ANTENNA ENGINEERING LABORATORY

DESIGN AND SIMULATION OF A DUAL-BAND MICROSTRIP PATCH ANTENNA

RESONATING AT 10 GHZ AND 21 GHZ

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PROJECT OUTLINE

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- Result & Discussion
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INTRODUCTION

Microstrip Patch Antenna:

- A flat, rectangular antenna mounted on a dielectric substrate and a ground plane.
- Key features: compact size, ease of fabrication, seamless integration with circuits.
- Widely used in wireless communication systems.

Dual-Band Antenna :

- Operates at two distinct frequency bands, increasing versatility.
- Ideal for applications requiring multiple communication protocols like satellite communication, 5G, and radar.

MOTIVATION

- The increasing demand for **compact**, **high-frequency** antennas for advanced wireless systems.
- Dual-band operation provides the capability for simultaneous communication over **different frequency bands.**
- Exploring high frequencies **(10 GHz and 21 GHz)** unlocks potential in cutting-edge domains such as IoT, aerospace, and defense applications.

OVERVIEW

Design Focus:

- Develop a dual-band antenna operating at 10 GHz and 21 GHz using microstrip technology.

Applications:

- Satellite communication
- High-speed wireless networks
- Radar and defense systems
- IoT devices operating in high-frequency bands

OVERVIEW

Simulation Tool:

- CST Studio Suite for precise modeling and performance evaluation.

FEATURES

- Dual-band operation at 10 GHz and 21 GHz for enhanced versatility.
- Compact design using an FR4 substrate and copper layers.
- Efficient power transfer with return loss (S11) below -10 dB and VSWR < 2.
- High gain with directional radiation patterns optimized for both frequency bands.
- Wide bandwidth ensures reliable communication in high-frequency systems.

OBJECTIVE

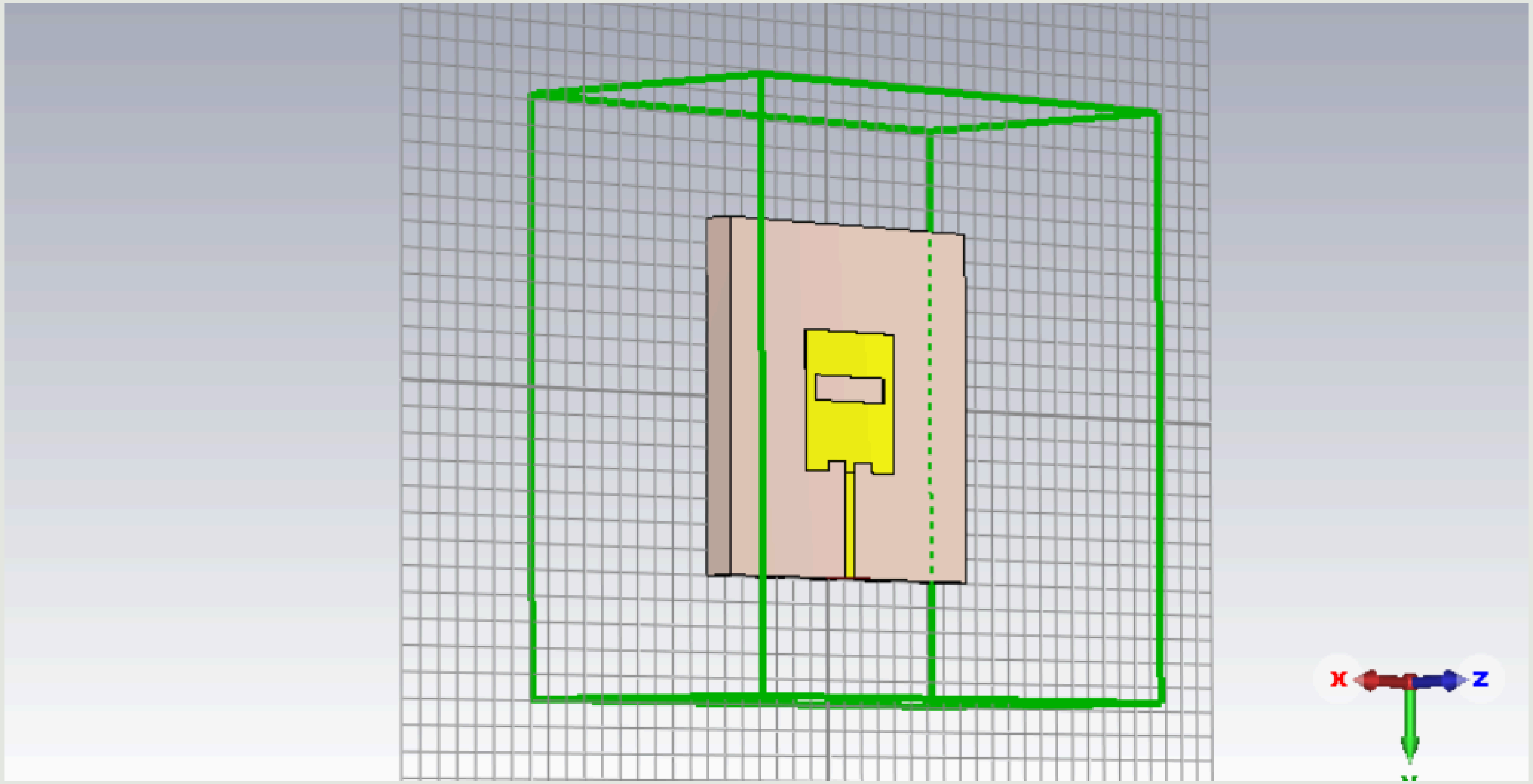
- Design and simulate a dual-band microstrip patch antenna resonating at 10 GHz and 21 GHz.
- Optimize key performance metrics: bandwidth, gain, directivity, and impedance matching.
- Evaluate performance using critical parameters: return loss, VSWR, and radiation patterns.

