Antenna Modeling for 110’ Cutter

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Project Advisor: Dr. M. E. McKaughan

Projects in Electrical & Computer Engineering
United States Coast Guard Academy
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ABSTRACT

Coast Guard 110-foot patrol boats currently have unreliable HF communication from 50 to 500 miles. The problem was presented to cadets to find a solution. Telecommunications and Information Systems Command (TISCOM) has also noted this problem, and is the sponsor for this undertaking.

Coast Guard 110’ patrol boats currently have whip antennas that produce a radiation pattern that extends outwards rather then vertically. This is what causing the current dead zone. We planned on building a towel bar antenna that would produce a Near Vertical Incidence Skywaves (NVIS) in order to reducing or eliminating the current dead zone.

We tested this theory using two computer antenna modeling programs, NEC and WIPL-D. We used these programs to confirm that our chosen towel bar antenna design was the best solution to solve this problem. We also used our finding in both programs to submit a conference paper discussing the possible validation of the WIPL-D by comparing results generated by NEC. We were able to attend and present this paper at the 2005 ACES/IEEE Wireless Communications & Applied Computational Electromagnetics Conference.

We then acquired an assortment of measurements on a 110’ for the purpose of accurately building a mock antenna. We used these measurements to make sure that a prototype antenna that could be installed on a Coast Guard 110’ patrol boat.

The next step in this project will be to install a prototype antenna and perform tests. Although a test plan was developed, we were never able to install and take actual antenna radiation and driving point impedance measurements due to logistics and time constraints.

INTRODUCTION

Coast Guard patrol boats rely on communications from nearby ashore units and other close by units to complete their missions. However, short-range, high frequency communication is very unreliable on the 110’ Coast Guard cutters. This problem can be, in part, attributed to the high frequency whip antennas currently on board. The current whip antennas produce a radiation pattern that looks much like a donut that is cut at the equator. This can be seen in figure 1.

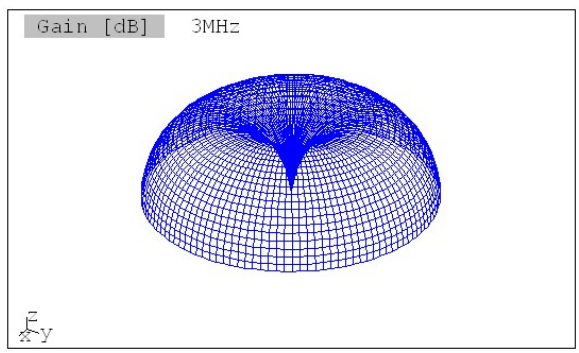


Figure 1. The Radiation Pattern Produced by a Whip Antenna at 3MHz Produced in WIPL-D

The whole in the center produces a very low take off angle (angle at which radiation from an antenna moves in the air) relative to the surface of the water. A low take off angle causes a large skip zone, thus causing a dead zone where communication is possible. This dead zone is from the end of the ground wave, which extends about 50 miles from the ship, to the point where the sky wave returns to the Earth, approximately 500 miles from the ship. This occurrence can be seen visually in figure 2.

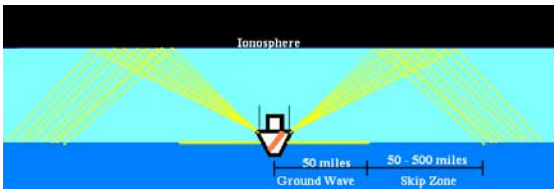


Figure 2. Large Skip Produced from a Low Take Off Angle

Mr. Sean Barnhill (2002-2003) and ENS James Miller (2003-2004) each did research on different antenna configuration that could be used to solve this problem using computer modeling. They then tested these antennas in different locations on the ship to determine which would produce the best-desired results using computer programs and metallic models. Part of their goals were to meet the Personnel Exposure Limits (PEL) for the amounts of radiation personnel on board can be exposed to as described in Commandants Instruction 10550 shown in APPENDIX 1.

