PROJECT PROPOSAL
MITRE Corporation
Project Center

Project Number: REL0719

Compact COMM-NAV Antenna for Handset Application

Designing an Antenna for both Military UHF Communications and GPS Navigation on a Handset

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Introduction

Antennas are a convenient form of communication and remain the only method through which individuals may communicate rapidly and wirelessly across long distances. Most consumers, with highly mobile lifestyles, have seen wireless communication and transmission of data to be a necessity. For the military, the antennas are essential for navigation, guidance, communications, detection, and many more applications. Unfortunately, a soldier is often given a significant amount of equipment, and any antenna, whether protruding from a backpack or a handset, provides an extra burden and present a prime target for opposing forces. Consequently, research and development in the area of small combined communication and navigation antennas are needed to reduce the equipment encumbrance of soldiers.

MITRE Corporation has started an investigation of building small combined UHF and GPS antennas for military handset applications. The mission of this investigative study it to develop a UHF antenna that is smaller than currently available designs, covers the entire UHF band, and maintain comparable gain and efficiency across the entire band. This will allow for “frequency hopping,” where both the transmitter and receiver rapidly change frequency (synchronously) within the band in order to avoid jamming. The GPS antenna needs to function for both L1 and L2 bands for navigation, but with minimal interference with the UHF antenna.

Objective

This project assists MITRE in attempting to combine the communication and navigation antennas, miniaturize them, and combine them on a single ground plane. The communication antenna is a UHF antenna, a significant design challenge, as it must cover a very wide band: 225-400 MHz (56% bandwidth), which is very difficult at such a low frequency. Furthermore, it is desired to be as small as possible to limit encumbrance a avoid presenting a target. Current designs for this project suggest a prototype that is a 254 mm tall sleeve monopole. An example of a sleeve monopole that is currently under investigation can be seen in Figure 1 (without any dielectric or ferrite loading).