DESIGN METHODOLOGY

1. **Design Calculations:**
   - Patch dimensions calculated using standard resonance formulas for **10 GHz and 21 GHz frequencies.**
2. **Slot Technique:**
   - **Rectangular slots** integrated into the patch to enable dual-band operation.
3. **Material Selection:**
   - **FR4** substrate with an optimized dielectric constant.
   - **Copper layers** for better conductivity and performance.
4. **Simulation:**
   - **CST Studio Suite** employed to ensure precise design, simulation, and optimization.

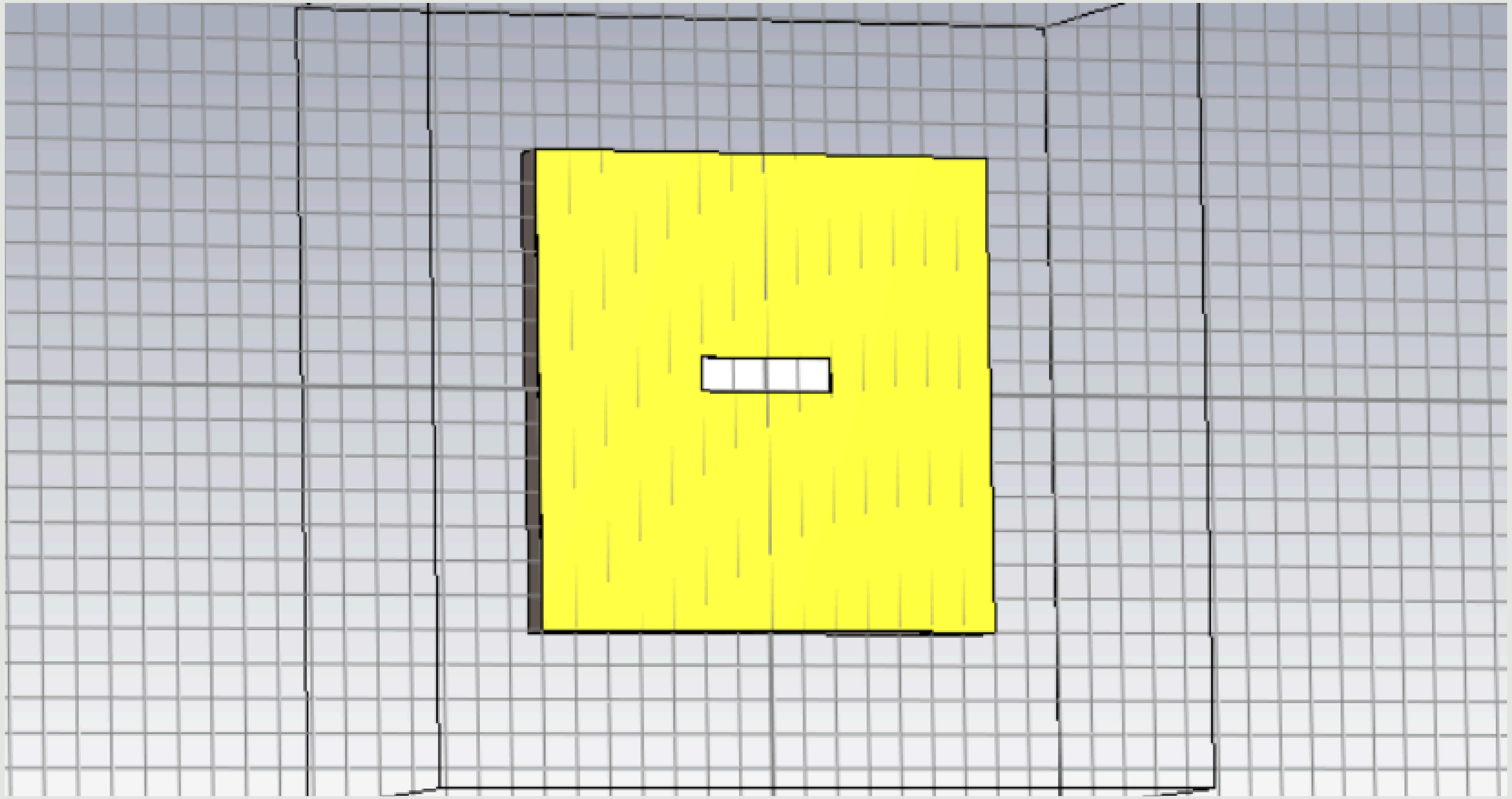
DESIGN

GEOMETRY (FRONT) :



DESIGN

GEOMETRY (BACK):



ANTENNA GEOMETRY (FRONT AND BACK VIEWS)

Purpose

- To present the detailed geometry of the designed dual-band microstrip patch antenna.
- Highlight the structural layout and components critical to achieving dual-band resonance at 10 GHz and 21 GHz.

ANTENNA GEOMETRY (FRONT AND BACK VIEWS)

Key Observations

1. Front View:
    - The yellow region represents the patch, including slots for resonance tuning.
    - A feed line connects the antenna to the input port, enabling efficient signal transmission.
2. Back View:
    - The back view shows the ground plane, providing proper shielding and ensuring the antenna's performance by maintaining desired electromagnetic characteristics.

PARAMETER LIST:

Name	Expression	Value	Description
insl	= .4	.4	Inset Length
txw	= .54	.54	Transmission Line Width
insw	= 1	1	Inset Width
varw	= 1	1	Slot 1 Variable Width
var1w	= 1	1	Slot 2 Variable Width
subd	= 1.2	1.2	Substrate Depth
varl	= 2	2	Slot 1 Variable Length
var1l	= 2	2	Slot 2 Variable Length
antw	= 5.208	5.208	Antenna Width
antl	= 5.559	5.559	Antenna Length
subw	= 14	14	Substrate Width
subl	= 14	14	Substrate Length

