Using MATLAB modeling perform analysis and comparison of different antenna arrays designed to operate in the High-Frequency radio band (3-30) MHz

ECE 487 Midterm Proposal

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ODU Honor Pledge

"I [we] pledge to support the Honor System of Old Dominion University. I [we] will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism. I [we] am aware that as a member of the academic community it is my responsibility to turn in all suspected violations of the Honor Code. I [we] will report to a hearing if summoned."

Abstract

This proposal is for the utilization of the MATLAB program and the integration of its performance analysis functions is to perform analysis and comparison of different antenna arrays designed to operate in the High-Frequency radio band (3-30) MHz. In this program, we have decided to use three different types of antenna designs: dipole, log periodic, and the Yagi-Uda antenna. To perform proper analysis and comparison we will be taking the propagation information captured from the various antenna, spacing, and other design factors into consideration. The Matlab program, as mentioned prior, provides performance analysis functions for the programmer to use t best experience for the user. Not only does the program provide functions such as those, but it also provides a graphical representation of the antenna that the user wishes to design. Properties such as element, size, rowspacing, columnspacing, etc. can be implemented by the user to further describe their design for the program to then analyze using different methods to visualize their array. These different kinds of methods include a visual layout of the array, a geometrical visualization of the array, a plot radiation pattern of the array, and the plot azimuth and elevation patterns of the array. All of these functions that are provided through the Matlab program offer a more concise understanding of both the design and its properties.

List of Figures

Figure 3. Default Log Periodic Dipole Antenna: Similar to Figure 2, this image shows a default LPDA. This is going to be heavily modified before being used in our design.

Figure 4. Linear Array Layout: this is a simple XY plane showing where elements would be set in a linear array design.

Figure 5. Rectangular Array Layout: this is a simple XY plane showing where elements would be set in a rectangular array design. The rectangular array defaults to a square lattice, as shown in this image. A Triangular option is also available for use.

Figure 6. Circular Array Layout: this is a simple XY plane showing where elements would be set in a linear array design.

Figure 7. Optimization program running: is an image of a completed optimization run showing the convergence of our directivity as more iterations are run.

Figure 8. Optimized Linear Array Pattern: This is an image of the directivity compared to an omnidirectional antenna of our linear array after having run through the optimization program with dipole antennas.

Figure 9. Optimized Rectangular Array Pattern: This is an image of the directivity compared to an omnidirectional antenna of our rectangular array after having run through the optimization program with dipole antennas.

Figure 10. Optimized Circular Array Pattern: This is an image of the directivity compared to an omnidirectional antenna of our circular array after having run through the optimization program with dipole antennas.

I. Introduction

This design proposal is to use MATLAB software to analyze and compare three different antenna arrays. These different antenna arrays are the dipole, Yagi-Uda, and log periodic. Each one of these antenna types will be able to be used as inputs for our antenna array models as defined in IEEE standard 145-2013. These array models will also have a variety of options such as circular, linear, and rectangular arrays. These arrays are used to achieve higher gain than would otherwise be possible. These arrays use constructive and destructive wave interference to further our goal of creating a directable High-Frequency (HF) antenna. These factors can be changed to improve the overall quality of the antenna array. In the program associated with this proposal, we will use functions provided in the MATLAB software to optimize a series of antenna arrays.

To further explain the process that our team has taken on to utilize these functions provided in the MATLAB program effectively, we will highlight the important parts of the process throughout this report using references, figures, graphs, and our program. This highlighting will begin with our approach to this design, followed by the constraints associated with our design, which will then be followed by alternative solutions that could perhaps improve performance, user experience, or even the amount of power used in the most optimal design, and end with a discussion of the several kinds of impacts that should be considered during the design process. Together, these sections of the report will serve to provide a cohesive understanding of the process of this design.

II. Design Approach

1. Design Methodology

The design that we have elected is meant to be simple to use and provide the best answer possible to a prospective customer. We have considered six factors for optimization spread out amongst 2 categories. Each of these factors has to combine with every factor from the other group. From this, we plan to draw trends to give a general answer to how best to improve the antenna gain while the larger program allows a more tailored design should a customer require it in the future.

Our first category of factors is the optimization of the individual antenna elements. We are considering the optimization of dipole antennas, Yagi-Uda antennas, and Log Periodic Dipole antennas. The second category is the array layout. The array layout options are linear, rectangular, and circular. This gives us a total of nine optimizations to run and draw conclusions on.

While progress has been made on the optimization there have been large roadblocks and limitations to what we can do. The biggest challenges have come to the Log Periodic Dipole antenna and computation power. Solutions are being discussed; however, it remains possible that school funding may be required to complete our strongest wishes for the program while we provide instructions to build from.

We have four goals when dealing with this project. The four goals are: (1) Optimize the array elements for an HF signal, (2) creating an effective simulation for a variety of array layouts, (3) to control and optimize array layout and spacing of each element, and (4) Verify that our results are a realistic description of how the array would function. These goals are listed in the order that they will be completed. The antenna design should be chosen before any other process begins. We then select the array type that we are looking at and move on to the optimization. Once the optimization is finished running we have the option to accept the new values, rerun the program, or return to the old values. If the new values are accepted we check that the given parameters are within the acceptable range of the program verifying the accuracy of our solution.

1.1 Antenna design

There are three major antenna designs that this project is focused on. These designs are the dipole antenna, Yagi-Uda antenna, and log periodic dipole antenna. MATLAB has a command for each of these. However, it is important to mention that some of the commands work better than others. The default appearance of each of these antennas can be seen in figures 1-3. Each one of these antennas has customizable aspects of them which we intend to take full advantage of. One of the major issues of this part is going to be verifying the validity of the model when we make the antenna large enough to fit the needs of our system.