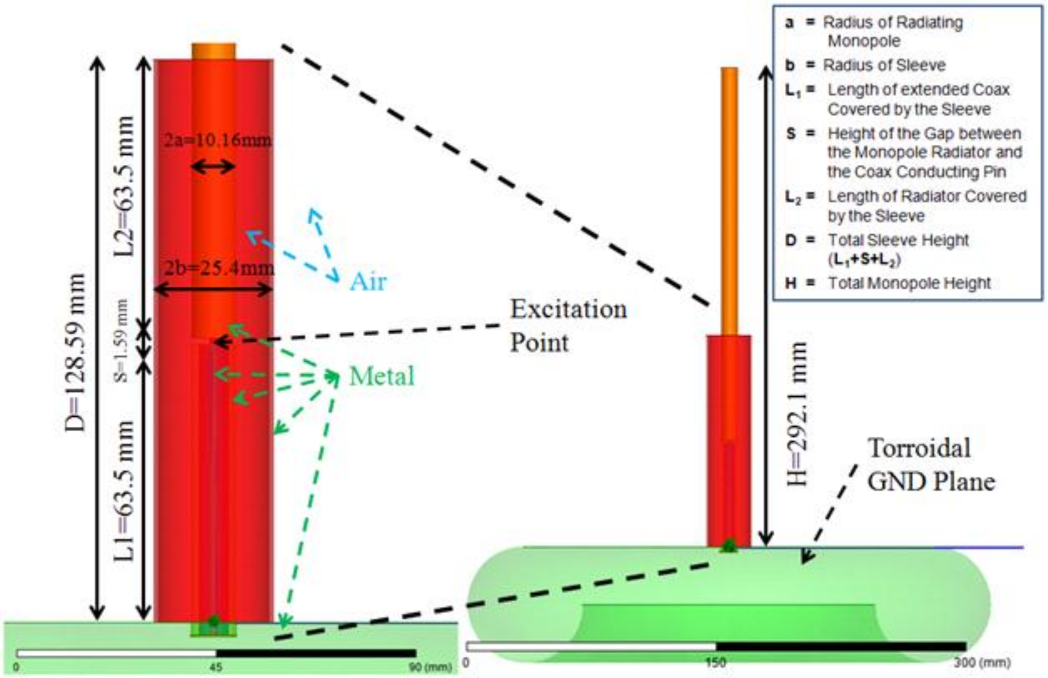

Figure 1-Sleeve Monopole Design

Currently, these sleeve monopole designs are being investigated because the metal barrier around the feed allows for wider bandwidth and limits the effect of a finite ground plane. The wider bandwidth is believed to be caused by the sleeve allowing a second path of current, causing a secondary resonance, thus the length of the sleeve itself determines this second resonance. These designs are currently being simulated and optimized using antenna simulation software as preparation for future testing on the torroidal ground plane as seen in Figures 1 and 2. This is a standard testing procedure and minimizes the effect of a finite ground plane by reducing the diffraction effects that are associated with the sharp edges of a typical planar metal ground plane. However, the sleeve monopole is an attractive option as it will allow one to limit the negative effect on antenna gain (caused by the small ground plane) by raising the excitation point. Furthermore, this design, being analogous to two concentric coaxial cables, allows for the use of the corresponding lengths L1 and L2 to act as an impedance matching network within the antenna itself. The sleeve monopole will also be optimized for, and tested on the receiver ground plane, as this is the intended application.

However, the main objective of this study performed at the MITRE Corporation is to investigate the advantages of ferrite loading. A ferrite is a material with magnetic properties or a magnetic permeability greater than one. Although dielectric loading has been investigated in the past as a method of electrically lengthening an antenna (allowing an antenna to become smaller, but maintain a low resonant frequency), magnetic materials are known to have high losses in the UHF band due to their high magnetic loss tangents. Normally, this would result in an extremely inefficient antenna (as the fields would be dissipated in the ferrite as opposed to being radiated into free-space). However, a special ferrite, CO2Z (made by Trans-Tech), has been selected for investigation in this project. Within the UHF band, this ferrite has a low magnetic loss tangent of 0.06, and an average magnetic permeability of 8. A ferrite bead with a fixed radius (for manufacturing reasons) of 12.7 mm has been selected for study in reducing the height of the sleeve monopole. An example of a sleeve monopole design with ferrite loading can be seen in Figure 2.