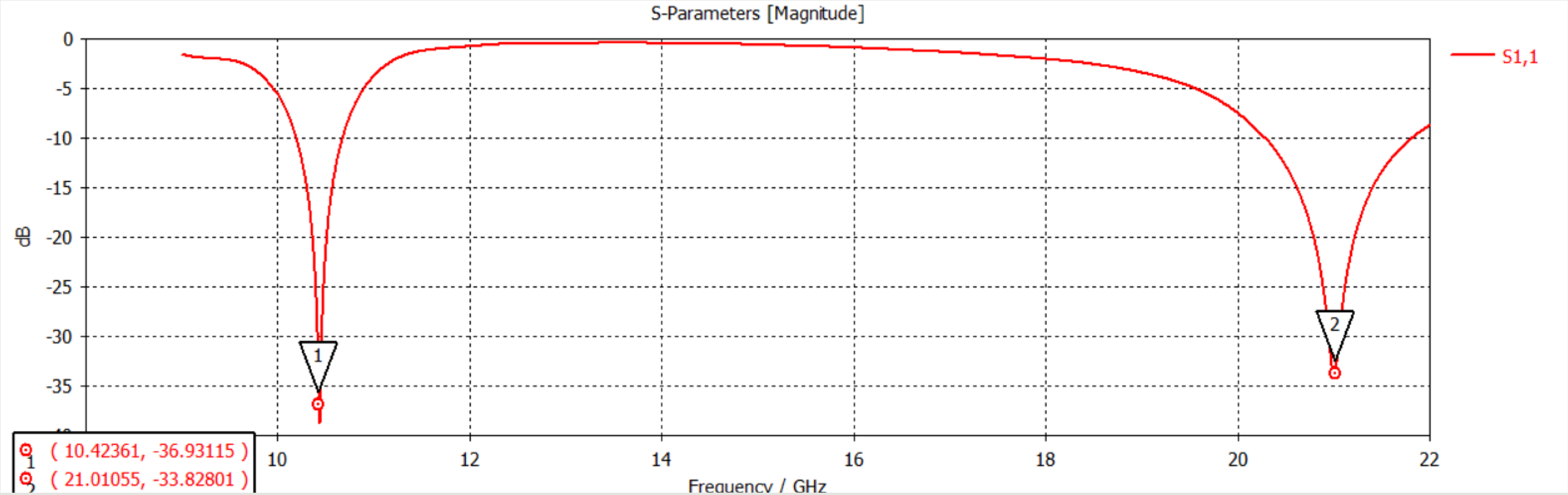
RESULT & ANALYSIS

S-PARAMETERS (REFLECTION COEFFICIENT S11):

Purpose

- The S11 parameter (reflection coefficient) measures the power reflected back from the antenna.
- A lower S11 value indicates **better impedance matching** and **efficient power transfer**.

S-PARAMETERS :



S-PARAMETERS (REFLECTION COEFFICIENT S11):

Key Observations

- The S11 graph shows two resonance points at the dual-band operating frequencies:
  - At 10.42 GHz, the S11 value is -36.93 dB, indicating excellent impedance matching.
  - At 21.01 GHz, the S11 value is -33.83 dB, also showing excellent matching.
- Both S11 values are significantly below the -10 dB threshold, confirming minimal reflection and efficient operation at both frequencies.

RESULT & ANALYSIS

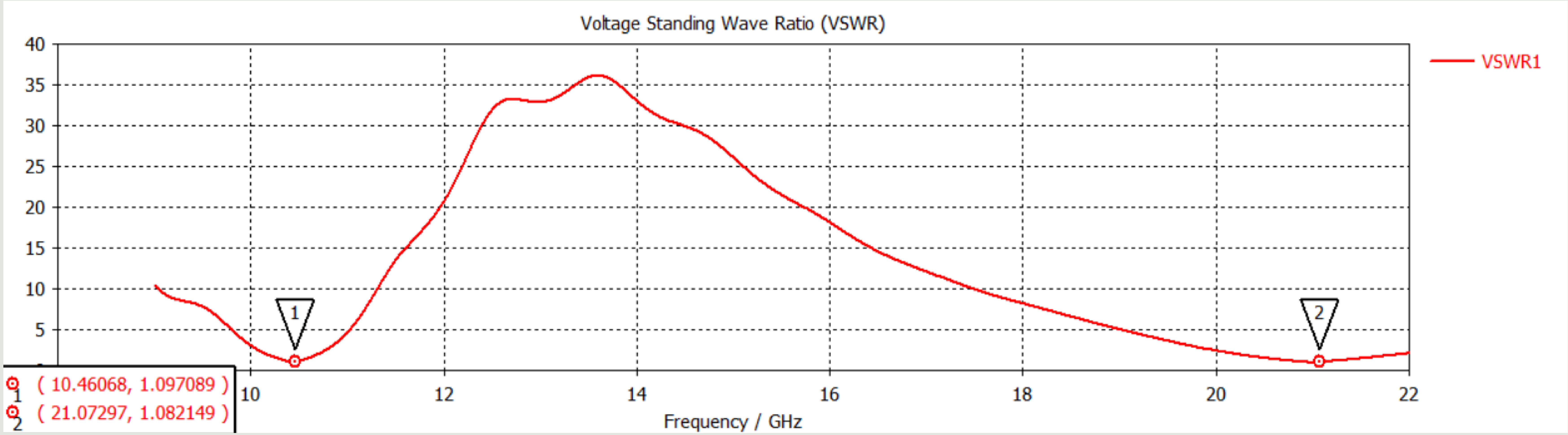
VOLTAGE STANDING WAVE RATIO (VSWR) :

