

Antenna Design

by Henry Rennison

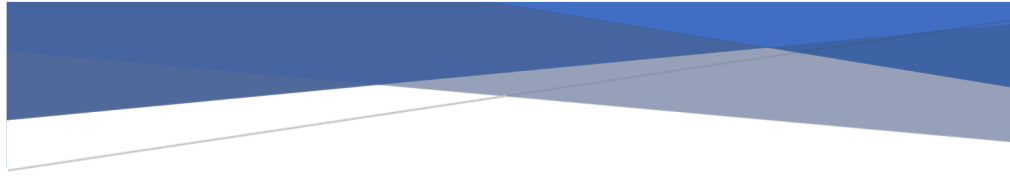
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Design and Analysis of RF Antennas

Advanced Radio Frequency Systems

Henry Rennison (2218326)

Abstract

This report presents the design and simulation of multiple RF antennas based on a given student ID. Utilizing HFSS and MATLAB, the report explores patch, dipole, horn, helix, and array antennas, analysing their performance through radiation patterns, impedance characteristics, and frequency response. Key theoretical and simulation insights are discussed to assess suitability for RF applications.

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1 Introduction

This assignment will critically evaluate RF transmission and reception systems through the use of MATLAB and CST. The antennas that will be created and tested in the software are a Rectangular Microstrip Patch Antenna, a Cylindrical Dipole antenna, Folded dipole antenna, a Horn Antenna, a Helix Antenna and a Helix Array antenna. These are all examples of RF antennas which are devices used to transmit or receive electromagnetic waves in the radio frequency range, usually ranging from 3kHz to 300 GHz. They work by converting electrical signals into radio waves for the transmission part and then radio waves back to electrical signals for receiving. [1]

2. Methodology

2.1 Task 1: Rectangular Microstrip Patch Antenna Design

This part of the report will cover the design phase of the Rectangular Microstrip Patch Antenna. Patch antennas have a wide array of use cases including but not limited to Wi-Fi Routers, Bluetooth devices and Mobile phone internal antennas. It is ideal for these applications as a patch antenna can be compact and can be embedded onto PCBs. The antenna will be operating at 2.2GHz. It will have a substrate made from FR4 with a relative permittivity of 4.4 and a relative permeability of 1.

The first task was to calculate the dimensions of the patch antenna, ground plane and the substrate. This was done using the following formulas:

For Width (W) the formula is:

$$Width = \frac{c}{2f_0 \sqrt{\frac{\epsilon_R + 1}{2}}};$$

Where C= speed of light (3x10⁸ m/s), f_0 = resonant frequency (Hz) and ϵ_r = relative permittivity of the substrate. The point of this formula is to gain the optimal; width for good radiation efficiency.

The next formula is to work out the Effective Dielectric Constant:

$$\epsilon_{eff} = \frac{\epsilon_R + 1}{2} + \frac{\epsilon_R - 1}{2} \left[\frac{1}{\sqrt{1 + 12 \left(\frac{h}{W} \right)}} \right]$$

Where h = height (thickness) of the substrate and W = width of the patch. This accounts for the fringing fields, these are the fields that extend into the air around the edges of the patch.

The final formula is the Length (L):

$$Length = \frac{c}{2f_0 \sqrt{\epsilon_{eff}}} - 0.824h \left(\frac{(\epsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \right)$$



In this formula the first term is working out the resonant length for the effective dielectric, the Second term subtracts the fringing extension which then works out the actual patch length.

For this patch Antenna the Dielectric constant is 4.3 despite in the assignment brief it stating 4.4. This is because CST says the relative permittivity of FR4 epoxy substrate is 4.3. The Dielectric height used for this antenna is 1.6mm. The operation frequency in this case was 2.2GHz. The outputs of the formulas after putting the above numbers in were:

Width: 41.85 mm

Length: 32.51 mm

Once the dimensions had been worked out and input into CST the patch antenna was then created:

Parameter List				x	
Name	Expression	Value	Description		
W	= 41.85	41.85	Width		
L	= 32.51	32.51	Length		
H	= 1.6	1.6	Dielectric Height		
Wg	= W+6"H	51.45	Width of Ground Plane		
Lg	= L+6"H	42.11	Legth of ground plane		
Hg	= 0.05	0.05	Height of ground plane		
Epsilon_r	= 4.3	4.3	Dielectric Constant		
Length	= 1.0000e+00	1.0000e+00			
SubstrateHeight	= 1.6	1.6			
TraceWidth	= 3.137	3.137			
TraceThickness	= 0	0			
GroundThickness	= 0	0			
SubstrateWidth	= 18.948	18.948			
Wf	= 3.13	3.13	Width of Microstrip		
<new parameter>					
Parameter List				Result Navigator	

Figure 1 Patch Antenna Parameters

The following 3D image is of the patch antenna once all the above information had been added:

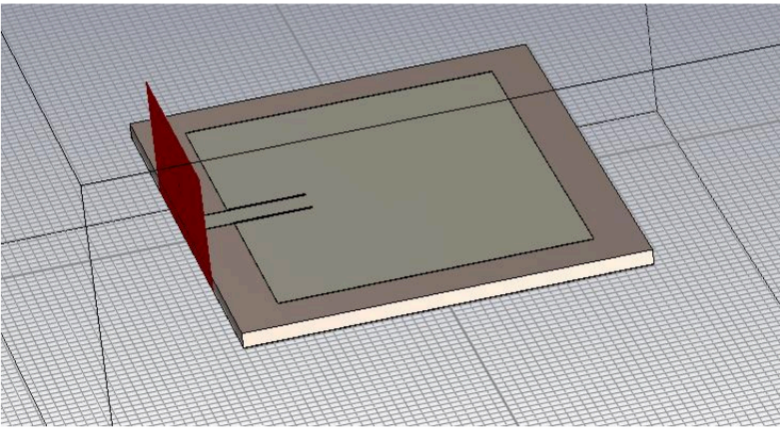


Figure 2 3D Patch Antenna

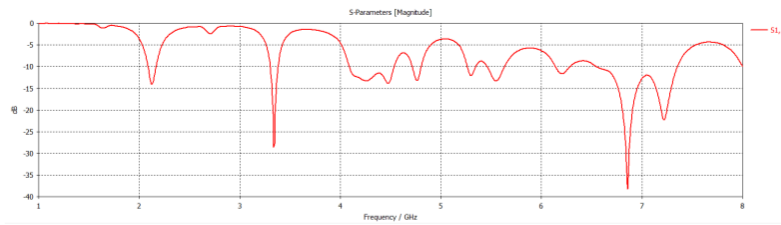


Figure 3 Patch S Parameters

This figure shows the S11 parameters for the patch antenna over a frequency range of 1GHz to 8GHz. This graph shows multiple deep dips (resonant frequencies) around 2.2GHz, 3.4GHz and 6.9GHz. This indicates that this antenna has good impedance matching and effective radiation at those frequencies. A dip below -10dB is generally considered acceptable for antenna performance, meaning that less than 10% of the power is reflected. [2]

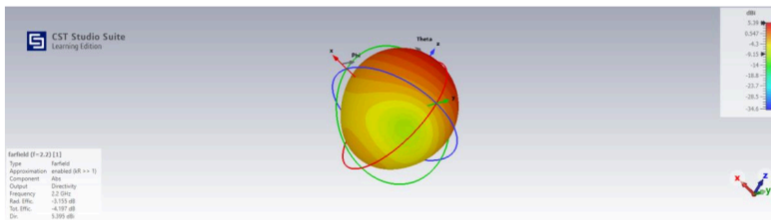


Figure 4 Patch Antenna radiation pattern

This figure shows the radiation pattern of the rectangular patch antenna. It visually represents how the antenna radiates energy. In this diagram it can be seen that the strongest radiation is perpendicular to the surface of the patch.