They each determined that a towel bar antenna would be the best solution to this problem because it created a Nearly Vertical Incident Skywave (NVIS) that increases the take off angle. A towel bar antenna will produce a radiation pattern that is seen in figure 3.

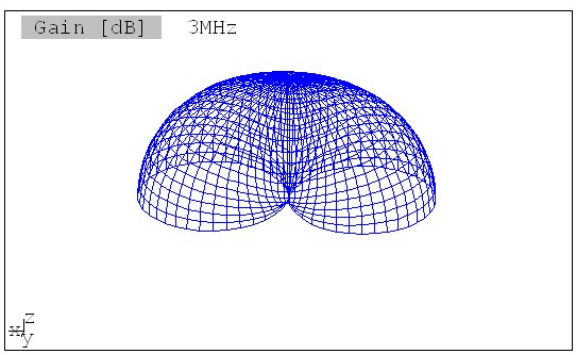


Figure3. The Radiation Pattern Produced by a Towel Bar Antenna at 3MHz in WIPL-D.

The radiation pattern has a similar shape to a slinky. We are concerned with only the top 20 – 30% of this because this is where the NVIS will be produced, at angles above the horizon between 60 and 90. The top portion of the pattern should be fairly circular thus producing an omni-directional signal.

Their research also concluded that the most effective location for the new antenna was along the front of the cutter's superstructure.
The towel bar antenna located in the front of the ship should allow the overlapping of the ground waves with the sky wave. This effect can be seen in figure 4.

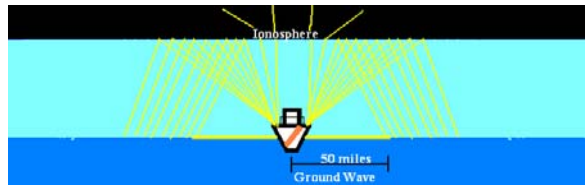


Figure 4. The Predicted Skip Zone, Allows for Overlapping of the Sky Wave and Ground Wave.

This should eliminate, or at least decrease the size of the dead zone. The signal that is escaping through the ionosphere should not cause concern as long as the majority of the nearly vertical sky waves return.

We have spent time verifying the results determined from previous years and analyzing it in order to determine all the details needed to implement the antenna on a 110-foot Coast Guard cutter.

OBJECTIVE

The objective of the new antenna was to be able to replace the current whip antennas on the 110' cutter with little to no modifications. No new or additional antenna equipment, including the antenna couplers, should be needed for installation. The antenna must be able to withstand the rough conditions that a 110' cutter goes through daily. It must function in all weather and sea conditions. It must also not interfere with the cutter's crew daily work onboard both while in port or underway. In addition, basic maintenance of the antenna must be able to be done by Coast Guard Electronic Technicians. Parts to repair the antenna must be easily attainable. We wanted to be able to physically build a towel bar antenna suited for these needs. The purpose was to install it on a 110' cutter and use a test method we designed to gather actual results. We would use these results to improve the antenna design in order to solve the problem with HF communication onboard.

A secondary objective we had for this project was to validate our theoretical data produced by WIPL-D and NEC by comparing it to the actual data collected once the antenna was installed. Before that was to occur our goal was to identify any differences in code and results generated between the two modeling programs and presenting our findings at a conference.

SYSTEM DESIGN

The project intended for the design, building, and installation of the new antenna on the 110-foot Coast Guard Cutters. Testing of the antenna model occurred in both GNEC and WIPL-D, two antenna-modeling programs, for the purpose of gathering theoretical

data. Using these programs, we were able to graph the radiation patterns of each candidate, so we can determine which will increase the short-range communication onboard a 110-foot cutter, based on its vertical radiation strength. The programs also provide data on the driving point impedances of the antenna at each testing frequency.