:

Purpose

- The Voltage Standing Wave Ratio (VSWR) is a measure of impedance matching between the antenna and the feed line.
- A **lower** VSWR indicates **better matching** and **minimal signal reflection.**

VOLTAGE STANDING WAVE RATIO (VSWR) :



VOLTAGE STANDING WAVE RATIO (VSWR) :

:

Key Observations

- The VSWR graph shows two key resonance points corresponding to the designed dual-band frequencies:
  - At 10.46 GHz, the VSWR is 1.097, indicating **excellent impedance matching.**
  - At 21.07 GHz, the VSWR is 1.082, also showing **near-perfect matching.**
- Both values are below 2, confirming the antenna operates efficiently at both frequencies.

RESULT & ANALYSIS

MESH CONVERGENCE TEST :

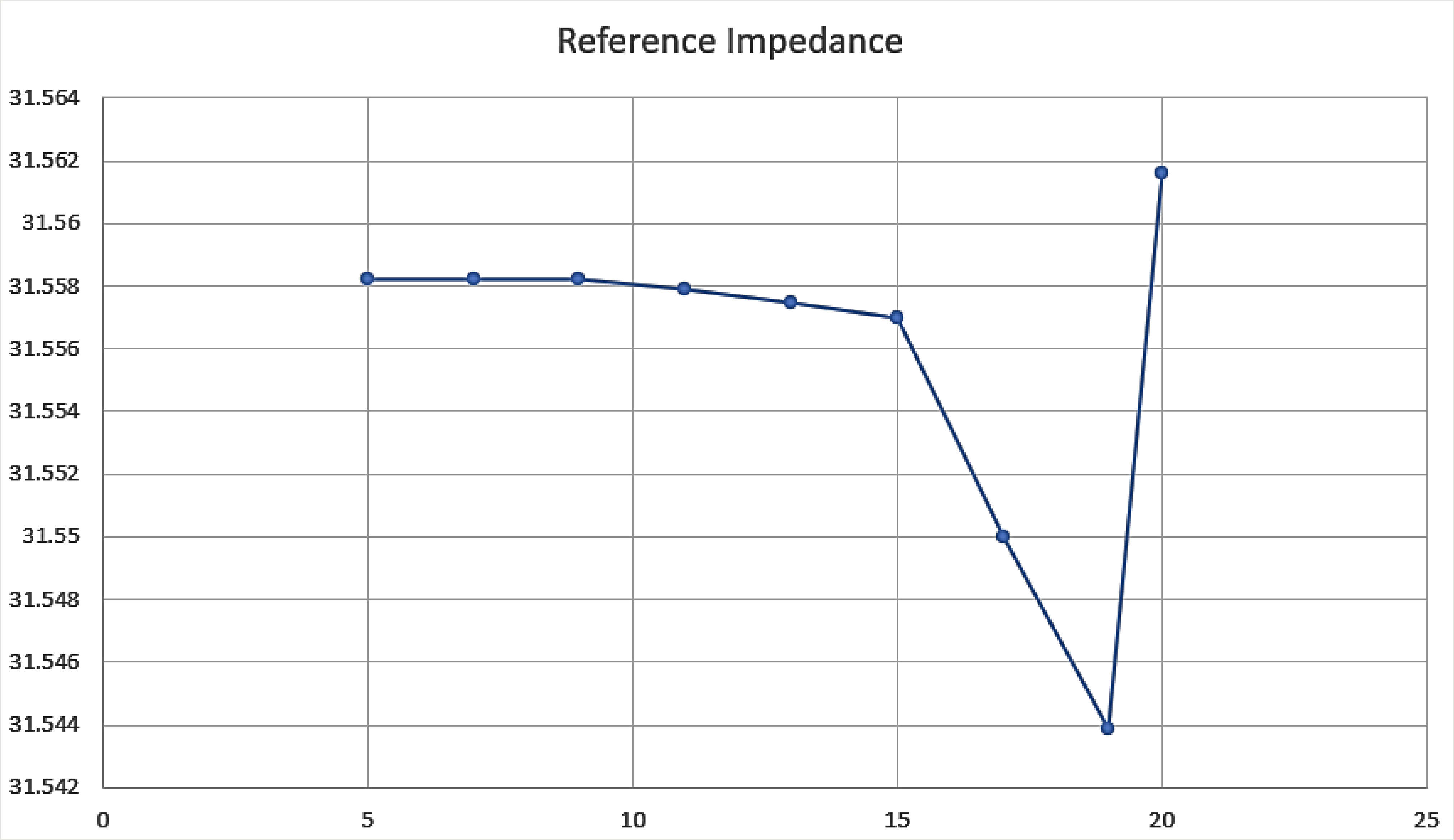
Purpose of the Test

To ensure the accuracy of simulation results by refining the mesh density until results stabilize.