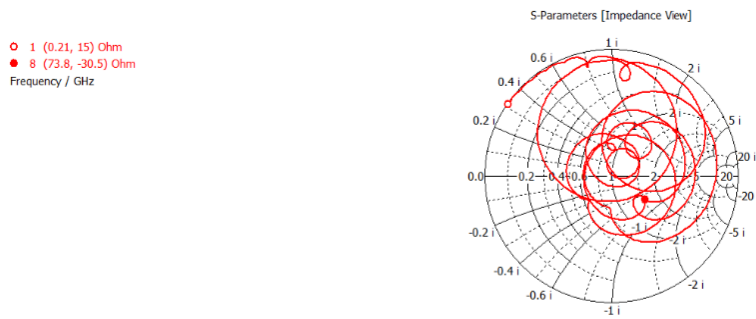


Figure 5 Patch Antenna Smith Chart

This figure is a Smith chart that represents the input impedance characteristics of the patch antenna across the 1 to 8 GHz range. The red line represents how the input impedance of the antenna varies with frequency. The markers correspond to specific frequency points and their associated impedance values. The closer the impedance curve passes by the centre means the antenna performs well at those frequencies.

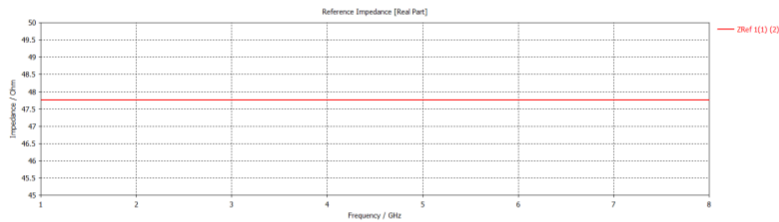


Figure 6 Impedance Patch

The figure above shows the reference impedance value. This figure is typically 50 ohms to 75 ohms however in this example the reference impedance is around 47.8 ohms. This value is used to calculate the power dissipated by the antenna to interpret the S-parameter measurements. [2]

2.2 Task 2: Design and Simulation of Various Antennas in MATLAB

This part of the report will go over the designs and compare the results of a Cylindrical dipole antenna, a folded dipole antenna, a helix antenna and a Horn antenna. All of the antennas in this section have been created and simulated using the MATLAB Antenna Design function.

Cylindrical DIPOLE Antenna

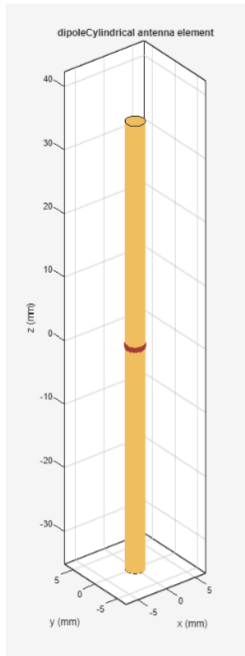


Figure 7 Dipole Antenna

The figure above is a 3d model of a cylindrical dipole antenna that was generated in MATLAB. The dipole antenna consists of two conductive elements and is one of the simplest types of RF antennas. This model shows the physical layout which is essential for understanding how it supports current distribution. The operating frequency for the dipole antenna is 2GHz.

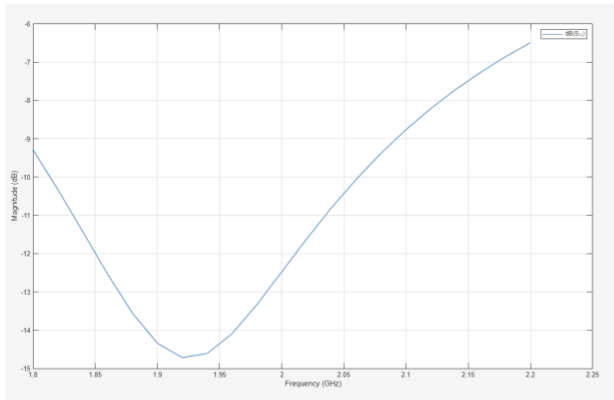


Figure 8 S-Parameter Dipole

This figure shows the S11 (reflection Coefficient) parameter for the cylindrical dipole antenna which indicates how much power is reflected back to the antenna port. In the figure above the S11 value is around 1.92GHz.

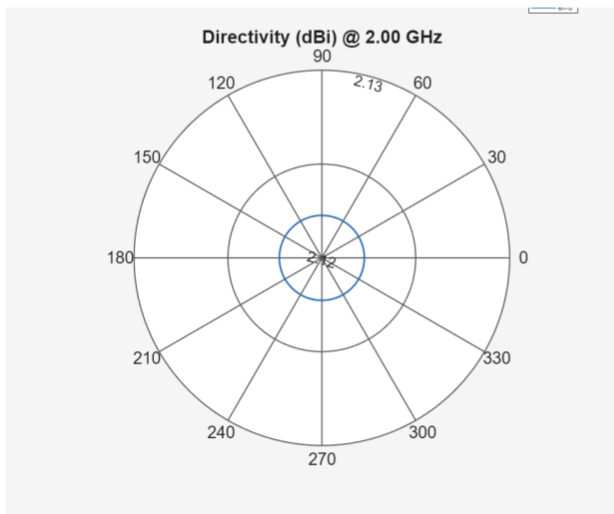


Figure 9 2D Radiation pattern

This figure is shows the 2D radiation pattern of the dipole antenna, it represents how the antenna radiates in a specific plane.