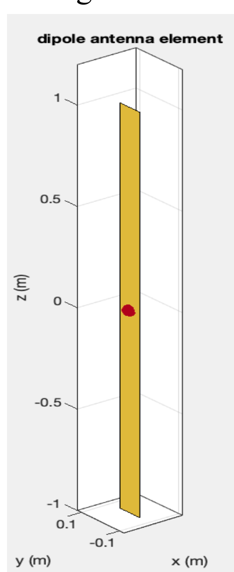

Figure 1. Default Dipole Antenna

The dipole antenna shown here is the simplest and cheapest antenna to manufacture of any antenna that we will be exploring. Without any editing to the antenna, we are given a two-meter tall strip antenna with a feed in the center. The antenna will need to be heavily modified to work successfully with the high-frequency system that we are proposing. This is because typically the most reactive dipole will be half of the wavelength; making our dipole between 5 and 50 meters in length. Standard dipole antennas are often omnidirectional and so they will require the array to make the most of its directivity. [1]

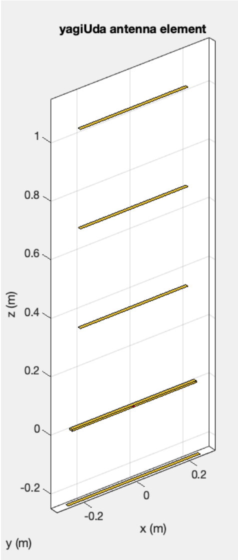

Figure 2. Default Yagi-Uda Antenna

The default Yagi-Uda antenna is composed of three directors, an exciter and a reflector; however, there is no boom as would be expected. A Yagi-Uda antenna is normally associated with VHF and UHF signals.[2] One of the major concerns is increasing the size of the antenna to work in the HF spectrum. We do not believe that the array missing its boom is going to be detrimental to modeling the antenna and will make the optimization much easier than attempting to add the boom.

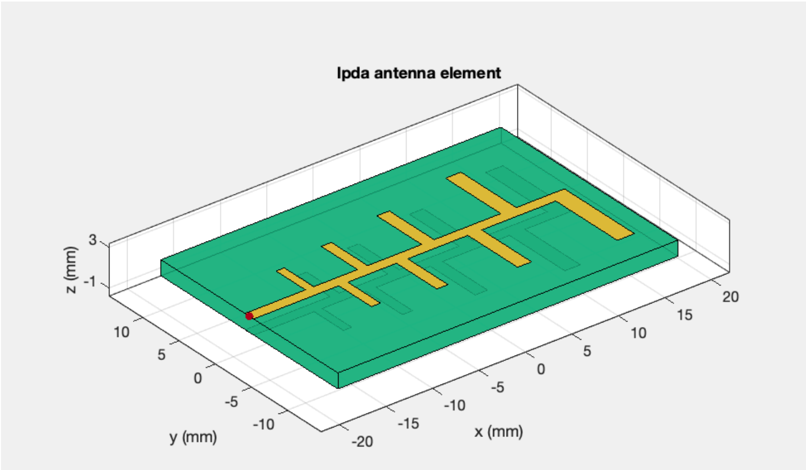

Figure 3. Default Log Periodic Dipole Antenna

The Log Periodic Dipole antenna (LPDA) is by default much different than the other two antenna designs. By default, the LPDA is a small embedded antenna. For our purposes, this antenna will not work and so we have two options that need to be created. The first is a large upright version of the antenna shown above without the enclosing material. The other is much more similar to the Yagi-Uda antenna because it does not have the alternating pattern but would instead have the elements straight across from each other following a logarithmic equation for the element length relative to its distance from the feed. These new antennas can be created in our application but may run into difficulty running an optimization for both the array and the antenna at the same time. This would require the two optimizations to run separately and could weaken the results. The LPDA may require further investigation after this iteration of our project has concluded.

1.2 Array Layout

There are currently three array types that we have a large interest in for this experiment. Each one offers different advantages and disadvantages. The linear array is the most traditional but can take up a very large amount of space and requires the antennas to be largely spaced. The rectangular array is more compact and can offer different options when it comes to steering the beam, but could get more crowded or cost significantly more to add the same degree of spacing. The circular array is great for transmitting and receiving from any direction; however, the direct ability can be a problem.

We will be required to input each antenna design into each of the array layouts. Figure 4 shows a simple linear array that has not been optimized. By default, the array will have an equal spacing of each antenna and the distance between each antenna will be given by the user. This layout gives a high directivity in the direction normal to the array, but it does a poor job focusing the beam along the length of the array. When it is run through the optimization program it is possible to find that even spacing is not the preferred answer, but it is possible to set an antenna distance without it being optimized. We will see later a pattern generated from a non-uniform spacing.

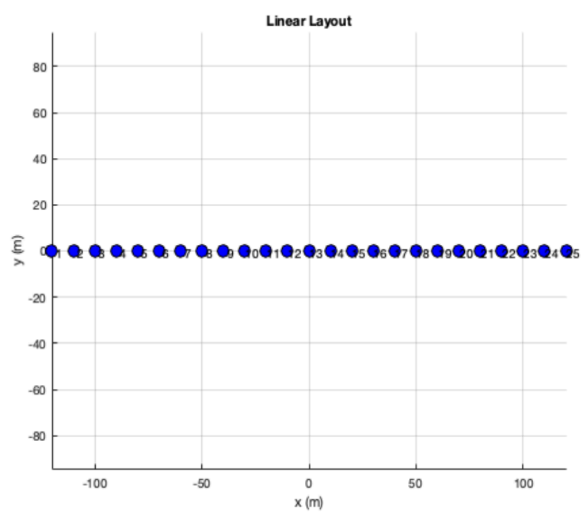

Figure 4. Linear Array Layout

We can also create a matrix of these systems in a rectangular array. This system will allow for a greater amount of digital beamforming to create a more versatile array. While this is a positive development towards the goals of the program there are numerous challenges to using this array that will be discussed in section 2.2 of this report.

