

Final Advanced RF

by Joseph Gillespie

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Design and Analysis of RF Antennas

ADVANCED RADIO FREQUENCY SYSTEMS
(ACDA6019)

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Abstract

Within this report, six different antennas (Rectangular Patch Antenna, Cylindrical Dipole Antenna, Folded Dipole Antenna, Horn Antenna, Helix Antenna and a 3x3 Helix Array Antenna) have been created within two separate simulation software. This software consists of CST Studio Suite 2024 and MATLAB R2024b, with CST used solely to develop and simulate the Patch Antenna, and MATLAB simulating the remaining five antennas.

Within the antenna's respective software, in which they were constructed, four simulations were carried out. These simulations were impedance matching, S-parameters, 3D Radiation Pattern and the 2D radiation pattern of each one. These results were then compared to their calculated outputs, proving a discrepancy between the simulated and calculated results.

The report then concludes with an acknowledgement that physical calculations, simulated results and physical results all differ due to human error, operating in perfect conditions and general external factors' interference.

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Introduction

Designed in 1886 by Heinrich Hertz, the first antennas constructed were a simple dipole and a loop antenna. These antennas were the start of a test which looked into wireless communication, with the dipole acting as the transmitter and the loop as the receiver for the transmission [1]. This test proved to be successful over short distances. But it wasn't until 12th December 1901 that Marconi achieved the first trans-Atlantic transmission [2]. The antennas used within this test were basic yet again, as the antennas were an array of wires attached to the ground and held up by pylons, but they proved successful and changed communication for the years to come.

These early antennas did not take the traditional look as those seen today and their transmission radiation fields were omnidirectional resulting in some transmissions being received unclearly at the receivers, the possibility of easy interception from other receiving devices and excessive amounts of power needed for long distances. It wasn't until the invention of the Yagi-Uda antenna in the 1920's that directional transmission and receiving was accomplished [3]. Now the Yagi-Uda is commonly seen in suburban homes as the TV antenna, but it was the starting point to the vast range of antennas seen and used today.

It is within this report that six different antennas will be examined, comparing the theoretical calculations to that produced by the simulation software that each antenna has been constructed. The first antenna looked at within this report is that of Rectangular Patch antennas constructed within CST, followed by a Cylindrical Dipole, Folded Dipole, Horn, Helix and a 3x3 Helix array with each of them simulated within MATLAB. The following sections follow the same structure starting with a brief description of the antenna, its construction/theoretical calculations and its simulation results before concluding on an overview of the content of the report.

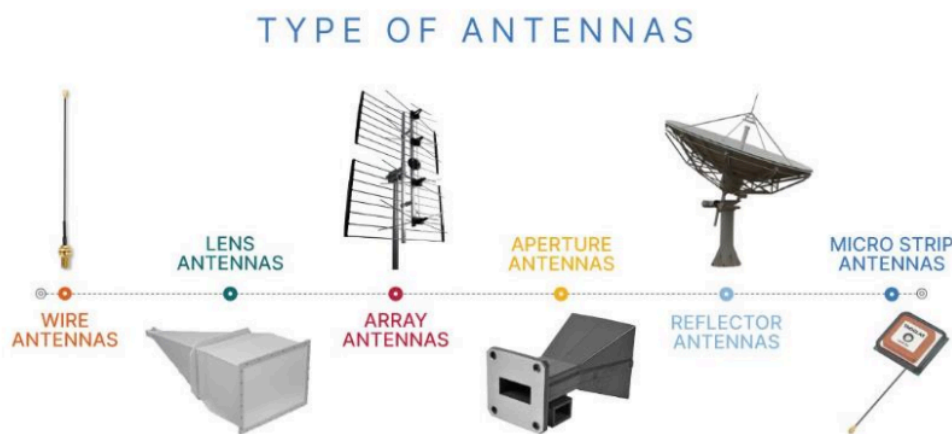


Figure 1, A Collection of Antennas [4]

(1:0) Rectangular Patch Antennas

Patch antennas are becoming more and more popular as technology advances. This is due to their small size and low profile meaning that they can be designed directly onto the printed circuit boards (PCB) alongside systems they are operating in. Due to their reduced size, they are commonly used within mobile phones, GPS tracking devices, Aircraft, spacecraft and many more systems that require limited spacing or subtlety in their purpose [5].

(1:1) Patch Construction

The patch antenna in this report has been constructed using the simulation software CST and designed according to the specifications given to the author of the report. These specifications and the construction process will be examined in the following section.

To start, a patch antenna is split into three primary sections the patch, the ground plane and the substrate. The patch is the primary focal point in which its transmission and received signals are sent and received. The ground plane controls the antenna impedance and specifies the radiation field shape [6]. Whereas the substrate acts as a dielectric by separating the patch from the ground plane, this results in the forming of an electromagnetic field allowing the antenna to operate. The substrate also acts as a mechanical rigidity to help structure the antenna [7].

The patch antenna seen within this section has the following specifications:

Operation Frequency (f) = 2.2GHz

Substrate material = FR4 epoxy

Substrates relative permittivity (Er) = 4.4

Substrates relative permeability (H) = 1

Ground plane and patch material = Perfect Electric Conductor (PEC)

Rectangular microstrip connection impedance = 50Ω

Speed of Light (C) = 3×10^8

What should be noted within this specification is that critical measurements and dimensions are missing. The following equations are the calculations carried out to find the missing dimensions.

Width:

$$W = \frac{C}{2f_0 \sqrt{\frac{\epsilon R + 1}{2}}}$$

$$W = \frac{3 \times 10^8}{2 \times 2.2 \times 10^9 \sqrt{\frac{4.4 + 1}{2}}}$$

$$W = 0.0415$$

$$W = 4.149 \times 10^{-2}$$

Effective permittivity:

$$\epsilon_{eff} = \epsilon R + \frac{12}{\epsilon R - 12} \times [11 + 12 \times (HW)]$$

$$\epsilon_{eff} = 4.4 + \frac{12}{4.4 - 12} \times [11 + 12 \times (14.149 \times 10^{-2})]$$

$$\epsilon_{eff} = 2.8$$

Length:

$$L = \frac{C}{2f_0 \epsilon_{eff}} - 0.824H((\epsilon_{eff} + 0.3)(WH + 0.264)(\epsilon_{eff} - 0.258)(WH + 0.8))$$

$$L = \frac{3 \times 10^8}{2 \times 2.2 \times 10^9 \times 2.8} - 0.824 \times 1((2.8 + 0.3)(4.149 \times 10^{-2} + 0.264)(2.8 - 0.258)(4.149 \times 10^{-2} + 0.8))$$

$$L = 0.218$$

With the above calculations completed, the patch antenna was constructed resulting in the image seen in Figure 3. Before testing could be carried out, the port extension coefficient required calculating. This calculation was purely done within CST and scaled the near-field radiation power of the designed antenna so that the far-field power density could be estimated to base further simulations off. This calculation can be seen in Figure 2.

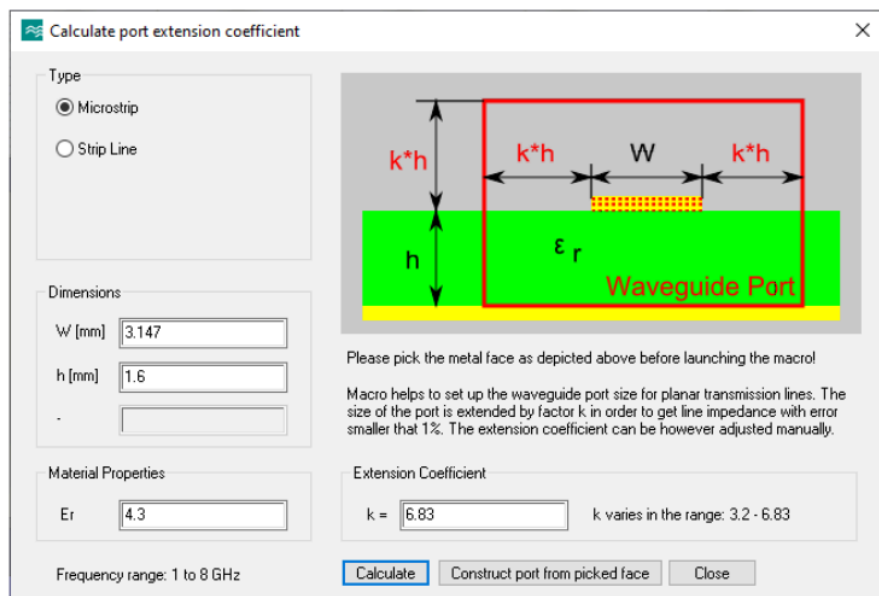


Figure 2, Port Extension Coefficient

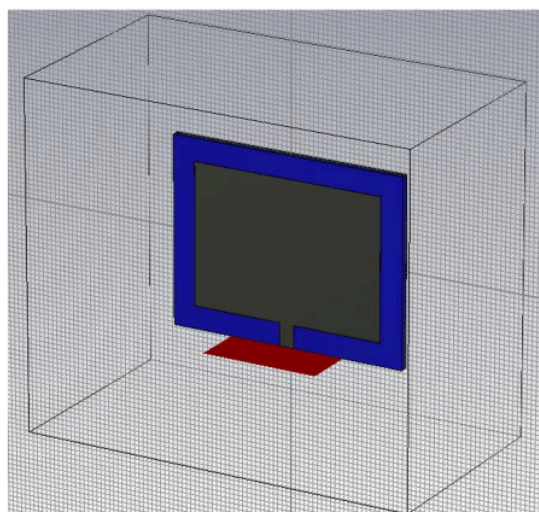


Figure 3, CST's Patch Antenna

(1:2) Simulated Patch Results

The simulated testing began after the construction and specifications had been set up for the patch antenna. The first stage was setting up a frequency sweep from 1GHz to 8GHz to test the antenna over a range of frequencies. The following will cover and describe the simulated results while comparing the theoretical calculations of the resonant frequency to that gained from simulation results.

Shown in Figure 4 is the S-Parameter graph of port S1,1. This graph represents the reflection coefficient seen at the input port of the Patch Antenna. The first of the troughs on this graph shows that the antenna (following the previously mentioned specifications) radiates best at 2GHz. This does not match up with the requirements that specify the operation frequency to be 2.2GHz, making the simulation out by 0.2GHz. At the marker signifying the 2.2GHz frequency point, there is a very little dip showing a pore match.

The other dips shown in Figure 4 are the reflection coefficient of the remaining ports. These ports are S1,2, S2,2 and S2,1. With each one representing the transmission from and to the number port. For example, port S1,2 will be a transmission from the antenna to the receiver and S2,1 is the reverse.

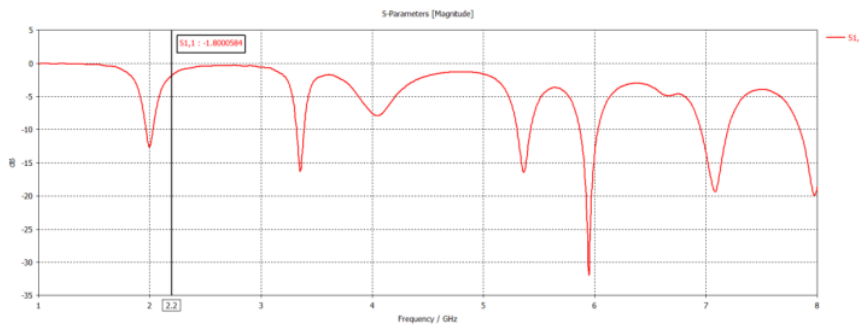


Figure 4, S-Parameter Graph

Due to the simulated patch antenna not matching that of the calculated operation frequency, an adjustment was carried out on the design of the patch. This can be seen in Figure 5 below where the patch length was adjusted until the 2.2GHz frequency was reached. In Figure 5 this is represented by the light green results, this was achieved by changing the length of the patch to 31.036mm.