Confirms that the simulation results (e.g., reference impedance) are independent of the mesh resolution.

MESH CONVERGENCE TEST :

Cells per wavelength	Reference Impedance
5	31.5582
7	31.5582
9	31.5582
11	31.55788
13	31.55744
15	31.55696
17	31.55001
19	31.54389
20	31.56159



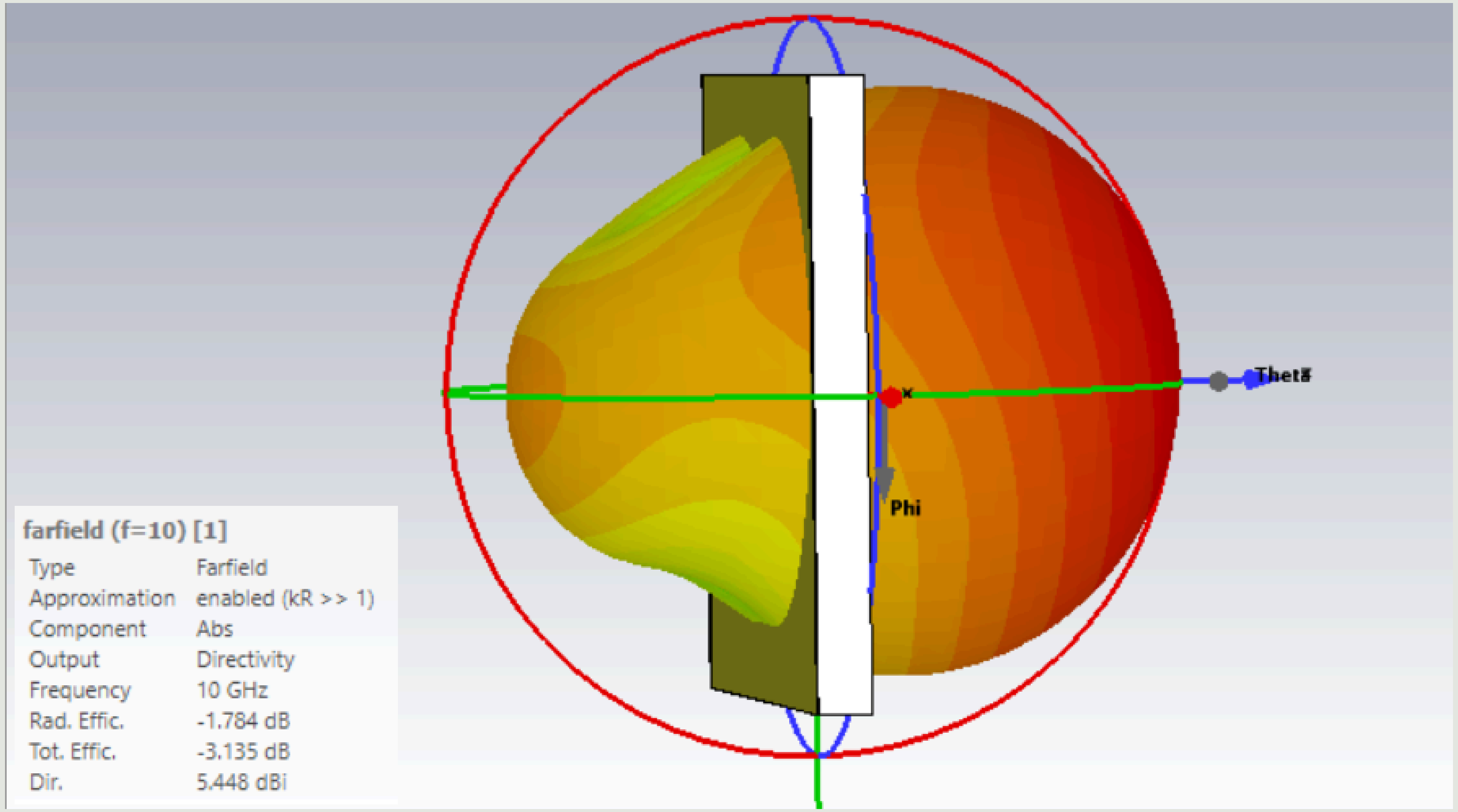
MESH CONVERGENCE TEST :