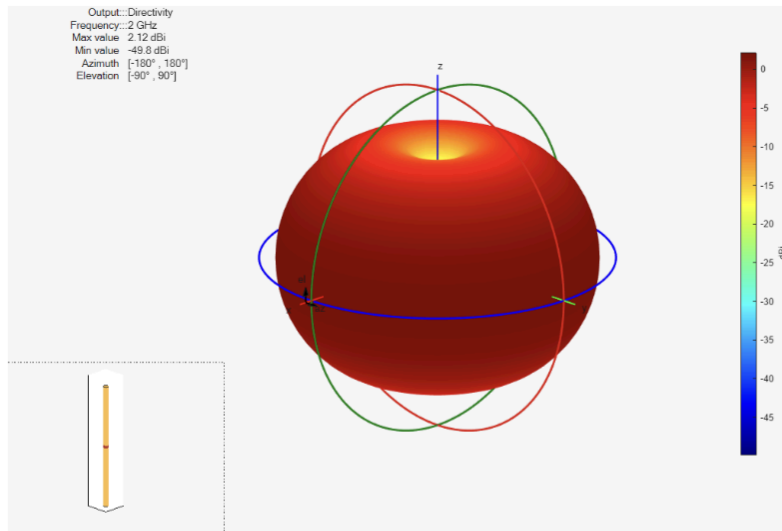


Figure 10 Radiation Pattern Dipole

This figure shows the 3d radiation pattern of the cylindrical dipole antenna at a frequency of 2GHz, the Z-axis represents the direction perpendicular to the antenna. The Azimuth and Elevation show the horizontal and vertical angles of radiation. The coloured bar on the right side shows the gain in dBi where red/yellow regions have a stronger radiation (higher gain) and the blue regions represent very low radiation.

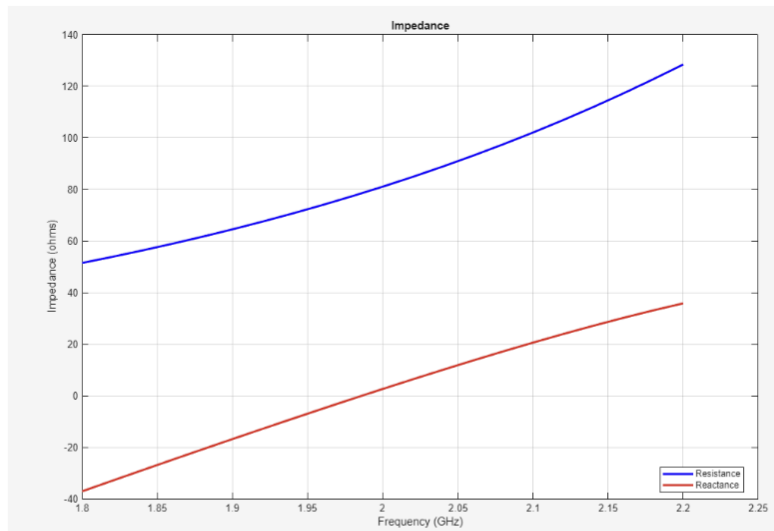


Figure 11 Dipole Impedance

This figure shows the impedance of the cylindrical dipole antenna. Impedance refers to the total opposition and antenna offers to an alternating current. In order to achieve this, it consists of two components Resistance and reactance. The resistance line shows the actual energy dissipation and reactance represents the energy temporarily stored in the magnetic fields. [3]

Folded Dipole Antenna

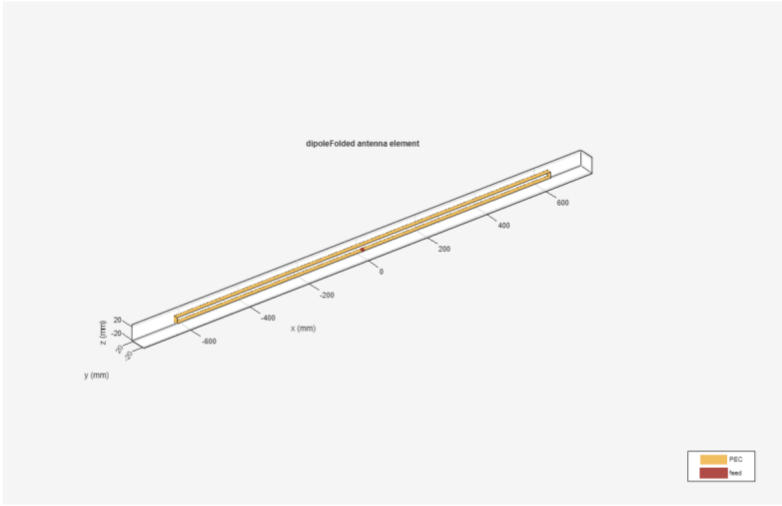


Figure 12Folded 3D Image

The above figure shows a 3D representation of a folded dipole antenna at a frequency of 110.5MHz.

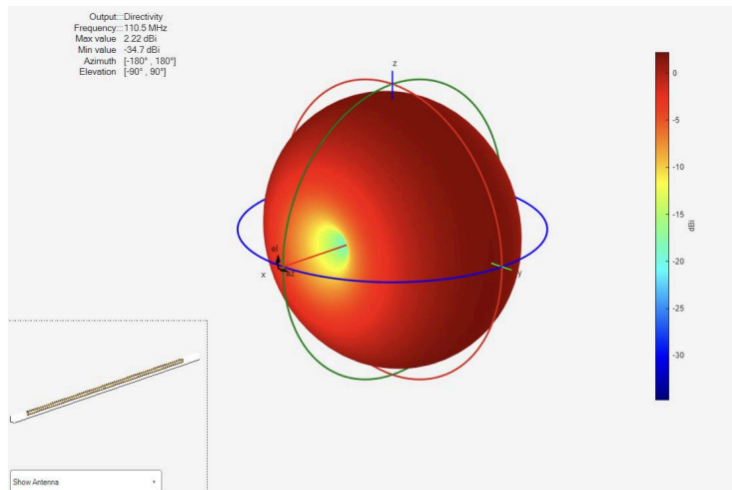


Figure 13 Folded Radiation patter

This figure shows the 3D radiation pattern of the folded dipole antenna, as seen in the figure above it is very similar to a regular (half-wave) dipole. Only with some minor differences. Like the other dipole antenna radiation is strongest in directions perpendicular to the antenna's length.

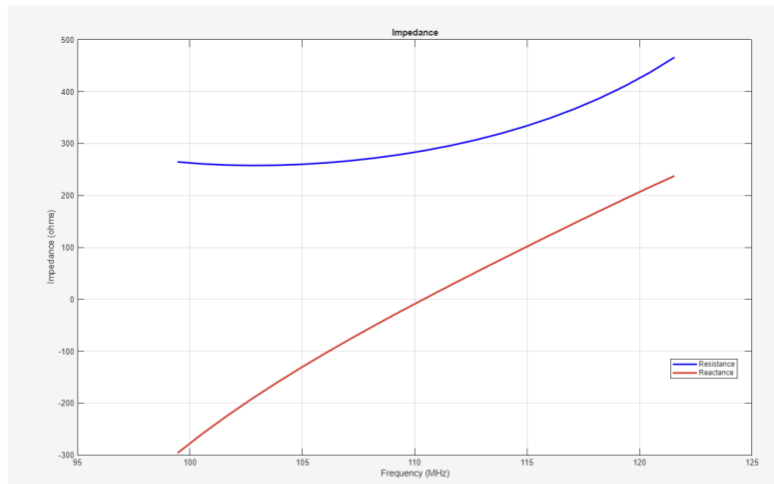


Figure 14 Folded impedance

The above figure is showing the impedance of the folded dipole antenna.