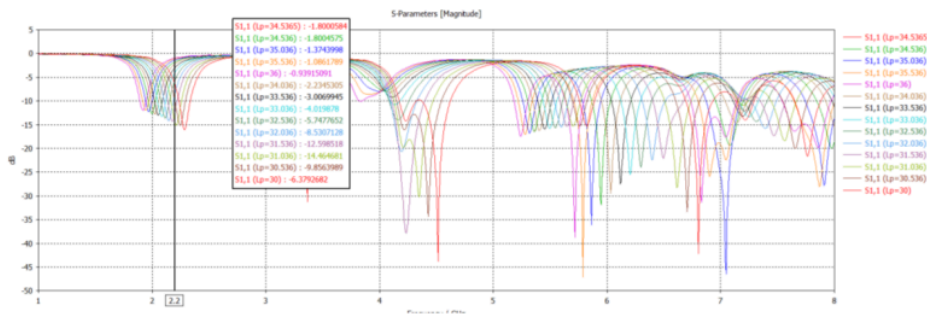


Figure 5, Amended S-Parameter Graph Matching The 2.2GHz Frequency

The image shown in Figure 6 is that of the 3D representation of the radiation field of the antenna. What is not hear is that there is a strong directional concentration of radiation from the antenna itself in one direction, this is the transmission field from the patch itself. There is also a noticeable lesser radiation field emitting from the back of the antenna. This limited but not completely nullified radiation is due to the back plate concentration the radiation field forward in comparison to the antenna itself.

When operating the Patch antenna, the receiver or transmitter would preferably be within the red zone of the antenna radiation field. This is the optimal operation area of the patch antenna.

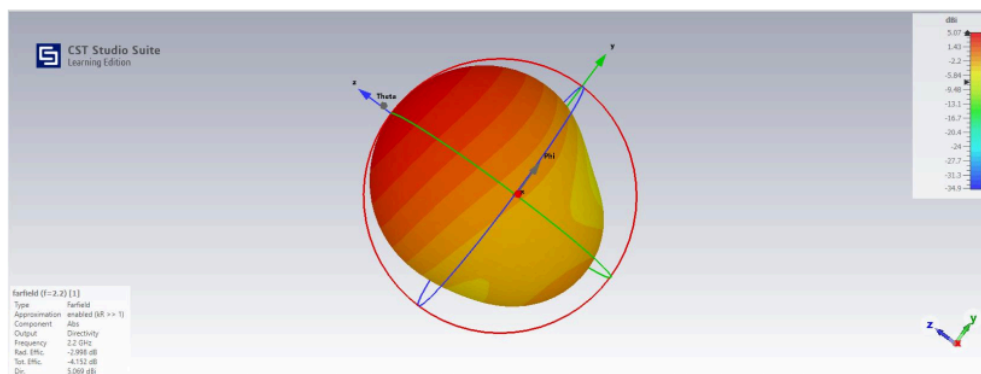


Figure 6, 3D Radiation Pattern Of Patch Antenna

Figure 7 shows the simulated antenna reference impedance. What is interesting hear is that normally the reference impedance is standardized at a value of 50Ω when carrying out calculations but from the simulation, the impedance value is at 47.9Ω . This value could be partly related to the abnormal values seen within the S-Parameter graph in Figure 4.

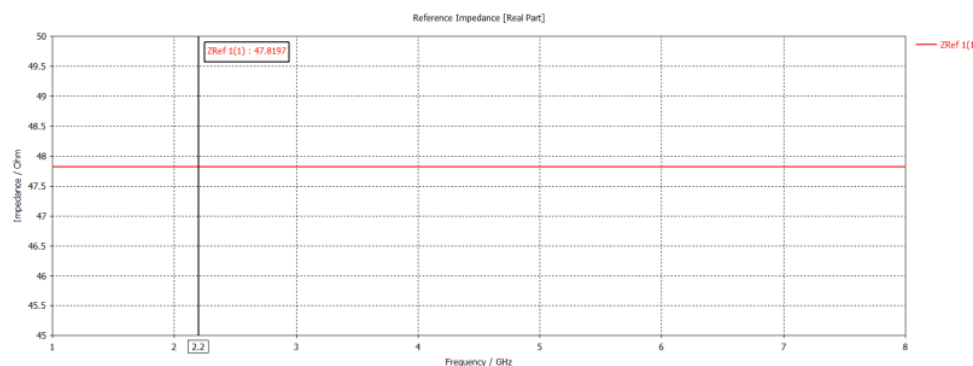


Figure 7, Reference Impedance

(2:0) Cylindrical Dipole Antennas

Second only to a monopole antenna, a dipole is one of the simplest designs in the antenna world. Constructed from two of the same conductive materials such as wires or metal rods and separated by an insulator [8], the dipole is used for a range of systems like FM radios, Satellites and communication systems.

(2:1) Dipole Construction

The Dipole looked at in this report was constructed within MATLAB vier, its antenna design package. By using the antenna design package, no prayer construction calculations were needed other than the operation frequency. This was gained by selecting the second number within the author's student identification number resulting in an operation frequency of 2GHz.

The following figures are the specifications given to the antenna via MATLAB:

$$\text{Length (L)} = 70.451\text{mm}$$

$$\text{Radius} = 1.4009\text{mm}$$

$$\text{Conductor material} = \text{PEC}$$

When calculating these values manually there is variations in their results, this can be seen below.

Wavelength:

$$\lambda = \frac{c}{f}$$

$$\lambda = \frac{3 \times 10^8}{2 \times 10^9}$$

$$\lambda = 0.15$$

Length:

$$L = \frac{\lambda}{2}$$

$$L = 0.075$$

$$L = 75\text{mm}$$

The image seen in figure 8 is the dipole made within MATLAB.

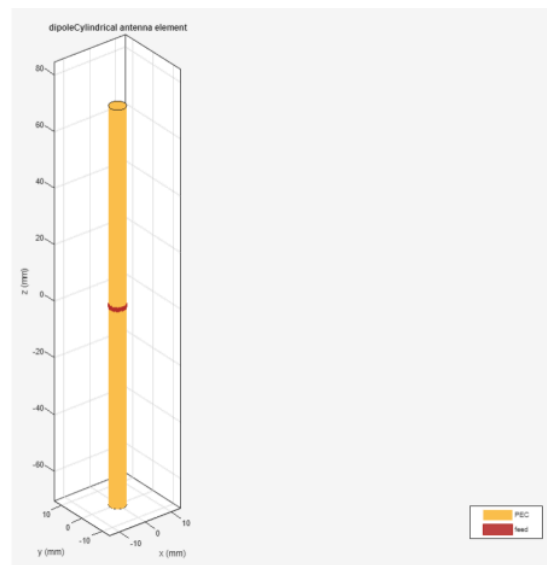


Figure 8, Cylindrical Dipole Antenna MATLAB

(2:2) Simulated Dipole Results

All the following results were simulated within MATLAB and will be supported with a breath description.

The graph in Figure 9 shows the increase in resistance as the frequency increases, this maxes out at a frequency of 2.2GHz and an impedance of 125 Ω .

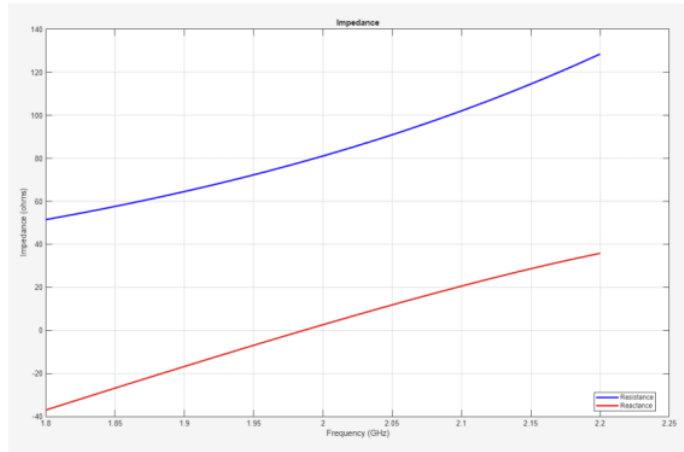


Figure 9, Dipole Impedance

The S-Parameter plot seen in Figure 10 shows that the antenna operation frequency is at 1.93GHz. This is 0.07GHz lower than the intended operation frequency.

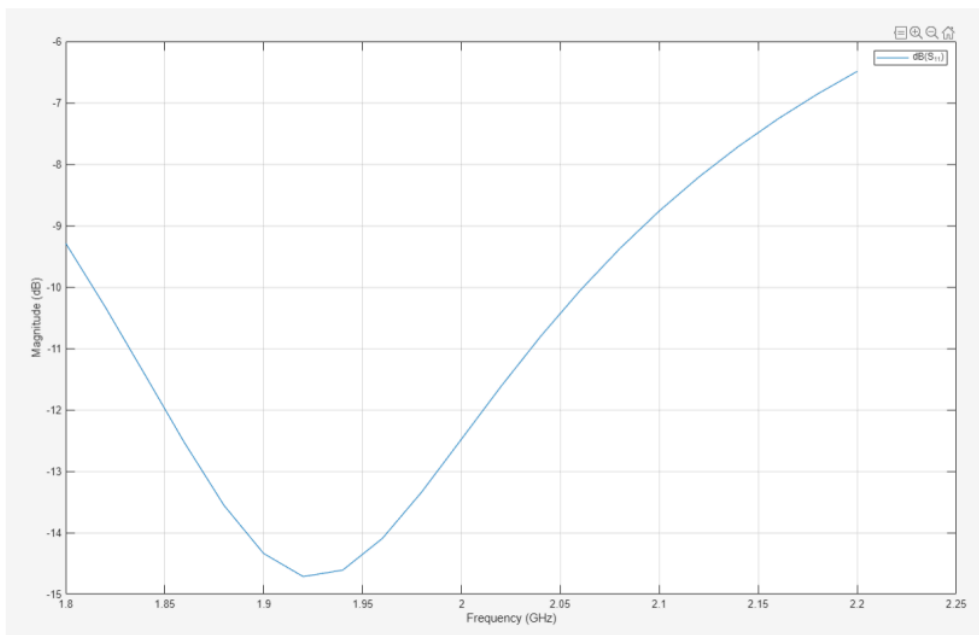


Figure 10, Dipole S-Parameter Graph

Figure 11 shows the radiation field of the dipole. What can be seen here is that the field is omnidirectional meaning that the antenna has a good coverage in all directions when transmitting and receiving signals.