In figure 5 we can see the rectangular array set up in a 5x5 square pattern; however, this may not always be the case. A rectangular array can be set up in many ways for the desired directivity. This array does not necessarily have to be square and can have a major and minor axis. On top of the number of rows and columns the array also does not have to be evenly spaced as seen in the next section.

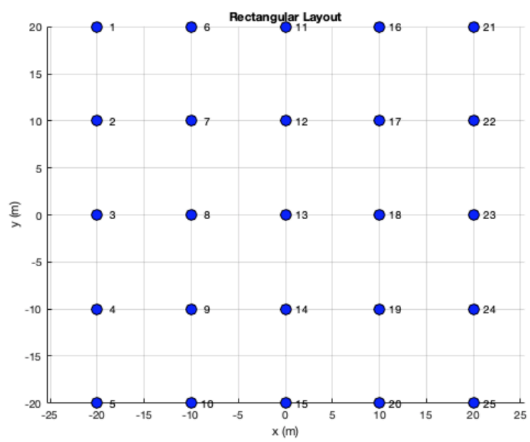

Figure 5. Rectangular Array Layout

There is one final array layout that we are going to test in our program, the circular layout. This layout is simple enough in theory and provides efficient use of space. Each element is placed at a specified distance from a central point and has an equal distance from the elements on either side of it.

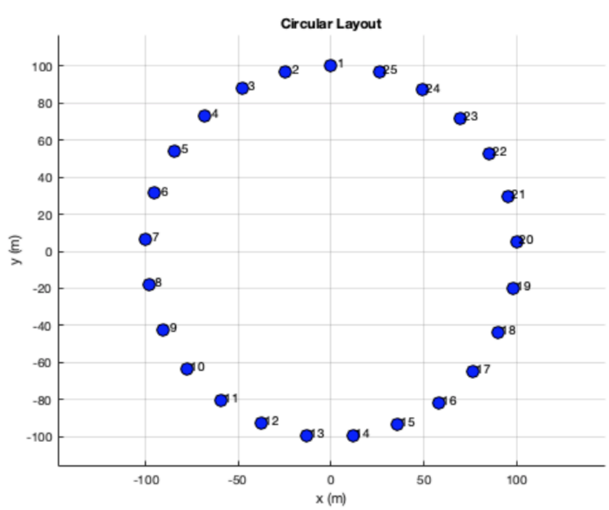

Figure 6. Circular Array Layout

We are leaving it to the customer to know the limits of the available space. The amount of space given to each array is a major design constraint. Typically we can increase the coverage and direct ability of an array by increasing the distance between each element at least to a certain point. The frequency will also play an important role in the constructive and destructive interference depending on the near field and far-field equations of each element.

1.3 Optimization

Creating the antenna and the array layout are essential first steps but the largest aspect of our design is the optimization process. Our optimization requires a range of possible values to be input by the user. The program then runs a defined number of iterations picking random values until it sees a pattern and starts to converge on the highest possible value. MATLAB recommends that 100 or more iterations be run. In some cases, a convergence won't be seen until almost 200 iterations have been run. A larger variety of possible values will cause a longer run time for the program to optimize the array. Figure 7 shows the program working and its conclusion after running 100 iterations on a rectangular array within the design parameters that were input into it.

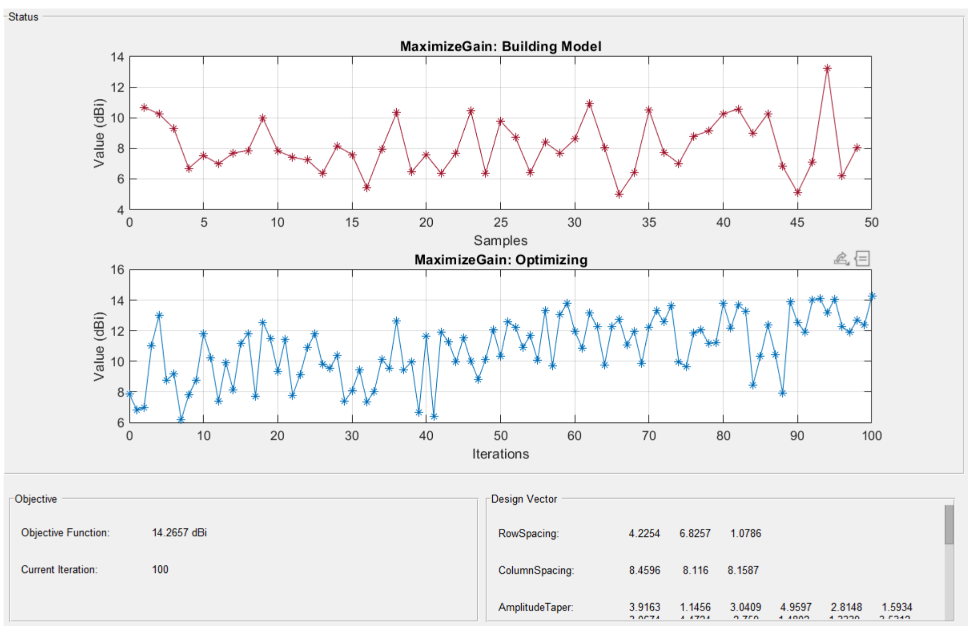

Figure 7. Optimization program running

In the top graph, colored in red, of figure 7 we can see that the program picks an array of values and tries to get an idea of what is a good system and what is not. A narrower range of possibilities will decrease the time it takes to generate the models. The bottom graph, colored in blue, is the optimization of the most promising models. We can see that after 90 iterations the system was much more consistent between 12dBi and 14dBi when compared with the first 50 iterations ranging from about 6dBi to 13dBi. This proves that the optimization function is working but is very computationally demanding.