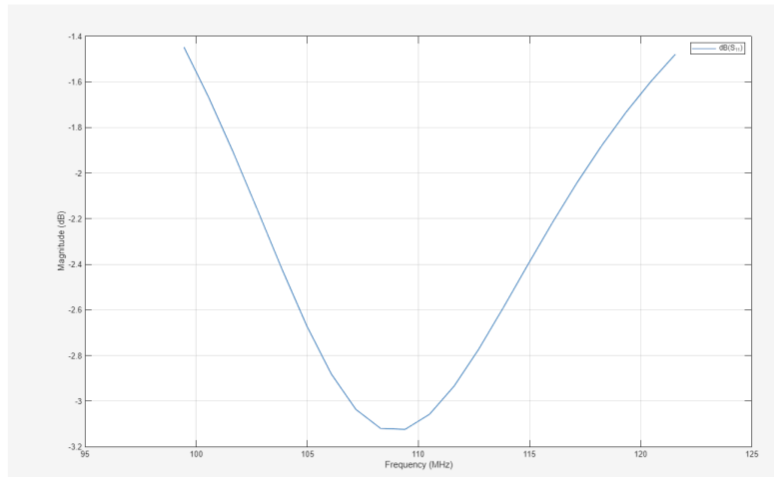


Figure 15 Folded S Param

This shows the S11 parameter for the folded dipole antenna. As visible above the S11 value is around 109MHz.

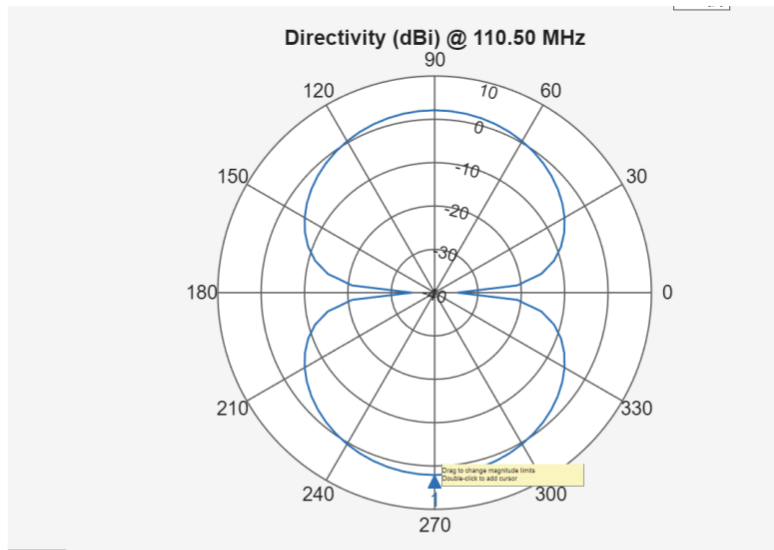


Figure 16 2d Radiation Folded

This figure shows the 2D radiation pattern of the folded dipole antenna.

Horn Antenna

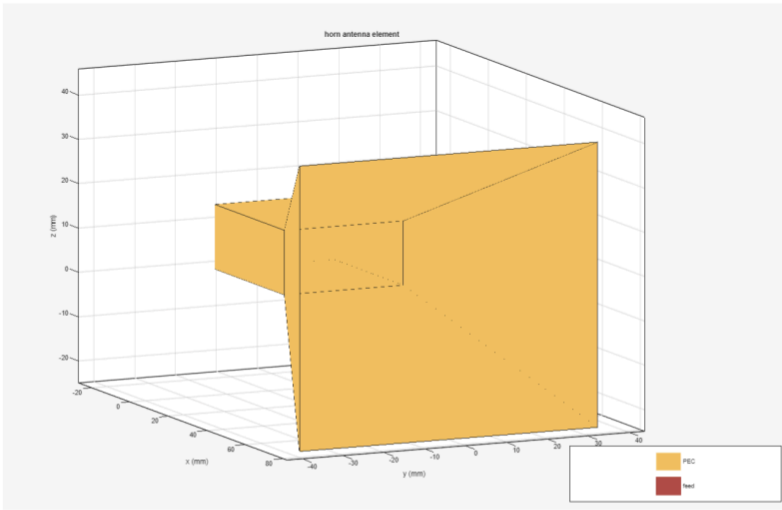


Figure 17 Horn Antenna

This figure shows the 3D design for the Horn antenna set at a frequency of 9GHz.

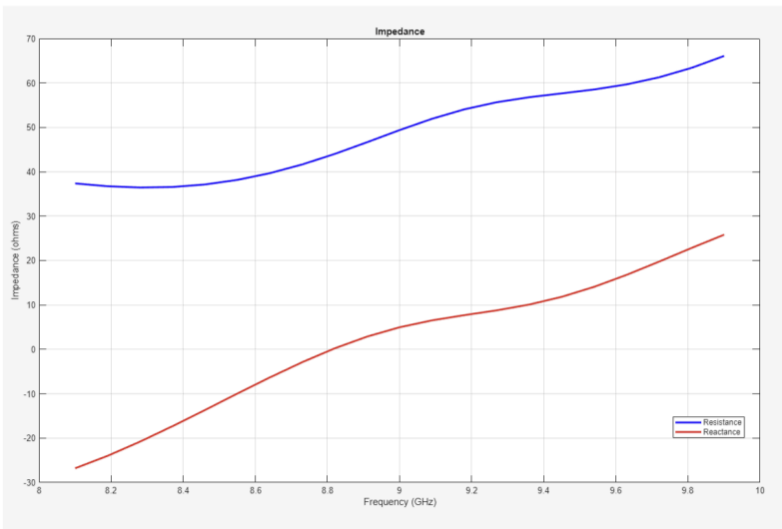


Figure 18 Impedance Horn

This figure shows the impedance values for the horn antenna.