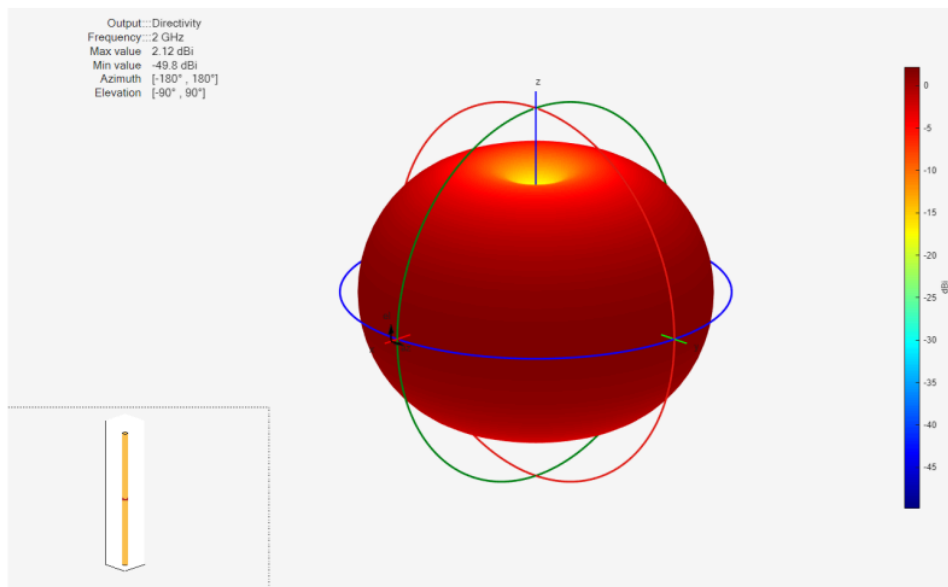


Figure 11, 3D Radiation Field of Dipole

Figure 12 shows the directive power of the dipole along the EL (XY) axes. What can be seen here is that there are two strong lobes to aver side of the antenna and two weaker points found at the top and bottom of the antenna. Looking at this and when using the dipole, the receiving/transmitting antenna must be parallel to the dipole to receive the best transmission.

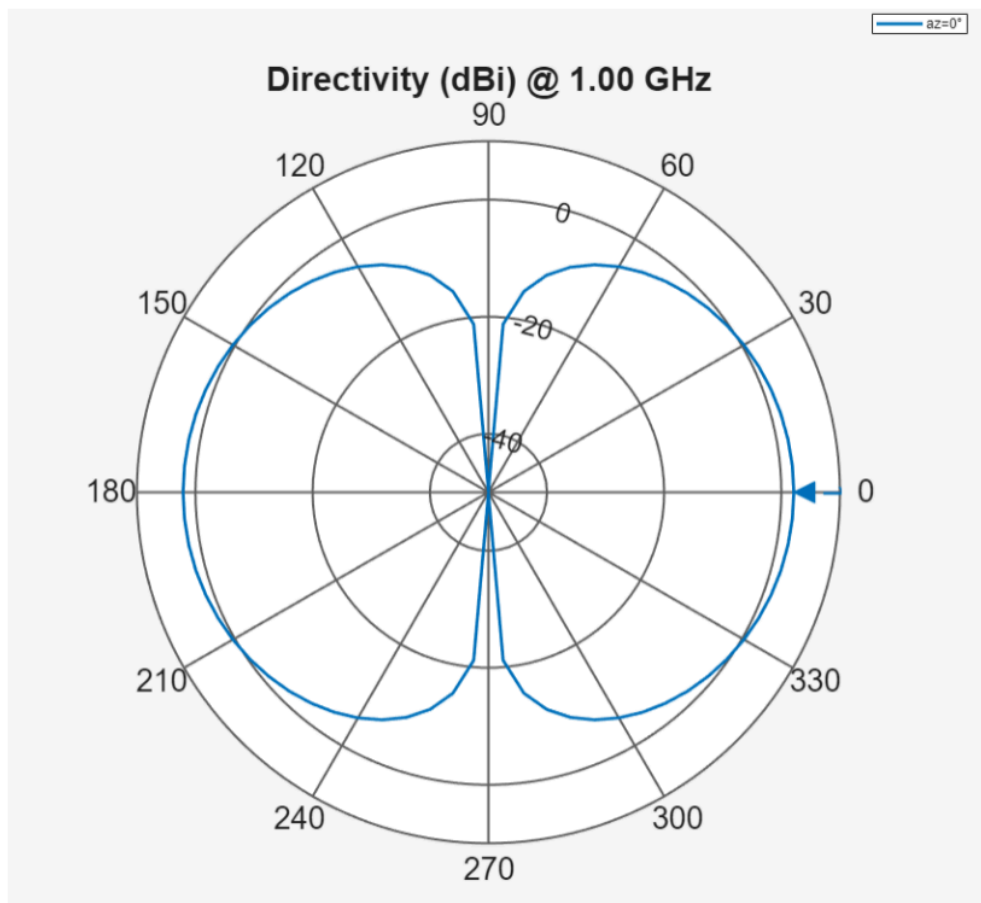


Figure 12, Dipole 2D radiation Field in the EL Plane

(3:0) Folded Dipole Antennas

The folded dipole is a variant of the dipole antenna where the two conductive materials are folded onto themselves forming a loop. This results in the folded dipole being smaller than a standard dipole. This makes it easier to install into systems and more efficient at radiating transmission at a longer distance. Due to this, the antenna is commonly used as a receiving and transmitting antenna for VHF and UHF frequency systems such as broadcasting and WiFi communications [9].

(3:1) Folded Dipole Construction

Much like the dipole antenna, the folded dipole was constructed within MATLAB. The following is the calculation done for the operation frequency using the authors student identification number and the specifications set by MATLAB.

Operation Frequency:

$$F = 2212$$

$$F = 110.5\text{MHz}$$

MATLAB set specifications:

Length = 1.2616m

Width = 0.013565m

Spacing = 0.018087m

Figure 13 shows the simulated folded dipole antenna.

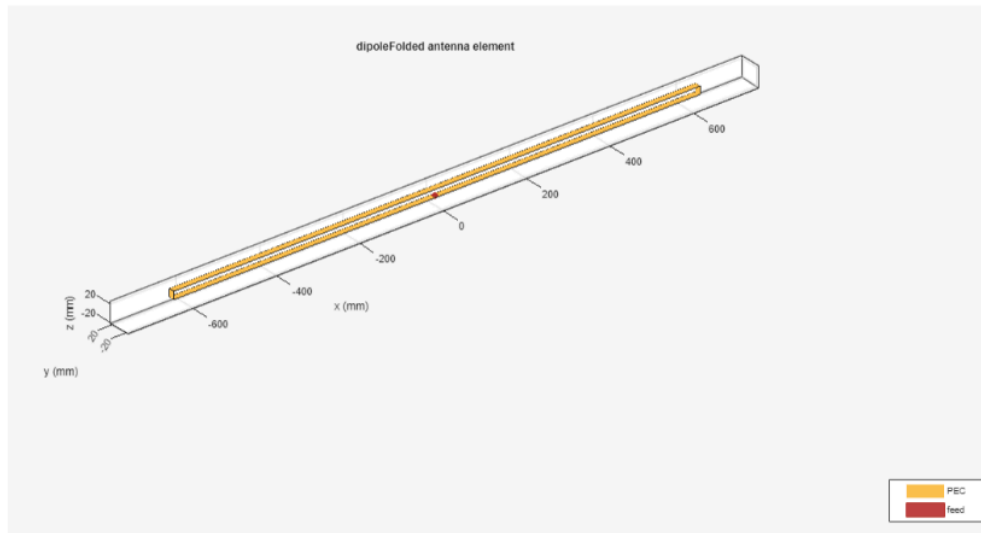


Figure 13, Folded Dipole Antenna MATLAB

(3:2) Simulated Folded Dipole Results

As seen in section 2.2, and will be repeated through sections 3.2, 4.2, 5.2 and 6.2, the simulated results were all produced within MATLAB.

The graph shown in Figure 14 is the folded dipole impedance graph. The red line represents the imaginary part of the antenna (The power stored within the device), where this crosses the 0Ω line is the resonating frequency of the antenna, this sites at 111MHz. The blue line represents the real part of the antenna and its resistance that sites around 270Ω to 290Ω

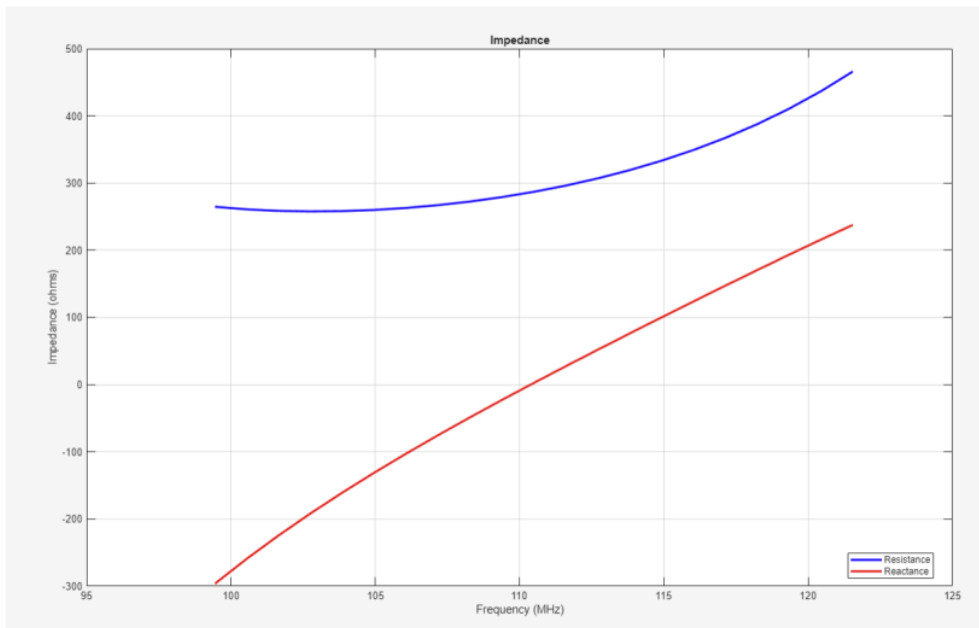


Figure 14, Folded dipole Impedance Graph

Figure 15 shows the S-Parameter S_{1,1} for the folded dipole. What can be seen here is that the operation frequency of the antenna is around the 108MHz to 109MHz range.

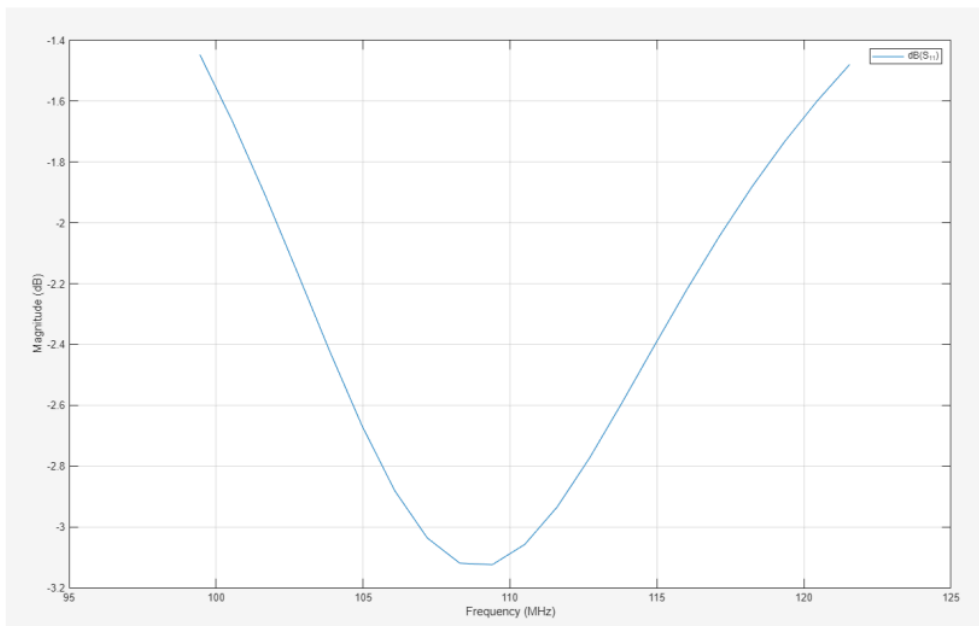


Figure 15, Folded Dipole S-Parameter Graph

Figures 16 and 17 both display the radiation pattern of the folded dipole antenna. What can be seen here is that both radiation field diagrams show a similar pattern to that seen in the

dipole in section 2.0 but rotated 90°. Where a difference comes in is what is shown in Figure 17, the power of the field emitted from the antenna is the same as the dipole even known that the operation frequency is lower than that of the dipole.

