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Design and Analysis of RF Antennas

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Abstract

This report examines the radio frequency design, simulation, and analysis of Microstrip Patch, Dipole, Horn, and Helical antenna structures. Operating frequencies were determined using established antenna theory and computational techniques before performance analysis was conducted using Dassault Systemes CST Studio Suite 2024 and MATLAB R2024b Antenna Designer.

This experiment found that antennas operate most efficiently when their structures exhibit purely resistive characteristics, with the resistive component matching the characteristic impedance and the reactive component at zero. It was also observed that all simulated resonant frequencies were higher than the theoretical values calculated except for the Helix Array antenna.

Introduction

The Rectangular Microstrip Patch antenna was simulated using Dassault Systemes CST Studio Suite 2024, while the Cylindrical Dipole, Folded Dipole, Horn, Helix and Helix Array antennas were simulated using MATLAB R2024b Antenna Designer. [1][2]

Simulation data captured antenna configurations, detailing materials, dimensions, resonant frequencies, radiation patterns, and impedance characteristics. By analysing the findings of these simulations, insights are offered as to antenna selection criteria. This report also examines how Impedance matching effects antenna performance and the consideration of environmental and societal factors in antenna design.

TASK 1

Task 1 covers designing and modelling a Rectangular Microstrip Patch antenna using CST Studio Suite 2024, considering antenna theory. [1]

Calculating Antenna Dimensions for Rectangular Microstrip Patch Antenna

To design and simulate the Rectangular Microstrip Patch antenna I needed to determine its operating frequency. As instructed by the assignment, my student number of '2227990' was considered:

$$f_{\text{rectangular microstrip patch}} = \text{<first digit of student ID> . <second digit of student ID>} = 2.2 \text{ GHz}$$

Figure 1 – Operating Frequency Formula – Rectangular Microstrip Patch Antenna

Methodology for Calculating Microstrip Feed Line Width

The Microstrip Feed Width was calculated using the Analytical Line Impedance tool within CST Studio 2024; shown by Figure 2. This was modelled as a thin Direct Microstrip Feed, rather than an Inset Feed. The width was adjusted to achieve a Characteristic Impedance (Z_0) of 50 Ω for an epoxy FR4 dielectric substrate of 1.6 mm thickness, working at a 2.2 GHz operating frequency.

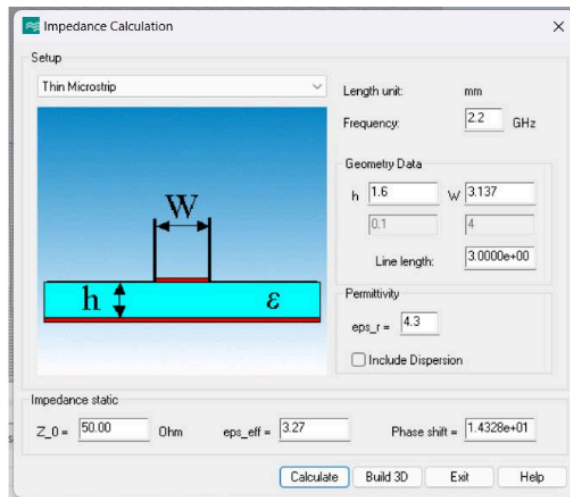


Figure 2 – Calculating Analytical Line Impedance for a Thin Microstrip Feed [1]

Calculating Antenna Dimensions for Rectangular Microstrip Patch Antenna

Width of Microstrip Patch (W)

The Patch Width was calculated using the formula in Figure 3:

$$W = \frac{c}{2f_r \sqrt{\frac{\epsilon_r + 1}{2}}}$$

Where:

W – Width of Rectangular Patch (m)

c – Velocity of Light (m/s)

f_r – Operating Frequency (Hz)

ϵ_r – Relative Permittivity of Dielectric Substrate (unitless)

Figure 3 – Patch Width Formula [3]

Therefore:

$$W = \frac{(3 \times 10^8)}{2(2.2 \times 10^9) \sqrt{\frac{(4.3 + 1)}{2}}} = 0.0419 \text{ m (5sf)} = 41.9 \text{ mm}$$

Effective Relative Permittivity of Microstrip Patch Antenna (ϵ_{reff})

The Effective Relative Permittivity was calculated using the formula in Figure 4:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{w}\right)}} \right]$$

Where:

ϵ_{reff} – Effective Relative Permittivity of Dielectric Substrate (unitless)

ϵ_r – Relative Permittivity of Dielectric Substrate (unitless)

h – Height of Dielectric Substrate (m)

w – Width of Rectangular Patch (m)

Figure 4 – Effective Relative Permittivity Formula [3]

Therefore:

$$\epsilon_{reff} = \frac{(4.3 + 1)}{2} + \frac{(4.3 - 1)}{2} \left[\frac{1}{\sqrt{1 + 12\left(\frac{(1.6 \times 10^{-3})}{(41.9 \times 10^{-3})}\right)}} \right] = 4.0164 \text{ (5sf)}$$

Actual Length of Microstrip Patch (L)

To calculate the Actual Patch Length (L) consider the formula in Figure 5:

$$L = L_{eff} - 2\Delta L$$

Figure 5 – Actual Patch Length Formula [4][3]

Figure 6 shows the components of this formula:

$$L_{eff} = \frac{c}{2fr\sqrt{\epsilon_{reff}}}$$

Where:

L_{eff} – Effective Length (m)

c – Velocity of Light (m/s)

f_r – Operating Frequency (Hz)

ϵ_{reff} – Effective Relative Permittivity of Dielectric Substrate (unitless)

$$\Delta L = 0.412h \left[\frac{(\epsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \right]$$

Where:

ΔL – Length Extension (m)

w – Width of Rectangular Patch (m)

h – Height of Dielectric Substrate (m)

ϵ_{reff} – Effective Relative Permittivity of Dielectric Substrate (unitless)

Figure 6 – Effective and Extension Length Formulas [4][3]

Therefore, the Actual Length was calculated from the follow equation:

$$L = \frac{c}{2fr\sqrt{\epsilon_{reff}}} - 0.824h \left[\frac{(\epsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \right]$$

Therefore:

$$L = \frac{(3 \times 10^8)}{2(2.2 \times 10^9)\sqrt{4.0164}} - 0.824(1.6 \times 10^{-3}) \left[\frac{(4.0164 + 0.3)\left(\frac{(41.9 \times 10^{-3})}{(1.6 \times 10^{-3})} + 0.264\right)}{(4.0164 - 0.258)\left(\frac{(41.9 \times 10^{-3})}{(1.6 \times 10^{-3})} + 0.8\right)} \right] = 0.0325 \text{ m (5sf)} = 32.5 \text{ mm}$$

Width of Ground Plane (W_g)

The Ground Plane Width was calculated using the Figure 7 formula:

$$W_g = W + 6h$$

Where:

W_g – Width of Ground Plane (m)

W – Width of Rectangular Patch (m)

h – Height of Dielectric Substrate (m)

Figure 7 – Ground Plane Width Formula [5][6]



Therefore:

$$W_g = (41.9 \times 10^{-3}) + 6(1.6 \times 10^{-3}) = 0.0515 \text{ m} = 51.5 \text{ mm}$$

Length of Ground Plane (L_g)

The Ground Plane Length was calculated using the Figure 8 formula:

$$L_g = L + 6h$$

Where:

L_g – Length of Ground Plane (m)

L – Width of Rectangular Patch (m)

h – Height of Dielectric Substrate (m)

Figure 8 – Ground Plane Length Formula [5][6]



Therefore:

$$L_g = (32.5 \times 10^{-3}) + 6(1.6 \times 10^{-3}) = 0.0421 \text{ m} = 42.1 \text{ mm}$$

Overview of Microstrip Patch Antenna Parameters

Figure 9 shows an overview of the calculated parameters for the Rectangular Microstrip Patch antenna.