2. Realistic Constraints

In every theoretical solution, such as the one we are creating this program for there are bound to be issues that arise in an attempt to implement the theory. It is the duty of the engineer or scientist developing the model to account for and mitigate as many of these issues as possible. The issues that are unable to be mitigated must be known and proven that they won't have a huge impact unaccounted for.

2.1 Antenna Constraints

Unknown material will affect the wave velocity changing the frequency slightly and causing our theoretical free-space wavelengths to be slightly off from the measured wavelength being transmitted and will affect its efficiency. No wave can travel faster through material rather than free-space so no matter what material the system is made from it will need to be larger than half of the theoretical wavelength.

The model given to us by Matlab is that of a two-dimensional strip dipole. This may introduce some errors between the software and a realistic design. There are also a limited number of variables that can be changed for the antenna in any given design. We also know that once an antenna is created we are not able to add a second type of antenna to the array or even a different sized antenna of the same type.

With a closer examination of the antenna provided in figure 2, we can see that there is no boom connecting the various elements of the antenna. To the greatest efforts of our engineers, we have not come up with a solution to create antenna elements able to hover unassisted by a supporting structure. This introduces another small discrepancy between the model and a real design; however, we believe that our answer will still be reasonably accurate.

The Log Periodic Dipole Array (LPDA) runs into a similar spacing issue as the Yagi-Uda antenna. This antenna will also require us to create a new version rather than being able to expand the MATLAB default. We will do our best to ensure that what we create is capable of outputting the information the customer needs; however, the system may not have access to some of the antenna toolbox-specific commands.

2.2 Array Constraints

Creating a large and constantly updating system is going to be computationally taxing and is likely to slow down any device that it is run on. It is unlikely that we will be able to create an interactive array as has been proposed because of the necessary delays caused in running the program.

The linear array is the simplest array to create; however, keeping objects perfectly straight over the long distances required by our frequency range may prove difficult and costly for a potential consumer. We are currently not able to program error into the system to predict how problematic such factors would have on the directivity.

There are limitless possibilities to the lattice structure of a rectangular array. Support in this program is limited to rectangular and triangular lattices, though uneven spacing is an option. We determined that the required customization and optimization for every possible lattice would be too great to require of the customer. We also may run into spacing issues that we are currently unable to predict because of the large directors, reflectors, and exciters on the Yagi-Uda antenna. It may turn out that certain sized rectangular arrays would not be a viable option for our frequencies.

2.3 Optimization Constraints

The large variability in the uses for a high-frequency radio wave system means that without knowing the exact conditions required by a customer we are unlikely to give them the ideal system. The minimum computer performance required by the software is a computer with at least 4GB of RAM, any Intel or AMD x86-64 processor, and: 2.9 GB of HDD space for MATLAB only. We conducted experiments to determine the reasonable elements recommended for the simulation based on a specific characteristic computer. Thus, the results are based on a Windows computer with Intel Core i7 processors, 16GB of RAM, and a 64-bit operating system. [3] However, with 50 iterations, the MATLAB program failed to respond, which means it requires more than 16GB RAM to optimize as few as 10 elements when the ideal design incorporates up to 100 or 200 array elements. The performance of the software is highly dependent on the RAM.

3. Alternative solutions

The best design is rarely the first one considered. With that fact in mind, we have created several different options for our final product but brainstorming and innovation should never be ignored. This section will detail some of the options that we considered while at the same time explaining why we have decided not to proceed with them. As our project progresses it is possible for some of our current actions to transition into this section as better methods towards meeting our objective are discovered. In section 3.2 of this paper, we will go over some potential designs for the future of this experiment that we have not confirmed as the proper action.

3.1 Discarded solutions

The best design is rarely the first one considered. With that fact in mind, we have created several different options for our final product but brainstorming and innovation should never be ignored. This section will detail some of the options that we considered while at the same time explaining why we have decided not to proceed with them. As our project progresses some of our current actions might transition into this section as better methods towards meeting our objective are discovered. In section 3.2 we will go over some potential designs for the future of this experiment that we have not confirmed as the proper action or have determined are beyond the scope of our task with this program.

We have also been using the antenna designs and array layouts as inputs to help understand the directivity of the design. Additionally, we have applied a MATLAB optimization command to determine the highest gain, depending on the range of values the user inputs. We have designed the basic layout to help create an interactive interface.

3.2 Future Features

We are in the process of creating custom antennas that better model real-world examples rather than the default ones provided by the antenna toolbox. Depending on the needs of the customer we may enable an optimization setting that allows for weighted priorities amongst gain, Front/Back lobe ratio, and maximum impedance bandwidth. We may find alternative solutions to minimize the simulation running time. This will be easier and ability to have full control of our design if we could create a web-based application then implement our functionalities.

III. Project Deliverables

Since the beginning of the project, our goal has been to utilize the MATLAB program to design an efficient and user-friendly program. With the development of a Graphical User Interface (GUI), the implementation of antenna-type options, and also thinking about the user's own choices, we have made substantial progress towards our end goal. As mentioned in the past our program is also meant to maximize the reliability, quality, and efficiency of the user's customized antenna design.

Since we have started, we have developed a program that is capable of generating custom arrays for the following antenna types: Yagi-Uda, Dipole, and Log Periodic. This program has been improved with a newly developed GUI created using the App designer software that is offered via Matlab. In this newly developed GUI, the user can test a range of frequencies on an array that is optimized for the frequency range provided in the optimization app. The default optimization application is only able to visualize a single frequency and so we plan to export that system into our GUI which allows a premade antenna to act as the frequency hopper antenna required for HF communications.

This program allows us to generate many useful images. One of which can be seen for each of our array layouts using a dipole antenna.