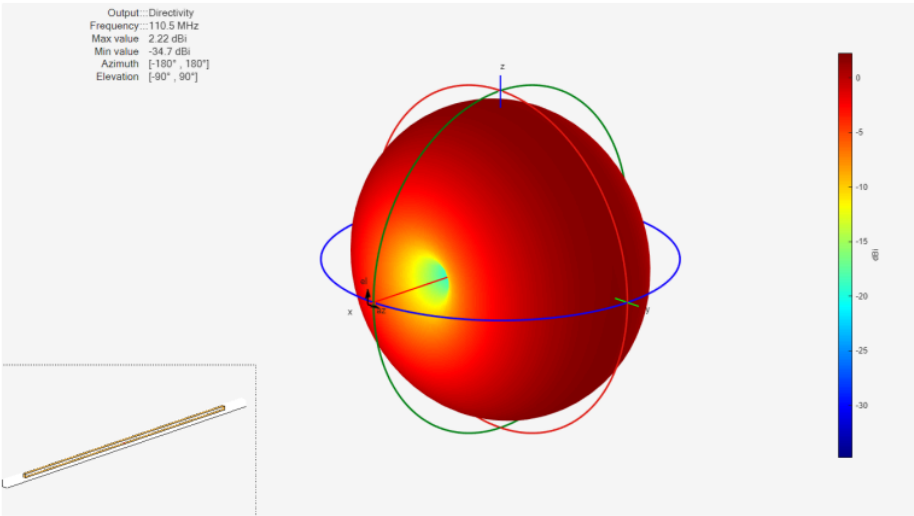


Figure 16, 3D Radiation Pattern of the Folded Dipole

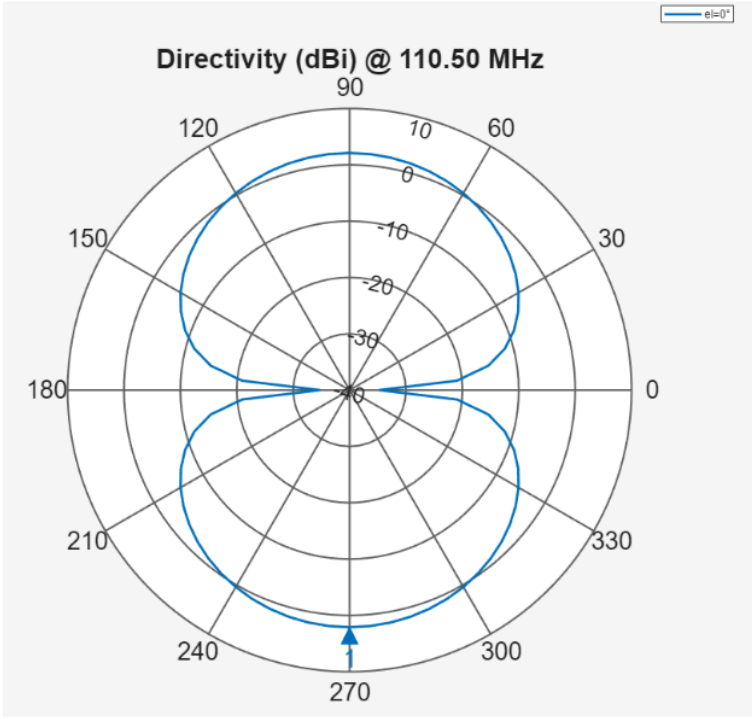


Figure 17, Directivity of Folded Dipole

(4:0) Horn Antennas

The horn antenna is a variation of an aperture antenna meaning that it is a form of waveguide that has an opening on one end to emit or receive transmissions. This opening is flared resulting in a wide directional transmission or a larger receiving area for incoming signals primarily those found within the microwave frequencies of 300MHz to 300GHz. Due to this, the horn antenna is often used in RADAR, microwave radiometers and various other test equipment [10].

There are several different designs for the horn antenna depending on its intended operation. These are the Corrugated Horn, Exponential Horn, Conical Horn, Sectoral Horn and Pyramid Horn which are looked at in this report [10].

(4:1) Horn Construction

The following calculation was used to work out the operation frequency for the antenna:

Operation Frequency:

$$F = 142$$

$$F = 7\text{GHz}$$

The following are the specifications set by MATLAB:

$$\text{Flare Length} = 70.63\text{mm}$$

$$\text{Flare Width} = 93.89\text{mm}$$

$$\text{Flare Height} = 82.75\text{mm}$$

$$\text{Length} = 46.85\text{mm}$$

$$\text{Width} = 37.475\text{mm}$$

$$\text{Height} = 18.735\text{mm}$$

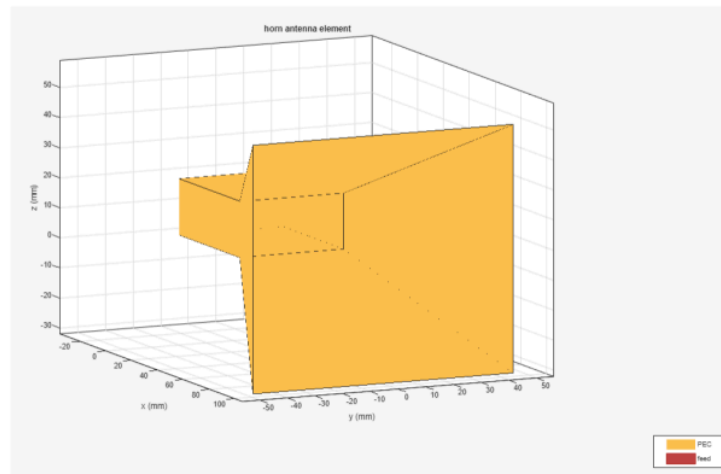


Figure 18, Horn Antenna MATLAB

(4:2) Simulated Horn Results

The impedance graph in Figure 19 shows the impedance frequency of the horn antenna to be at approximately 6.83GHz from the imaginary lines (red) intercept through the 0Ω line. This gives the real resistance of the antenna a range of 38Ω to 44Ω, represented by the blue line.

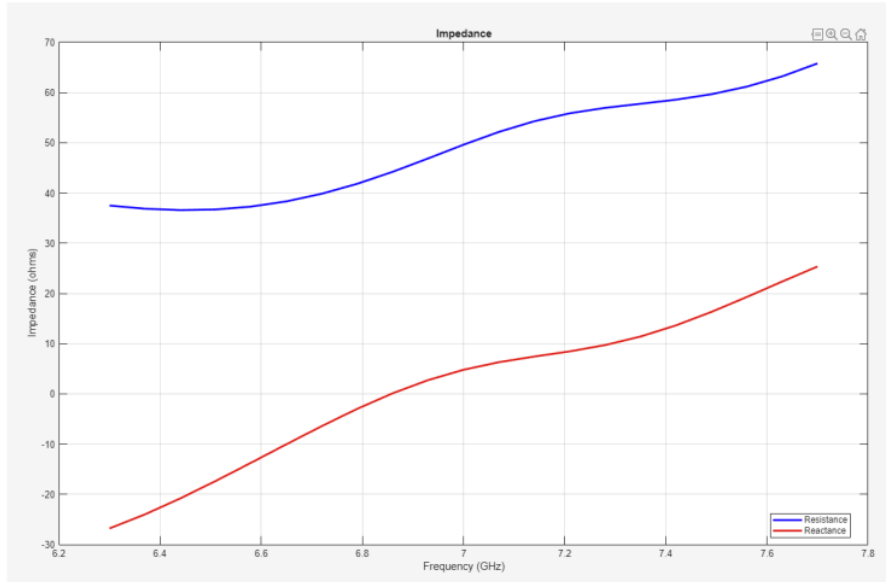


Figure 19, Horn Antenna Impedance Graph

The S-Parameter graph in Figure 20 gives a much clearer operation frequency than those seen in sections 2.2 and 3.2. This is represented by the sharp trough signifying a clear operation frequency of 6.92GHz.

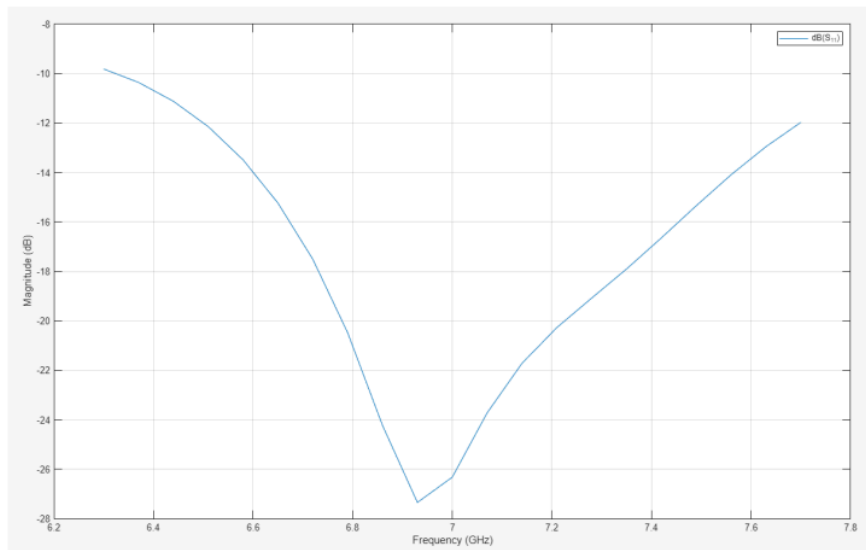


Figure 20, Horn Antenna S-Parameter Graph

Shown in the 3D radiation field diagram in Figure 21, there is a distinctive concentration of radiation fields emitting from the front of the horn antenna, this is the main beam and the primary position a receiving or transmitting device will be seated within. To the top and bottom of this main radiation lobe are two smaller but distinct radiation fields, which are known as side lobes. At the main body of the antenna, there is little to no radiation emissions.