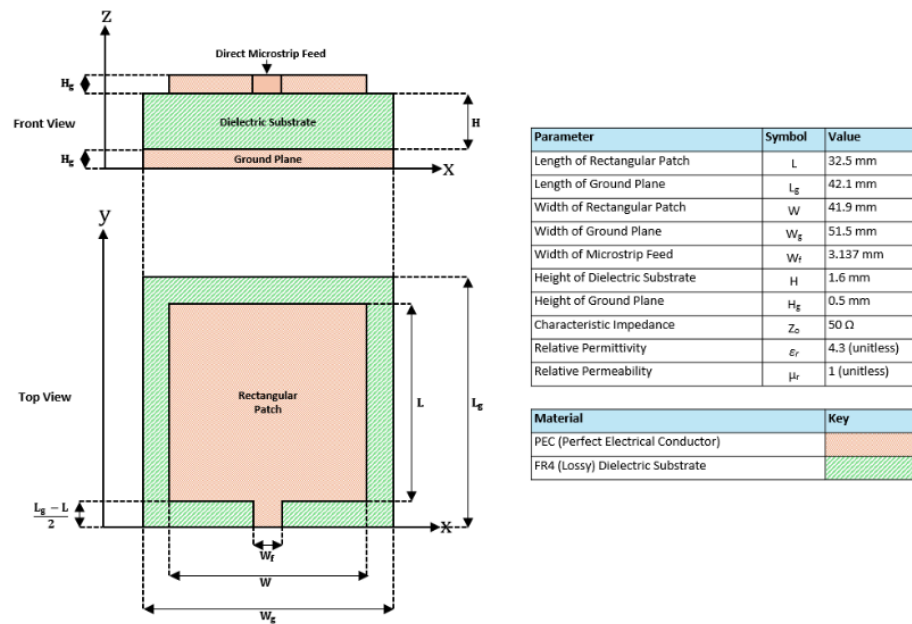


Figure 9 – Rectangular Microstrip Patch Antenna Design Specification

Simulation Results for the Microstrip Patch Antenna

CST Studio 2024 was used to categorise the antennas behaviour across the span of 1 to 8 GHz, generating the radiation pattern, impedance and S-parameter plots. [1] Figure 10 shows the Microstrip patch antenna design.

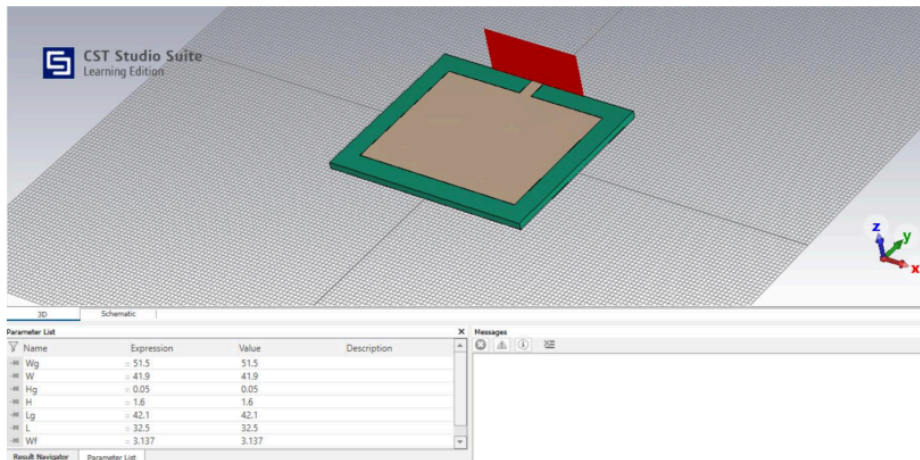


Figure 10 – Microstrip Patch Antenna Design in CST Studio Suite

Radiation Pattern

Figure 11 shows the Radiation Pattern as a Far Field Plot for the Microstrip Patch Antenna.

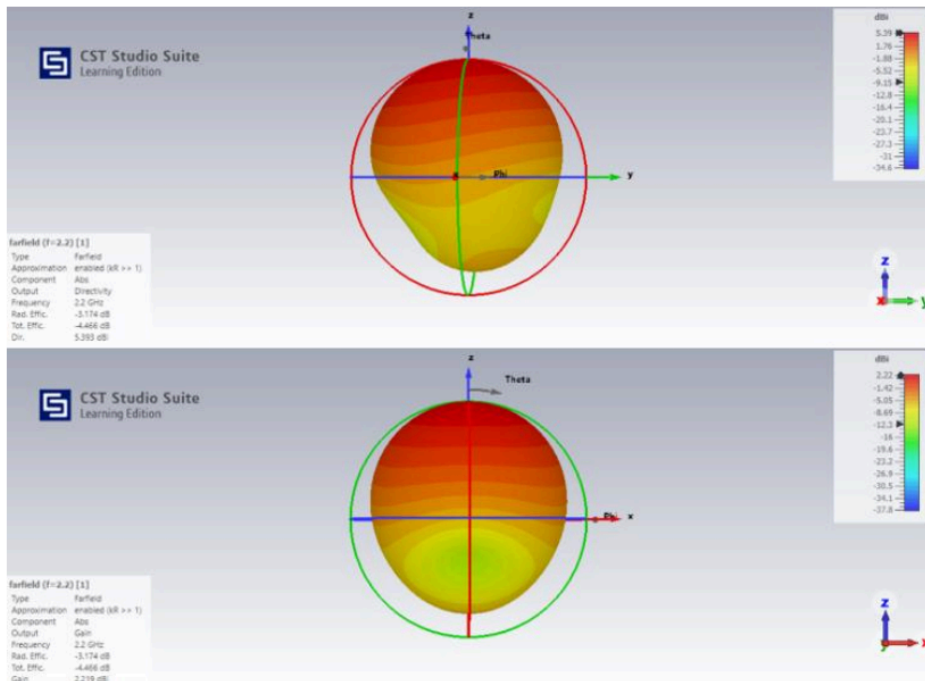


Figure 11 - Microstrip Patch Antenna Far Field Plot of Radiation Field

Impedance Plot

Figure 12 shows the Smith Chart for Microstrip Patch antenna.

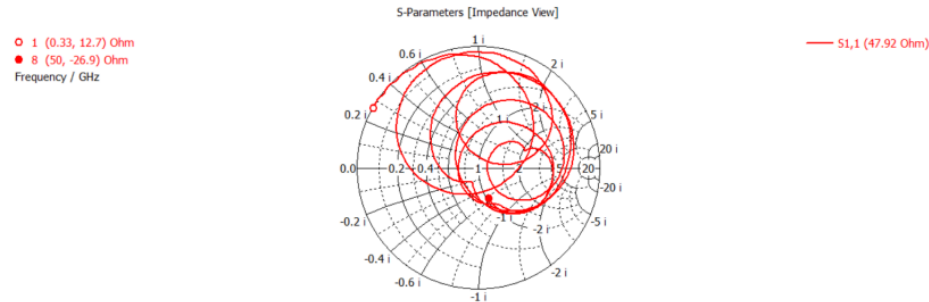


Figure 12 - Smith Chart showing Impedance

S-Parameter Plot

Figure 13 shows the S-Parameter plot displaying the Resonant Frequency of the Microstrip Patch antenna.

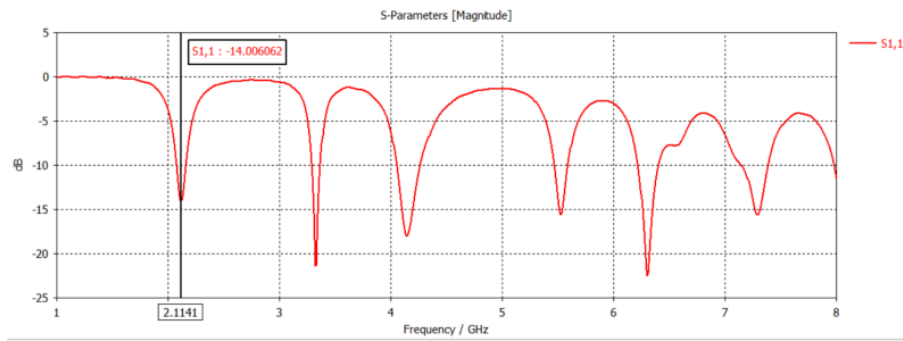


Figure 13 – S-parameter Plot for Microstrip Patch Antenna

VSWR

Figure 14 shows the Voltage Standing Wave Ratio (VSWR) of the Microstrip Patch antenna. VSWR is a measurement of how efficiently power is transmitted an antenna. This indicates how much energy is reflected due to impedance mismatching. [7]

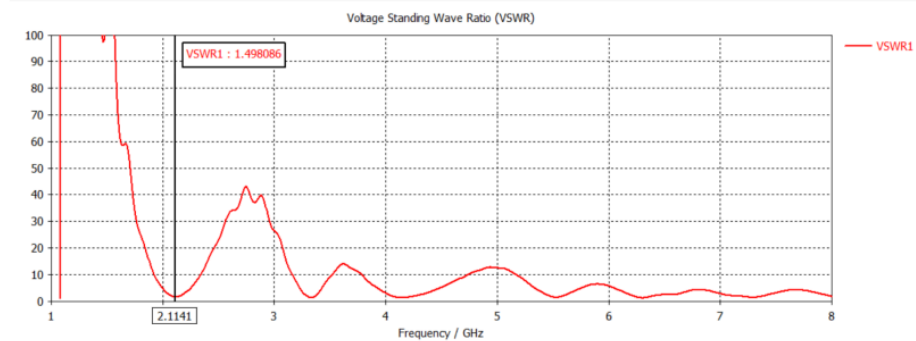


Figure 14 - VSWR of Microstrip Patch Antenna

1D Polar Plot

Figure 15 shows the 1-dimensional Polar Plot showing how energy is radiated by the Microstrip Patch antenna.