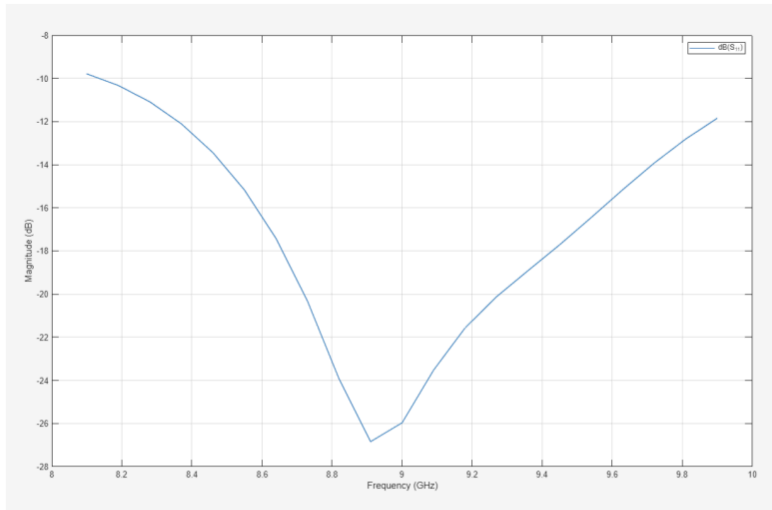


Figure 19 S Parameter Horn

This figure shows the S11 parameters for the horn antenna as visible in the figure the S11 value is around 8.86GHz

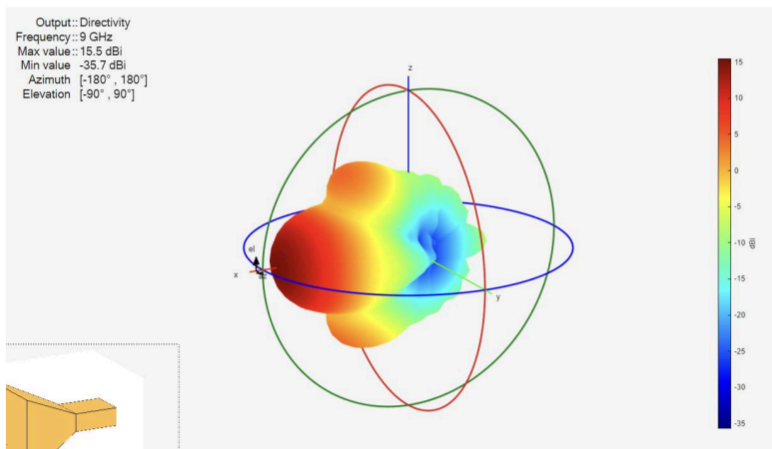


Figure 20 Radiation pattern horn

This figure shows the 3D radiation pattern of the horn antenna.

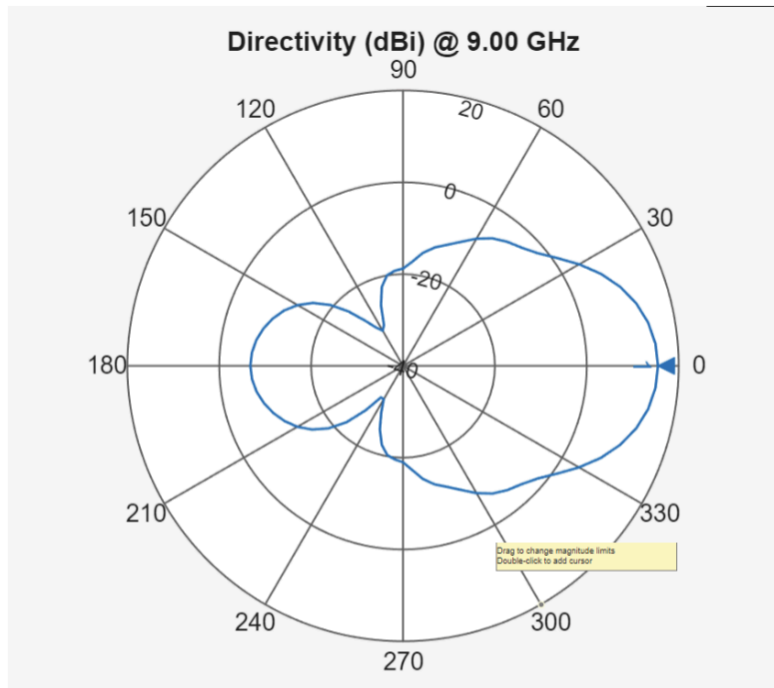


Figure 21 2D radiation pattern

This figure shows the 2D radiation pattern of the horn antenna.

Helix Antenna

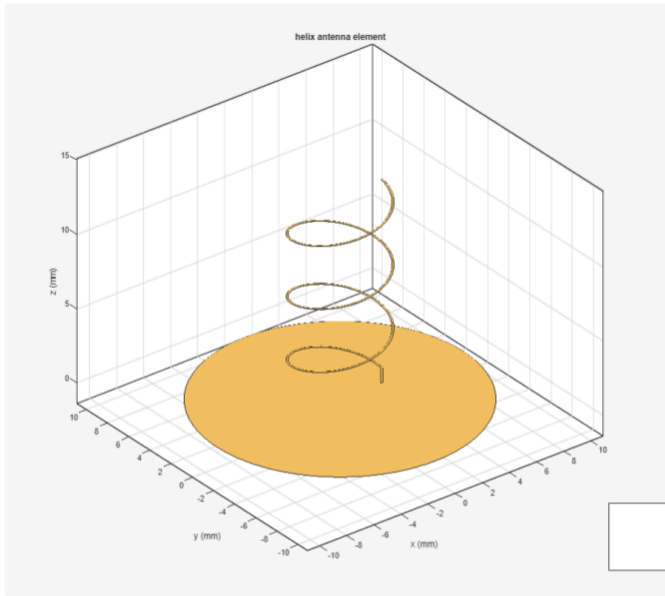


Figure 22 Helix Antenna

This figure shows the 3D image of the Helix antenna generated in MATLAB at a frequency of 21GHz.

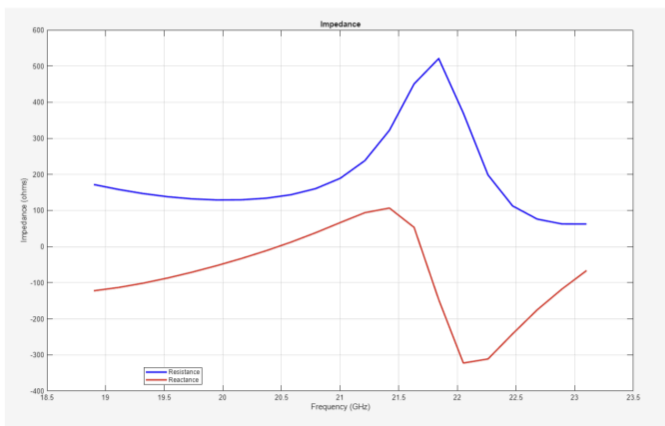


Figure 23 Impedance Helix

This figure shows the impedance of the helix antenna.