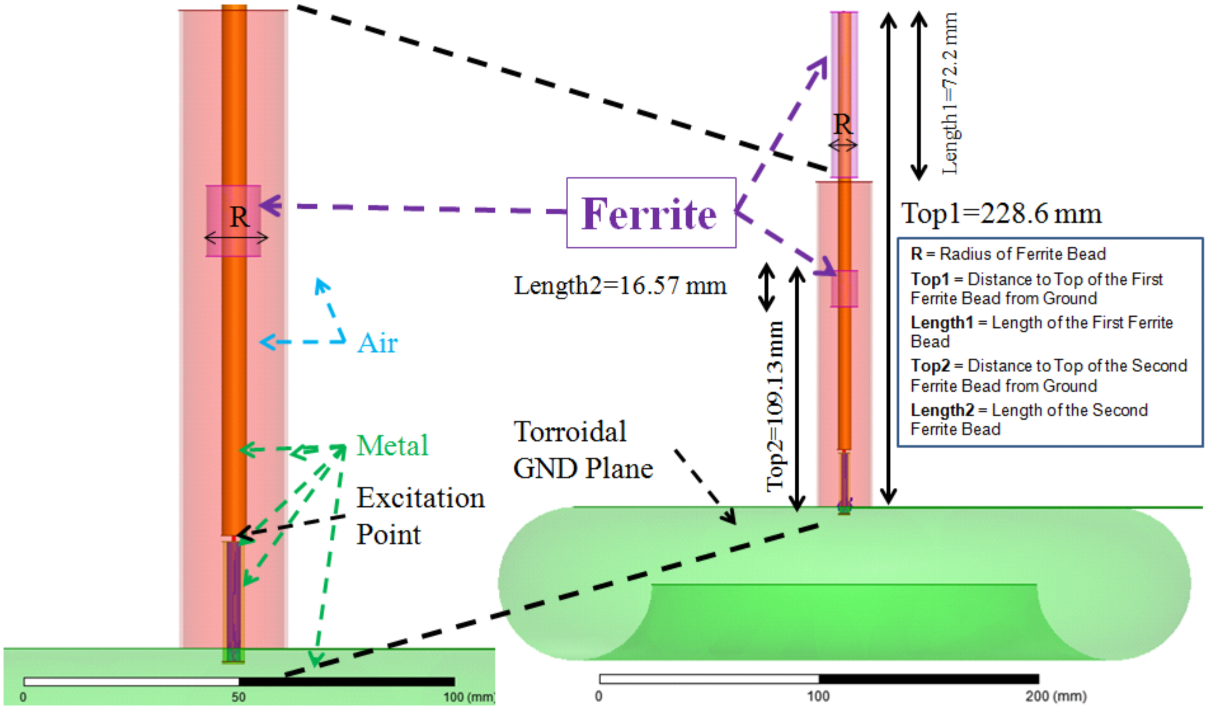

Figure 2-Sleeve Monopole with Ferrite Beads

This new ferrite compound is currently under investigation. It has a relative dielectric permittivity (11.7) nearly equal to its relative magnetic permeability (8), while maintaining a low loss tangent in the UHF band. This rare combination allows for the ferrite to be closely matched with the impedance of free-space ($\frac{\mu_r}{\varepsilon_r} \approx 1$), allowing the antenna to be shortened considerably past the resonant length, while minimizing the losses that one would expect from loading the antenna.

Approach

The task of designing an antenna for multiple frequencies across different bands is a challenging undertaking. Any type of frequency sweeping software would be required to scan very large frequency bands in order to find the resonant frequencies, consuming significant amounts of time, and computational resources. This project proposes that the two bands (UHF and GPS) are considered separately and an antenna designed for each of these. The major concern with this plan is the potential for interference between the two different antennas. Taking this into consideration, the antenna designs will need to avoid radiating into one another. The shorted annular ring (for GPS) and the sleeve monopole (for UHF) assist in meeting this requirement by radiating along the outer periphery (the short of the annular ring), and providing a metal barrier (the sleeve of the sleeve monopole).

UHF (COMM) Antenna

In this stage, the UHF communication antenna is nearing completion, and design of the GPS antenna will commence shortly. Further refinement of the UHF antenna design will be conducted throughout the course of this project, and a matching network may be designed if it is deemed necessary. Currently, research is being conducted in this field, and it is hoped that the Agilent Advanced Design System (ADS) software can be used for the purposes of designing a lumped circuit matching network, thus improving the performance over a wide band. Alternatively, MATLAB based scripts may be used to compute an appropriate matching network once the input impedance of the antenna is provided by the antenna simulation software. The GPS antenna will be used for navigation, and it must share the same ground plane as the UHF antenna with minimal interference. Ultimately, both will be tested on a JTRS (Joint Tactical Radio System) Rifleman radio receiver casing, which is acting as a 215.9 mm tall ground plane. Figure 3 shows an example of the sleeve monopole (without the GPS antenna) on the receiver casing. Initial simulations show that the receiver casing may assist in increasing the electrical length of the sleeve monopole (acting as a wing of a dipole) and further enhancing performance, especially at the lower end of the band. Figure 3 shows only one type JTRS receiver casing currently in use; however, handsets in other military UHF applications are of similar dimensions, thus this design may be applicable to variety of different applications.