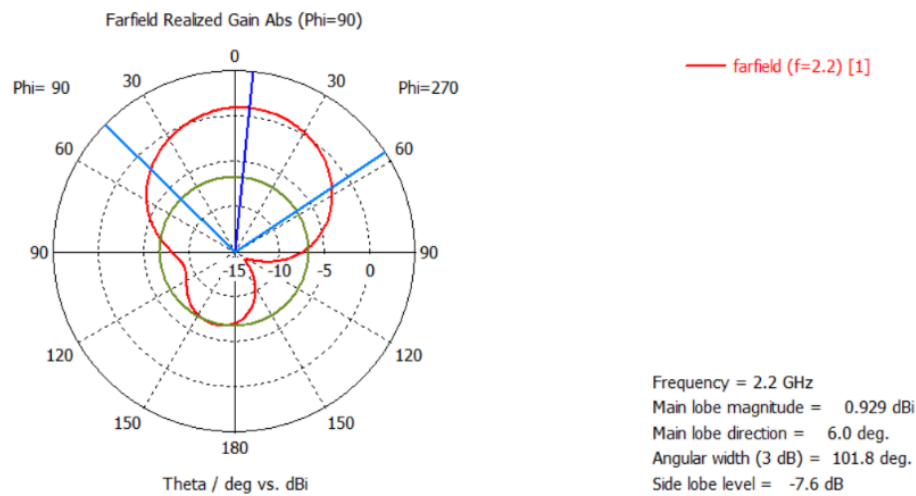


Figure 15 – Microstrip Patch Antenna Far Field 1D Polar Plot

Analysis of Microstrip Patch Antenna Performance

For this model, the theoretical resonance frequency was 2.2 GHz, while the simulated yielded 2.1141 GHz, showing a slight deviation, 3.9% below the desired value.

Figure 11 shows that the antenna has moderate gain, concentrating most of its radiated energy into its main lobe, having Directivity of 5.393 dBi. This would indicate it behaves slightly more directional than an omnidirectional antenna. [8]

Figure 12 provides an S_{11} value for the Microstrip Patch antenna of 47.92Ω. This identifies an impedance mismatch of 2.18Ω in terms of reflection coefficient, therefore showing reduced antenna efficiency. However, as the antenna has a VSWR of 1.498 the antenna only has a small portion of signal reflected, therefore being acceptable for most radio-frequency applications. [9]

The S-parameter plot in Figure 13 identifies that the antenna could be considered wideband having a Half-Power Bandwidth (-3dB) of 52.4 MHz, spanning from 2.0888 GHz to 2.1412 GHz. From this we can determine the Quality factor of the antenna, indicating sharpness of the frequency response being 40.35 (4sf). [10] Figure 15 also indicates that the antenna has a wide Half-Power Beamwidth (HPBW) of 101.8°.

TASK 2

MATLAB R2024b Antenna Designer was used to model and analyse four antenna types: Cylindrical Dipole, Folded Dipole, Horn, and Helix. [2] These simulations help understand their structure and performance.

RF Antenna Calculations

Theoretical operating frequencies were determined for the antenna structures. My student number of '2227990' was considered to calculate these values.

$$f_{\text{cylindrical dipole}} = <\text{second digit of student ID}> = 2.2 \text{ GHz}$$

Figure 16 - Operating Frequency Formula – Cylindrical Dipole Antenna

Folded Dipole Antenna:

$$f_{\text{folded dipole}} = \frac{< \text{first digit student ID} > < \text{second digit student ID} > < \text{third digit student ID} >}{2} \text{ MHz}$$

$$f_{\text{folded dipole}} = \frac{222}{2} = 111 \text{ MHz}$$

Figure 17 – Operating Frequency Formula – Folded Dipole Antenna

Horn Antenna:

$$f_{\text{horn}} = \frac{< \text{third digit student ID} > < \text{fourth digit student ID} >}{2} \text{ GHz}$$

$$f_{\text{horn}} = \frac{27}{2} = 13.5 \text{ GHz}$$

Figure 18 – Operating Frequency Formula – Horn Antenna

Helix Antenna:

$$f_{\text{helix}} = < \text{second digit of student ID} > < \text{third digit of student ID} > = 22 \text{ GHz}$$

Figure 19 – Operating Frequency Formula – Helix Antenna

Antenna Design in MATLAB

MATLAB R2024b Antenna Designer was used to model each of the specified antennas.

Cylindrical Dipole Antenna

Figure 20 shows the Cylindrical Dipole properties and design.

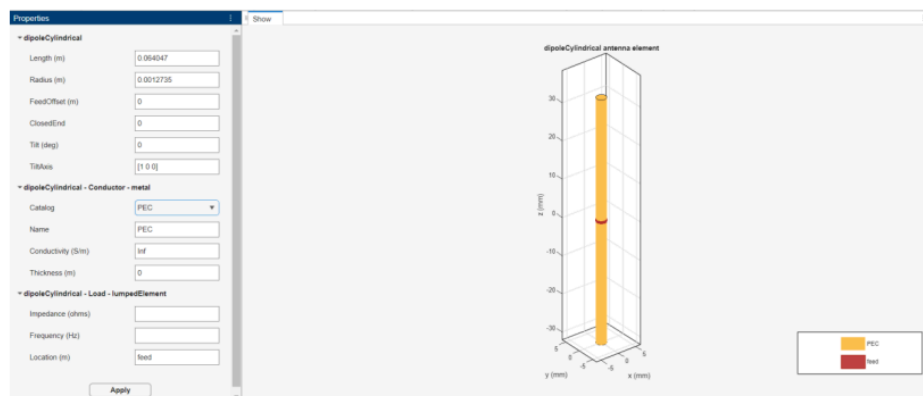


Figure 20 – Cylindrical Dipole Design in MATLAB Antenna Designer

Folded Dipole Antenna

Figure 21 shows the Folded Dipole properties and design.

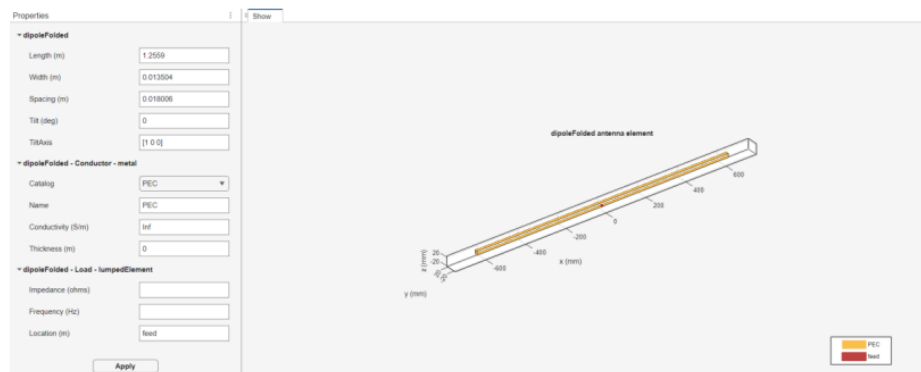


Figure 21 – Folded Dipole Design in MATLAB Antenna Designer

Horn Antenna

Figure 22 shows the Helix antenna properties and design.

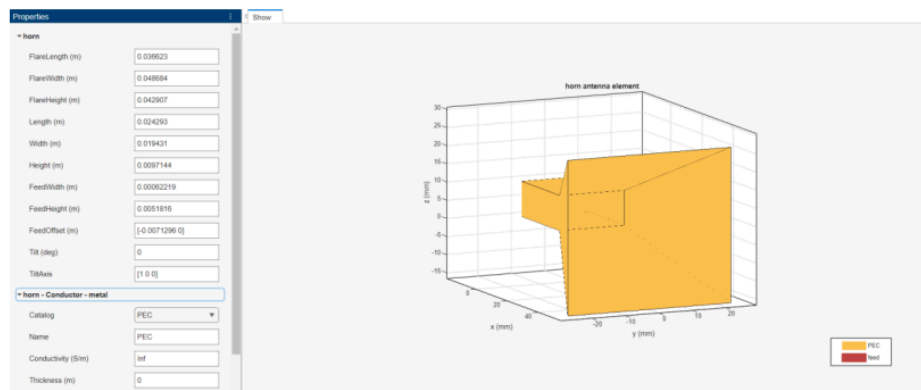


Figure 22 – Horn Design in MATLAB Antenna Designer

Helix Antenna

Figure 23 shows the Helix antenna properties and design.

