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Design of Helical Antenna for CubeSat Using CST Tool

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Abstract: In this paper,the design of a 2.45 GHz helical antenna for CubeSat communications. Helical antennas, known for their high gain, circular polarization, and wide bandwidth, are ideal for the stringent size and performance requirements of CubeSats. The design process involves optimizing key parameters such as the number of turns, pitch angle, and diameter to achieve optimal performance in the axial mode, which offers a directional radiation pattern suited for satellite links. The report covers theoretical principles, design considerations, and simulation results, demonstrating the antenna's ability to maintain robust communication links, support high data rates, and withstand space conditions. Its compact, lightweight design ensures it fits within the limited space of a CubeSat, making. The design process of a 2.45 GHz helical antenna for CubeSat communications, optimizing key parameters to achieve optimal performance in the axial mode for satellite links.

Keywords:*Helical antenna,CubeSat communications,Circular polarization, Directional radiation pattern,Axial mode, High gain.*

1.Introduction

CubeSats, also known as Cube Satellites, have surged in popularity due to their cost-effectiveness and the ability to be assembled using readily available commercial components. These compact satellites are

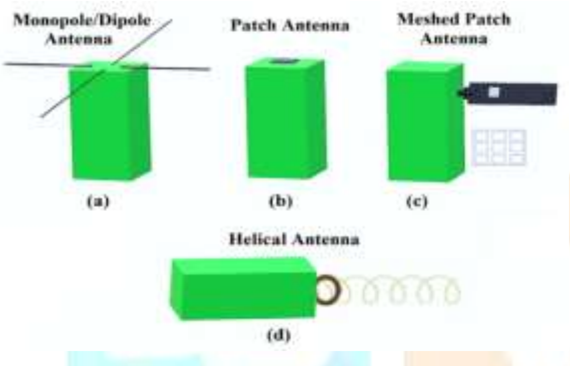


Figure 2: Popular antenna designs proposed in the literature. (a) Monopole/Dipole; (b) Patch; (c) Meshed Patch and (d) Helical Patch.

typically built in standard units of 10 cm x 10 cm x 10 cm (1U), and can be configured into larger sizes like 1.5U, 2U, 3U, or more, depending on the specific mission requirements. The use of commercial off-the-shelf (COTS) components significantly reduces the development and production costs, making CubeSats an attractive option for a wide range of applications.

CubeSats play a vital role in diverse fields such as remote sensing, where they can monitor environmental changes, agricultural health, and natural disasters. In space exploration, CubeSats can be used to test new technologies, perform scientific experiments, and gather data from space environments. Their ability to conduct extensive area measurements allows them to collect data over large geographical regions, which is invaluable for scientific research and environmental monitoring.

In deep space telecommunications, CubeSats can serve as communication relays, enabling data transmission between distant space probes and Earth. Their adaptability and versatility in inter-space communication and dialogue with ground stations make them indispensable tools for maintaining contact with other satellites and spacecraft.

Figure 1 shows that the CubeSat standards vary in size, from 1U (10x10x10 cm) to larger configurations

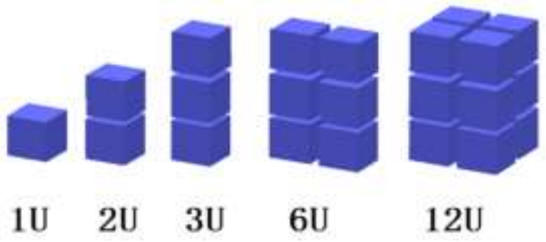


Figure 1: Different CubeSat standards

like 6U or 12U, enabling diverse scientific, commercial, and educational missions with modular and scalable designs.

The communication system of CubeSats serves as a pivotal element that determines their efficacy. When designing antennas for CubeSats, factors such as gain, polarization, frequency selection, pointing accuracy, coverage, and deployment mechanisms must be taken into consideration.CubeSat missions typically operate within the VHF, UHF, or S-band frequencies. Antennas are positioned on the surfaces of CubeSats and must be tailored to fit within the compact confines of a CubeSat structure while upholding excellent radiation performance. Various types of antennas, including whip antennas, patch antennas, inflatable antennas, helical antennas, and planar arrays have been suggested for CubeSat applications.

Figure 2 shows that the Popular antenna designs include Monopole/Dipole for simple and efficient radiation patterns, Patch for compact and planar structures, Meshed Patch for reduced weight and flexibility, and Helical Patch for circular polarization and broad bandwidth.