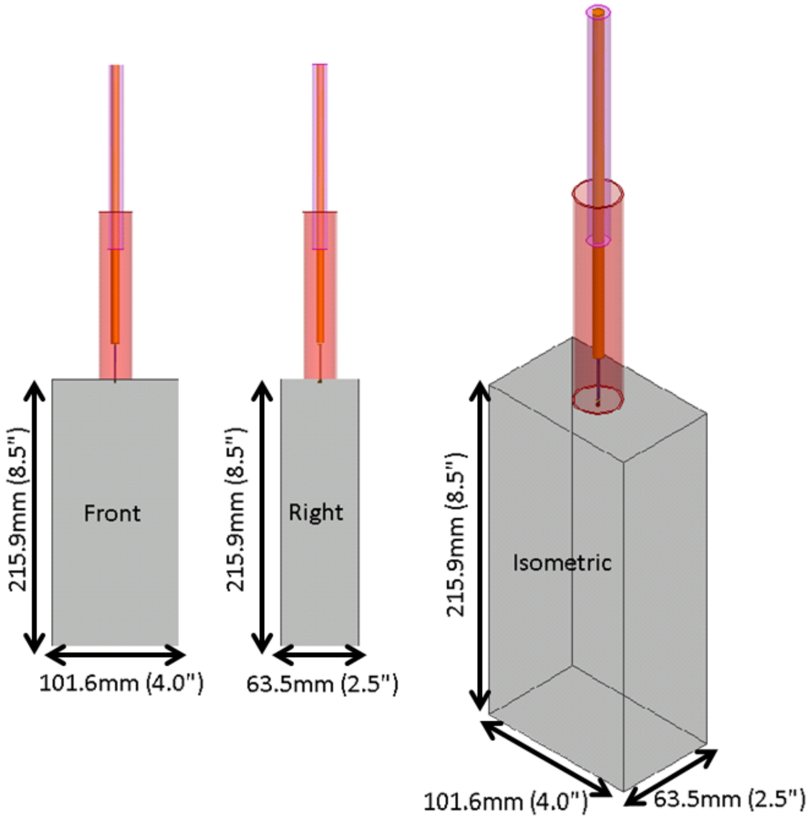

Figure 3- UHF Antenna on JTRS Receiver Casing

GPS (NAV) Antenna

In designing the GPS antenna (navigation), it is desired to have resonances at 1.5754 GHz, 1.2276 GHz, and optionally 1.176 GHz, to best cover all three bands. Each of these bands should have sufficient bandwidth to cover 12 MHz above and below these resonant frequencies; however, it should not be very wideband (otherwise it will be highly susceptible to jamming). These bands correspond to the L1, L2, and L5 bands respectively. The first two bands, L1 and L2 are necessary to cover as these are responsible for precision navigation and receiving coded signals in military handsets. The L5 band (being the longest wavelength and more difficult to implement) is viewed as optional as it is part of a new modernization program and was primarily designed for aircraft navigation and civilian applications (less applicable for infantry).

Investigation into designing the GPS antenna was recently started, and preliminary designs are still under investigation. The current design concept involves a "shorted stacked dual band annular ring microstrip antenna." The inner circumference of the annular ring patch is connected to the ground (thus shorting it), and the UHF sleeve monopole can be coaxially mounted in the center of the ring. It is important to note that the sleeve itself is also connected to ground. This allows a compact, nested arrangement of both the UHF and GPS antennas (widely separated bands) to be placed on the military handset receiver casing with minimal mutual coupling. In order to minimize the size of the GPS antenna, a substrate with a high dielectric constant will be used, allowing a convenient placement on the handset. A preliminary example of the design (without shorting the central ring) is shown in Figure 4. This design does not show the anticipated sleeve monopole, which will occupy the center hole (the short of the annular ring will make electrical contact to the sleeve).