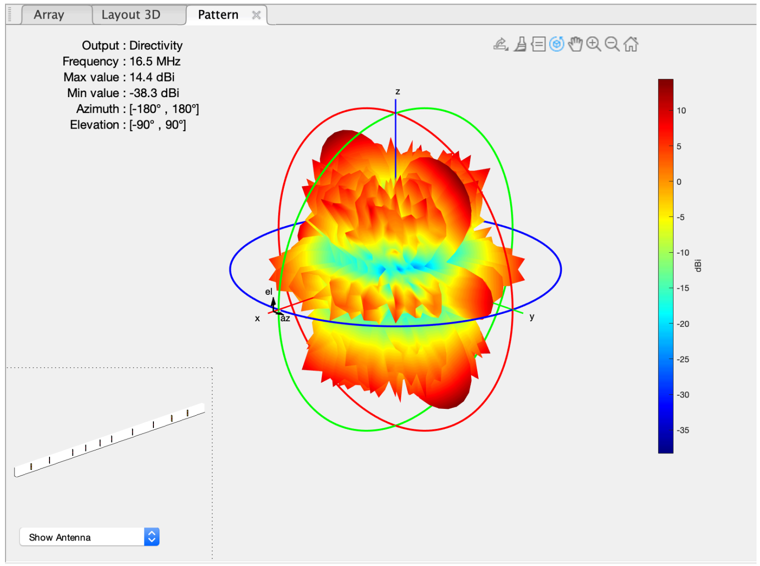

Figure 8. Optimized Linear Array Pattern

Figure 8 is an array design created by running our optimization program through 35 iterations with fairly conservative spatial limits. While the program can run a significantly more complex optimization, many computers will not be able to handle the computation.

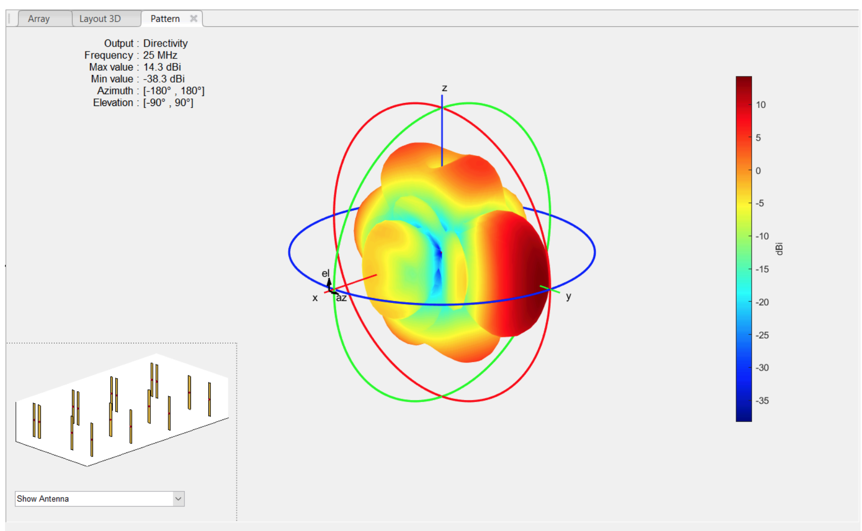

Figure 9. Optimized Rectangular Array Pattern

Figure 9 is a similar creation as figure 8 using a rectangular array. One interesting detail of the optimization is that symmetry and row spacing can vary greatly allowing for much more complex arrays than we had previously accounted for.

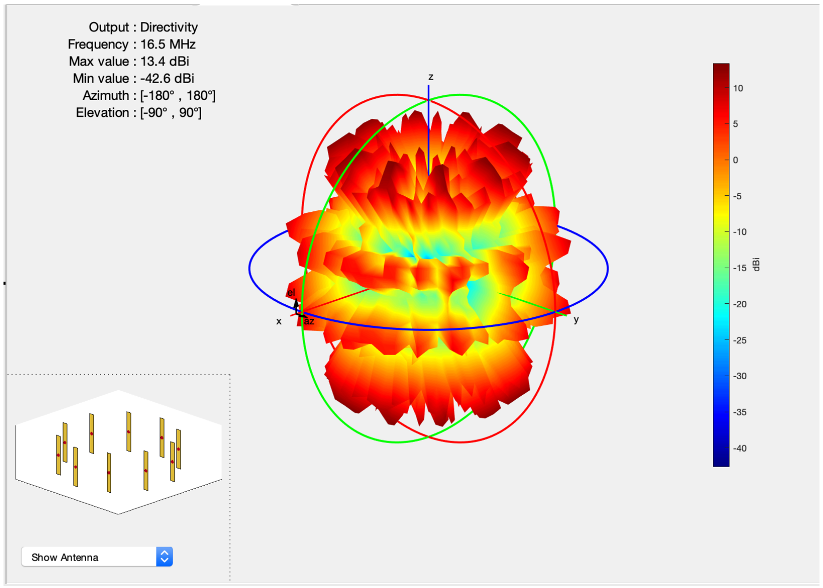

Figure 10. Optimized Circular Array Pattern

Figure 10 shows that this optimization can also be done using a circular array. The circular array has just as many options as the linear array; however, we do not believe that uneven spacing is worth testing. The option is available, but because the advantage of a circular array is its symmetry in every direction we have elected to forgo that variable.

IV. Engineering Standards

Standardization and definitions are essential for creating a product for market use. Antennas have been around for many years with the first radio being invented in the 1890s and the first use of high frequency being used for mass communication in the 1930s. Standardization is always an ongoing process. For example, the use of Hertz was adopted by the International Electrotechnical Commission in 1933; however, radios sold up until the 1960s could still be found using "kilocycles." To avoid such mistakes we used the most updated technical definitions supplied by the Institute of Electrical and Electronics Engineers (IEEE) in their standard 145-2013. This is the IEEE Standard for Definitions of Terms for Antennas and has been updated as recently as 2013 by a group of subject matter experts who have been elected to a council for matters such as this. [4] In a similar fashion for confirming proper use of the propagation terms, we used the IEEE Standard for Definitions of Terms for Radio Wave Propagation, IEEE Std 211-2018. [5] Our final engineering standard has large differences from the other two. This standard, IEEE Std. 356-2010, is about the complex mathematics of electromagnetic propagation through the earth's atmosphere. While this paper is largely focused on the ground wave, unlike our project, many of the more basic characteristics and theories can be used or built on when developing our program. Our largest interest regarding this standard is the creation and testing of different dipole antennas which may be useful in modeling our custom antenna if we are unable to verify the real-world accuracy of the default Matlab model. This standard also gives us a better interpretation of the other two by using several of the terms for practical uses and giving standardized symbols such as the Peak-toNull Ratio (PNR) relating to the Fresnel reflection coefficient. Proper usage of these variables would be very important to building an ionospheric model should our time and progress allow for preliminary modeling to take place. [6]

