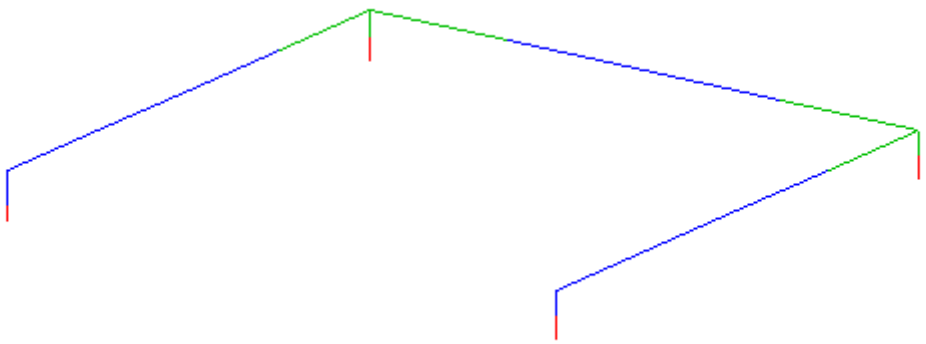

Figure 3: GNEC Representation of U Antenna

There is also a GPS receiver, DGPS receiver, secondary HF antenna, several searchlights, several loudspeakers, and VHF antennas present on top of the pilot house or on the mast. The CGAAT was not as concerned with these electronics due to the nature of their RF energy emission, which would be relatively low.

Additionally, the “U” shaped design was modeled with the current whip antennas still in place. The starboard side whip antenna is only designed to received HF signals, whereas the port side whip antenna both transmits and receives HF signals. Eventually, when the final design is

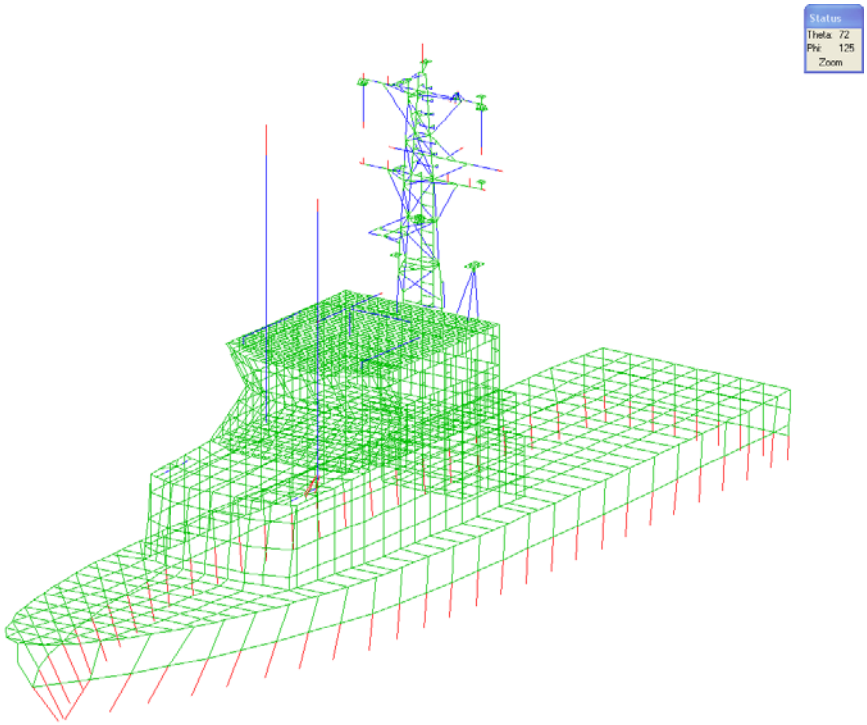

Figure 4: GNEC Representation of 87’ CPB With Antenna

implemented, the antenna may or may not remain. The final design will be grounded at one end, and the other end will be connected to a coupler that will be mounted on the overhead in the bridge. It is fed via an RT-9000 HF transceiver mounted onto the bridge.

Figure 4 is the GNEC representation of the “U” shaped antenna mounted on the 87’ CPB and clearly shows the aforementioned electronic equipment.[1]

The prototype antenna was built at a local machine shop- Watrous Machine Shop of Mystic. The contracted work was necessary due to the workload of the Academy staff. The total cost of manufacturing the antenna was $1500.

The installation of the antenna onto the CHINOOK was scheduled to be done by the NVIS team, with minimal cost. The estimated time to install the antenna onto the CHINOOK was only 1 day.

