Modeling and Testing a Prototype HF Towel-Bar Antenna on a Coast Guard Patrol Boat - 110-Ft Working Patrol Boat (WPB)

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Abstract: An undergraduate capstone project is described where students have designed a Near-Vertical Incidence Skywave (NVIS) for a Coast Guard 110-foot working patrol boat (WPB). This paper presents follow-on work to that reported at the 2005 ACES conference. The emphasis of this part of the project is the installation and testing of a prototype antenna on a patrol boat. Test results of preliminary antenna measurements are discussed. The projection of the actual installation process and testing are also included.

Keywords: Skip zone: A skip zone is the distance from where the ground wave ends and where the sky wave returns to earth after reflecting off of the ionosphere.[1]

NVIS: Near Vertical Incident Skywave. NVIS antennas radiate HF waves at nearly vertical angles. The HF waves reflect off of the ionosphere and return to earth at distances between 50 and 500 nm.[2]

LQA: Link Quality Analysis is a percentage ranging from 30 to 70 based on the radio's signal to noise ratio at a given frequency. [3]

ALE: Automatic Link Establishment. ALE is a radio transceiver function that automatically runs through a pre-programmed set of frequencies in search of the highest possible Link Quality Analysis value. When the transceiver arrives at a frequency with a good LQA it automatically uses that frequency for transmission.[3]

1.0 Introduction

The 110-foot Patrol Boat (WPB) cutters are an important asset for the Coast Guard, but their capabilities have thus far been hindered by a significant communications problem. These cutter's primary missions include search and rescue (SAR) and law enforcement (LE) operations. The execution of these missions takes the cutters offshore, beyond the capabilities of very high frequency (VHF) communications.

Mid-range communications using the current high frequency (HF) antenna configuration on the 110-ft cutter has proven unreliable.[4] 110-foot cutters use two whip antennas for HF communications. The whip antennas generate a low take-off angle for outgoing HF signals. This take-off angle causes a large skip zone around the cutter. As a result, the cutter's HF communication within the range of 50 to 500 miles is poor. Near Vertical Incident Skywave (NVIS) antennas are currently being tested by the Coast Guard on large cutters. Shore-based NVIS antennas are also being investigated. NVIS antennas send out HF waves at nearly vertical angles.[5] Thus a NVIS antenna should eliminate the skip zone that currently plagues 110-ft WPB HF communications.

2.0 Previous NVIS Modeling and Development

The development of a NVIS antenna for a 110-ft WPB cutter began as a U.S. Coast Guard Academy capstone senior design project three years ago. Each year cadets have one year to work toward an answer to the problem before they graduate, leaving the work to be resumed by the next year of cadets assigned to the project.

a) The project began with the work of Cadet 1/C Sean Barnhill. Barnhill determined that the best design was a "towel bar" NVIS antenna. Barnhill's work consisted mainly of computer modeling, using two antenna-modeling programs called NEC4 and WIPL-D.[6]
b) The project continued with the work of Cadet 1/C James Miller who compared the computer models created by NEC4 and WIPL-D.[7]
c) The most recent year's work involving the towel bar NVIS antenna was done by Cadet 1/C Darla Mora and Cadet 1/C Chris Weiser. Mora and Weiser initially used computer antenna modeling software to develop various NVIS antenna models. Mora and Weiser confirmed that a "towel-bar" shaped NVIS antenna was the most effective design. Mora and Weiser modeled and compared characteristics such as the radiation patterns, driving point impedance, and signal strength for the NVIS antenna at various locations on the cutter. Last year's work determined that the best location for the NVIS antenna was on the superstructure in front of the bridge. In addition to computer modeling, Mora and Weiser constructed a prototype antenna.[4] 1/C Mora and 1/C Weiser presented a paper to the 2005 ACES conference discussing their findings for NVIS antennas on 110-ft WPB class cutters.[8] This present work describes the continuation of last years work.