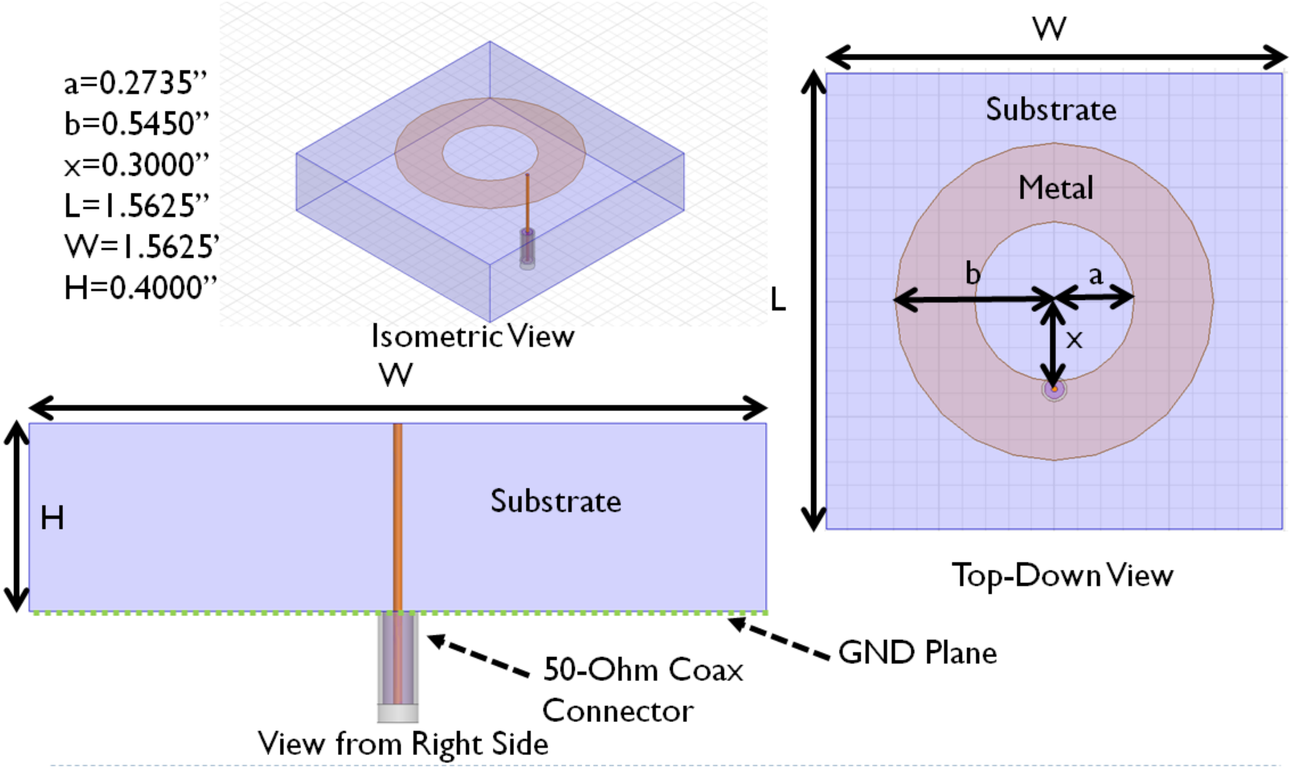

Figure 4-Annular Ring Design

Tentative Schedule

The proposed project is intended to take place over the course of A-Term (August 26, 2011 to October 14, 2011); however, permission was granted to begin immediately (before July 30, 2011). As can be seen in Table 2, a tentative schedule has been proposed to complete this project on time. These deadlines are subject to change based on the needs to the project and the suggestions of the project advisors as the MQP progresses. Although it is not explicitly stated, it is assumed that the final report will be completed in sections throughout the length of the project itself, resulting in additional research in the fields of GPS, polarization, and antenna theory throughout the first several weeks. Another major concern is arranging time at the MITRE machine shop to construct the antennas for testing. Unfortunately, their busy schedule limits the amount of testing iterations that can occur, meaning significant simulations will be need to be conducted in Ansoft HFSS before beginning the manufacturing and testing processes.

Overall, the design process is separated into two general stages. First, the UHF communication antenna will be designed. This design is well underway and is nearing the testing stage at the time of writing. Upon achieving satisfactory results with the UHF antenna, a GPS antenna will then be devised for the purpose of navigation. The design of the GPS antenna is not as well established at this time, and it will be the major focus over the next several weeks. Once this design is completed and tested, both antennas should be assembled together and optimized such that they do not interfere with one another; however, the testing of this final stage depends on the schedule of the machine shop to produce the physical structure to test. All of these general steps are outlined in the tentative schedule, as seen in Table 1.