V. Broader Impacts

Public Health, Safety, and Welfare

People who usually live or work near high frequency are concerned about the long-term adverse effects these devices may have on their health, including cancers, reproductive function disorders, cataracts, or abnormalities in children's development or behavior. Although the HF seems to negatively affect human life, the scientific community has clarified that the HF is far from the most dangerous radiation that we expose ourselves to daily. Nonetheless many sites using RF, in general, have strict man aloft rules and ensure that no unauthorized people are too close to the antenna. These safety precautions can be further proven in a report from the World Health Organization (WHO) which declares that "Large size radars often evoke concern in communities living around them. However, because its power is radiated over a large surface area, the power densities associated with these systems vary between 10 and 100 W/m2 within the site boundary. Outside the site boundary, RF field levels are usually unmeasurable without using sophisticated equipment," [7]. This is to say that due to the directional nature of a system, the fact that it is sending pulses rather than a continuous wave, and that there are defined safe distances from the system that health concerns stemming from HF waves are negligible. The exposure of a human being at a frequency of 27 MHz, close to the highest energy categorized as HF, is well simulated in terms of the expected biological effects. The exposure of a small rodent at a much higher frequency, by the rules of the physical scale, can produce effects that can be beneficial. This justifies the fact that diathermy therapy is now the most used in the medical field. For example, the shortwaves used in thermotherapy have a wavelength of 11.06 m, which is a 27.12 MHz frequency [8].

Impact of Engineering Solutions

Engineering impacts are the effects of any man-made solution to an issue. In our context, we will be looking into the engineering impacts of a MATLAB model for the optimization of different antenna arrays at the High-Frequency radio band (3-30) MHz. If our models are implemented, we will also bring attention to potential impacts with this modeling in mind. As a group, we are focusing on the comparison between antenna arrays for this project. Antenna arrays or array antennas are used to transmit and receive radio waves. There are three primary uses of these: (1) to increase communication reliability, (2) to lessen the amount of interference or noise during transmission, and (3) to adjust the direction in which radio waves are beamed. Antenna arrays originated from the observation of individual antennas and the ideas that engineers thought would allow these antennas to produce more efficient outputs. The antenna array was created with different elements added to make the antennas more efficient. Individual radiators are one of the elements that were added. These radiators work together with the assignment of individual induction fields for each antenna. Induction fields deal with the magnetic environment. Storing energy into each antenna is what these fields are used to do. These individual antennas are often placed very close to one another and the induction fields associated with each antenna tend to overlap. Not only are the types of antennas considered during the construction of antenna arrays, the spacing and the length should also be considered. The individual antennas all work together to form a radiation beam that is high in efficiency, performance, directivity and gain. There are five advantages of antenna arrays. These advantages are: (1) an increase in signal strength, (2) the obtaining of higher directivity, (3) a higher signal-to-noise ratio (SNR), (4) a reduction in the waste of power, and (5) an overall increased performance. These advantages help to improve satellite communications, wireless communications, military radar communications, and more studies involving astronomy. While there are many advantages to antenna arrays, they also have their disadvantages. Some disadvantages are: (1) increased loss in resistivity, (2) many difficulties involving the maintenance and mounting of the many elements that make up the antenna array, and (3) the fact that it requires a lot of space. In the remainder of this report, this group will discuss how these disadvantages and advantages impact the world on a global, economic, environmental, and cultural/societal scale

Global Impact

Military system security is constantly undergoing improvement due to the use of HF antennas. The use of high-frequency antennas provides effective tracking, security, and surveillance. Additionally, it provides advanced caution against incoming aircraft weapons. With increased concern about the compromise of cybersecurity, most countries are relying on HF antennas to protect their citizens against attacks. The US Navy uses many HF antennas in the vessels and aircraft for better communication.[9] . Wullenweber, created by Dr. Hans Rindfleisch, is a large round antenna array. This is a historical example of how this technology has been used and could be used again though with many additional capabilities. The original intent of the site was for using HR radio waves to locate the horizon assets. This was particularly useful for locating emergency transmitters for search and rescue, navigation of ships and aircraft, and locating illegal or interfering transmitters. This system was incredibly important to the German war efforts during WWII because it enabled them to track ships in the Atlantic without having ideal coastal territory. [10]

Economic Impact

The local economic impacts of the models that we are running are the potential funding of our project for further research and if results are promising even a full-scale implementation of the project. This would bolster Old Dominion University's prestige amongst the RF community along with providing increased funding to research or design these systems for students and faculty. These local effects are a primary objective for our group, but there is a broader impact to consider in the industrial world.

On a larger scale, the theory behind our project can bring about a resurgence of high-frequency radio communication. The use of high-frequency or over-the-horizon communication radars (OTHR) has dropped significantly with the large-scale commercialization of satellite communication (SATCOM). Our project can bring new life into the industry if we can prove that a particular array is efficient, reliable, and cost-effective. Currently, there are arrays called "Wullenweber" or Circularly Disposed Antenna Array (CDAA) scattered throughout the world used for long-range HF detection, which were originally put into place for listening to adversary communication and triangulation of offshore assets. Should our analysis show a more effective system it would be possible to rebuild obsolete technology with new transmission capability and provide a security net should our SATCOM systems degrade. [10] This infrastructure overhaul would cost millions if not billions of dollars and be funded in both the defense field and the telecommunications field.