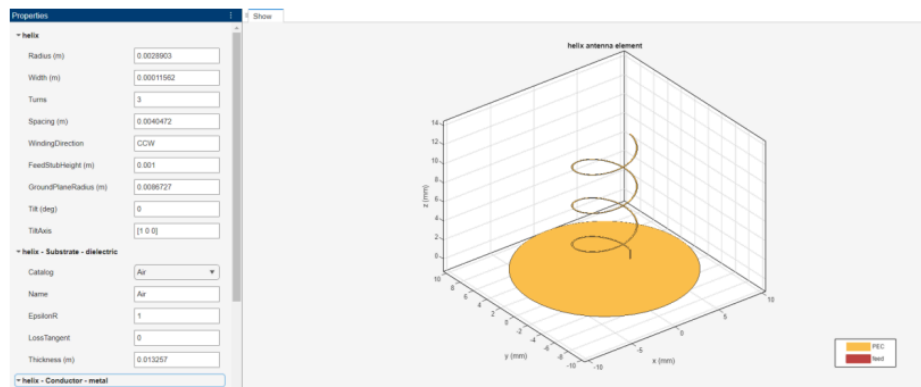


Figure 23 – Helix Design in MATLAB Antenna Designer

Antenna Simulation Results in MATLAB

For each of the antenna simulated using MATLAB antenna designer, details have been captured to verify and evaluate performance characteristics.

Cylindrical Dipole Antenna

Figure 24 shows the Cylindrical Dipole impedance characteristics.

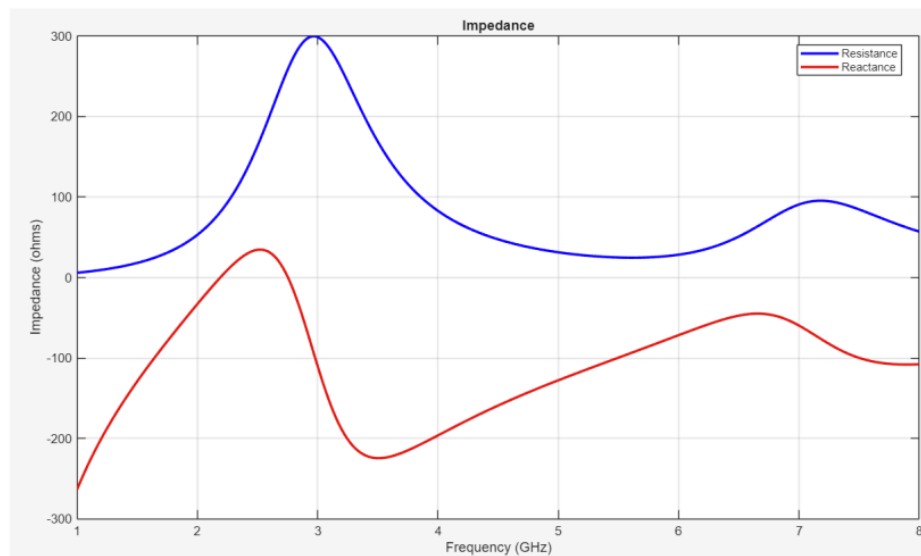


Figure 24 – Impedance Plot for Cylindrical Dipole Antenna

Figure 25 shows the Cylindrical Dipole S-parameter plot.

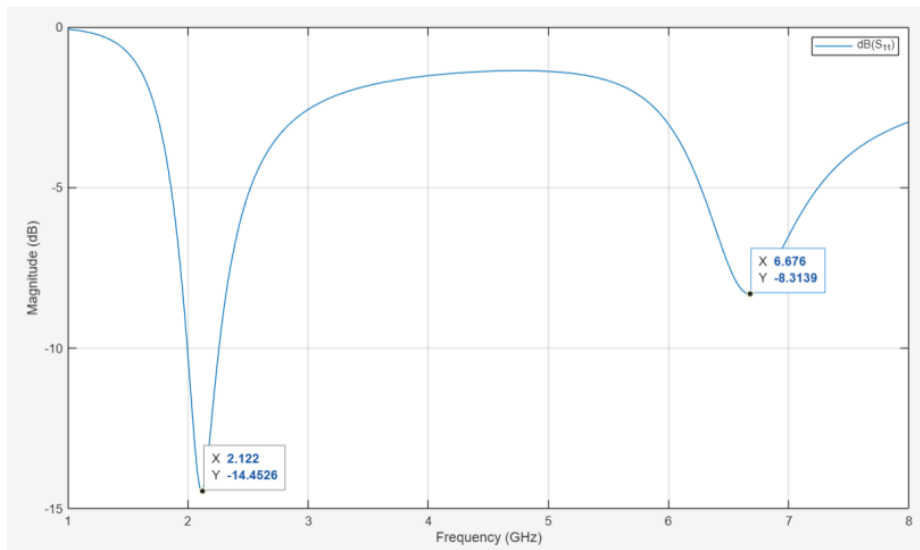


Figure 25 – S-Parameter Plot for Cylindrical Dipole Antenna

Figure 26 shows the 3-dimensional (3D) Radiation Pattern of the Cylindrical Dipole.

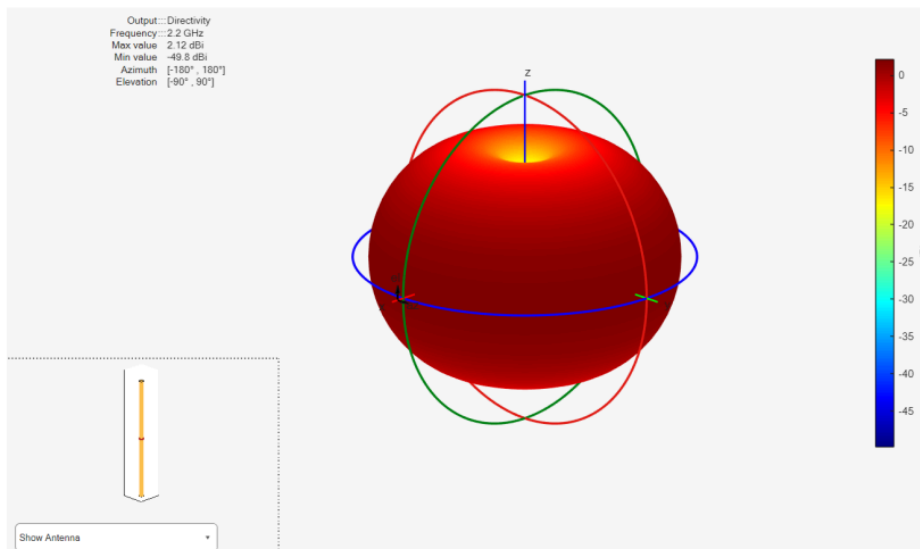


Figure 26 – 3D Radiation Plot for Cylindrical Dipole Antenna

Figure 27 shows the Azimuthal (H-plane) and Elevation (E-plane) polar plots for the Cylindrical Dipole.

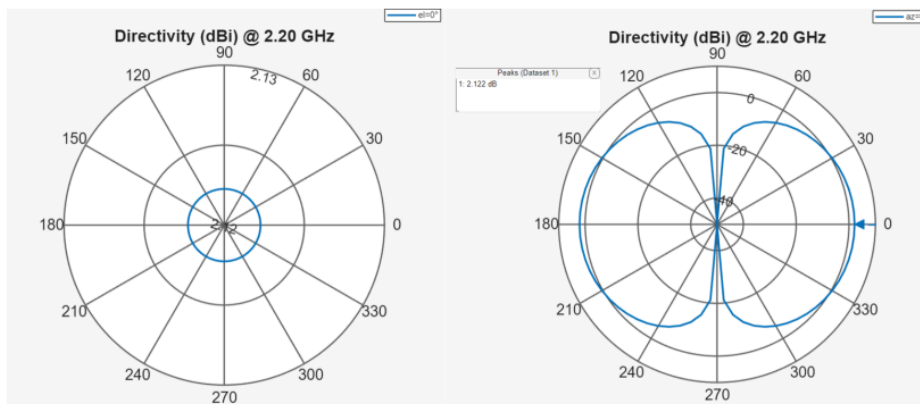


Figure 27 – 2D Azimuthal (left) and Elevation (right) Plots for Cylindrical Dipole Antenna

Folded Dipole Antenna

Figure 28 shows the Folded Dipole impedance characteristics.

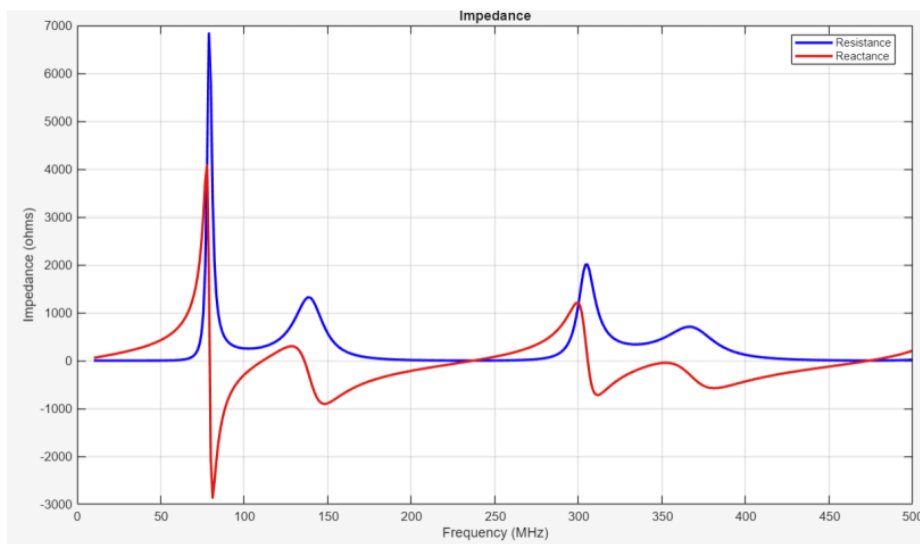


Figure 28 – Impedance Plot for Folded Dipole Antenna

Figure 29 shows the Folded Dipole S-parameter plot.