Table 1-Tentative Schedule

Week	Date	Primary Goals
1	07/18/11	-Revise draft for Project Proposal -Ansoft HFSS Simulations optimizing UHF Antenna Design -Begin Research on Antenna Theory and CEM
2	07/25/11	-Submit draft for Project Proposal to academic advisors for review -Experiment with ground plane effects on UHF antenna
3	08/01/11	-Submit final draft of Project Proposal -Submit dimensions of UHF antenna to Machine Shop for Construction -Begin rough design of GPS antenna in Ansoft HFSS -Continue simulation UHF antenna on handset ground plane
4	08/08/11	-Testing of UHF antenna Design at MITRE -Conduct necessary changes to the UHF design -Establish patterns in changing dimensions of the GPS antenna -Consider alternative designs in case of failure of either design component
5	08/15/11	-Continue testing and revisions of UHF design as necessary -Develop a secondary plan for the GPS antenna in case of failure of current one
6	08/22/11	-UHF antenna should be completely operational and fully optimized at this point -Optimize GPS antenna for the handset ground plane
7	08/29/11	-(Official start of A-Term at WPI this week) -GPS design should be completely ready at this point (finalize dimensions for test)
8	09/05/11	-Build GPS antenna and begin testing (depending on machine shop schedule at MITRE)
9	09/12/11	-Continue testing of GPS antenna -Complete Literature Review
10	09/19/11	-Revise GPS antenna design -Simulate combined GPS and UHF antenna designs
11	09/26/11	- Revise combined GPS and UHF antenna designs -Test the combined GPS and UHF antennas (if time permits)
12	10/03/11	-Allow extra time to compensate for any setbacks in the process
13	10/10/11	-Finish entire written MQP report

Deliverables

Ultimately this project will culminate in the generation and presentation of results for a combined COMM-NAV antenna that will meets the objectives outlined in previous sections of this proposal. Although not all of these may be physically obtainable parameters, the antenna will be optimized to meet as many requirements as possible in the time allotted for this project. These results will be presented in the form of physical products and reports (here referred to as “deliverables”) to be presented to both the faulty of the Worcester Polytechnic Institute as well as the MITRE Corporation sponsor for mutual benefit. An outline of these deliverables can be observed in Table 2. Similar to Table 1, this list of anticipated deliverables is not finalized, and both the date of completion and required content is subject to change based on encountering unforeseen difficulties in the project itself.

Table 2-List of Anticipated Deliverables

Deliverable	Estimated Date of Completion	Description
Project Proposal	July 31,2011	Define the scope and purpose of the project for both MITRE and WPI parties
First Model of 254 mm UHF Antenna	August 5, 2011	Finalize optimized dimensions for the UHF antenna on the receiver casing. Actual completion depends on machine shop scheduling (228.6 mm design is optional pending on machine shop accessibility)
Simulation and Tested Results of UHF Antenna	August 15, 2011	Test the aforementioned antenna on MITRE far-field range for gain and return loss. Completion time depends on available scheduling
First Model of the Annular Ring at L1 Frequency only	August 20, 2011	Completion time depends on available scheduling of the machine shop. Only using a single patch at L1, without receiver casing.
Simulated and Tested Results of the Annular Ring	September 1, 2011	Test the L1 ring at the MITRE Anechoic chamber
Complete Design of Stacked Annular Ring for both L1 and L2 Frequencies	September 12, 2011	Redesign previous antenna to work at both L1 and L2. If there is not enough time, L1 alone is sufficient and the project will continue with this design
Simulated and Tested results of the Stacked Annular Ring Antenna	September 22, 2011	Test the aforementioned antenna in the same configuration as the previous Annular Ring
Finalized Design for COMM-NAV Antenna	September 30, 2011	Combine UHF and GPS antennas and optimize for minimal interference
Simulated and Tested Results of the Final Design	October 7, 2011	Test entire configuration of the JTRS receiver
Final MQP Report	October 11, 2011	Should contain a literature review demonstrate an understanding of the subject area, as well as a discussion of empirical observations through both simulations and testing regarding the antenna

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[3] Ulaby, F. T., Michielssen, E., & Ravaioli, U. (2010). *Fundementals of Applied Electromagnetics.* Upper Saddle River: Pearson Education Inc.