Environmental Impact

The creation of the model does not have significant environmental impacts; however, large-scale implementation of our findings would result in major changes to large plots of land and our upper atmosphere. Our current ideology is that a series of up to two hundred antennas would need to be placed at specific intervals along either an arc or a straight line depending on the desired effects before optimization takes place. These antennas are propagating energy up to 1kW each into the ionosphere, the layer of the atmosphere known for its ions, the aurora borealis, and the aurora australis. Historically, use tells us that there should not be any visible effects of that energy; however, there is a large concern for interference between similar frequencies. Beyond the electromagnetic impacts, the required infrastructure for implementation of our models would take up square kilometers at a time and require multiple of the systems to be built in the United States and allied nations, such as Australia and the United Kingdom. [10]

Cultural and Social Impact

The cultural and social implications are a result of the health and public safety implications. This technology is not meant to be used by the public at large and is meant for very specialized communications channels. It is because of this disuse by the public that the main social impact will be a higher amount of worry if you live too close to a radiating facility. As noted earlier in this paper, all radiation sites undergo thorough environmental studies making them safe for the local populace; however, a perceived danger can still meet many set back. [7] The creation of these arrays has two main possible outcomes, either the general population will accept its safety and is simply another means of communication or they will further distrust companies and governments and their dictated safety regulations.

Should our modeling prove that a more efficient and directional antenna is feasible future installations could be designed with a lower required output voltage and a high gain limiting the radiation exposure in unintended directions. Given the FCC's derived link between RF energy density and frequency with cancer the ability to better aim these antennas could prove to be locally significant to the cancer rates in the surrounding areas. [11]

VI. Individual Contributions

Our group has created a less formal meeting structure this semester. We have been working in smaller teams to finish or improve on individual parts of the program. With such a large project and future engineers creating a strong ethic towards teamwork and supporting group members is an important part of this project that each member of our group is taking seriously. Contributions to the assignment can not be measured simply by the task that each person completes but also their attitude towards assignments and group members, the thoughts towards the design process, and the insights they request from our advisors. While any written explanation will not sufficiently show the effort and dedication of each team member we have endeavored to do exactly that in the section below.

Eric Appia was in charge of the project deliverable and contributed to a realistic constraint and future features in this paper. He also contributed to the optimization of the antenna elements using the Matlab application.

Brandon Blair was in charge of the impact of engineering solutions and cultural impact on this paper. He also contributed to the economic and environmental impact.

Rain Spann was in charge of the introduction and abstract sections of this paper. Using the program provided by Dylan Winebarger, Rain was able to create a clear and concise explanation for the program and how the group has decided to move forward with creating the program in the future. Rain also assisted in collecting information for the project deliverables section using the new GUI antenna array design application and the previous MATLAB program. He has assisted in grammar corrections, choosing which information was relevant to the current phase of this project, and also provided ideas. Rain also took part in the progress presentation assignment and the other assignments before it as well. As well as contributing to the weekly assignments and goals presented by the instruction board, Rain strives to make sure the quality of the content that makes up the assignments are the best the group can offer

Dylan Winebarger was in charge of a large portion of the design approach on this paper along with the explanation of how the engineering standards were used. Dylan has taken the role of organizing the group and ensuring no work is repeated while keeping the group's understanding of the project even amongst members. He was the main technical support for running the software and decided the optimization ranges used in the early application of the software.