In conclusion, spiral antennas offer advantages such as high potential gain compared to other designs, simple construction, automatic deployment features due to spring force, and suitability for high-data rate connections. Further research could explore enhancing the layout and deployment mechanisms of spiral antennas in orbit to optimize their performance in CubeSat missions.

2.Design a 2.45 GHz Helical Antenna for CubeSatandAnalysis

CST Studio Suite is a comprehensive software package for electromagnetic simulation. It allows for the design, analysis, and optimization of a wide range of electromagnetic devices, including antennas, filters, and circuits. For CubeSat applications, CST provides the tools necessary to design a helical antenna that meets specific performance criteria at 2.45 GHz.

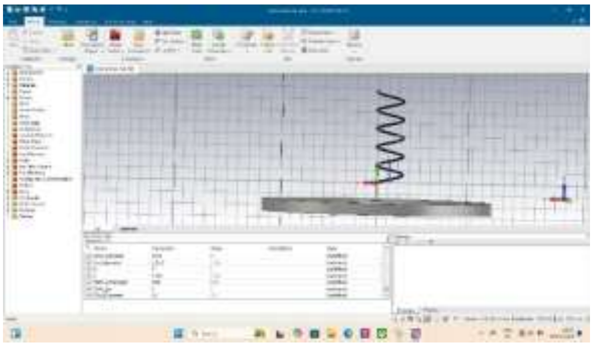


Figure 3: Helical Antenna Design Using CST Tool

➢ **Define Antenna Specifications**

- **Frequency**: Set the operating frequency to 2.45 GHz.
- **Gain**: Determine the required gain for the antenna.
- **Polarization**: Ensure circular polarization to reduce signal fading and polarization mismatch.

➢ **Create the Helix Structure**

- **Number of Turns**: Define the number of turns for the helical antenna.
- **Diameter**: Set the helix diameter to match the desired resonant frequency.
- **Pitch Angle**: Adjust the pitch angle to achieve the necessary axial mode radiation.

➢ **Design the Ground Plane**

- **Size and Shape**: Define the size and shape of the ground plane, typically a circular or square plane that reflects the radiated energy.
- Use the "Polygon" or "Cylinder" tools to create the ground plane in CST.

➢ **Define Material Properties**

- **Conductor**: Assign the appropriate material properties to the helical wire and ground plane (e.g., copper).
- In CST, select materials from the library or define custom materials if necessary.

➢ **Set Up Excitation and Boundary Conditions**

- **Excitation**: Apply a lumped port or waveguide port to the feed point of the helix.
- **Boundary Conditions**: Define open (radiation) boundary conditions to simulate free-space radiation.

➢ **Mesh Generation**

- Generate a mesh that accurately captures the geometric details of the helical antenna.
- Use adaptive meshing techniques in CST to ensure convergence and accuracy.

➢ **Simulation and Analysis**

- **Run Simulation**: Perform a frequency-domain or time-domain simulation to analyze the antenna's performance.
- **Post-Processing**: Analyze key parameters such as S-parameters, radiation patterns, gain, and axial ratio.

➢ **Optimization**

- Use CST's optimization tools to fine-tune the antenna design.
- Optimize for parameters such as gain, bandwidth, and impedance matching.

➢ **Validation and Verification**

- Compare simulation results with theoretical calculations or measurements from prototype testing.
- Ensure that the antenna meets all design requirements and performance criteria.

Table 1 complies Dimensions of a helical antenna include its diameter, pitch, and length, tailored to the operating frequency and design requirements.

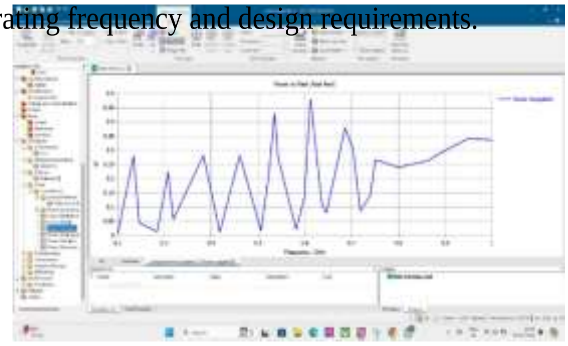


Figure 4: Simulated radiation patterns of proposed antenna at 2.45 GHz

Table 1: Dimensions

Size	Dimensions	Wet Mass
1U	10 cm × 10 cm × 10 cm	1.3 kg
2U	10 cm × 10 cm × 20 cm	2.6 kg
3U	10 cm × 10 cm × 30 cm	3.9 kg
6U	10 cm × 20 cm × 30 cm	7.8 kg
12U	10 cm × 10 cm × 60 cm	15.6 kg

Figure 4shows how the strength of the signal varies with the angle away from the antenna. Typically plotted in polar or 3D coordinates, it indicates the intensity of radiation in different directions from the antenna.