Key Observations

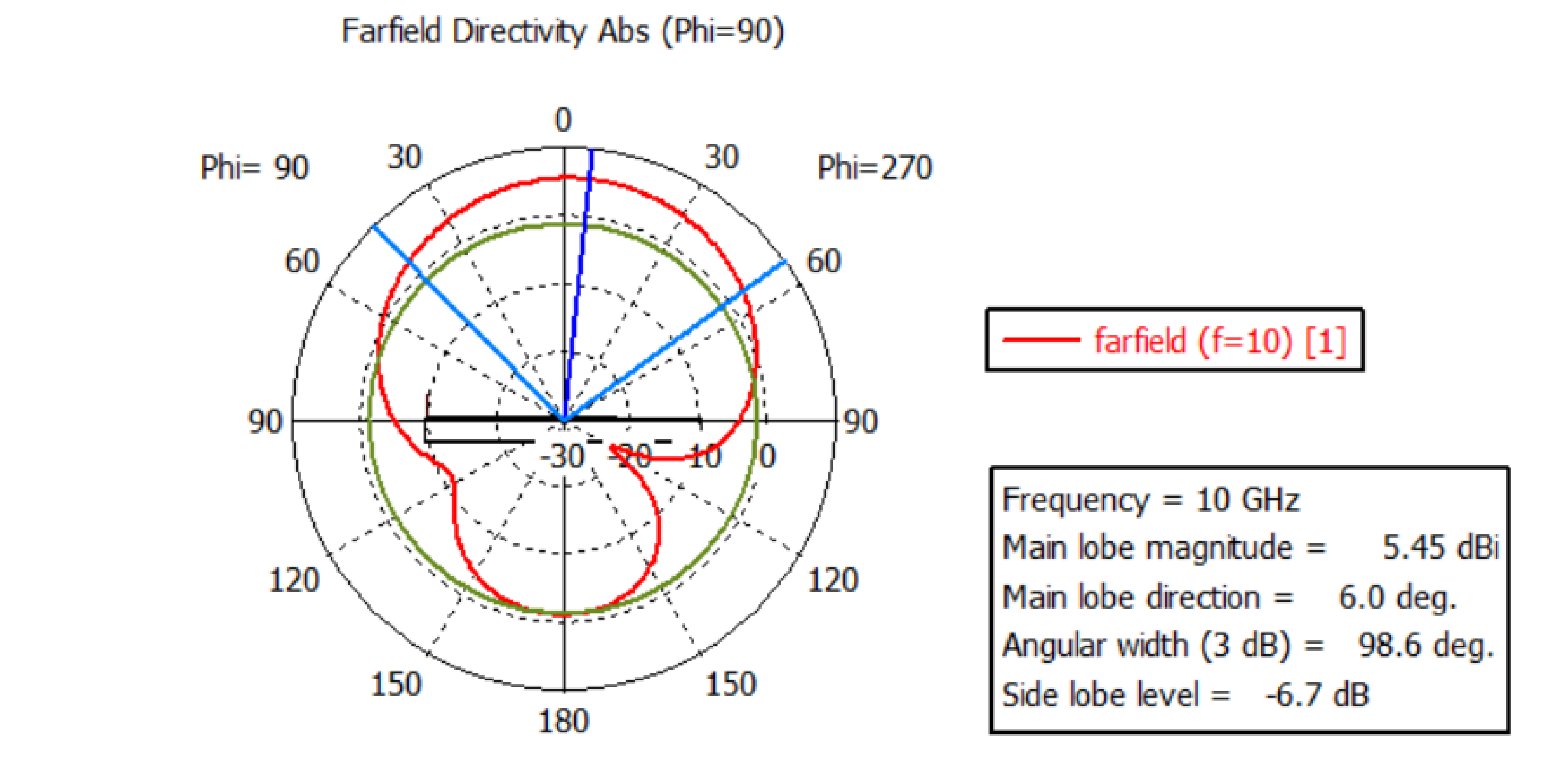
- The table shows how reference impedance varies with increasing mesh density (cells per wavelength).
- The graph demonstrates that:
  - Reference impedance stabilizes between **9 and 15 cells per wavelength around 31.5582.**
  - Further refinement (e.g., 17 to 20 cells) shows **minimal variation**, confirming convergence.