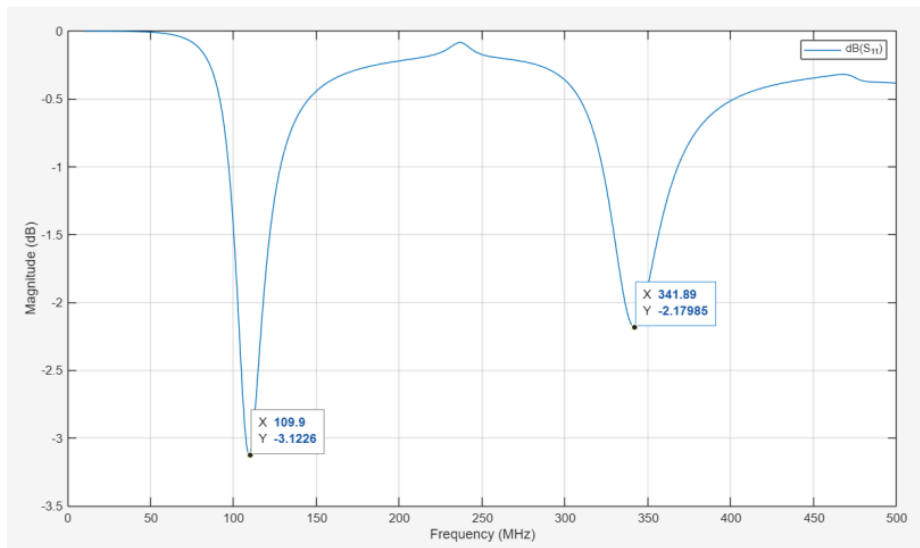


Figure 29 – S-Parameter Plot for Folded Dipole Antenna

Figure 30 shows the 3D Radiation Pattern of the Folded Dipole.

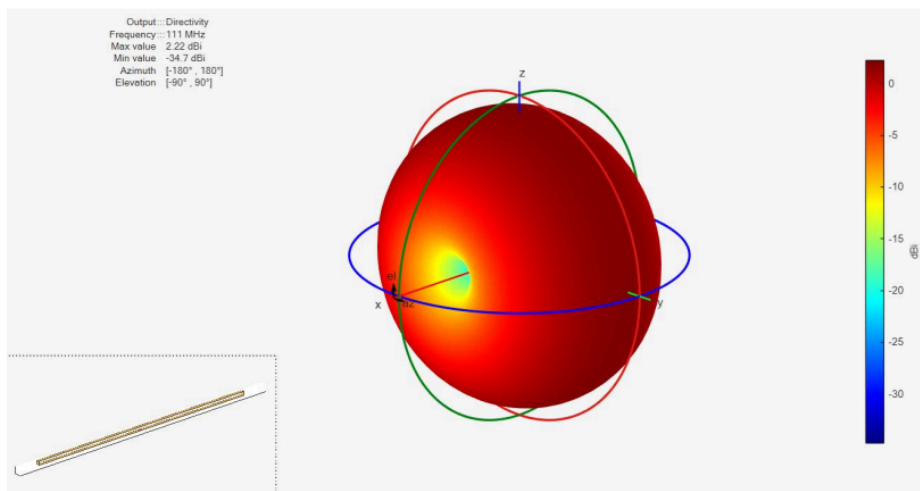


Figure 30 – 3D Radiation Plot for Folded Dipole Antenna

Figure 31 shows the Azimuthal and Elevation polar plots for the Folded Dipole.

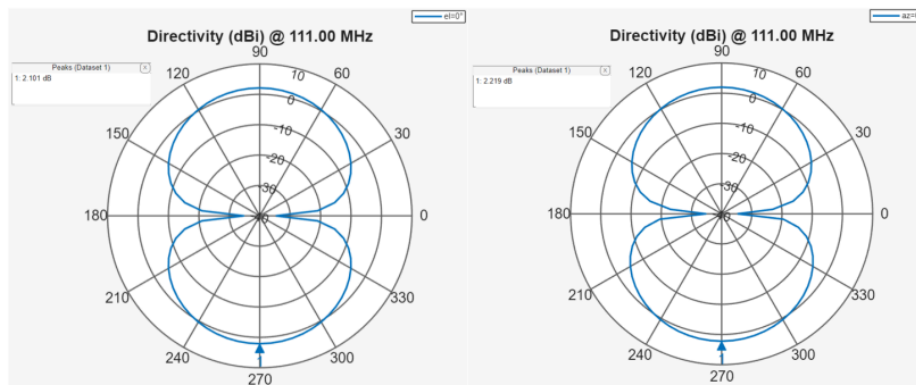


Figure 31 – 2D Azimuthal (left) and Elevation (right) Plots for Folded Dipole Antenna

Horn Antenna

Figure 32 shows the Horn antenna impedance characteristics.

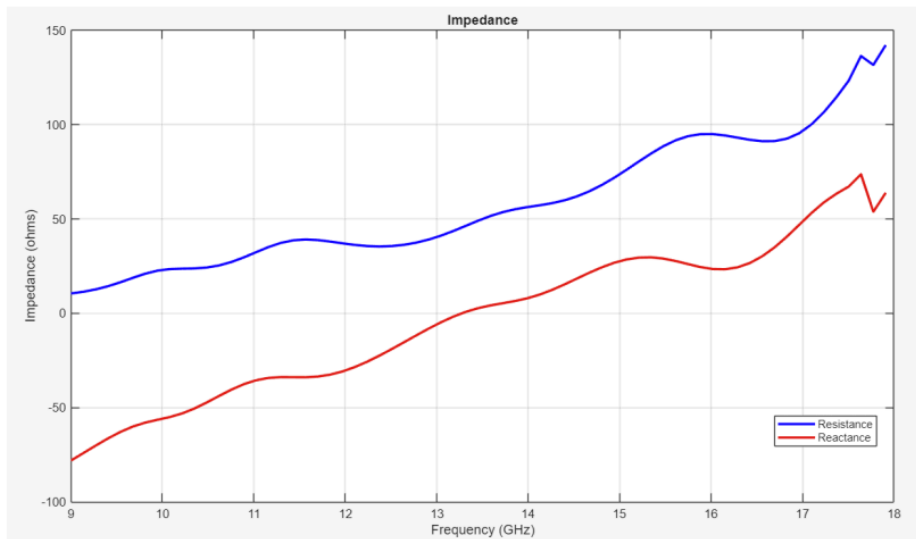


Figure 32 – Impedance Plot for Horn Antenna

Figure 33 shows the Horn antenna S-parameter plot.

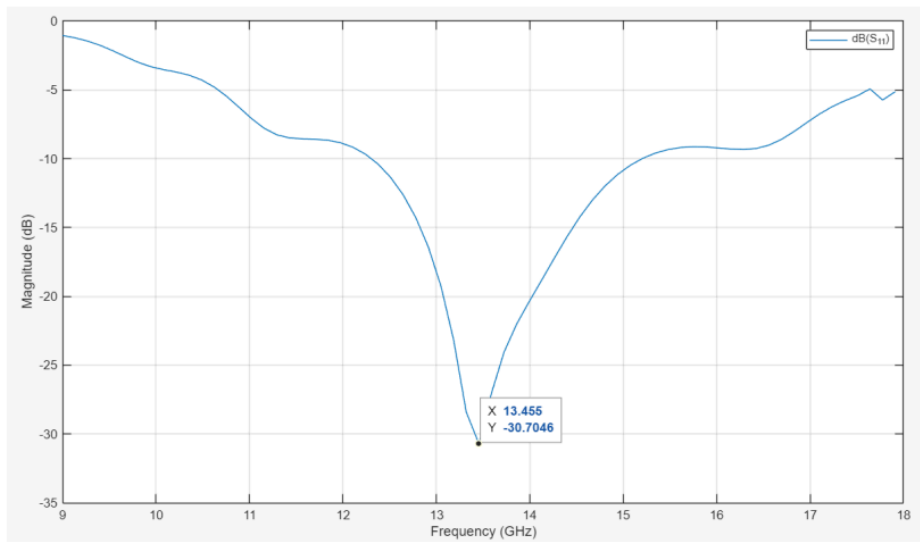


Figure 33 – S-Parameter Plot for Horn Antenna

Figure 34 shows the 3D Radiation Pattern of the Horn antenna.