Our first undertaking was to make the two computer program models, NEC and WIPL-D, be as similar as possible. NEC has is an accredited antenna modeling program and has been used for over 20 years by the Coast Guard Academy. WIPL-D has only been used in the last five years and is still trying to make its way as a reliable source for antenna modeling. The model built in WIPL-D by ENS Miller was used as a baseline and caused us to make several changes to the GNEC model that was created by ARINC. The changes made were: moving the entire model forward on the y-axis so that origin on both coordinate systems was in the center of the model and replacing the direction of the antenna. The original design on GNEC had the towel bar parallel with the surface (water) and WIPL-D had the antenna perpendicular with the surface.

After the two programs were as close to being identical as possible the next step was looking at the radiation patterns produced by the antenna at each frequency, 3 MHz – 12 MHz at .5 MHz intervals. These frequencies were chosen based on the research conducted in previous years on the subject. The data we were looking at were the radiation patterns and driving point impedances. Because of the differences between the two modeling programs, a MATLAB program was developed to take the tabular data from both programs and plot the radiation patterns simultaneously on one plot. This allowed for easier comparisons. Aspects of the radiation plots we were concerned with were the overall shape, location of nulls and depth of nulls at each frequency. Driving point impedances were plotted to observe relative signal strengths at each frequency. During this process we noted similarities and differences among the two computer modeling program's code and generated results.

After confirming the recommendations that were made by Mr. Barnhill and ENS Miller, through favorable results that were produced by the two computer programs. They both recommended using a towel bar placed on the front section of the superstructure of the cutters as in figure 5.

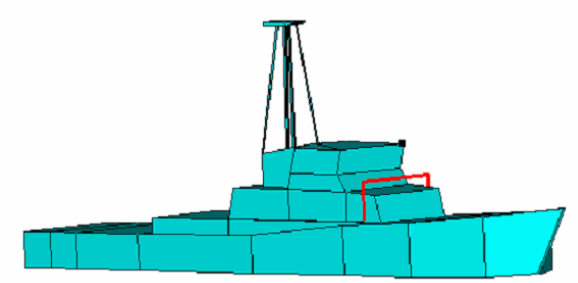


Figure 5. WIPL-D model of 110- foot cutter with the towel bar antenna on the front

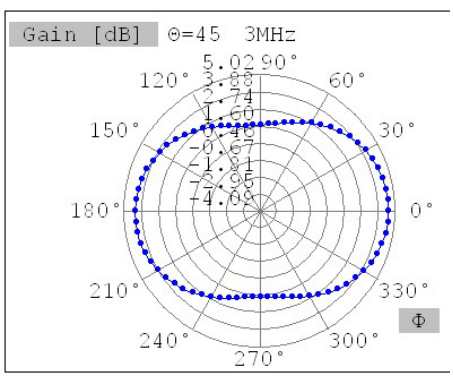
We verified and further defined this location after making a visit to the SANIBEL, a Coast Guard110' in Woods Hole MA. While on the SANIBEL we took measurements of various lengths, slopes, and locations of lights on a 110 so we could accurately build a mock antenna. We used the mock antenna to produce a prototype antenna that can be installed on a Coast Guard 110' patrol boat.

We designed a test plan to obtain data that would verify whether our theoretical results were correct. We planned on testing in Hawaii, Florida, or Puerto Rico. We decided those locations would be best because of the large amount or shoreline they each have. We are aware that the same communication difficulties caused in the dead zone occur when the skywave's low take off angle come into contact with mountains or tall obstructions on land. If we could conduct testing in any of the three locations mentioned above, we would install an NVIS antenna on land as well as the towel bar antenna on the 110' cutter. We would try to transmit and receive from both locations at frequencies between 3MHz and 12MHz, while underway. Using our results, we would be able to determine the accuracy of the antenna's data transfer and range abilities. Also we could infer the antenna's radiation pattern and driving point impedances. The same procedures would be conducted for the current whip antennas obtain an control set of data.