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Appendices

Appendix A - MATLAB Code

```
/////////////////////////////////////////
clc
close all
workspace;

disp('You Will be asked to fill out some general information about your requirements')
%Define the High and Low Frequencies
FrequencyLOW = input('Enter the lowest Frequency');
FrequencyHIGH = input('Enter the highest Frequency');
MaxElements = input('Enter the number of available elements');



%Which arrays to test
Linearinput = input('Do you wish to see a linear Layout? (Y/N)', 's');
LinearONOFF = upper(Linearinput);
Rectangularinput = input('Do you wish to see a Rectangular Layout? (Y/N)', 's');
RectangularONOFF = upper(Rectangularinput);
Circularinput = input('Do you wish to see a Circular Layout? (Y/N)', 's');
CircularONOFF = upper(Circularinput);

%Not being used yet
%Define Universal Customizations
AmplitudeTaper  = 1          ;
PhaseShift      = 0          ;
ArrayTilt       = 0          ;
ArrayTiltAxis   = [1 0 0]    ;

%
antennatype = input('What type of antenna would you like to test, Dipole, Yagi, or log periodic?', 's');
holdantennatype = lower(antennatype);

switch holdantennatype
  case 'yagi';
    MyAntenna = yagiUda;
    MyAntenna.Exciter ;
    MyAntenna.NumDirectors ;
    MyAntenna.DirectorLength ;
    MyAntenna.DirectorSpacing ;
    MyAntenna.ReflectorLength ;
```

```
        MyAntenna.ReflectorSpacing ;
        MyAntenna.Tilt ;
        MyAntenna.TiltAxis ;
        MyAntenna.Load ;

    case 'dipole';
        MyAntenna = dipole;
        MyAntenna.Length ;
        MyAntenna.Width ;
        MyAntenna.FeedOffset ;
        MyAntenna.Load ;
        MyAntenna.Tilt ;
        MyAntenna.TiltAxis ;

    case 'log periodic';
    MyAntenna = quadCustom;
    %Define 4th Element from the top / Element with the Feed
    MyAntenna.Exciter ;
    %Define Top 3 elements types (default dipole)
    MyAntenna.Director ;
    %Define Spacing between the Directors
    MyAntenna.DirectorSpacing ;
    %Define bottom most Element (default dipole)
    MyAntenna.Reflector     ;
    %How far away is the Bottom Element
    MyAntenna.ReflectorSpacing      ;
    %Length of the boom in meters (height)
    MyAntenna.BoomLength    ;
    %Width of the boom in meters
    MyAntenna.BoomWidth     ;
    %Signed distance from center of antenna elements, specified as a three-element vector with each
element unit in meters.
    MyAntenna.BoomOffset    ;
    %Antenna tilt
    MyAntenna.Tilt          ;
    %Tilt Vector
    MyAntenna.TiltAxis      ;
    %Lumped elements added to the antenna feed (default 1x1), can also be
    %thought of as impedence
    MyAntenna.Load          ;

 show(MyAntenna);end

for N=1
```

```
%Sets up a Linear Array
if LinearONOFF == 'Y'
   LinearSpace  = input('Enter the amount of linear space available in meters ') ;              ;  %Meters
between Elements
   ElementSpacingL = LinearSpace / MaxElements;
   PhaseShiftL = input('Enter a Phase Shift');
   LinearArray = linearArray;
%Array Properties
   LinearArray.Element = MyAntenna;
   LinearArray.NumElements = MaxElements;
   LinearArray.ElementSpacing = ElementSpacingL;
   LinearArray.PhaseShift = PhaseShiftL;
   LinearArray.Tilt = ArrayTilt;
   LinearArray.TiltAxis = ArrayTiltAxis;

   figure;
   layout(LinearArray);
   title('Linear Layout');

   figure;
   pattern(LinearArray,FrequencyLOW);
   title('Linear Pattern Low Frequency');

   figure;
   patternAzimuth(LinearArray,FrequencyLOW);
   title('Linear Azimuth Pattern Low Frequency');

   figure;
   pattern(LinearArray,FrequencyHIGH);
   title('Linear Pattern High Frequency');

   figure;
   patternAzimuth(LinearArray,FrequencyHIGH);
   title('Linear Azimuth Pattern High Frequency');
else if LinearONOFF == N
      return;
   end
end
end

for N=1
%Sets up a Linear Array
if RectangularONOFF == 'Y'  %Sets up a Rectangular Array
RectangularArray = rectangularArray;
```

```
%Array Properties
RectangularArray.Element = MyAntenna;
RectangularArray.Size =[5 5]  ;
RectangularArray.RowSpacing  ;
RectangularArray.ColumnSpacing  ;
RectangularArray.Lattice  ;
RectangularArray.AmplitudeTaper  ;
RectangularArray.PhaseShift  ;
RectangularArray.Tilt  ;
RectangularArray.TiltAxis  ;
figure;
layout(RectangularArray);
title('Rectangular Layout');

figure;
pattern(RectangularArray,FrequencyLOW);
title('Rectangular Pattern Low Frequency');

figure;
patternAzimuth(RectangularArray,FrequencyLOW);
title('Rectangular Azimuth Pattern Low Frequency');

figure;
pattern(RectangularArray,FrequencyHIGH);
title('Rectangular Pattern High Frequency');

figure;
patternAzimuth(RectangularArray,FrequencyHIGH)
title('Rectangular Azimuth Pattern High Frequency');

else if RectangularONOFF == N
        return;
    end
end
end

for N=1
%Sets up a Linear Array
if CircularONOFF == 'Y'%Sets up a Rectangular Array
    Radius  = input('Enter the Radius available in meters ') ;                ;  %Meters between Elements
    PhaseShiftStart = input('Enter a Starting Position for the first element');
CircularArray = circularArray;
%Array Properties
CircularArray.Element = MyAntenna;
```

```
CircularArray.NumElements = NumberofElements;
CircularArray.Radius = Radius;
CircularArray.AngleOffset = StartingAngle;
CircularArray.AmplitudeTaper = AmplitudeTaper;
CircularArray.PhaseShift = PhaseShift;
CircularArray.Tilt = Tilt;
CircularArray.TiltAxis = TiltAxis;
figure;
layout(CircularArray);
title('Circular Layout');

figure;
pattern(CircularArray,FrequencyLOW);
title('Circular Pattern Low Frequency');

figure;
patternAzimuth(CircularArray,FrequencyLOW);
title('Circular Azimuth Pattern Low Frequency');

figure;
title('Circular Pattern High Frequency');
pattern(CircularArray,FrequencyHIGH);

figure;
patternAzimuth(CircularArray,FrequencyHIGH);
title('Circular Azimuth Pattern High Frequency');
else if CircularONOFF == N
        return;
    end
end
end
```

Appendix B - Group Activity Log

Meeting Date	Topics
14-Sep	Contacts, Introductions, Shared Drive folder, and safety quiz requirements

23-Sep	Project expectations and motivations, discuss research done by Dr. Watson and Dr. Vahala regarding virtual SATCOM systems.
02-Oct	Engineering design process corrections, References for our paper and what to look for, further explanation of the virtual SATCOM system and how our project relates.
09-Oct	MATLAB antenna toolbox update, findings from references research
16-Oct	Pubic presentation, sponsorship, the requirement to begin coding
23-Oct	Code which has been created, expectations moving forward, and limitations on our current design, midterm presentation expectations
30-Oct	Midterm presentation review, coding knowledge distribution, marketability of our presentations, discussion of the code, and how to share edits made to the code amongst everyone.
6-Nov	Discussed Engineering standards paper and how which standards should be expanded on from the midterm
13-Nov	Discussed the results of the midterm paper and expectations of the group's work in the future. Began to assign official roles and responsibilities to each group member
20-Nov	The final meeting for the class to confirm everyone understood their role and expectation toward compiling this paper
21-Jan	Discussed progress and new ideas developed over the winter break. Decided on a new UI version of the project.
09-Feb	Meeting with advisors to go over our new plan and get approval for the new optimization method.

** Various phone calls, emails, and discussions amongst individuals towards these topics have not been officially logged though they have taken place between 9/14 when the log began and 3/11 when this report was compiled.