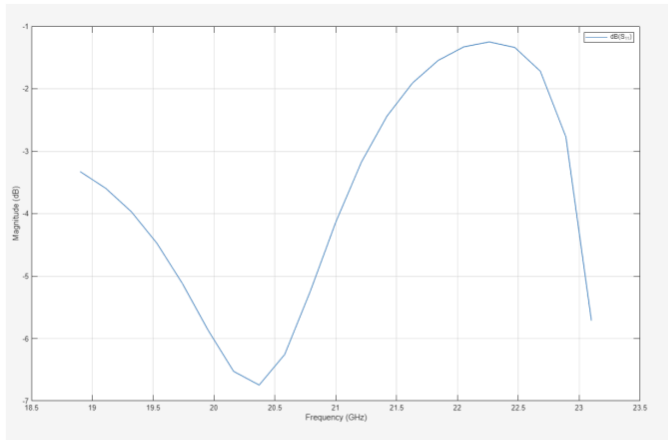


Figure 24 S Parameter Helix

This figure shows the S11 parameter for the helix antenna and in this example it shows the figure to be around 20.4 GHz.

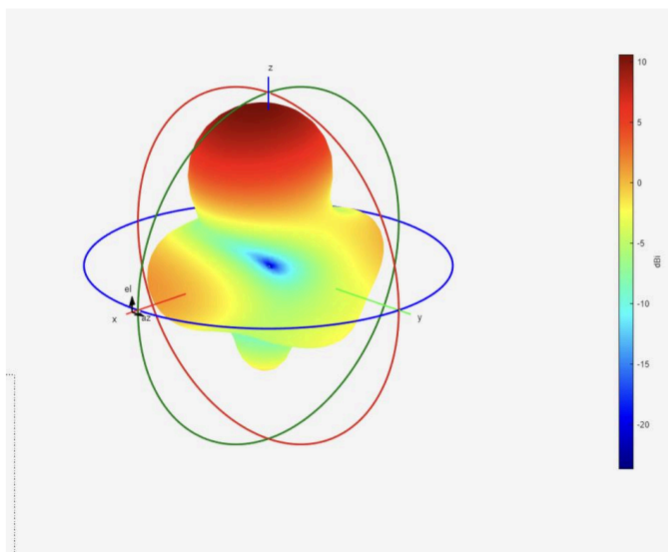


Figure 25 Radiation Pattern Helix

This figure represents the 3D radiation pattern of the helix antenna.

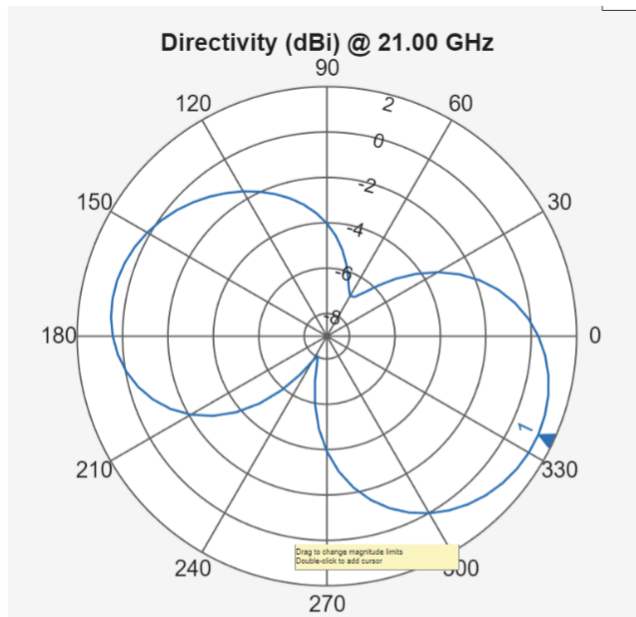


Figure 26 2D radiation Helix

This shows the 2D radiation pattern of the helix antenna.

3.1 Task 3: Helix Array Antenna Design

This part of the report will show the creation of the Helix array antenna using MATLAB. A helix array antenna is a group of helical antennas arranged in a specific layout. Usually in a linear or planar array to enhance gain and directivity compared to a single helix antenna.

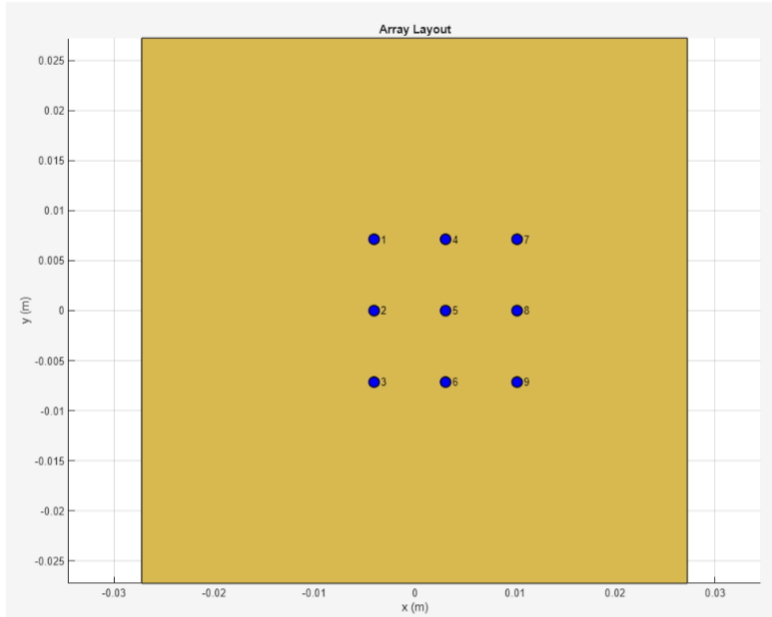


Figure 27 2D layout array

This figure shows the 2D layout of the array antenna, this one was created as 3x3 and at a frequency of 21GHz.

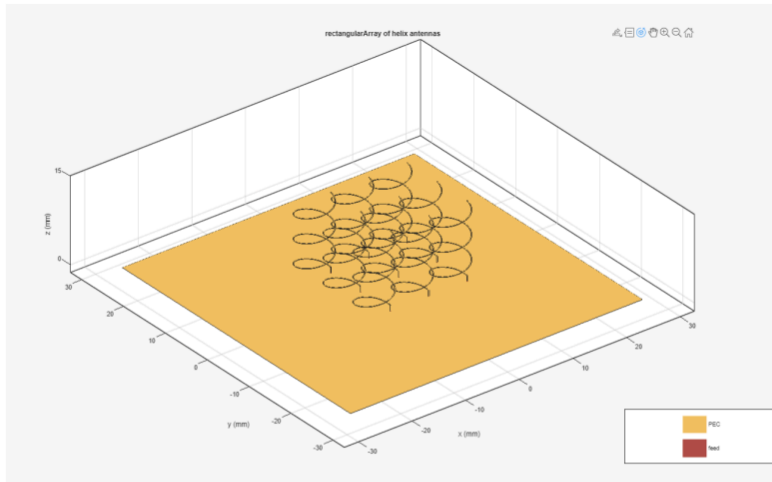


Figure 28 Array 3D layout

This figure shows the 3D design of the array antenna.