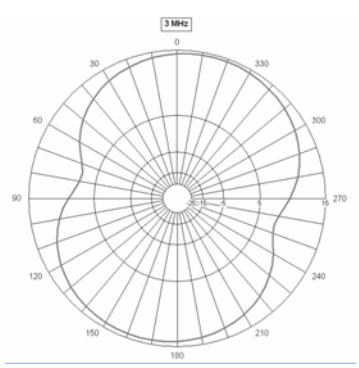
RESULTS

Both radiation patterns and driving point impedances generated by WIPL-D and NEC were examined. One of the first differences in the two codes we noticed was the way they polar plot radiation patterns were plotted. When referring to elevation angles, WIPL-D ranged from 0 degrees to 90 beginning at the horizon and ending at zenith. However, NEC referred to elevation angles as from zenith to horizon. In other words, a zero angle of elevation would be at the horizon in WIPL-D, but at zenith in NEC. This

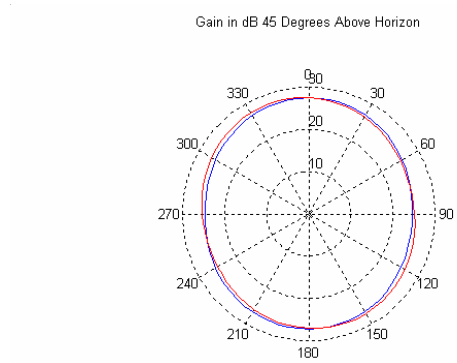
difference was noted and for future plotting purposes the WIPL-D convention of referring to angles of elevation was used. Also, both polar plots were shown in a counterclockwise direction. We chose to reverse this because when discussing bearing angles with reference to any water vessel, degrees are discussed in 360 degrees relative around the ship in a clockwise direction. Figure 7 shows radiation patterns plotted in WIPL-D and NEC separately for the same elevation angle and frequency. Each pattern is taken 45 degrees above the horizon and 360 degrees around the center, and the bow of the ship is oriented at zero. However, WIPL-D places its zero degree on the right, while NEC places the same angle at the top of the plot. These differences made it difficult to compare results. Therefore, we created a MATLAB code to create polar plots of radiation patterns for both codes on the same plot. This code can be found in Appendix 2. The tabular data from both modeling programs was inserted into an excel spreadsheet and normalized for comparison reasons. Therefore, signal strength differences can be compared relative to each other. The MATLAB code accessed this data and plotted both data gathered for the same frequency on one plot with zero at the top of the plot and degrees increasing clockwise. This output plot can be seen in figure 7(c).



(a)



(b)



(c)

Figure 7. Polar Plots of Radiation Patterns for a Towel Bar Antenna at an Angle of Elevation of 45-degrees at a Frequency of 3MHz. (a) Plot Generated by WIPL-D. (b) Plot Generated by NEC. (c) Plot Generated by MATLAB Code of Same Data Used to Create Plots (a) and (b).

From that point we continued to use the MATLAB polar plots to make conclusions based on our data. These plots can be seen in Appendix 3.

What we are looking at in each pattern is the directions in which the information is going to (the overall shape of the radiation pattern), especial the location and depths of the nulls. The direction is important because we need to know if the information will be sent no matter which direction the ship is heading. From the patterns it can be seen that there is never a perfect circle around the point of origin on the cutter. However, the main concern is that the information will be sent in all directions and from our patterns this can be seen that it does happen for each tested frequency. The nulls are important because they explain where communication is not going to occur. The visual representation of nulls was decreased in the MATLAB plots due to normalization of the data.

In our comparison of the two computer modeling programs, we also examined the driving point impedances generated by each program. These can be seen in figure 8 and figure 9.