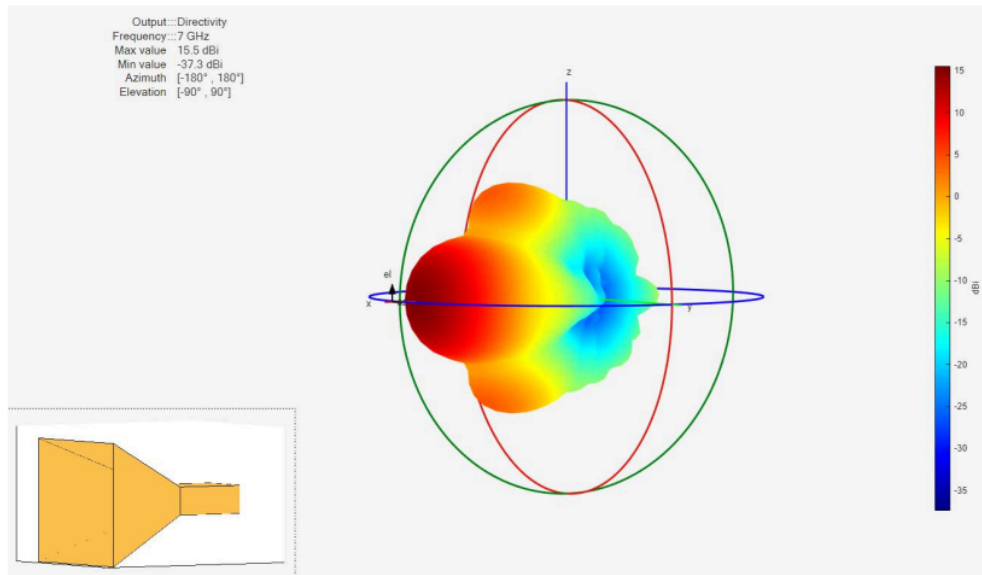


Figure 21, 3D Radiation Field of the Horn Antenna

Figure 22 shows the antenna's directivity and clearly shows several sidelobes, a main lobe and back lobes relating to the radiation field of the antenna. The side lobes of the antenna are produced by diffraction effects caused by light affecting the radiation, these lobes are unwanted and can cause interference as well as false readings if not taken care of or considered. Side lobes can be minimised by controlling the power which the antenna emits or simply improving the antenna's design [11].

What can be seen in Figure 22 is a distinctive back lobe. A back lobe is a radiation field that is placed 180° to the main lobe. This is undesirable as the direction of radiation is not correct alongside showing that there is a distinct amount of reflection from the transmission. Back lobes can cause a decrease in gain from the main lobe which subsequently affects the signal quality and increases interference.

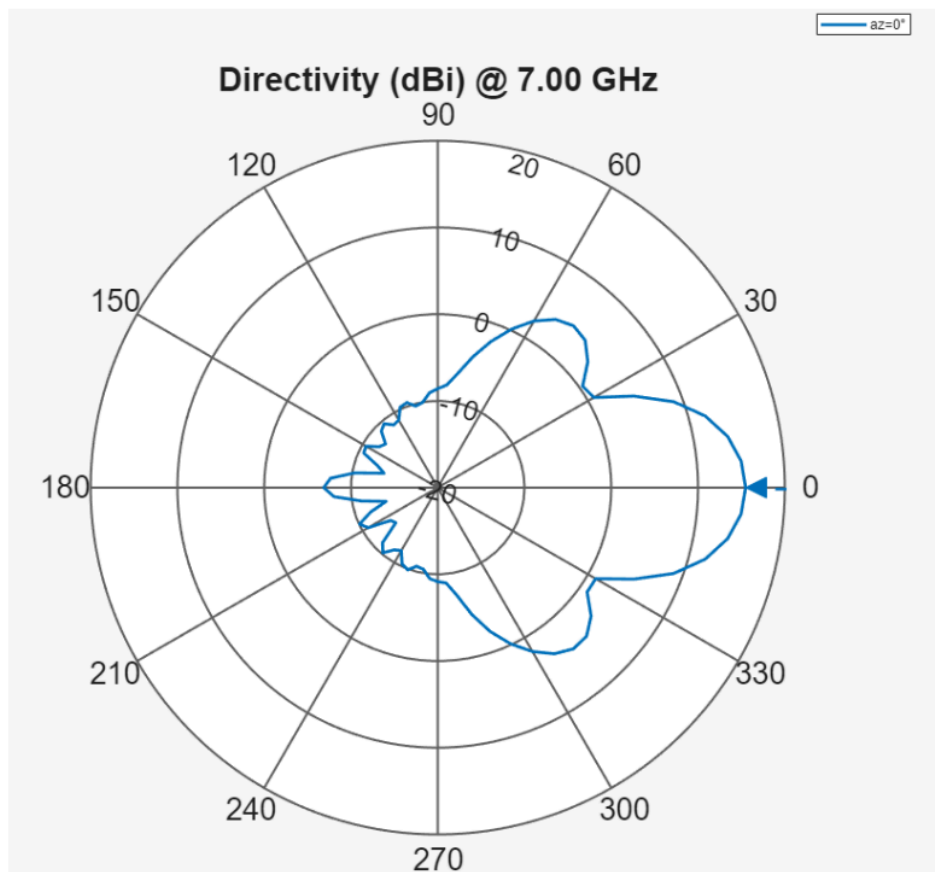


Figure 22, Directivity Diagram of the Horn Antenna

(5:0) Helix Antennas

Seen as a more unusual antenna compared to others within this report, the helix antenna is commonly used to enhance space communications such as satellite relays and ground-to-satellite communication. This is due to it operating within the UHF and VHF frequencies, which range from 30MHz to 3GHz when transmitting and receiving [12].

Another feature that makes the helix antenna stand out is its capability to operate in two modes. One of these modes is recognised as normal, where the radiation pattern to the antenna is perpendicular, and the other mode being axial, where the radiation field is horizontal to the antenna. These modes go hand in hand with the antenna's wide bandwidth, high gain and circular polarisation characteristics [12].

(5:1) Helix Construction

The Helix antenna was set with the following construction specifications within MATLAB.

Radius = 3.0279mm

Width = 0.12113mm

Turns = 3

Spacing between turns = 4.2399mm

All these specifications were based on the operation frequency given to the antenna. Following the guidelines for gaining the operation frequency, the 2nd and 3rd digits of the author's student identification number were used to produce the following operation frequency.

Operation Frequency = 21GHz

With these specifications, the antenna seen in Figure 23 was constructed.

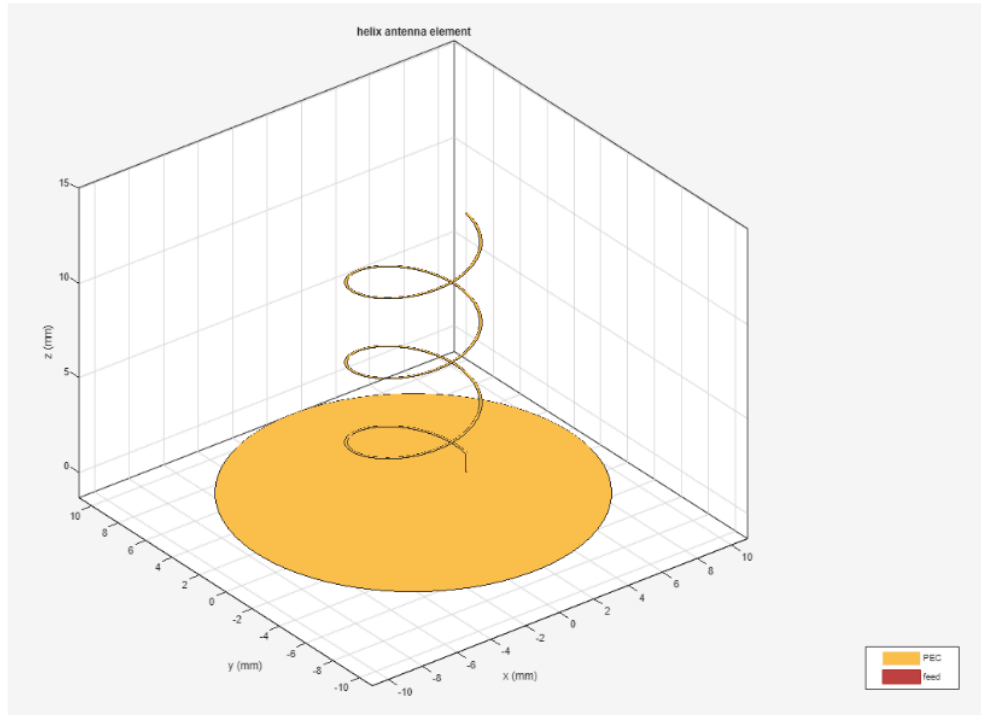


Figure 23, Helix Antenna MATLAB

(5:2) Simulated Helix Results

The impedance graph seen in Figure 24 shows a completely different impedance graph when compared to those seen in this report. The reasoning behind this is due to the two different settings that the antenna can operate in. This has resulted in two impedance frequencies which will relate to both fields in the antenna, the first of these frequencies is at 20.4GHz and the second is at 21.7GHz.

The resistance of the antenna peaks at 530Ω before dropping to 80Ω.

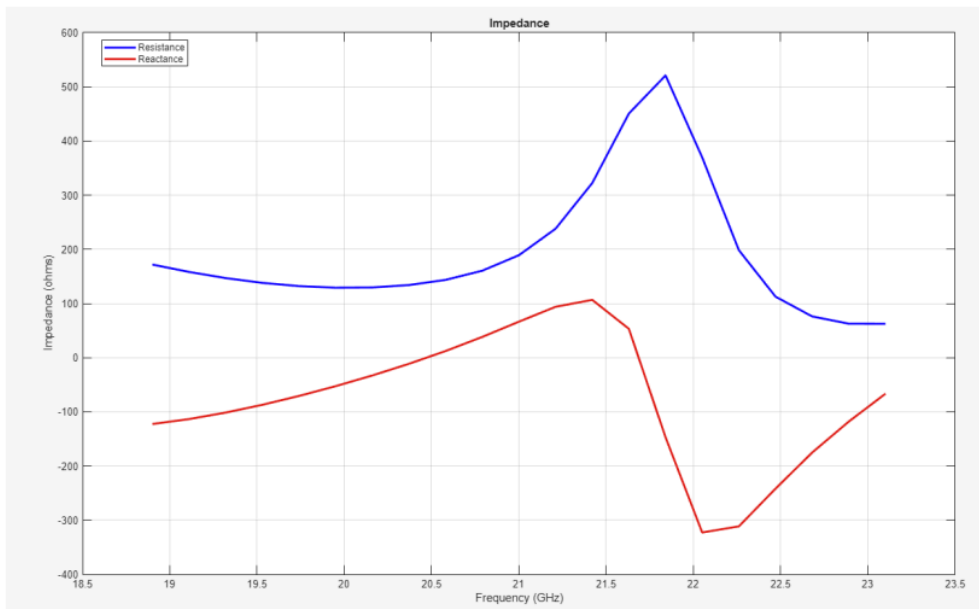


Figure 24, Helix Impedance Graph

Figure 25 shows the operation frequency of the antenna to be at 20.4GHz.