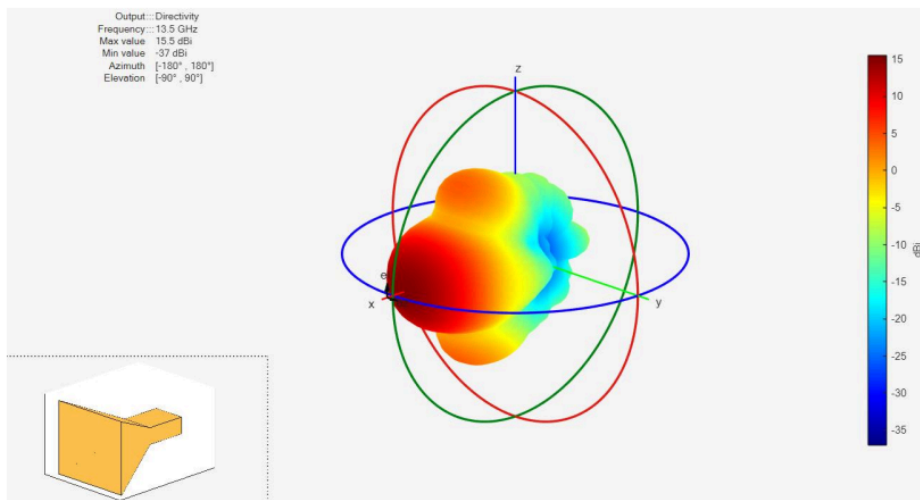


Figure 34 – 3D Radiation Plot for Horn Antenna

Figure 35 shows the Azimuthal and Elevation polar plots for the Horn antenna.

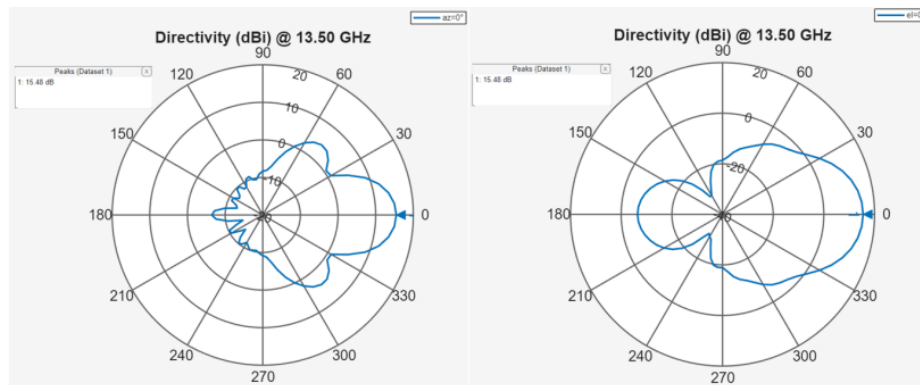


Figure 35 – 2D Azimuthal (left) and Elevation (right) Plots for Horn Antenna

Helix Antenna

Figure 36 shows the Helix antenna impedance characteristics.

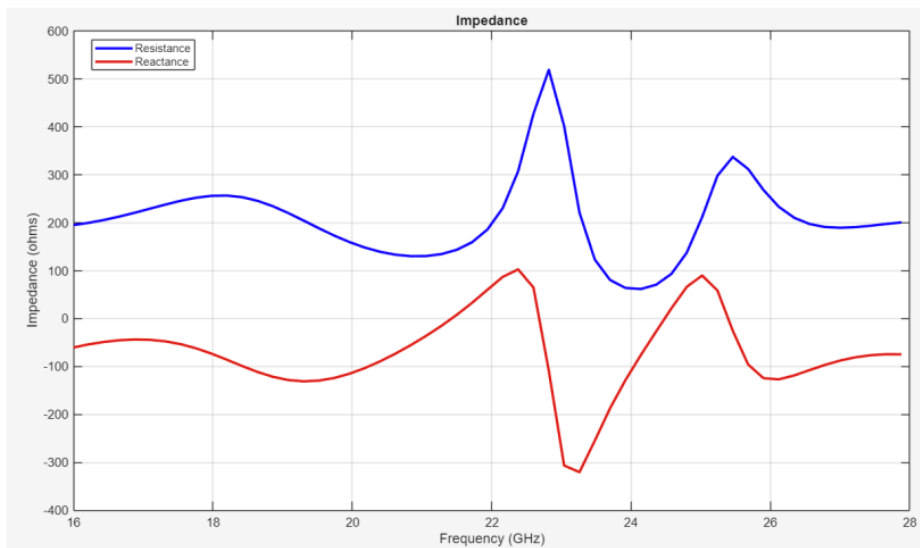


Figure 36 – Impedance Plot for Helix Antenna

Figure 37 shows the Helix antenna S-parameter plot.

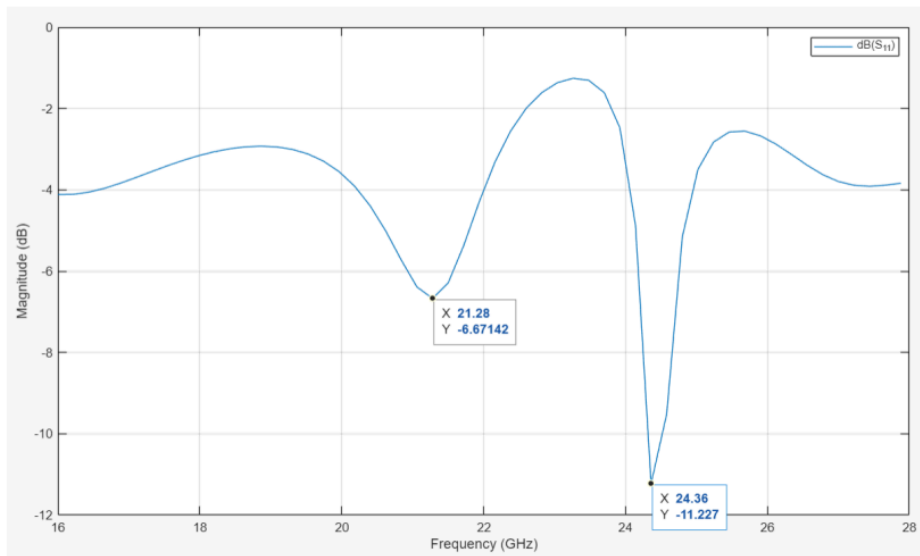


Figure 37 – S-Parameter Plot for Helix Antenna

Figure 38 shows the 3D Radiation Pattern of the Helix antenna.

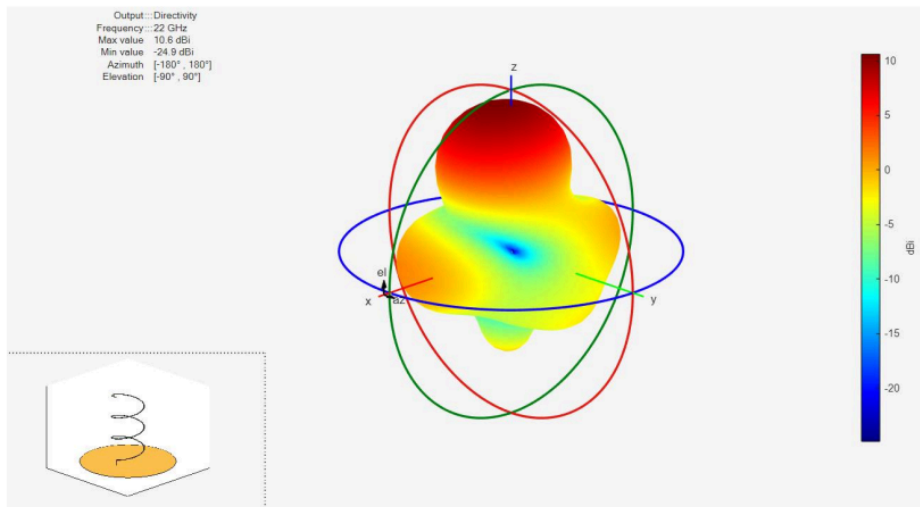


Figure 38 – 3D Radiation Plot for Helix Antenna

Figure 39 shows the Azimuthal and Elevation polar plots for the Helix antenna.

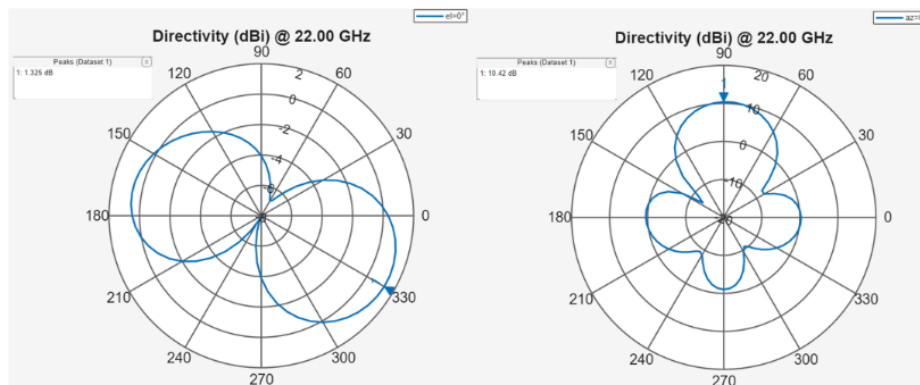


Figure 39 – 2D Azimuthal (left) and Elevation (right) Plots for Helix Antenna

Analysis of Antenna Performance

Operating Frequency

Table 1 displays the theoretical values calculated for resonant frequency of the antenna structures, compared with the values derived from the S-parameter plots in Figure 25, Figure 29, Figure 33 and Figure 37 respectively.