3.0 Fall Semester Work

The purpose of this year's project is to test a "towel-bar" NVIS antenna on a 110-ft WPB cutter to determine if the NVIS antenna corrects the current mid-range HF communication problems.

a) Thus far, a land-based set up was created to test the antenna. The antenna built last year was bolted to a grounded aluminum beam on the roof of McAllister Hall, the engineering building at the Coast Guard Academy. It was connected to the RT-9000 HF radio transceiver. The RT-9000 is the ALE-capable transceiver used by all Coast Guard 110-ft WPB cutters. This land-based set up was created for preliminary prototype antenna comparisons with predictions generated by the computer modeling results.
b) The impedance of the prototype antenna was measured over the frequency range of 2 MHz to 20 MHz. These data were then compared to prior year's computer modeling predictions.
c) We attempted to communicate with Coast Guard Station, Woods Hole, MA. This quick test was unsuccessful. As of this writing, we have not yet determined why the test failed. This will become a priority for the second semester of our work.
d) Other land-based testing still to be completed includes: Measuring near field radiation characteristics to compare to past year's computer models, and validating the test plan that we will use on the 110-ft WPB cutter in the field.
e) The test plan consists of using the RT-9000 ALE capabilities to run through a range of CG HF frequencies at increasing distances from a shore based NVIS antenna. For the land test, we will run through the CG HF frequencies using the ALE capabilities. We will record the LQA values given by the RT-9000. This will be the quantitative test of the quality of communications when we test our towel bar on the 110-ft WPB test platform. We will run the test on land first to ensure that it is possible to electronically observe and record the LQA values produced by the transceiver.
f) The ultimate purpose of land based testing is to ensure that the entire set up, consisting of the transceiver, antenna and coupler, functions as expected and to trouble shoot our process before we arrive for testing on the 110-ft WPB test platform.

4.0 Analysis of the Impedance Data

The primary source of objective data analyzed so far this year is the results of impedance testing on the land based McAllister Hall antenna. These tests were intended to compare the fabricated antenna's driving-point impedance to that predicted by WIPL-D over the intended frequency range. The results of the comparison showed that the modeled and measured values are not identical; but are related. In fact, the differences between the two impedances can be described by the differences between real and ideal antenna environments.

a) Reflection coefficient data for the antenna were collected using an Agilent 4396B Vector Network analyzer to determine the actual driving point impedance. Data were recorded from 2 to 20 MHz. Figure 1 presents the Smith Chart display of data captured network analyzer. The figure shows that the antenna does not present a 50-Ω match to the analyzer. However, using an antenna coupler, it appears that the antenna can be interfaced to the RT-9000 HF transceiver without difficulty.

b) After reflection coefficient data were recorded, they were converted to real and imaginary impedance values using MATLAB®. The results of this conversion are presented in graphical form in Figure 2. In addition to the impedance data from the network analyzer, impedance data from the WIPL-D model have been included in this figure.

c) It is important to discuss the differences between the WIPL-D model and the impedance values obtained from the actual test antenna. In understanding these differences, we can predict the performance of the real antenna installed on the actual cutter. There are two distinct characteristics of the data that should be addressed. These are the frequencies of the resonant peaks, and the amplitude of the peaks. The amplitude of the resonance peaks are different. The WIPL-D model estimates a peak of approximately 22 kΩ at a frequency of 10 MHz while the measure peak amplitude is around 6 kΩ at 15 MHz. We believe that these differences can be explained by comparing the differences between the WIPL-D model and the actual test antenna on the roof of the engineering building. The WIPL-D model assumed a perfect electrically conducting (PEC) structure for the ship and the antenna. This would lead to a low-loss antenna structure with a high quality factor. The actual towel bar antenna on the roof of the building was made of aluminum. Additionally, the towel bar was bolted to an aluminum I-beam that was not securely grounded to the building lightning arresting system. Thus, one might expect the actual ground for the roof-top antenna to be much less efficient than the PEC hull of the patrol boat used in the WIPL-D model. To test this hypothesis, we plan to adjust the conductivity of our WIPL-D model and to gather some data from a NEC4 model of the same patrol boat. We also will attempt to provide a more secure ground to the roof-mounted antenna.