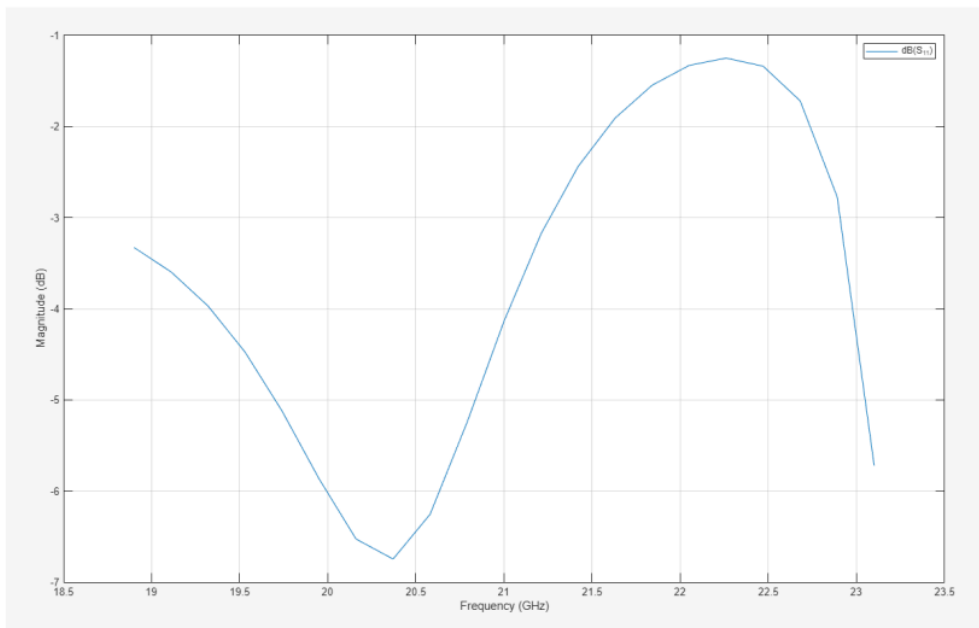


Figure 25, Helix S-Parameter Graph

The radiation field in Figure 26 presents strong directional radiation emitting from the top of the antenna, clearly representing the perpendicularly directed transmission field. Lower down around the main body of the antenna, two distinct radiation lobes can be seen that demonstrate the horizontal antenna's radiation capability.

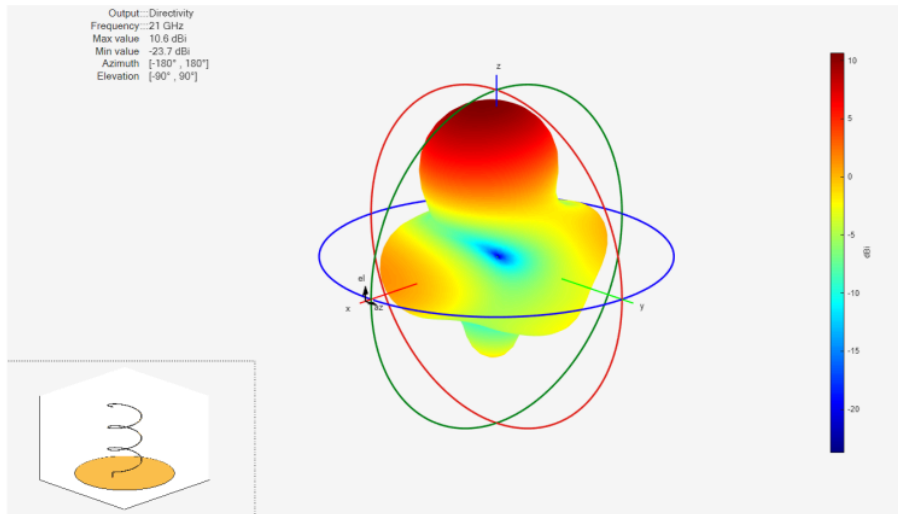


Figure 26, Helix 3D Radiation Diagram

Figure 27 clearly shows the two distinct radiation fields of the Helix antenna. Here, a clear back lobe can also be seen at the 270° point on the graph.

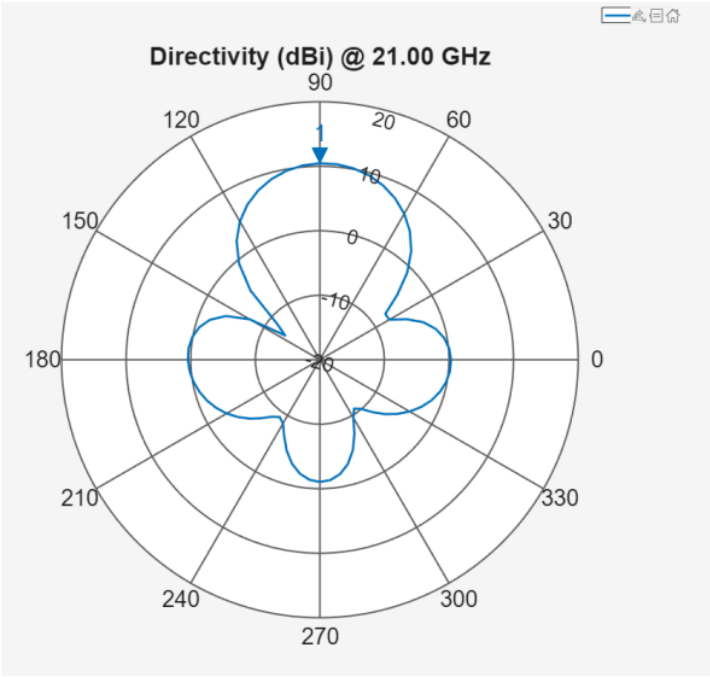


Figure 27, Helix Directivity Diagram

(6:0) [3,3] Helix Array Antennas

An Antenna array is a form of directional antenna that is constructed from multiple of the same type of individual antennas. They can vary in size from the one seen within this report to smaller formations like 2 by 2 or scaled significantly to sizes like 50 by 50, and can be in non-square formats like 2 by 3 depending on their requirements and base antenna.

The significance of array antennas is that they unify individual antennas to gain greater performance in signal strength, improve directivity, reduce unwanted radiation lobes, High gain, and reduce power wastage. This is achieved by all the antennae operating separately which can also allow the main radiation field to change directions without the array moving. How this change in indirection is achieved by certain antenna-stopping radiation resulting in a change in the main direction of radiation without moving the mechanical structure [13].

(6:1) Helix Array Construction

The array antenna examined in this report has been constructed using nine helix antennas set up in a 3 by 3 square format. Each helix antenna is constructed to the same specifications seen within section 5:0. The operation frequency for the array is set to that of section 5:0 with the only difference in construction being that of the spacings stated below:

Row Spacings = 7.1379mm

Column Spacings = 7.1379 mm

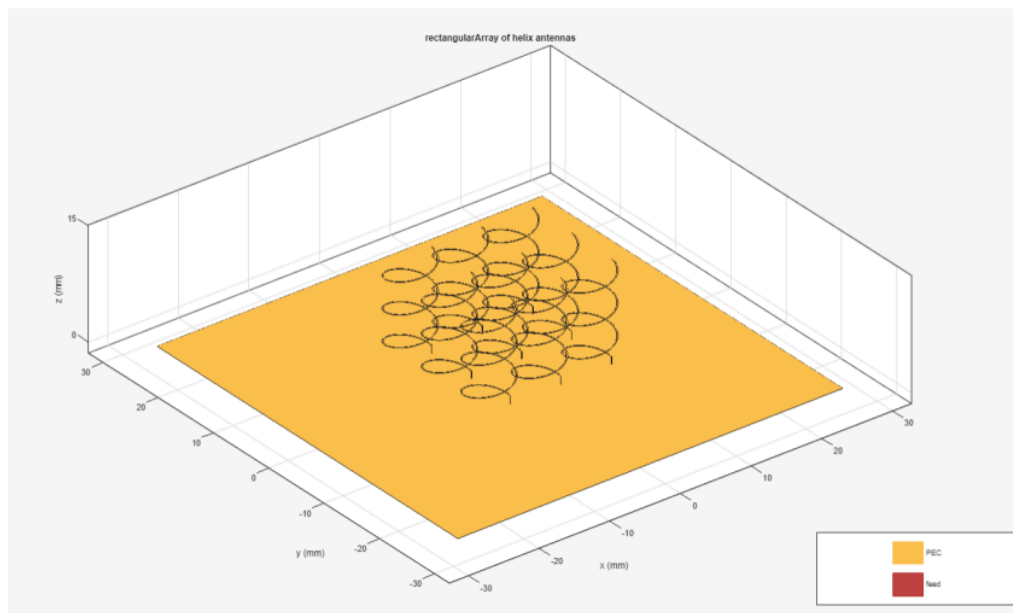


Figure 28, [3,3] Helix Array Antenna MATLAB

(6:2) Simulated Helix Array Results

Figure 29 shows the S-Parameter graph of the antenna array. What can be seen here is all the antennas in operation resulting in the many readings, but the point to take note is that most of the antennas form an operation frequency of 22.49GHz.

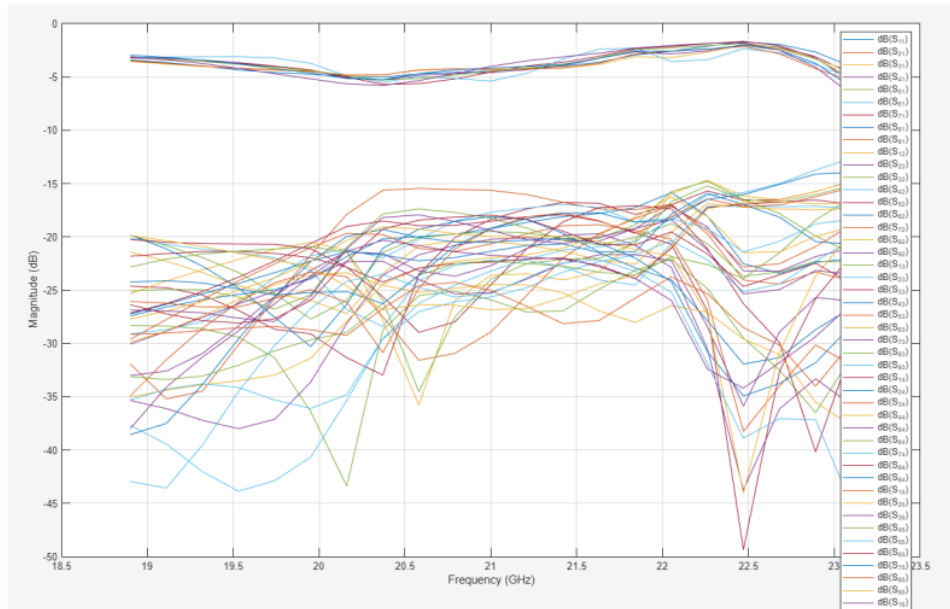


Figure 29, S-Parameters of Helix Array

The 3D radiation pattern in Figure 30 shows the elimination of the side lobes seen in Figure 26 and demonstrates a much improved and stronger directional radiation field in the vertical field.

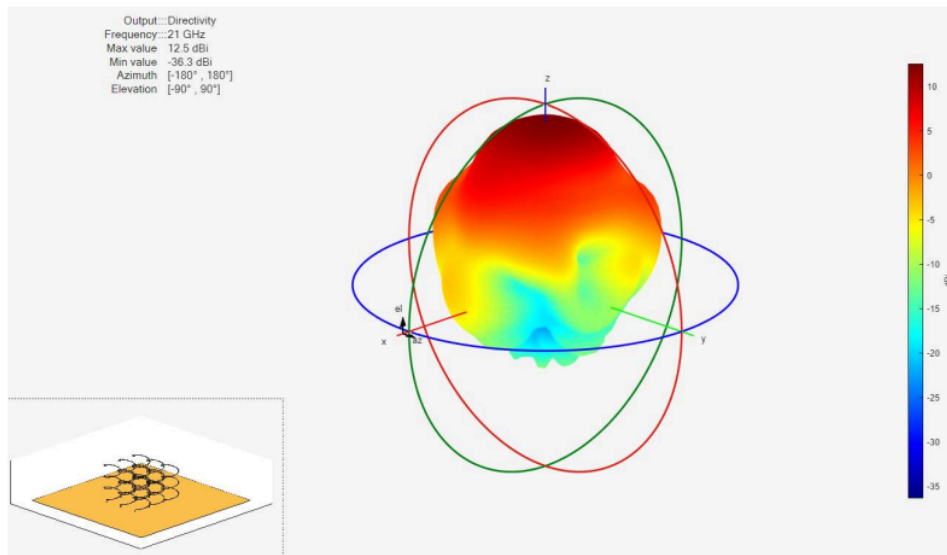


Figure 30, Helix Array 3D radiation Field

The directivity diagram in Figure 31 shows a highly diminished back lobe compared to the singular helix antenna. This demonstrates that there is less of a negative effect on the gain when the helix antenna operates as an array.