A prototype antenna was built at Watrous Machine Shop in Mystic, CT. An additional, similar prototype for the McAllister Hall tests was also built at Watrous. The total cost of manufacturing each antenna was $1500. After assuming control of the project, TISCOM may contract out the manufacturing of the antenna to other shops.

Some concerns with manufacturing and implementation involve the paperwork necessary to place a prototype antenna on CHINOOK. It proved to be too much for the project to handle given current time constraints. It will involve cooperation between TISCOM, ESU Boston, and ESD New Haven in order to run the tests smoothly. Both ESU and ESD New Haven are responsible for the electronics aboard CHINOOK. Additionally, because the 87' CPB is still in acquisition, Headquarters and the Engineering Logistics Center (ELC) must also get involved. The MacAllister Hall tests did not provide solid data on the antenna. However, the only way to determine if it will work well onboard the 87' CPB is to do an underway test. This test will occur at a later date and may be accomplished by a different CGAAT.

Results

Because the CGAAT was unable to perform any underway testing of the antenna at the time of publication of this paper, there are minimal results to show for the year of hard work put in by the CGAAT. Additionally, the MacAllister Hall prototype antenna also did not yield any results due to some un-known complications. More testing and diagnosis of both the antenna and RT-

9000 transceiver are necessary in order to conduct testing. The CGAAT attempted testing with both underway and ashore assets, but none of the tests were completed.

Unfortunately, the reality of the Coast Guard's process to install the antenna onto the 87' CPB proved insurmountable for the CGAAT. The hope is that a future cadet project will involve completing the testing of the antenna which can provide some valuable data to give to TISCOM to assist them in their decision to install the antenna on the entire fleet of 87' CPBs.

Conclusions

The CGAAT has worked hard to come up with a viable design to the problem posed by TISCOM. The CGAAT has researched NVIS propagation and applied knowledge based on previous projects to come up with a satisfactory design. This paper summarizes what we have accomplished and what future students need to do to continue the project and perform a test on the 87' CPB with the prototype antenna.

Unfortunately, due to the time and paperwork constraints placed on the project by the academic year, the project was left un-complete and results were minimal. The project is in a state such that a competent student from the 2009 graduating class of electrical engineers could pick it up and continue by simply routing the paperwork for testing through the necessary channels and then conducting the testing. Some future cadet is set up for success to complete the project. Based on our knowledge of the NVIS technology and the design of the 87' CPB, the antenna will fulfill the requirements set forth by TISCOM.

References

[1] McKaughan, Michael. "High frequency electromagnetic environment of the U.S. Coast Guard 87-foot coastal patrol boat." ACES Review of Progress in Applied Computational Electromagnetics. Monterey: Applied Computational Electromagnetics Soc , 1999. 449-454.

[2] Tooby, M.H. "Assessment of the propagation characteristics of the HF NVIS channel." International Conference on HF Radio Systems and Techniques. Guildford: Institution of Electrical Engineers, 2000. 263-267.

[3] D'Avignon, J. "NVIS Propagation." Short Wave Magazine (1998): 39.

[4] Cybert, Kevin. "USCG 270 prime Cutter - NVIS Antenna Study." Annual Review of Progress in Applied Computational Electromagnetics. Moterey: Applied Computational Electromagnetics Society, 2003. 867-872.

Bibliography

[1] Mora, Darla. "Modeling an HF NVIS towel-bar antenna on a Coast Guard patrol boat a comparison of WIPL-D and the Numerical Electromagnetics Code (NEC)." IEEE/ACES International Conference on Wireless Communications and Applied Computational Electromagnetics. Honolulu: IEEE, 2005. 140-143.

[2] Burgess, S.J. "Short-haul communications using NVIS HF radio." Electronics and Communication Engineering Journal (1999): 99-104.

[3] Austin, Brian A. "Application of characteristic-mode techniques to vehicle-mounted NVIS antennas." IEEE Antennas & Propagation Magazine (1998): 7-21.

[4] Jones, T.B. "HF PROPAGATION AT HIGH LATITUDES." IEE Conference Publication. New York: IEE, 1987. 155-169.

[5] Murray, K.P. "Synthesis of vehicular antenna NVIS radiation patterns using the method of characteristic modes." EE Proceedings: Microwaves, Antennas and Propagation (1994): 151-154.

[6] Austin, B.A. "Evolution of near vertical incidence skywave communications and the Battle of Arnhem." IEE Proceedings: Science, Measurement and Technology (2002): 92-98.

Appendices

[A] Business Case

[B] Functional Requirements Document

[C] Project Plan

[D] Support Plan

[E] Test Plan

[F] Design Specifications