Antenna Structure	Theoretical Resonant Frequency (MHz)	Simulated Resonant Frequency (MHz)	Absolute Difference (MHz)	Relative Error Percentage (%)
Cylindrical Dipole	2200	2122	-78	-3.55
Folded Dipole	111	109.9	-1.1	-0.99
Horn	13500	13455	-45	-0.33
Helix	22000	21280	-720	-3.27

Table 1 – Analysis of Resonant Frequencies [11]

Table 1 shows the simulated resonant frequency of each antenna. In evaluation, it has been observed that the theoretical values calculated were higher than that provided by the MATLAB antenna designer as simulation outputs.

How Impedance Matching Affects Antenna Performance

By analysing the impedance plots for the Cylindrical Dipole, Folded Dipole and Horn antennas, Figure 24, Figure 28 and Figure 32 respectively, we observe that reactance nears 0Ω and resistance nears 50Ω for the resonant frequencies shown in Table 1. This indicating good impedance matching. In contrast, Figure 36 shows the Helix Antenna has a higher resistive component, around 125Ω at its 21.28 GHz resonant frequency.

For perfectly matched antennas, feed impedance equals that of the transmission line and source, typically 50Ω or 75Ω , with a purely resistive characteristic and reactance at 0Ω [12]. This prevents inefficiencies like that from capacitive energy storage. Poor matching leads to signal reflections, reducing power transfer and causing standing waves, signal degradation, and distortion. This can be observed from the 3D radiation plots where impedance mismatching results in undesired side and back lobes, while polar plots show reduced gain and directionality. Higher SWR values, typically above 2, indicate worsened performance.

Antenna Choice

The MATLAB simulations for each antenna demonstrate that selection depends on specific application requirements, with key factors including Directivity, Beamwidth, Operating Bandwidth, and Efficiency.

Each antenna modelled exhibits unique directivity characteristics. Figure 26 and Figure 30 show the Cylindrical and Folded Dipole antennas have torus-shaped radiation patterns, indicating omnidirectional propagation characteristics. Figure 27 reveals the Cylindrical Dipole is linearly polarized in the Elevation Plane with nulls at 90° and 270°, while Figure 31 shows the Folded Dipole is linearly polarized in the Azimuthal Plane with nulls at 0° and 180°. These characteristics are suitable for IoT, wireless communication, and mobile applications.

Conversely, the Horn antenna is highly directional, with Figure 35 providing a Directivity of 15.48 dBi. Figure 34 shows a strong main lobe in the Azimuthal Plane, with linear polarization. The S-parameter plot shows the resonant frequency of 13.445 GHz occurring when there is a high negative S_{11} magnitude of -30.7 dB, indicating strong absorption and transmission, ensuring efficient energy transfer. These characteristics make Horn antennas suitable for satellite communications, radio astronomy, and radar.

From Figure 38 we can observe the Right-Hand Circularly Polarized (RHCP) propagation pattern exhibited by the Helix antenna. This is expected from its right-hand screw design. Its axial-mode operation focuses radiation along its vertical axis, appearing more polarized in the Elevation Plane. This behaviour aligns with its high-frequency design, operating at a 21.28 GHz resonant frequency.

Evaluation of Societal and Environmental Factors

When antennas are designed societal and environmental factors need to be considered to achieve compliance with regulations and make products more sustainable.

Antenna design must account for societal and environmental factors to ensure regulatory compliance and sustainability. Government guidelines, such as the Code of Practice for Wireless Network Development in England, aim to minimize disruption to wildlife and ecosystems, reducing environmental impact. For instance, when mobile network operators (MNOs) construct new infrastructure such as base stations. [13]

Spectrum management regulations require antennas to operate within approved frequency bands, as mandated by Ofcom under the 2003 Communications Act and 2006 Wireless Telegraphy Act, ensuring balanced spectrum use and mitigation of interference [14][15]. Additionally, systems must adhere to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, integrated into UK law, to maintain safe exposure limits [16].

Environmental factors include selecting materials that reduce reliance on non-renewable resources and hazardous substances. Designing with End-of-Life considerations improves recyclability, reducing Waste from Electrical and Electronic Equipment (WEEE) [17]. Energy-efficient antennas further enhance sustainability by lowering power consumption and minimizing resource wastage.

TASK 3

Helix Array Antenna Design

To construct and simulate a [3,3] Helix Array antenna operating frequency was determine using my student number of '2227990':

$$f_{\text{helix array}} = \text{<second digit of student ID> <third digit of student ID>} = 22 \text{ GHz}$$

Figure 40 – Operating Frequency Formula – Helix Array

Helix Array Design in MATLAB

Figure 41 shows the Helix Array Antenna design with a resonant frequency of 22 GHz.

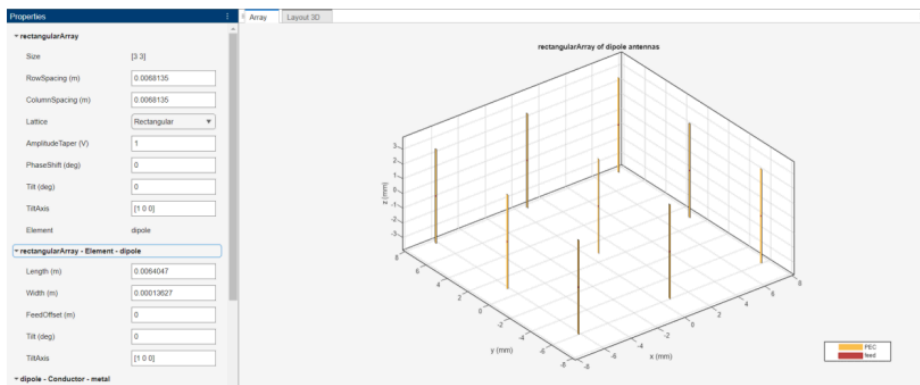


Figure 41 – Helix Array Design in MATLAB Antenna Array Designer

Helix Array Simulation Results in MATLAB

Details have been captured to verify and evaluate the performance characteristics of the Helix Array simulated using MATLAB antenna designer.

Figure 42 shows the Helix Arrays impedance characteristics.

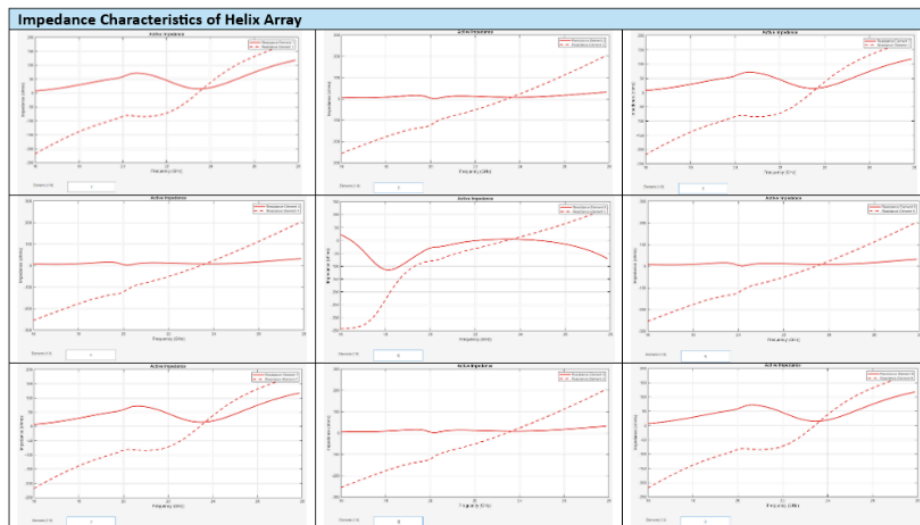


Figure 42 – Impedance Plots for Helix Array Elements

Figure 43 shows the Helix Arrays S-parameter plot.