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Appendices: Introductory Literature View

Before beginning testing of the antenna designs, it is first important understand the theory behind antennas the tools that are being used. Simulation software is a great aid to the design process by avoiding unnecessary (and highly expensive) design iterations; however, one cannot use such a tool without understanding the mechanisms behind it. Otherwise, one risks making false assumptions or extremely long simulations that will not yield accurate results. One should first have a general understanding of antenna theory and the simulation process before beginning a design.

Appendix I: Antennas

In a society dependent on electronics and remote transmission of data, antennas have become a necessity in day-to-day life. An antenna can be thought of as any device that is capable of radiating or receiving radiated electromagnetic waves. Stated more formally, Fundamentals of Applied Electromagnetics claims an antenna to be a "transducer that converts a guided wave propagating on a transmission line into an electromagnetic wave propagating in an unbounded [3]." In general, one may consider an antenna to be a transitional mechanism for transmitting either information or power through free-space, from one circuit to another.

Overall, most antennas are considered to be "reciprocal," meaning that they receive power just as well as they transmit it [3]. A complication in the current project is the concept of polarization, relating to the direction in which the antenna radiates. As one may assume by the definition of a reciprocal device, an antenna can only accept radiation of the same polarization, requiring any antenna, including those being designed in this project, to match the polarization of the transmitter [3]. It is important to match the polarization of the antenna, or one will suffer significant losses. Furthermore, one must note that the polarization of an antenna may differ depending on where it is measured from, as different components of an antenna may have different polarizations. Polarization can be thought of as the direction of propagation of the electromagnetic waves with respect to time [1].

In addition to polarization, it becomes vital to match the impedance of an antenna to that of the generator powering it, as one would do for maximum power transfer in any conventional circuit. Conversely, in the receiving mode, antenna impedance can be related directly to the power transferred from the receiving antenna to the load itself (often an amplification circuit) [3]. This includes both the useful radiation resistance (transmitting either power or a signal into free-space), as well as the resistive losses (converting this signal into typically undesired heat). In order to achieve a matched condition, one can use a method called "conjugate matching," in which one attempts to place a quantity of resistance in series with the antenna in order to have the sum of the load and resistive losses equal to the generator resistance, but one must also add either a capacitor or inductor to have the inverse reactance. This cancels out the negative effect caused by the antenna reactance[1]. Unfortunately, this becomes very challenging in the present situation for the UHF antenna, where wideband matching is required.

Ultimately, one of the most important antenna parameters is the gain, which is determined by the radiating fields. By definition, "gain" is not dependent on the losses due to polarization, impedance mismatch, reflection losses, or dielectric losses, but rather a ratio of the field intensity to the total input power per unit solid angle at which it is being measured, as seen in Equation (1) [1]:

$$Gain = 4\pi(\frac{U(\varphi,\theta)}{P_{in}}) \tag{1}$$

This equation relates the gain of an antenna to the radiation intensity and input power. Here, $U(\varphi, \theta)$ represents the radiation intensity per unit solid angle in spherical coordinates. However, it is arguably more common to see what is referred to as the "Absolute Gain" or "Realized Gain," which includes all losses for the antenna (as this is what one will actually measure in a laboratory setting). A definition of the Absolute Gain of an antenna is provided in Equation (2) [1]:

$$Absolute\ Gain = 4\pi\left(\frac{U(\varphi,\theta)}{P_{in}}\right)(1-|\Gamma|^2)(\frac{R_r}{R_r+R_L}) \tag{2}$$

As seen in Equation (2), in order to optimize performance and achieve maximum gain, it becomes necessary that one minimizes reflections (Γ) and resistive losses (R_L). This can be achieved by changing the geometry of the antenna itself.