5.0 Spring Semester Work

The second phase of this project involves installing a NVIS antenna on an actual Coast Guard patrol boat. We presently have permission to install and test our antenna on USCGC SAPELO, a 110-ft WPB cutter operating out of San Juan, Puerto Rico. This work is scheduled to be completed in February 2006.

This cutter was selected because it operates in the Greater Antilles region, and its operating schedule conveniently matches the schedule we anticipate for our project. In addition, the crew of the patrol boat is familiar with our work, and is interested in being involved in the research effort. A significant advantage of a platform in the vicinity of Puerto Rico is the presence of the mountains in the center of the island. It is well-know in Coast Guard operations that these cutters have difficulty communicating on HF back to the group commander once they sail around to the opposite side of the island. We believe that NVIS signals will propagate over the mountains by bouncing directly overhead off of the ionosphere. This will give us solid proof that the NVIS mechanism is working as we expect, and that this mode truly will help improve the HF capabilities of our Coast Guard assets.

The effectiveness of the antenna will be evaluated both subjectively and objectively in the distance and obstruction testing. One part of the test will be the subjective measurements of how well the test team members can hear and speak to each other, the other will be the objective link quality analysis (LQA), measurements taken from the radio itself. The results of the tests will be studied to determine if the NVIS antenna concept really is an answer to the Coast Guard's mid-range HF communications issue.

If the antenna testing is successful, the project can move forward toward the development of NVIS antennas for other Coast Guard assets. Another objective of this year's project is to model an NVIS antenna for the 87-ft Coastal Patrol Boat (CPB). This antenna will be based on the results found during the 110-ft WPB cutter testing. The NVIS antenna models and potential installation locations created this year for the 87-ft CPBs will create a solid knowledge and design base for future groups to prototype an antenna for the fleet of 87-ft CPB's.

6.0 Conclusions

We have presented the project plan to install and test a NVIS antenna aboard a Coast Guard 110-ft patrol boat. We have presented results from a WIPL-D model and from a prototype test antenna. We have also included our plan for a complete test of an antenna installed on a working Patrol Boat, plus the plan to investigate modeling a NVIS antenna for another class of cutter.