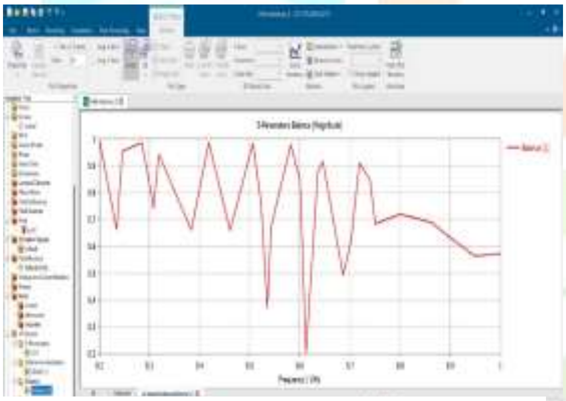


Figure 5:S Parameter Balance (Magnitude)

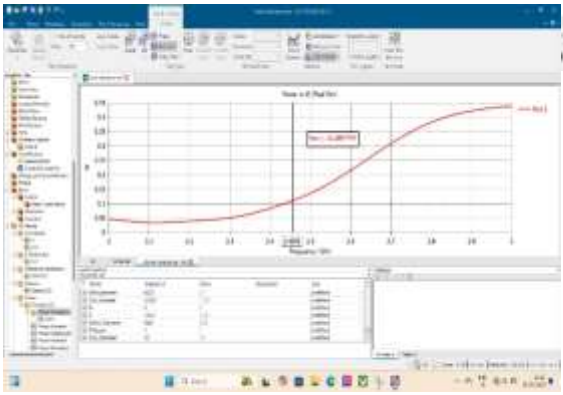


Figure 6: Power in Watt (real part)

Above Figure5 and 6 shows that the simulated radiation patterns of the proposed antenna at 2.45 GHz, along with S-parameter balance (magnitude) and real power in watts, provide insights into its efficiency, impedance matching, and radiation characteristics.

Table 2: Restrictions imposed by the CubeSat platform on antenna designs

Figure 13 Helical antenna

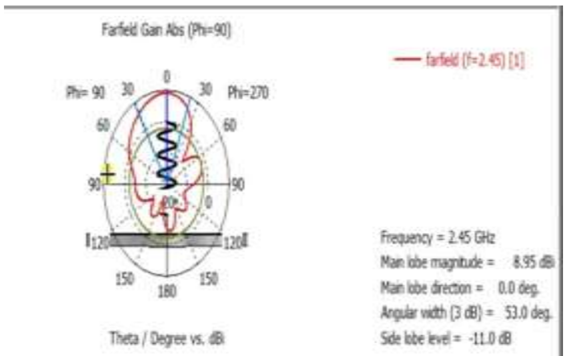


Figure 6: Reference Impedance (Real Part)

antenna is designed to operate efficiently, impacting its matching and performance.

Restrictions	Description
Size and Mass	Light weight and compact to fit the 10 cm × 10 cm size of a CubeSat surface in the case of 1U (without considering deployment volume).
Deployment	Deployment mechanism must be chosen or designed to minimize risk of deployment failure.
Attitude Control	Choice between active or passive control systems will determine the antenna pointing accuracy, as well as the choice of fixed or steering beam antenna.
Frequency Band and Bandwidth	Set by the mission specifications and allocated by the ITU or FCC. Dictates the uplink and downlink.
Loss	Antenna radiation or aperture efficiency must be higher than 50%. Antenna must match well with a reflection coefficient less than −10 dB.
Orbit (Communication Range)	Low Earth orbit: 400–2000 km Inter-satellite: Depends on swarm architecture Deep space: >2 × 10^6 km
Gain	Choice between low gain (LG), medium gain (MG), or high gain (HG), according to the available RF power budget and orbit.
Link Budget	High enough gain to provide the required SNR according to the modulation used.
Footprint	Dictate the beam width or the shape of the radiation pattern, as well as the size of the aperture.
Space Environment and Durability	Withstand thermal variations from −40 to +85 Celsius. Must pass thermal-vacuum cycling test (TVCT) and vibration test.
Cost	Off-the-shelf materials to reduce budget.
Polarization	Circular polarization to reduce losses due to polarization mismatch. Satisfy the cross-polarization levels set by the mission specifications.