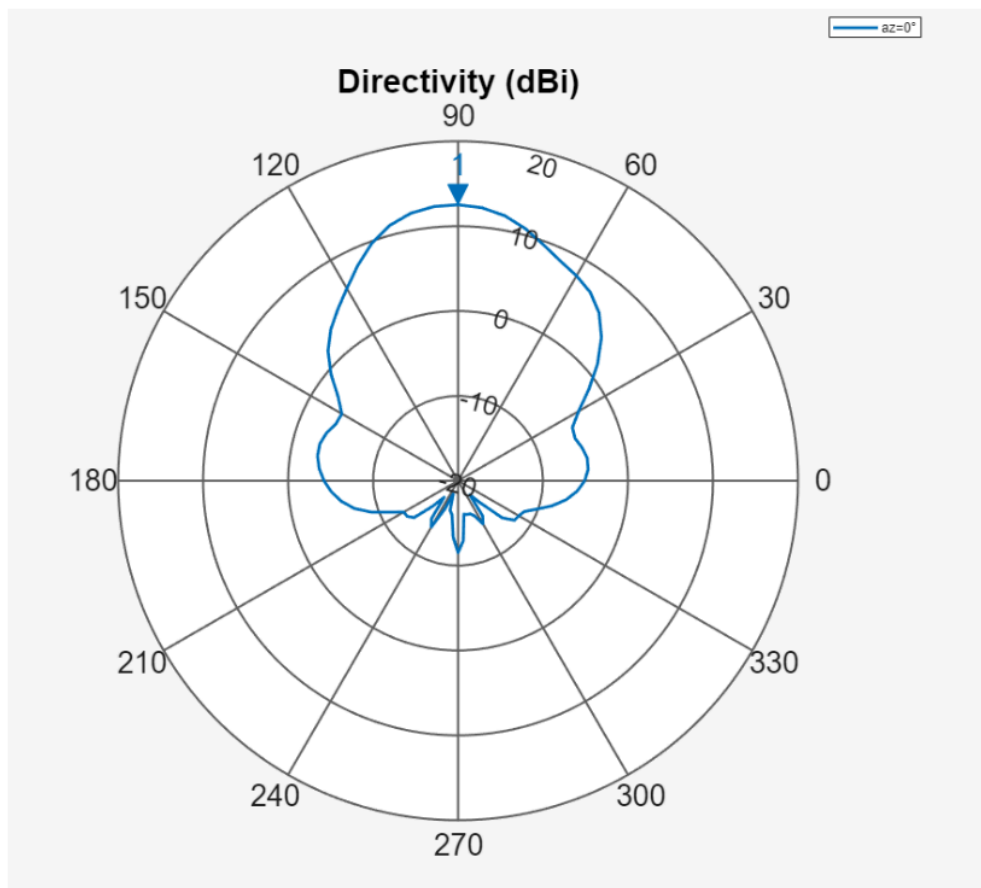


Figure 31, Helix Array Directivity Diagram

Conclusion

In conclusion, this report has demonstrated the capabilities and highlighted some common operation usages of six antennas. The variations and construction of each antenna depend on its intended use showing that choosing an antenna depends on the required system operations.

Another conclusion to take from this report is that theoretical calculations do not match up with those simulated within different software, resulting in mathematical answers not matching up with simulated ones. The main cause of this is rounding errors, as simulations can accept and deal with far more decimals than a person. The other is human error.

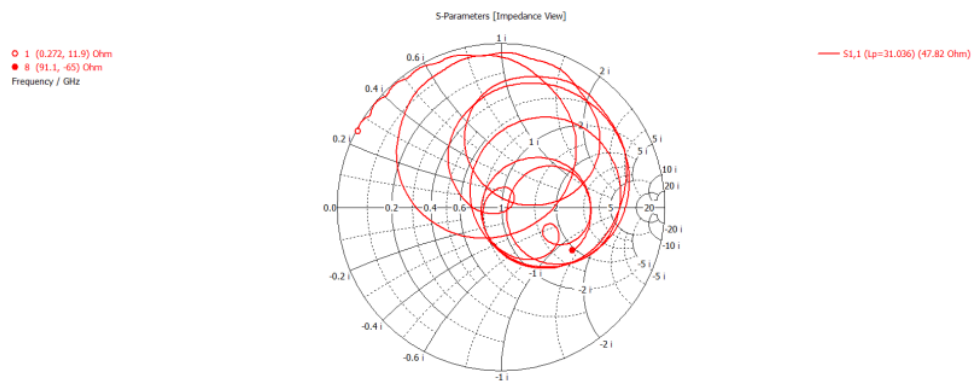
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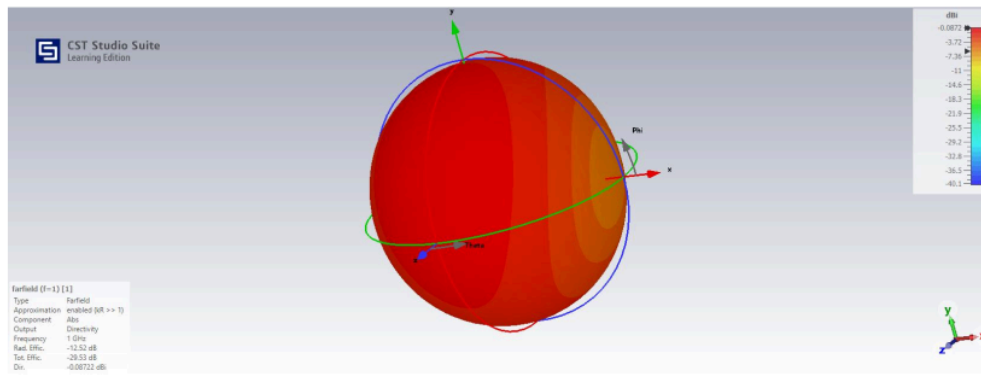
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Appendices