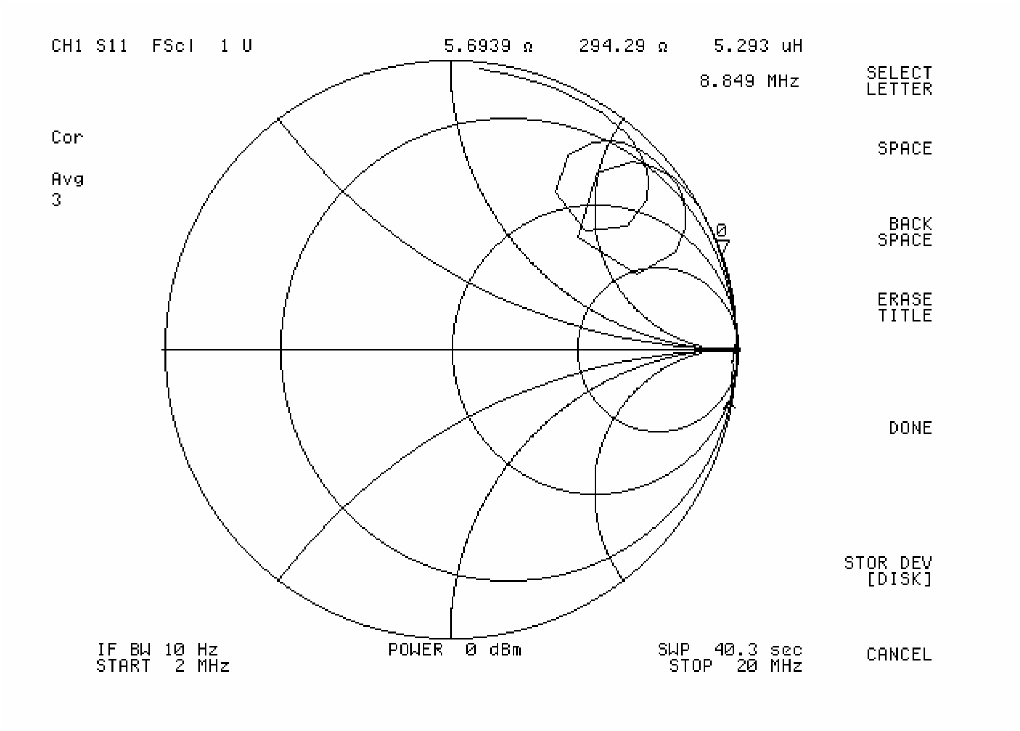

Figure 1: Smith Chart display of roof-top towel bar antenna driving point impedance collected using the Agilent 4396B Vector Network Analyzer over the frequency range of 2 - 20 MHz.

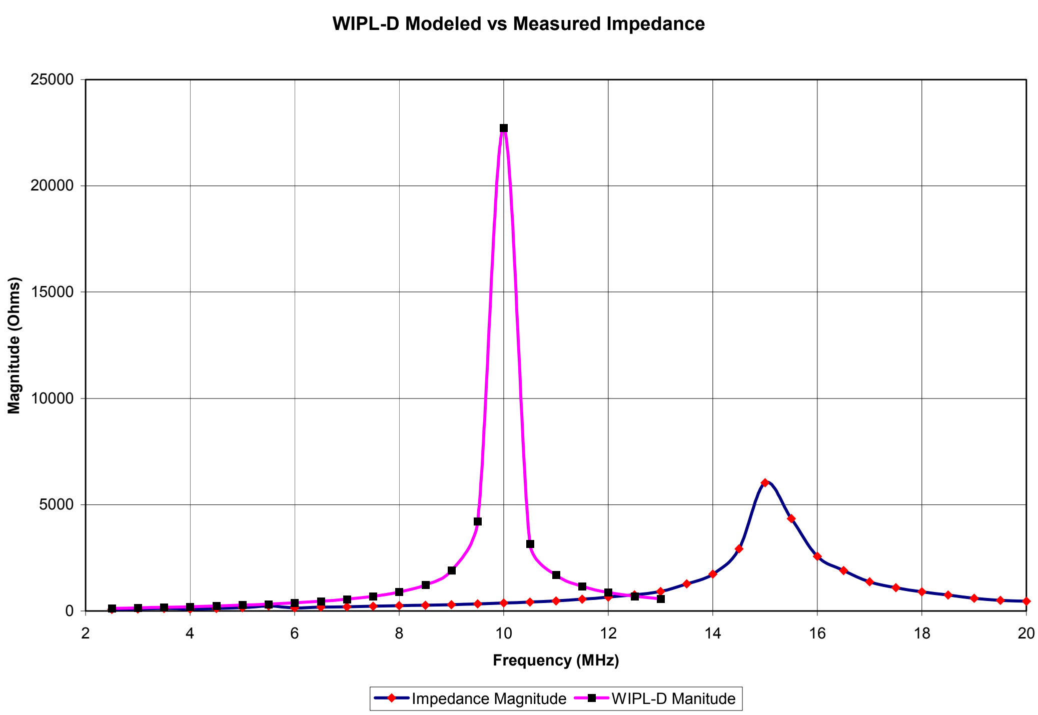

Figure 2 Graph comparing WIPL-D predicted impedance and measured impedances.

7.0 References:

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