Table 2 regarding the restrictions imposed by the CubeSat platform on antenna designs, here's a possible structure based on common limitations CubeSat platforms typically impose:

Above Figure7 Shows that the reference impedance (real part) indicates the resistance level at which the

3. Measurement Results and Discussion

The design of a helical antenna for a CubeSat using

Figure 7: Reference Impedance (Real Part)

CST optimizes the antenna's parameters to ensure reliable communication and efficient performance within the constraints of a small satellite.

3.1 Antenna Parameters

☐**Frequency:** The operating frequency or frequency range over which the antenna is designed to function

Figure 8: Results of modelling (dashed line) and measurements (full line) of the antenna's

effectively (e.g., 2.45 GHz for a helical antenna). This affects the antenna's size and design.

☐**Gain:** A measure of the antenna's ability to direct radio frequency energy in a particular direction, typically expressed in dBi or dBd. Higher gain antennas can transmit and receive signals over greater distances.

☐**Radiation Pattern:** The spatial distribution of the radiated energy from the antenna, showing how power is radiated in different directions. Can be omnidirectional, directional, or have other specific patterns.

☐**Polarization:** The orientation of the electric field of the radiated waves. Antennas can be linearly polarized (vertical or horizontal), circularly polarized (left-hand or right-hand), or elliptically polarized.

☐**Bandwidth:** The range of frequencies over which the antenna can operate effectively, typically characterized by acceptable performance metrics like VSWR (Voltage Standing Wave Ratio) or return loss.

☐**Impedance:** The ratio of voltage to current at the antenna's terminals, typically 50 ohms for most communication systems. Impedance matching is important to maximize power transfer and minimize signal reflection.

☐**Efficiency:** The ratio of the power radiated by the antenna to the total power input. High efficiency is essential for ensuring that most of the transmitted power is radiated, rather than lost as heat.

☐**Beamwidth:** The angular width of the main lobe of the radiation pattern, usually measured between the points where the signal strength drops to half of the maximum (3 dB points).

☐**Front-to-Back Ratio**: The ratio of the power radiated in the forward direction to the power radiated in the backward direction, which is especially important for directional antennas.

☐ **VSWR (Voltage Standing Wave Ratio)**: A measure of how well the antenna is impedance-matched to the transmission line. A lower VSWR indicates better matching and lower signal reflection.

3.2 Expected Results After Designing a 2.45 GHz Helical Antenna for CubeSat Using CST Studio Suite

➢ **Radiation Pattern**

- **Result**: The simulation will produce a detailed visualization of the antenna's far-field radiation pattern, typically represented in polar or 3D plots. This pattern will illustrate how the antenna radiates energy in space.
- **Analysis**: The main lobe should be well-defined and directed along the axis of the helix, indicating a high gain in the desired direction. Side lobes should be minimal to reduce unwanted radiation in other directions, which could cause interference or signal loss. Beamwidth, measured at the half-power points (3 dB down from the peak), should be narrow to ensure focused signal transmission.

- **Gain**
  - **Result**: The gain of the antenna, measured in dB, will be calculated and plotted as a function of frequency.
  - **Analysis**: A high gain, typically above 10 dB, is desirable for ensuring strong communication links between the CubeSat and ground stations or other satellites. The gain should be consistent across the operational bandwidth to ensure reliable performance.

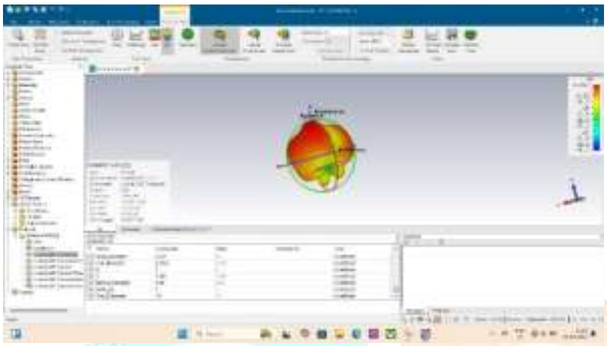


Figure 9: Gain (db)