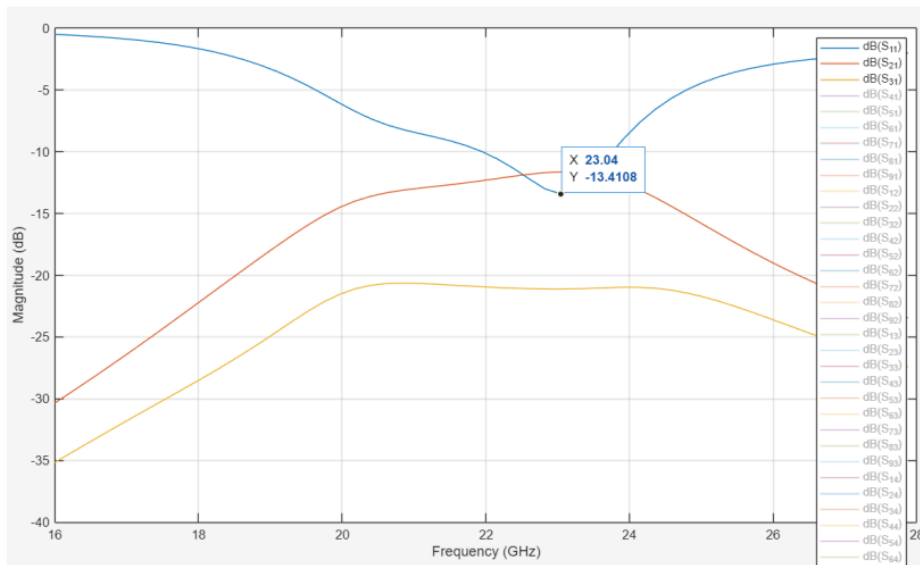


Figure 43 – S-Parameter Plot for Helix Array

Figure 44 shows the 3D Radiation Pattern of the Helix Array.

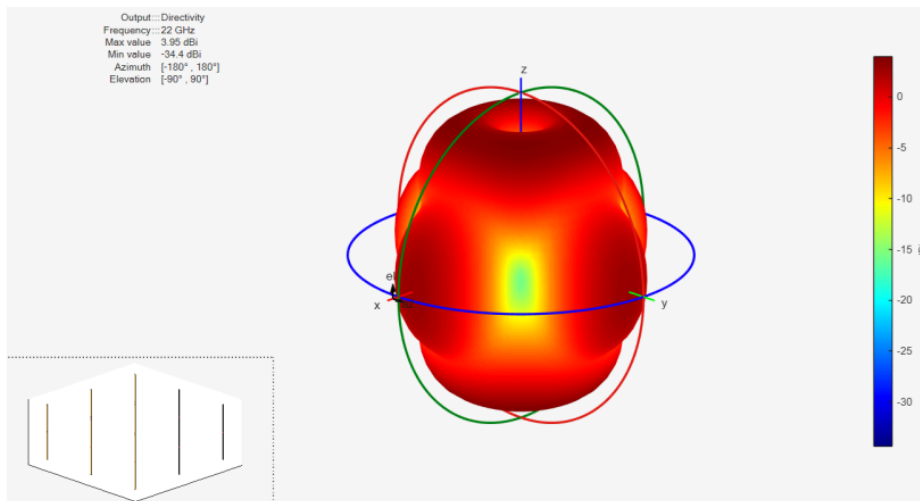


Figure 44 - 3D Radiation Plot for Helix Array

Figure 45Figure 44 shows the Azimuthal and Elevation polar plots for the Helix Array.

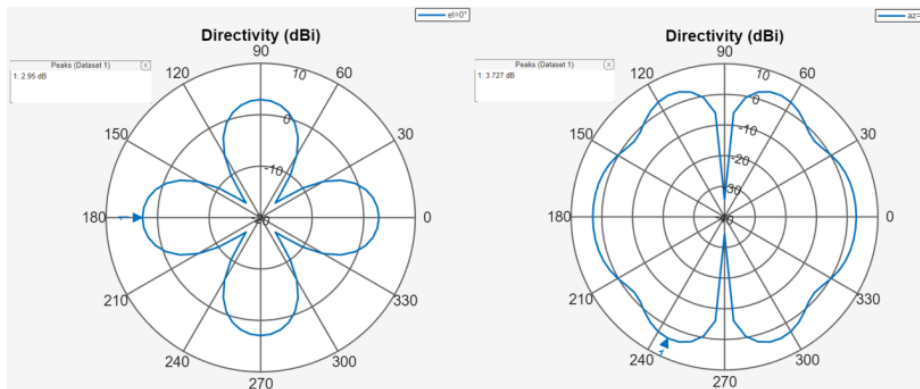


Figure 45 – 2D Azimuthal (left) and Elevation (right) Plots for Helix Array

Analysis of Helix Array Performance

When analysing the Helix Array performance, Figure 43 shows that the resonant frequency of the Helix Array is 23.04 GHz, being 1.04 GHz higher than that of the theoretical resonant frequency. The Figure 45 plots show that the Helix Array has narrow beam lobe, while exhibiting characteristics of circular polarisation. The 3D radiation plot in Figure 44 shows that Helix array Directivity of 3.95 dBi. This can be considered low for a Helix Array as they typically exhibit high directivity, often greater than 9dBi. This could be from poorly optimised spacing or the low amount of turns per helix element, as more turns correspond to increased directivity. [18] Therefore, in evaluation this antenna provides more effective propagation characteristics with design changes.

Benefits of using Array Antennas

Array antennas offer significant performance advantages in RF applications, providing higher directivity than single helix antennas, which enhances signal strength and efficiency in reception and transmission [19]. Unlike other designs, Arrays leverage digital signal processing and phase shifters for dynamic beam steering. Beamforming through constructive interference is valuable in radar and satellite communication, allowing target tracking over a broader horizon [11][20].

Beamforming and higher spatial resolution serve as a unique selling proposition for manufacturers, potentially increasing revenue. However, these arrays pose commercial challenges. Enhanced performance may come with cost asymmetry, as greater system complexity raises variable expenses and increases the likelihood of component failure (reduced robustness), necessitating more maintenance and system downtime. A thorough cost-benefit analysis is crucial to assessing the viability of this solution.

Conclusion

In this report it was determined that maximum power transfer occurs with good impedance matching, typically when antenna structures exhibit purely resistive characteristics. Specifically, when the resistive component equals the characteristic impedance and the reactive component is zero. This may be due to the capacitive and inductive properties of antennas; capacitance stores energy, while inductance causes phase shifting, leading to inefficiencies. These findings align with fundamental antenna theory. Additionally, all simulated resonant frequencies were higher than expected, except for the Helix Array antenna, likely due to modelling approximations, design choices, and material losses.

Future Recommendations

For further research, varying the mesh resolution in antenna designs could help analyse performance changes in simulations. Additionally, modelling with more realistic substrates and conductive materials instead of relying solely on Perfect Electrical Conductors (PEC) may improve accuracy. Physical testing in an RF chamber or Ramsey box could also provide more reliable data, addressing limitations of software simulations.

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FINAL GRADE

GENERAL COMMENTS

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GRADING FORM: ADV. RF SYSTEMS

ALISTAIR LOUNDS

76

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.



Demonstrate ability to engage with an extensive range of relevant and credible literature, informed by the latest research. References are well-integrated throughout the report and cited using the correct IEEE format. consider using more peer reviewed journals for referencing technical concepts.

7

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.



Excellent, coherent, and detailed knowledge with a systematic understanding of the principles and theories in Radio Frequency systems. Demonstrates a deep understanding of antenna theory, including resonant frequency, S-parameters, impedance matching, and beamwidth. Effectively applies first principles and theoretical analysis to support conclusions,

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particularly in the context of RF component behaviour.

Demonstrates good application of mathematical formulas, as well as engineering and natural science principles, in simulation design decisions. The discussion of radiation patterns and substrate effects would benefit from greater elaboration on electromagnetic field behaviour.

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



Excellent critical thinking, analysis, synthesis and evaluation. Good analysis of simulation vs. theoretical resonant frequencies and use of Smith Charts, VSWR plots, and radiation patterns to evaluate performance. Analysis thoughtfully explains the causes of discrepancies between theoretical and simulated results shows strong analytical thinking in electromagnetic theory. Demonstrates ability to apply first principles to interpret and explain complex antenna behaviours. Demonstrates performance-focused design refinements alongside consideration of regulatory compliance and sustainability, reflecting real-world engineering responsibilities is evident from the report.

23

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.



An advanced application of a range of methods, materials, tools and techniques.

20

Effectively used MATLAB and CST to model antenna systems, demonstrating a clear understanding of their applications, limitations, and simulation techniques. The use of lab simulation tools also reflects strong practical engineering skills in modelling and analysis. Demonstrates the ability to convert theory into practical, user-focused design solutions that consider societal and industry requirements. Material selection and design factors are well-discussed, with decisions clearly aligned to real-world engineering needs.

Improve design by addressing element spacing and mutual coupling in the helix array. Adding a summary table to clearly present antenna designs could have been better.

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.

7



Communicates professionally with a clear, well-structured report suitable for both technical and non-technical audiences. Societal, regulatory, and ethical considerations are well-integrated into the design and analysis process. The report reflects thoughtful attention to sustainability, spectrum management, safe frequency use, and compliance with relevant standards, demonstrating alignment with professional codes of conduct and responsible engineering practices. Better if, the conclusion could tie back more strongly to learning outcomes.