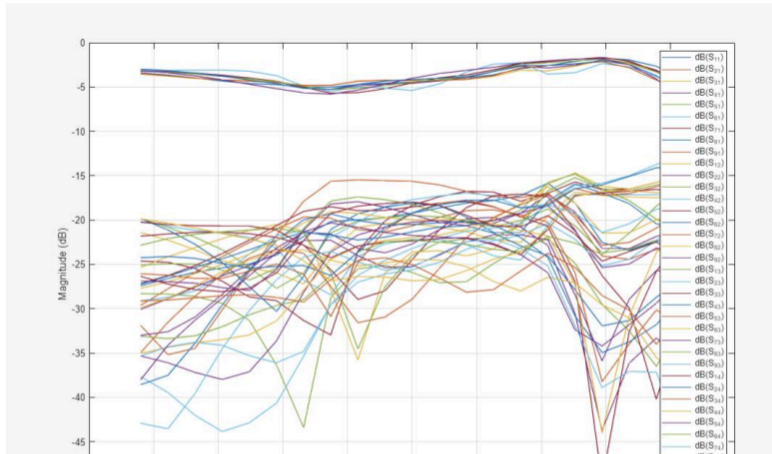


Figure 29 S Parameter Array

The above image is of the S parameters for the array antenna.

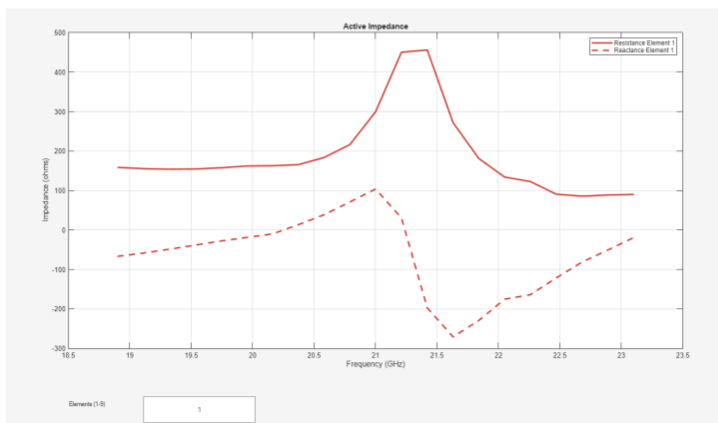


Figure 30 Impedance Array

This figure shows the active impedance of the array antenna.

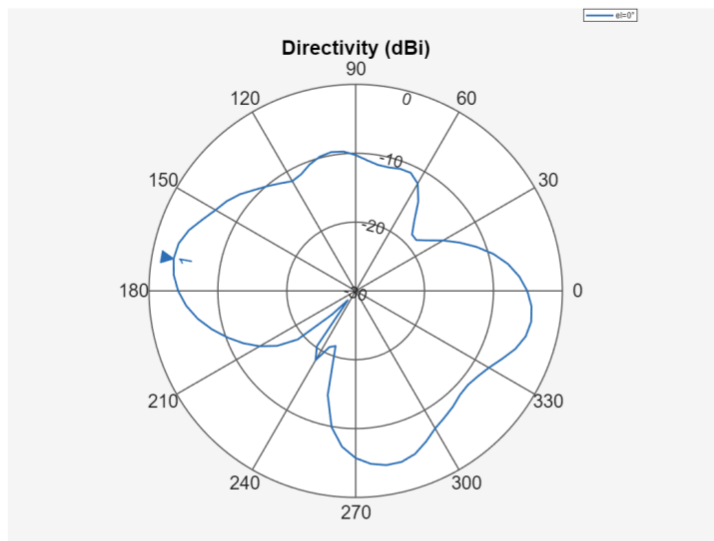


Figure 31 2D Radiation Array

This shows the 2D radiation pattern of the array antenna.

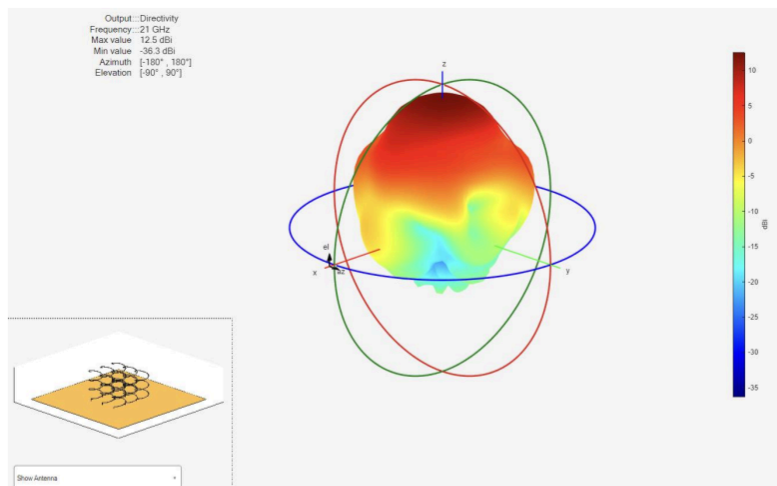


Figure 32 3D radiation array

This figure shows the 3d radiation pattern of the 3x3 array antenna.

3. Results

This section of the report will discuss the results of each of the antennas and highlight the S11 parameters, Impedance and the radiation patterns/ behaviours.

3.1 Task 1 Results: Microstrip Patch Antenna

The rectangular microstrip patch antenna was designed to operate at frequency of 2.2GHz. The simulation results showed multiple resonant frequencies with the notable points at 2.2GHz, 3.4GHz and 6.9GHz. The S11 dips well below -10dB which shows very good impedance matching and multi-band performance. The radiation pattern showed directional behaviours with the strongest radiation being perpendicular to the antenna surface. The smith chart also confirmed good impedance characteristics around the resonant frequencies.

3.2 Task 2 Results:

Cylindrical Dipole Antenna

The dipole antenna showed a resonant frequency of 1.92GHz with an S11 dip below -10dB indication good performance. The 3D radiation pattern showed the expected doughnut type shape with the maximum gain perpendicular to the antenna axis. The impedance plots showed a relatively close match to the resonance.

Folded Dipole Antenna

The folded dipole operating at 110MHz showed a similar radiation pattern to the cylindrical dipole with slightly increased input impedance. Its S11 curve showed a sharp dip around 109 MHz confirming good performance. This antenna offers broader bandwidth and higher impedance.

Horn Antenna

The Horn antenna was designed at 9GHz and showed great directionality as can be seen in both the 3D radiation plot and the 2D radiation plot. The S11 minimum occurred around 8.86GHz and the impedance chart confirmed strong matching at the operational frequency. Its high gain and narrow beam width make it suitable for high frequency point-to-point communication

Helix Antenna

The single helix antenna was simulated at 21GHz and showed circular polarisation and axial-mode radiation. Axial mode radiation is where the radiation is primarily directed along the axis of the helix rather than perpendicular. [4] The S11 was around 20.4GHz with strong directional radiation.

3.3 Task 3 Results: Helix Array Antenna

The 3x3 helix array antenna was also simulated at 21GHz like the single helix antenna. The array showed improved S11 matching and highly focused 3D radiation pattern.