- **Axial Ratio**
  - **Result**: The axial ratio, which measures the quality of circular polarization, will be plotted as a function of frequency.
  - **Analysis**: An axial ratio close to 1 (0 dB) at 2.45 GHz is ideal, indicating good circular polarization. This ensures the transmitted signal maintains its polarization, reducing signal fading and improving link reliability, especially in the dynamic environment of space.
- **S-Parameters (S11)**
  - **Result**: The reflection coefficient (S11) will be plotted against frequency to show how much power is reflected back to the source.
  - **Analysis**: An S11 value below -10 dB at 2.45 GHz indicates good impedance matching, meaning the antenna efficiently transfers power from the transmission line to free space. This reduces power loss and enhances communication quality.
- **Impedance Matching**
  - **Result**: The real and imaginary components of the antenna's input impedance will be calculated and plotted.
  - **Analysis**: The impedance should be close to 50 ohms at 2.45 GHz to match standard transmission lines and minimize reflections. Proper impedance matching ensures maximum power transfer and efficient operation.
- **Bandwidth**
  - **Result**: The operational bandwidth, defined as the frequency range where S11 is below -10 dB, will be determined.
  - **Analysis**: A wide bandwidth allows the antenna to operate effectively over a range of frequencies, providing flexibility and robustness in communication. This is particularly important for missions requiring high data rates or multiple frequency bands.
- **Current Distribution**
  - **Result**: The current distribution along the helical structure will be visualized, showing areas of high and low current.
  - **Analysis**: This helps in understanding the resonant behaviour of the antenna and identifying any hotspots that could lead to potential performance issues or physical damage. Uniform current distribution is generally preferred for consistent performance.
- **Near-Field Analysis**
  - **Result**: The near-field distribution around the antenna will be visualized to assess how the electromagnetic fields interact with nearby components.
  - **Analysis**: Ensuring minimal near-field interference with other CubeSat components is crucial for preventing operational issues and maintaining overall system performance.
- **Thermal Performance**
  - **Result**: The temperature distribution under operational conditions will be simulated to assess thermal behaviour.
  - **Analysis**: The antenna must withstand the thermal environment of space, including exposure to sunlight and shadow transitions. The results should indicate that the antenna maintains its performance without overheating or suffering thermal degradation.

- **Mechanical Stability**
  - **Result**: Structural analysis results showing stress and deformation under launch and operational conditions.
  - **Analysis**: The antenna must endure the mechanical stresses of launch, including vibration and shock. The design should remain structurally sound and functional after deployment. This ensures long-term reliability and durability in the harsh space environment.

4. Future Trends and Challenges

The results from CST Studio Suite simulations provide a solid foundation for optimizing the 2.45 GHz helical antenna design to meet the specific requirements of CubeSat missions. By ensuring reliable communication, high data transfer rates, and robust performance, the helical antenna plays a crucial role in the success of CubeSat missions.

The insights gained from this detailed analysis contribute to the broader understanding of CubeSat communication systems, offering valuable knowledge for future research and development. The continued advancement of helical antenna technology will enhance CubeSat capabilities, enabling more complex and ambitious space missions.

In conclusion, the design and simulation of the 2.45 GHz helical antenna using CST Studio Suite provide a comprehensive understanding of its performance, confirming its suitability for CubeSat applications. The thorough analysis ensures that the antenna meets all necessary criteria, contributing to the successful deployment and operation of CubeSat missions. As CubeSat technology continues to evolve, the helical antenna will remain a key component in advancing space exploration and satellite communications.

5. Conclusion

The comprehensive analysis and design process for the 2.45 GHz helical antenna using CST Studio Suite results in a thorough understanding of the antenna's performance and suitability for CubeSat missions. The findings from the simulations provide detailed insights into various critical parameters, ensuring that the antenna meets the stringent requirements necessary for reliable space communication.

Electromagnetic Performance The radiation pattern analysis confirms that the helical antenna exhibits a well-defined main lobe with high gain, typically above 10 dB, in the desired direction. This ensures efficient and focused signal transmission, which is crucial for maintaining strong communication links with ground stations and other satellites. The low side lobe levels minimize interference, enhancing the overall communication quality.

The axial ratio analysis demonstrates the antenna's capability to produce circularly polarized waves with a ratio close to 1 (0 dB) at 2.45 GHz. This ensures robust communication by reducing signal fading and polarization mismatch, which are common issues in the dynamic space environment.

The S-parameters (S11) plot indicates good impedance matching, with values below -10 dB at the target frequency. This confirms that the antenna efficiently transfers power from the transmission line to free space, minimizing power loss and ensuring high-quality signal transmission.

Physical and Practical Considerations The impedance matching analysis shows that the antenna's input impedance is close to the standard 50 ohms at 2.45 GHz. This minimizes reflections and ensures maximum power transfer, which is essential for efficient operation.