Appendix II: Computational Electromagnetics

Building and testing a prototype can be very expensive. An antenna is not an exception to this rule. In the past, the only effective manner of engineering an antenna design was through trial and error, using Maxwell's equations as a guide. These equations, as shown in Table 3, are fundamental mathematical relations (partial differential equations) relating voltage and current sources to the corresponding changes in electric and magnetic fields. Unfortunately, analytic solutions to these equations only exist for special cases, and are largely inapplicable to practical antenna problems because the of the complexity of solving these by hand, especially for multiple frequencies with non-trivial geometric patterns [2].

Table 3-Maxwell's Equations [3]

Name	Differential Form	Integral Form	Brief Description
Ampère's law	$\nabla \times \vec{\mathbf{H}} = \vec{\mathbf{J}} + \frac{\partial \vec{\mathbf{D}}}{\partial \mathrm{t}}$	$\oint_{\partial S} \vec{\boldsymbol{H}} \cdot d\vec{\boldsymbol{l}} = \vec{\boldsymbol{I}} + \frac{\partial \vec{\boldsymbol{\Phi}}}{\partial t}$	An induced magnetic field around a medium is equal to the sum of the current density through the medium and the change of electric flux with respect to time
Faraday's law	$\nabla \times \vec{\mathbf{E}} = -\frac{\partial \vec{\mathbf{B}}}{\partial \mathrm{t}}$	$\oint_{\partial S} \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{l}} = -\frac{\partial \vec{\boldsymbol{\Phi}}}{\partial t}$	An induced electric field through a medium is equal to (but in the opposite direction) the change in magnetic flux around the medium
Gauss's Law	$\nabla \cdot \vec{\mathbf{D}} = \rho$	$\oiint_{\partial V} \vec{\boldsymbol{D}} \cdot d\vec{\boldsymbol{A}} = Q(V)$	The total electric flux on any Gaussian Surface is always equal to the charge enclosed by this surface.
Gauss's Law for Magnetism	$\nabla \cdot \vec{\mathbf{B}} = 0$	$\oiint_{\partial V} \vec{\boldsymbol{B}} \cdot d\vec{\boldsymbol{A}} = 0$	The total magnetic flux through any Gaussian surface is always 0, meaning magnetic monopoles do not exist, and magnetic field lines neither begin nor end.

Recently, a new field of Computational Electromagnetics (CEM) has been created solely for the purpose of allowing computer programs to circumvent the human difficulty of mass quantities of labor intensive calculations, and solve Maxwell's equations for specific cases. However there are multiple algorithms within CEM for finding the solution to these equations. Each of these methods have their own strengths and weaknesses. The major solution methods include: Finite Differences (FD), Finite Element Method (FEM), Method of Moments (MoM), and Finite Difference Time Domain (FDTD) [2].

This project makes extensive use of the commercially available Electromagnetics package from Ansys: Ansoft HFSS (High Frequency Structure Simulation). This program uses FEM with tetrahedral meshes to solve for the fields in a given problem. Although the program itself is very versatile and complex, it is vital to have a sound understanding of the solution techniques before applying them to a project.

In general, any finite element solver will break a problem up into discrete shapes, calculate the fields for each of these shapes independently, and then unite them as the solution. Unlike the FDTD method, FEM is conducted on an "unstructured grid," thus allowing FEM to create meshes of shapes that are not constricted to Cartesian coordinates. This provides a significant increase in accuracy in comparison to the "staircase approximation" method that FDTD must use (where in order to increase accuracy, a much smaller step size is required). Unfortunately, this also requires considerably more computational time and resources in comparison to any other solution algorithm [2].

The key advantage of FEM is its ability to accurately represent curved geometries by approximating them with several shapes on this so-called "unstructured grid." This allows FEM to accurately compute time-harmonic or eddy current models, while providing more attention near boundaries, because each element of the mesh will only need to know the effects from its immediate neighboring elements. In comparison, MoM, also known as the Boundary Element Method (BEM), uses Maxwell's equations in their integral form (as seen in Table 3), which incorporates the source itself into the solution, requiring the computer to consider all elements at once. This becomes more computationally intense and is subject to numerical error; however, MoM can be better suited to thin structures with open spaces, as free-space does not need to be directly modeled in MoM (unlike FEM, which needs to mesh all free-space within the radiation boundaries) [2].