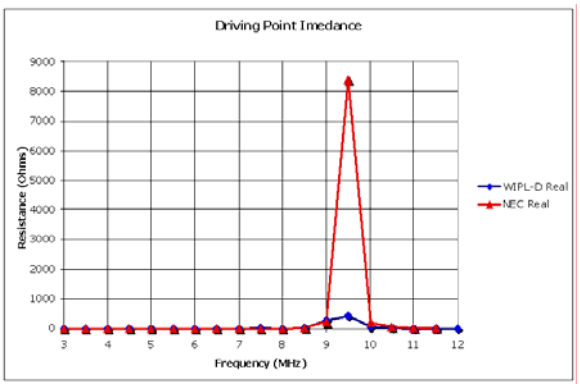


Figure 8. Resistance (Real) Portion of Driving Point Impedance for a Towel Bar Antenna on a 110' Cutter.
Driving Point Impedance Plotted from Data Points Generated by WIPL-D and NEC.

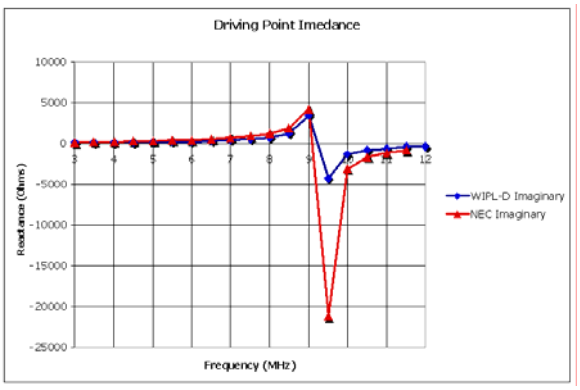


Figure 9. Reactance (Imaginary) Portion of Driving Point Impedance for a Towel Bar Antenna on a 110' Cutter.
Driving Point Impedance Plotted from Data Points Generated by WIPL-D and NEC.

In these graphs it appears as if the peak of the driving point impedance is different for the two programs. A possible reason for this is because there were almost a 1000 points taken for the NEC graph and only a few for WIPL-D. Since the two graphs appear to be slightly shifted, the data point in WIPL-D with a magnitude closer to that of NEC may have been missed since the increments of frequencies we looked at were so large. For example, the resistance peak at approximately 9.5MHz in figure 8 for NEC. A similar magnitude of peak may have occurred in WIPL-D, however, it is not evident because it occurred at 9.25MHz, a data point we did not plot. Nevertheless, the graphs do have similar looking shapes.

The results, from the two programs, where very favorable for a towel bar antenna. The graphs showed very few nulls, and they were small and fairly circular polar graphs. Therefore, we agreed that the towel bar antenna on the front of the 110' cutter would produce the best results needed to solve our problem with HF communication. We did however modify its dimensions, location, and design slightly after visiting an actual 110' cutter. We took our observations and discovery into account and built a mock antenna on site out of PVC pipe. The mock antenna built is shown in figure 10 on top of the ET shop of the 110' cutter being held in the location we wanted to install the prototype.

Figure 10. Mock Antenna Built Out of PVC Pipe

The actual antenna was built, at the academy, using 2-inch aluminum pipe. The length of the antenna was ten feet and had a height of two feet. The two 90 degree angles are welded at two 45-degree angles where the longitudinal and equatorial components meet. The antenna is cut in half at the center of the horizontal ten-foot portion. This was done in order to transport the antenna for testing purposes to the location of the 110' cutter. The base of the vertical portions is not flat due to the slope we discovered on the top of the ET shop, where we intended to attach this antenna to. Mater Chief Griswold conned the insulator that was made out of polyvinyl chloride. It can be seen in figure 11.