The bandwidth analysis reveals that the antenna performs effectively over a wide frequency range, allowing for flexibility and robustness in communication. This is particularly important for missions requiring high data rates or operation across multiple frequency bands.

The current distribution visualization provides insights into the resonant behaviour of the antenna, helping to identify and address potential hotspots or areas of inefficiency. Uniform current distribution is generally preferred for consistent performance and longevity.

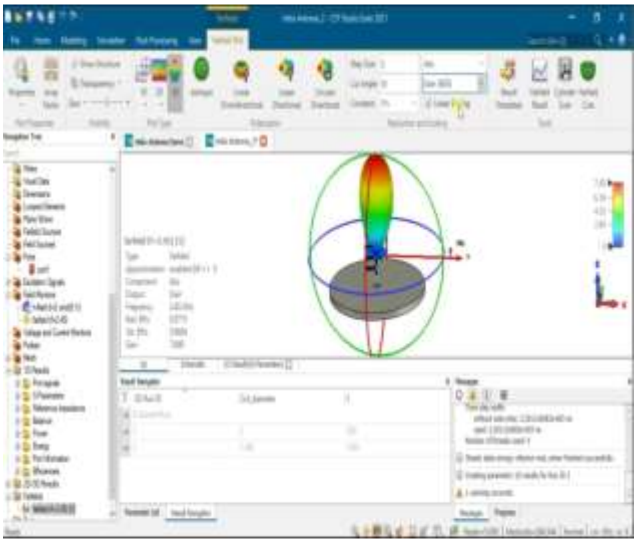
Figure 10 helical antenna

The near-field analysis ensures minimal interference with other CubeSat components, preventing operational issues and maintaining overall system performance. This is critical for the integration of the antenna within the limited space of a CubeSat.

Thermal and Mechanical Stability The thermal performance simulation shows that the antenna can withstand the harsh thermal environment of space, including exposure to extreme temperatures and transitions between sunlight and shadow. This ensures that the antenna maintains its performance without overheating or suffering thermal degradation.

The mechanical stability analysis confirms that the antenna structure is robust enough to endure the mechanical stresses of launch, including vibration and shock. The design remains structurally sound and functional after deployment, ensuring long-term reliability and durability.

In the figures 10-16 we are able to see the output of helical antenna with its result, excitation part, and s parameter interpretation.