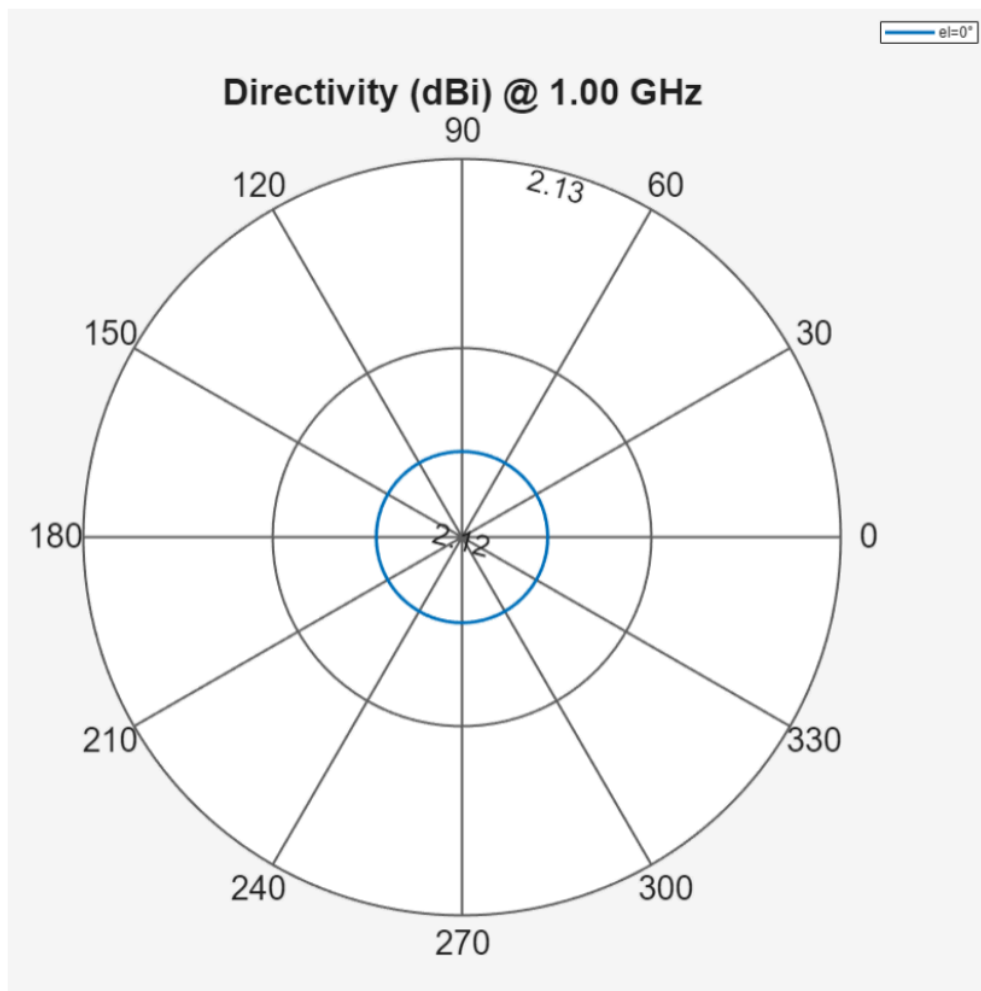
Patch antenna Smith chart



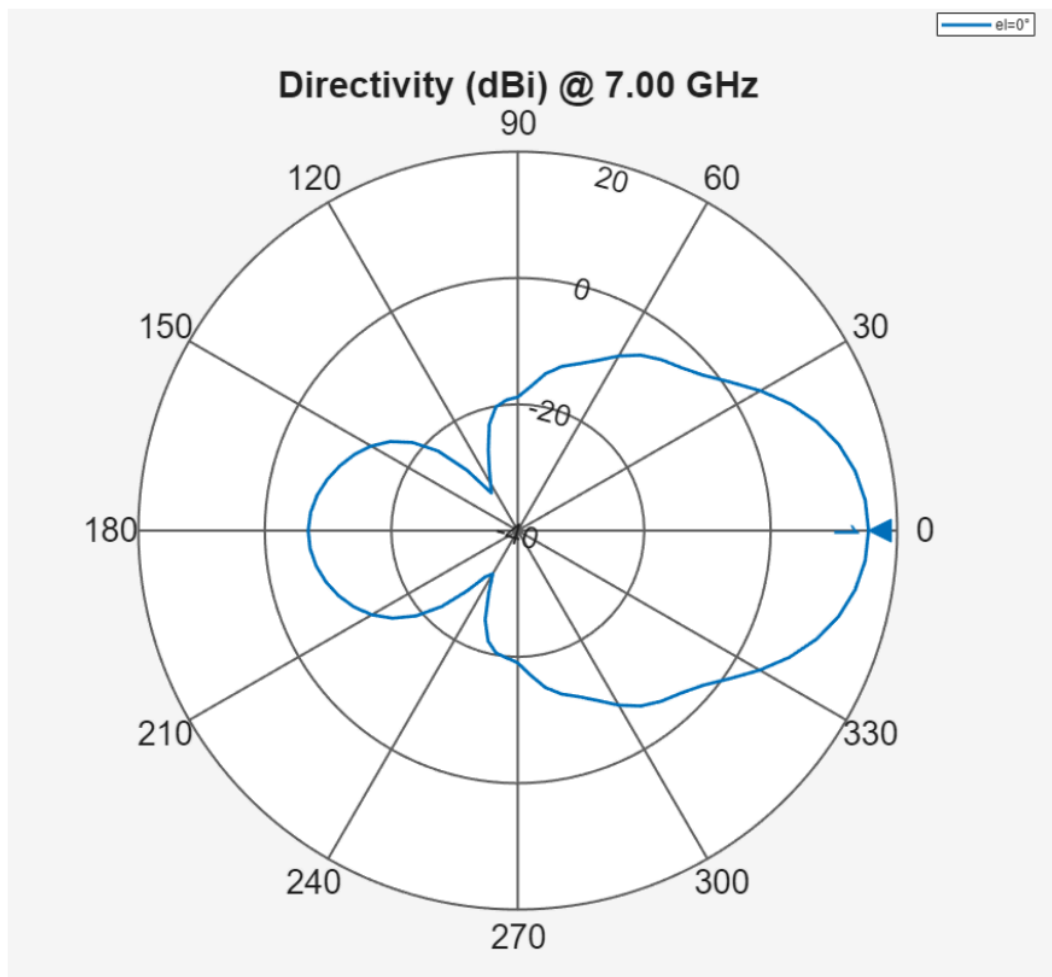
Patch antennas S_{1,1} Radiation field



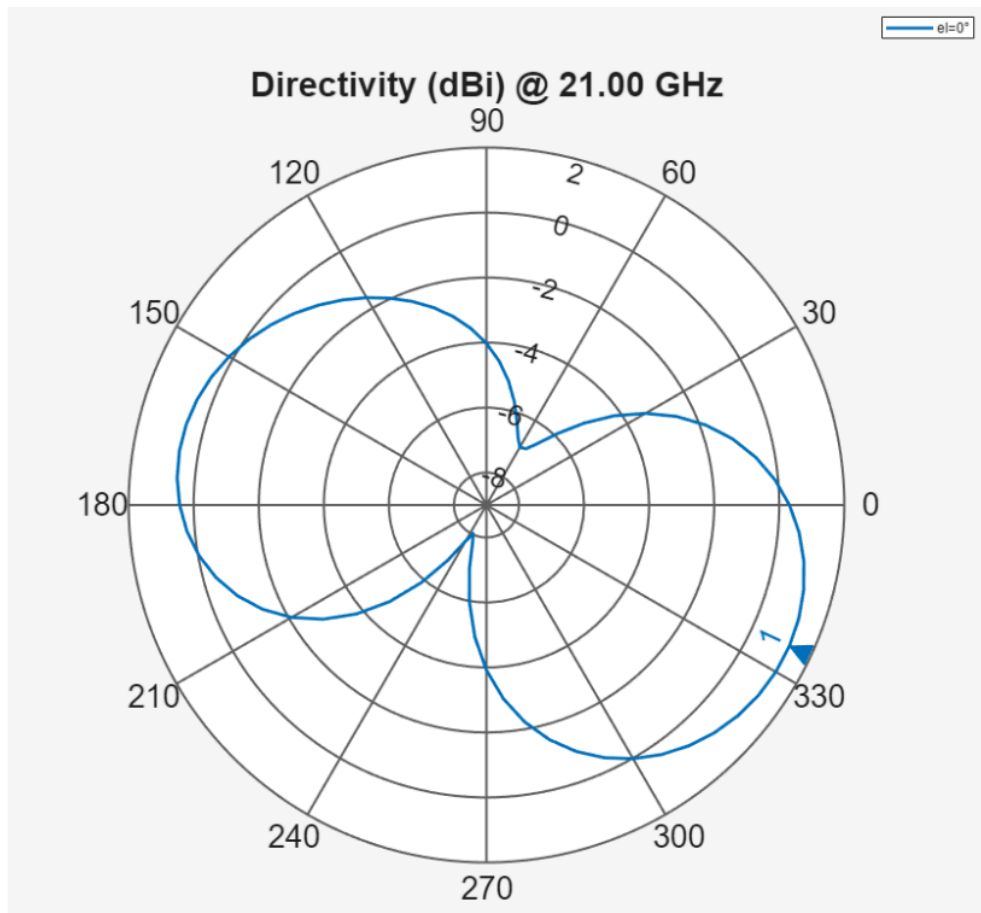
Cylindrical Dipole top down view



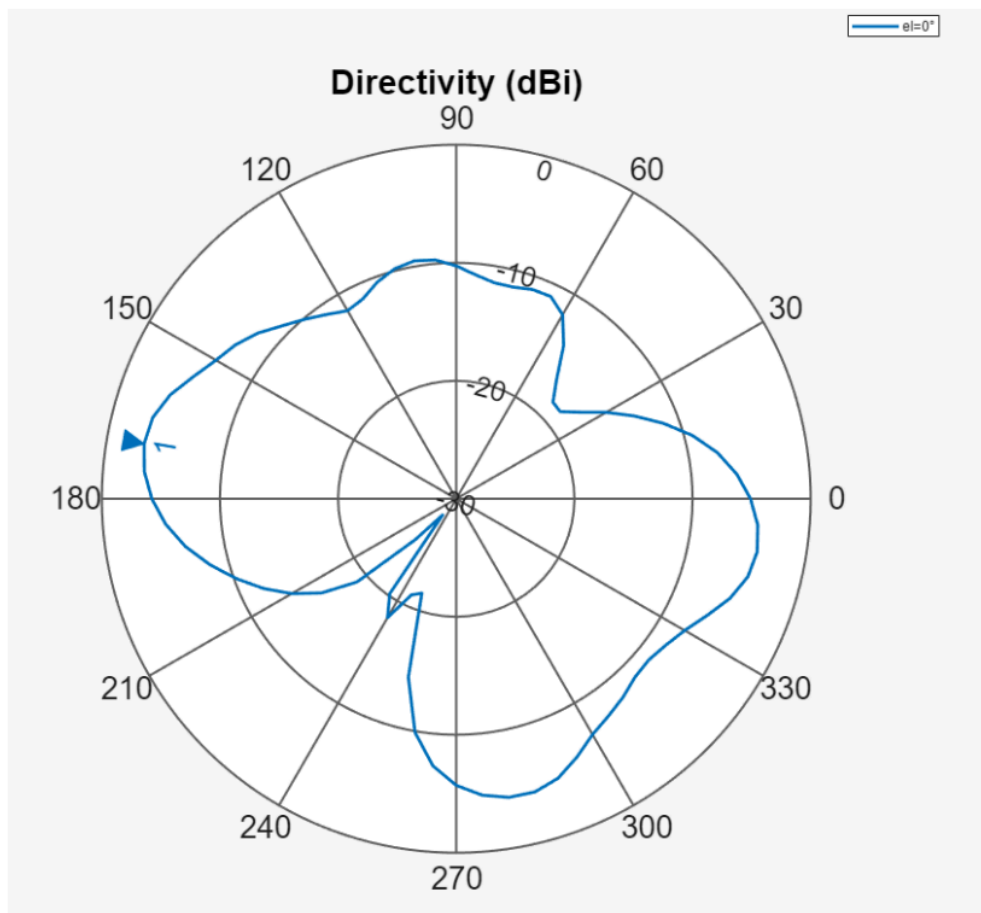
Horn antenna Top-down



Helix antenna Top down vue



[3,3] Helix array antenna top-down



Final Advanced RF

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

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Comment 1

It is better to include caption for the figure

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GRADING FORM: ADV. RF SYSTEMS

JOSEPH GILLESPIE

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ENGAGEMENT WITH LITERATURE

The report should demonstrate the use of relevant, high-quality academic and professional sources. Comprehensive research incorporating recent journal articles, textbooks, and reliable sources should be evident. The credibility of each source should be evaluated, favouring peer-reviewed materials. All references must follow IEEE format, with consistent in-text citations.



Engages with a wide range of research-informed literature, referencing various online materials to provide background on antenna types. However, in-text citations are inconsistent in several sections. Greater use of peer-reviewed journal articles, IEEE papers, or specialist textbooks is expected to support technical and theoretical explanations.

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KNOWLEDGE AND UNDERSTANDING

The report must exhibit sound knowledge of RF principles, and antenna theories. Theoretical concepts such as impedance matching, array antenna, resonance frequency, and antenna applications should be clearly explained. Concepts should be related meaningfully to practical contexts. The report should demonstrate how this knowledge informed the design decision and the application of core knowledge in mathematics, engineering, and natural sciences to solve broadly defined problems and analyse real-world RF systems.



Demonstrates excellent and detailed understanding of various antenna types and their roles in RF systems. Effectively explains key parameters such as radiation patterns, impedance, S-parameters, and

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directivity.

Demonstrates good application of mathematical formulas, as well as engineering and natural science principles, in simulation design decisions.

Applies theory to simulation results, identifying physical causes of deviations.

Uses first principles and engineering knowledge to design solutions meeting diverse user and societal needs. Acknowledges frequency discrepancies and links them to antenna performance.

COGNITIVE AND INTELLECTUAL

The report should present a critical analysis of simulation results and theoretical data. Findings must be discussed with evidence, leading to logical and valid conclusions. Comparisons between theoretical and simulation results should be presented. Discussions should include implications, limitations, and alternative solutions



Critical thinking, analysis, synthesis, and evaluation are evident. The comparison of theoretical and simulated frequencies across antenna types shows analytical effort. Observations on side lobes, back lobes, and radiation strength demonstrate awareness of how design impacts performance. However, stronger critical thinking and justification are needed. Including a table showing percentage deviation or discussing bandwidth would add intellectual rigour. Computational tools like MATLAB and CST are used appropriately, with simulations completed for each antenna. Antenna applications are mentioned, design choices are not explicitly linked to specific user needs, environmental

considerations. A stronger emphasis on real-world performance would enhance the analysis.

PRACTICAL SKILLS

Marks for practical skills will be provided based on the Practical application of engineering principles and skills in designing, simulating, or conducting experiments. Appropriate engineering software and methodologies should be applied to design antennas. The simulation process and parameters should be documented clearly, with justifications for methods used. Results should be presented with a neat plots and visuals. Problem-solving skills should be demonstrated through analysis and design refinements.. Proficiency with tools, and software to support your solutions.



Demonstrates advanced application of various methods, materials, tools, and techniques. The use of CST and MATLAB to simulate six antennas reflects strong working knowledge of modern engineering tools. Visual outputs (3D patterns, S-parameters, impedance plots) are clear and relevant, and simulation tools were used effectively.

Lacks critical detail about mesh settings, boundary conditions, or port configurations, which are essential for repeatability and clarity.

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TRANSFERABLE SKILLS FOR LIFE

The report should be clear and well-structured for technical and non-technical readers. Complex ideas must be communicated effectively, with appropriate terminology and visual aids. A logical flow from introduction to conclusion should be maintained. Professional

presentation elements such as clear headings, subheadings, and a well-organised reference list should be included.



Can communicate professionally confidently with technical and non-technical audiences. The report is structured in a clear and logical manner, and the inclusion of visual aids supports understanding. However, writing could be more precise and formal.

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