4. Discussion and Analysis

The rectangular patch antenna was designed theoretically using standard equations based on the dielectric properties of FR4 and an operation frequency of 2.2GHz. While theoretical dimensions were calculated to be 41.85mm wide and 32.51mm long the simulation results revealed multiple resonant frequencies including the target frequency of 2.2GHz. The slight variation in resonant behaviours is fairly consistent with practical modelling such as minor variations in substrate properties this is shown in where CST states the substrate to be 4.3 rather than 4.4. Both the S11 and impedance profiles match the expected behaviours somewhat validating the design and simulation process.

The Cylindrical Dipole antenna showed omnidirectional radiation in the azimuth plane with a Toroidal 3D radiation pattern which is to be expected [5] and resonant behaviour around 1.92GHz. Dipole is predictable and performs better in wideband application although it does lack directionality and high gain. [6]

The folded dipole showed very similar radiation characteristics to the Cylindrical antenna but with slightly higher impedance. This makes it more compatible with high-impedance transmission and increases the bandwidth. This can make it more versatile in different environments.

The Horn antenna provided highly directional radiation patterns making very useful for high frequency and long-range communication [7]. The simulation at 9GHz showed a sharp beam with high gain and a strong S11 response matching theoretical expectations.

The Helix antenna radiated in axial mode with a circular polarisation making it suitable for satellite communications. This is shown by the directional radiation along the antenna axis and decent S11 levels. Its spiral structure makes it best suited for wideband polarised radiation.

The 3x3 array showed greatly improved gain and directivity compared to the single helix. The focused beam helped to enhance the S-parameter match. This simulation showed that combining antennas can greatly enhance performance.

4.1 Array Benefits and commercial implications

The helix array showed that multiple antennas in a 3x3 can drastically improve gain and directionality making much more suitable for high speed point to point communication systems. The implications are that the design phase can take a lot longer and the end product is much larger. It also requires a lot more power and more complex power distribution between the antennas.

4.2 Environmental, Societal and Regulatory Considerations

When designing antennas all designs must consider electromagnetic exposure regulations and frequency band licensing. Patch Antennas due to their low profile and integration with existing electronics are best used in portable IOT devices. Horn and Helix arrays while being high performance are better suited for fixed beam control and spectrum efficiency are critical.

5. Conclusion and Recommendations

This report has highlighted that the patch, dipole, folded dipole, horn, helix and array antennas were successfully created and simulated using CST and MATLAB. The results show that each antenna has distinct strengths and is tailored to specific applications.

The best overall for versatility is the patch antenna due to its compact size and multi-band behaviour and is ideal for embedded and mobile applications.

Simplicity of design and predictability are the dipole and folded dipole antennas as they offer basic omnidirectional coverage with moderate gain and predictable radiation behaviour.

The antenna with the highest gain is the horn antenna and it also showed highly directional radiation which makes it best suited for higher frequency point to point links.

The antenna with the best overall performance is the helix array antenna. It demonstrated the highest gain and narrowest beam width, making it optimal for applications requiring focused high frequency transmission such as radar or satellites.

Possible future recommendations could include real-world testing and measurements in order to compare them to the simulations. Another possible recommendation could be to test all the antennas at the same frequencies in order properly test them alongside each other and compare results.

Bibliography

[1]

Rajiv, "How do RF Antenna Works - Simple Explanation," *RF Page*, Dec. 24, 2022.
<https://www.rfpage.com/how-do-rf-antenna-works-simple-explanation/>

[2]

L. Frenzel, "Back to Basics: Impedance Matching (Part 1)," *Microwaves & RF*, Jul. 19, 2021.
<https://www.mwrf.com/technologies/embedded/systems/article/21167982/electronic-design-back-to-basics-impedance-matching-part-1>

[3]

Interference Technology, "Antenna Fundamentals," *Interference Technology*, May 03, 2007.
<https://interferencetechnology.com/antenna-fundamentals> (accessed May 12, 2025).

[4]

"Helical Antenna (Helix Antenna)," *www.antenna-theory.com*. <https://www.antenna-theory.com/antennas/travelling/helix.php>

[5]

JEM Engineering, "Dipoles: The Simplest, Most Common Antenna - JEM Engineering Blog," *JEM Engineering*, Aug. 08, 2021. <https://jemengineering.com/blog-dipoles/>

[6]

X. Lin, J. Mai, H. He, and Y. Zhang, "Dual-Polarized Dipole Antenna with Wideband Stable Radiation Patterns Using Artificial Magnetic Conductor Reflector," *Sensors*, vol. 24, no. 12, p. 3911, Jun. 2024, doi: <https://doi.org/10.3390/s24123911>.

[7]

D. D., "Maximizing Signal Strength: The Ultimate Guide to Horn Antennas," *Space Machine*, Nov. 28, 2023. <https://www.space-machine.com/horn-antennas/>

Antenna Design

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

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GRADING FORM: ADV. RF SYSTEMS

HENRY RENNISON

62.50

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 an appropriate range of research-informed literature, using several references to support technical descriptions particularly in discussions of antenna operation and design. Some sources are credible and recent, but in-text citations need improvement. The work would be strengthened by including more peer-reviewed academic sources, such as journal articles or IEEE papers. Evidence of technical literature evaluation is present.

5.5

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, coherent, and detailed knowledge with a systematic understanding of RF antenna principles and theories, including microstrip, dipole, horn, helix, and array types. Core concepts such as S_{11} , impedance matching, and radiation behaviour are clearly explained and linked to simulation results. There is clear evidence of applying mathematical and scientific methods to support antenna modelling and design decisions. Dielectric properties and

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dimension calculations are well explained. The discussion acknowledges societal relevance and practical antenna applications.

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



Simulation results are clearly described, and interpretations across different antennas are well presented. You correctly highlight resonant frequencies, gain patterns, and impedance responses. Comparisons between antennas show good critical thinking. However, the analysis would be stronger with quantitative comparisons and more thorough evaluation of all results. Key performance indicators, such as resonant frequencies and impedance characteristics, are identified and linked to design structures. Simulation discrepancies are noted. Computational tools are used effectively.

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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 a range of methods, materials, tools, and techniques. CST and MATLAB are effectively used to design and

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simulate antennas. The work would be improved by a clearer description of the simulation methodology (e.g., solver settings, boundary conditions, and meshing). Laboratory components/tools were used successfully, and practical skills are evident.

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.



Communicates effectively, confidently, and consistently in a suitable format for both technical and non-technical audiences. The work is coherent, fluent, and well-organised, with clear headings, consistent formatting, and logical flow. Technical content is communicated effectively, supported by well-labelled figures and structured analysis. The conclusion is concise and summarises findings well.

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There is evidence of awareness of societal and environmental impact. Language is mostly clear, though occasional grammar and phrasing issues affect overall polish. The report addresses societal, regulatory, and user needs.