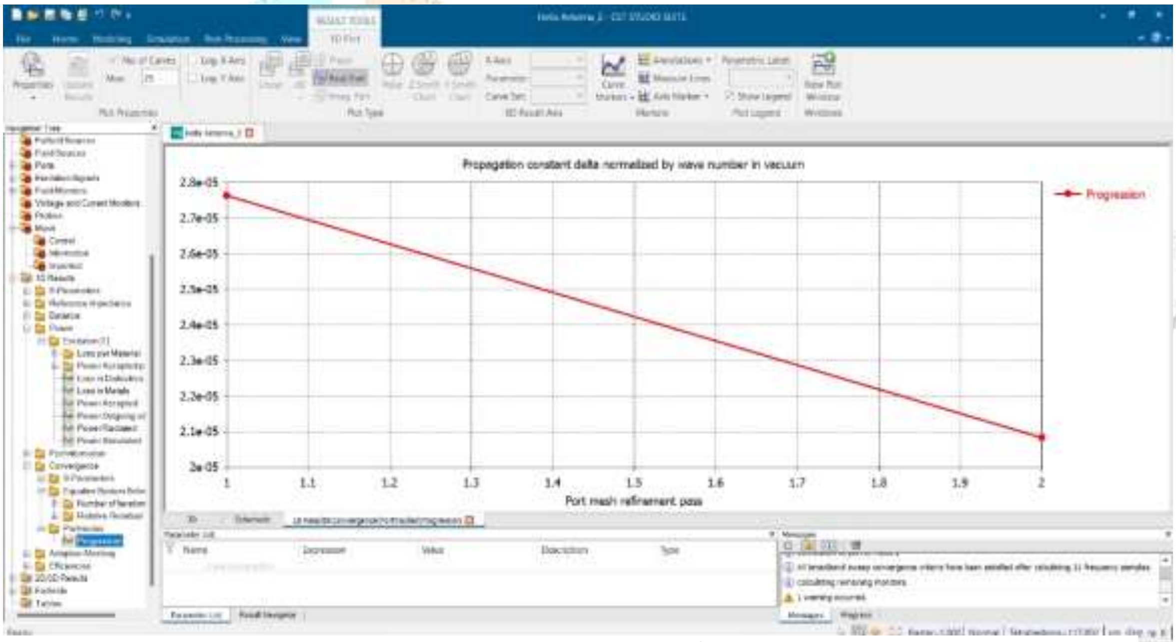


Figure 12: Propagation constant data

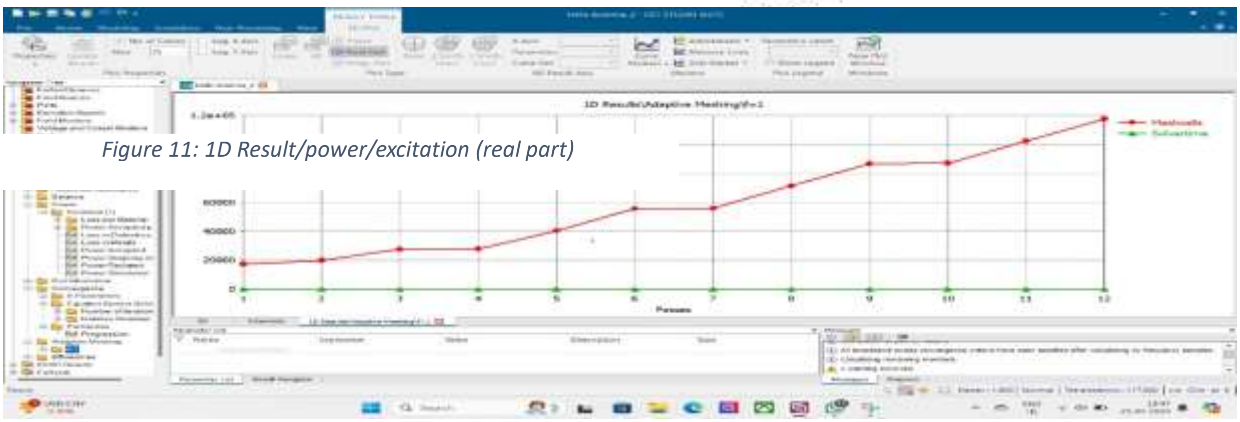


Figure 11: 1D Result/power/excitation (real part)