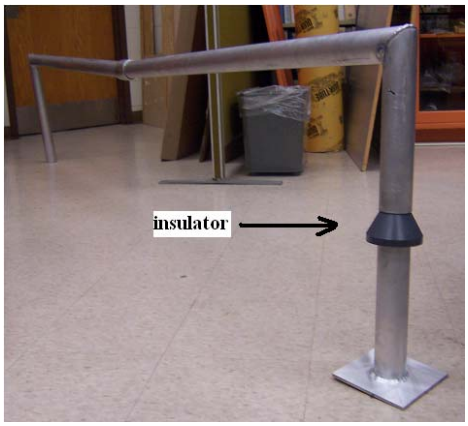


Figure 11. Aluminum Towel Bar Antenna Built at the United States Coast Guard Academy.

The final dimensions of the towel bar antenna were decides upon based on actual measurements taken from USCGC SANIBEL. We realized that in our initial design, we had taken into account other fixtures located on the cutter that may be in the way. For example, the antenna is 10 feet long because that

was the longest distance between the two already fixed coupler boxes we planned on using to excite the antenna. The same coupler boxes are currently used to excite the existing whip antennas. Using the same coupler would reduce any addition changes caused by the installation of the towel bar antenna, one of our objectives. The height was chosen in order not to obstruct the view from the pilot house or interfere with lights located nearby. The location in which we intended to affix the antenna also changed due to the matter in which it would be easiest to feed the antenna from the coupler boxes, Because these caused changes to our earlier models, we modified them and generated more data on the theoretical radiation patterns and driving point impedances. Our results did not vary much at all.

CONLUSIONS

Judging from the results, shown in the previous section, the towel bar antenna on the front portion of the cutter will send information nearly vertically in all directions. This will produce a Near Vertical Incident Skywave (NVIS), thus decreasing the skip distance and reducing the current dead zone. This confirm that theoretically the towel bar will produce the results that are necessary to improve the communication capabilities of the cutters, as suggested by Mr. Barnhill and ENS Miller. Next year the antenna will be placed on a cutter. This cutter will then perform tests on the antennas impedance, communication capabilities, and ensure PEL is met. These results then can be compared to the theoretical values obtained on GNEC and WIPL-D.

The observation made this year can provide a good base to start designing a new antenna for the 87' cutters. They currently use whip antennas and are having similar troubles. A towel bar antenna can be used on these cutters as well, but location may be better in different locations. It can be placed in a similar location as it is on the 110' cutters, thereby replacing the whip antenna; this is shown in figure 12. Or the antenna can be placed on top of the bridge near the radar antenna already present on the 87' cutter, shown in figure 13. The advantage of the location shown in figure 13 is that PEL is less of a concern since there are already areas of radiation there. However, the towel bar antenna will have to be low, not to interfere with the radar or any other equipment in the area.

Figure 12. Possible Location for Towel Bar Antenna on 87' Cutter. (Similar to area as on the 110'.)

Figure 13. Second Possible Location for Towel Bar Antenna on 87' Cutter.

The final steps, for next year's group will be to install the antenna on a WPB-110-foot Coast Guard Cutter, and test the antenna's various abilities of communication at multiple ranges and frequencies. Through tests, they will be able to find the driving point impedance, which will allow them to infer the actual radiation patterns produced by the antenna. One of the current whip antennas is to be used as a control object. Both antennas will be used to test communication efficiency. This data then can be used to verify if the antenna modeling results were correct and if the new antenna design was effective in improving short-range communications.

ACKNOWLEDGEMENTS

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DC1 J. Pals
Dr. Michael McKaughan
Coast Guard Academy Engineering Faculty

REFERENCE

[1] U.S. Coast Guard. Electronics Manual, Personnel Exposure Limits, COMDTINST M10550, 4.10.6.6
[2] Miller, James. "New Antenna for an Island Class Cutter." (2003).

APPENDICIES

APPENDIX 1:	U.S. Coast Guard. Electronics Manual, Personnel Exposure Limits, COMDTINST M10550, 4.10.6.6
APPENDIX 2:	MATLAB Code - Plotting
APPENDIX 3:	Output Plots from MATLAB