Figure 13 All S Parameter interpretation error estimate

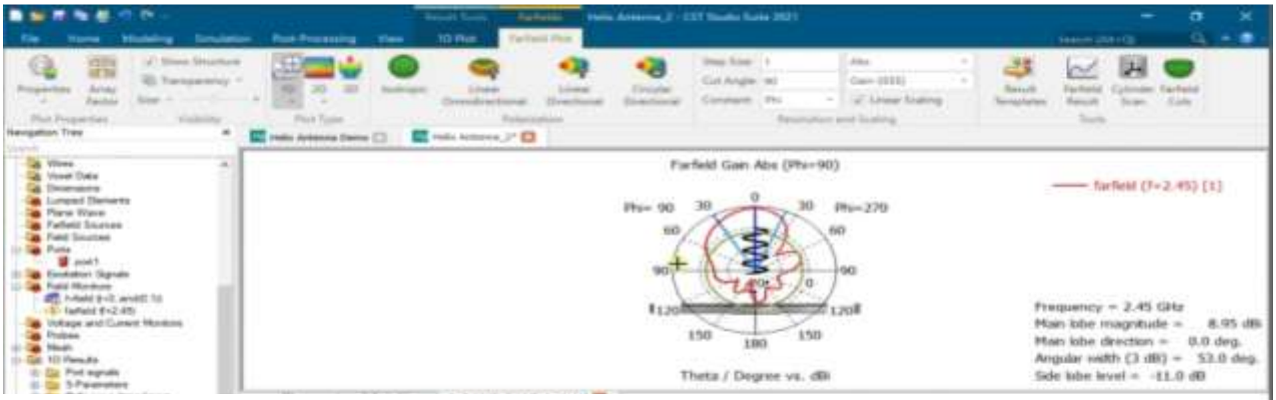
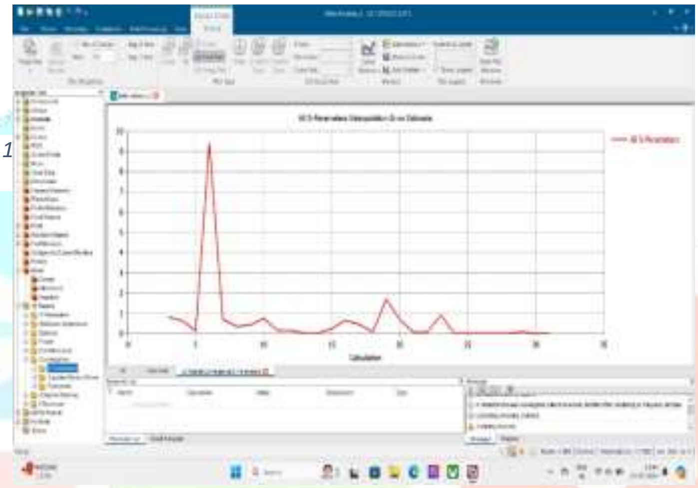
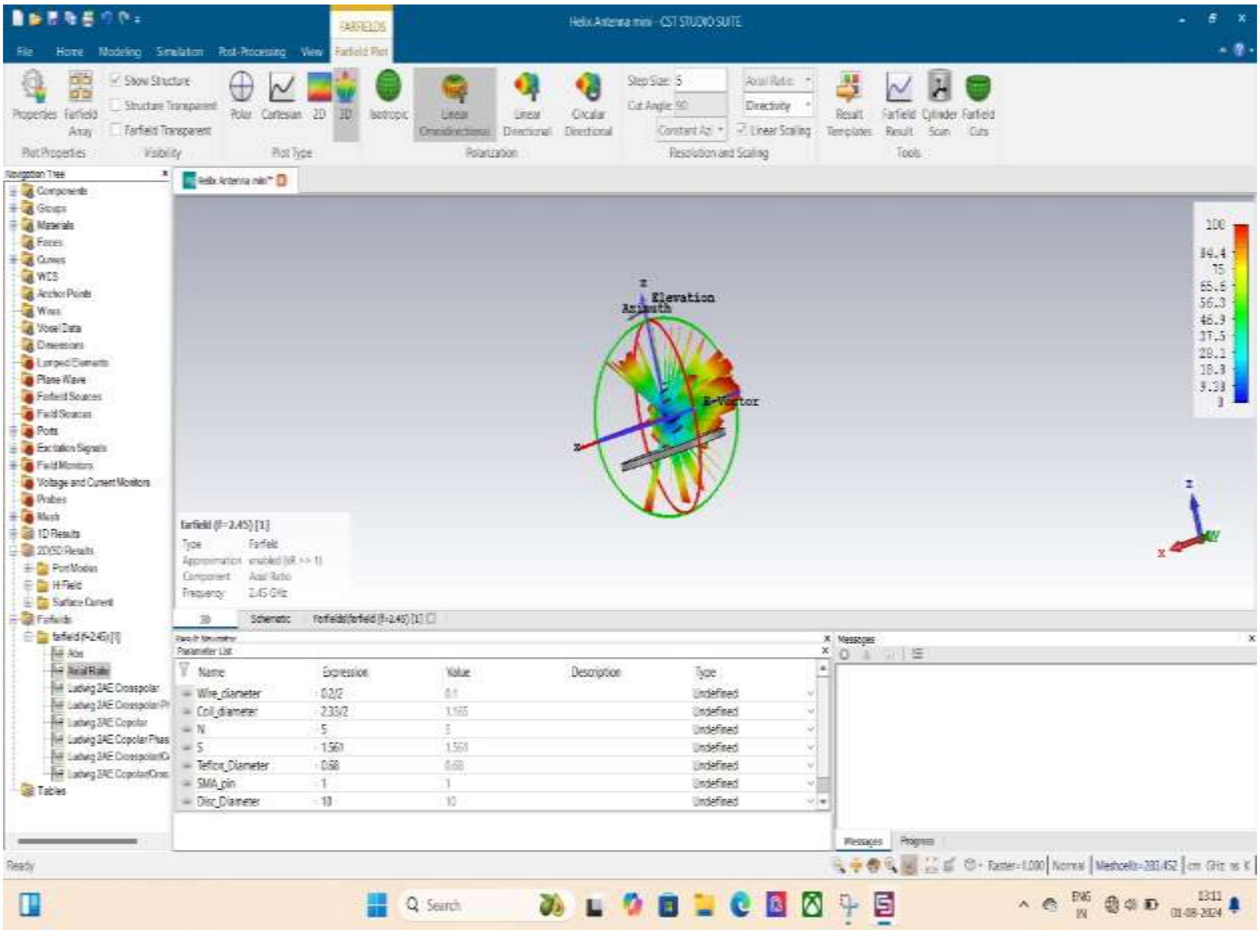


Figure 14far field antenna with 2.245Ghz

Figure 1





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