RESULT & ANALYSIS

RADIATION PATTERN AT 10 GHZ (3D) :



RADIATION PATTERN AT 10 GHZ (1D) :

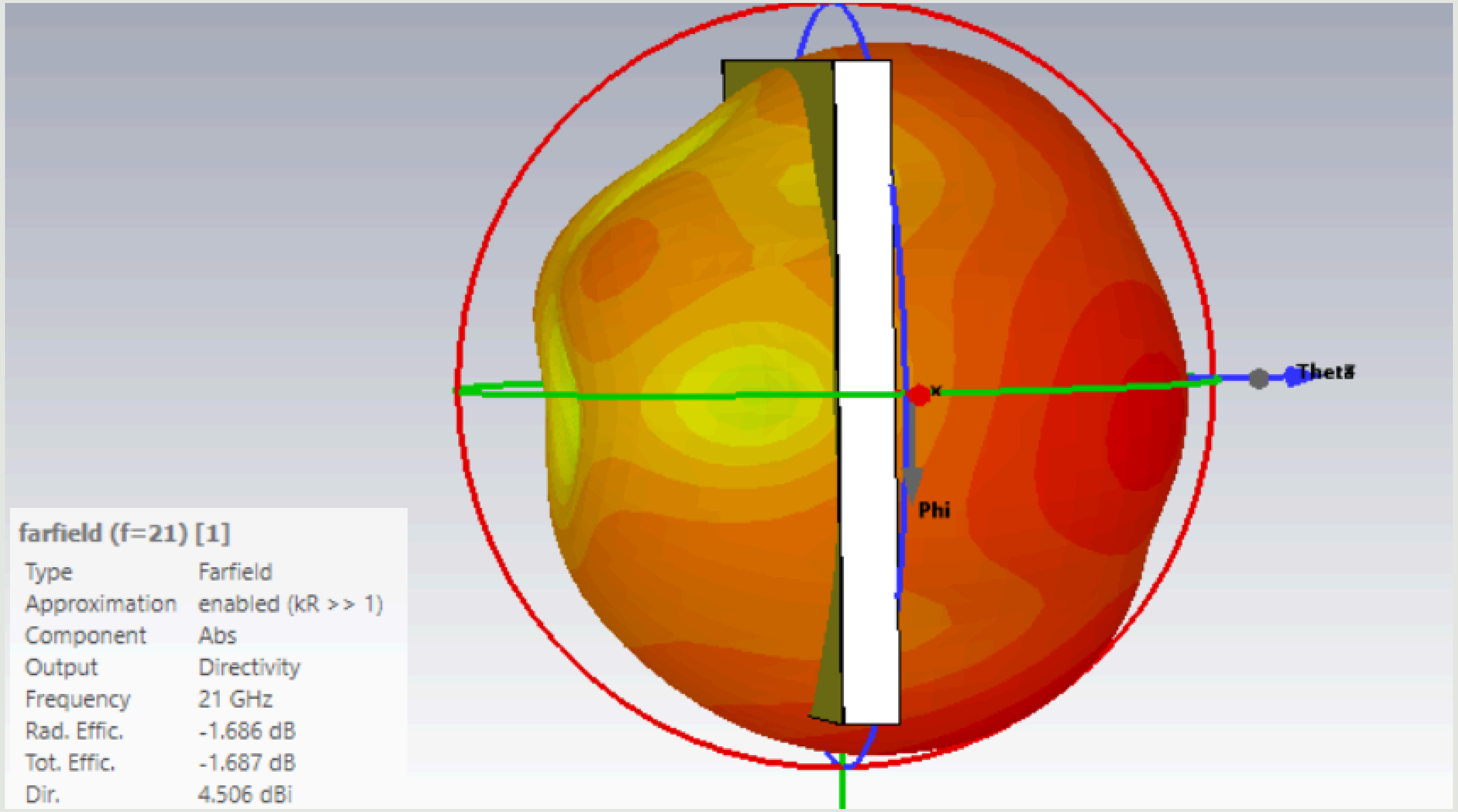


RADIATION PATTERN AT 10 GHZ :

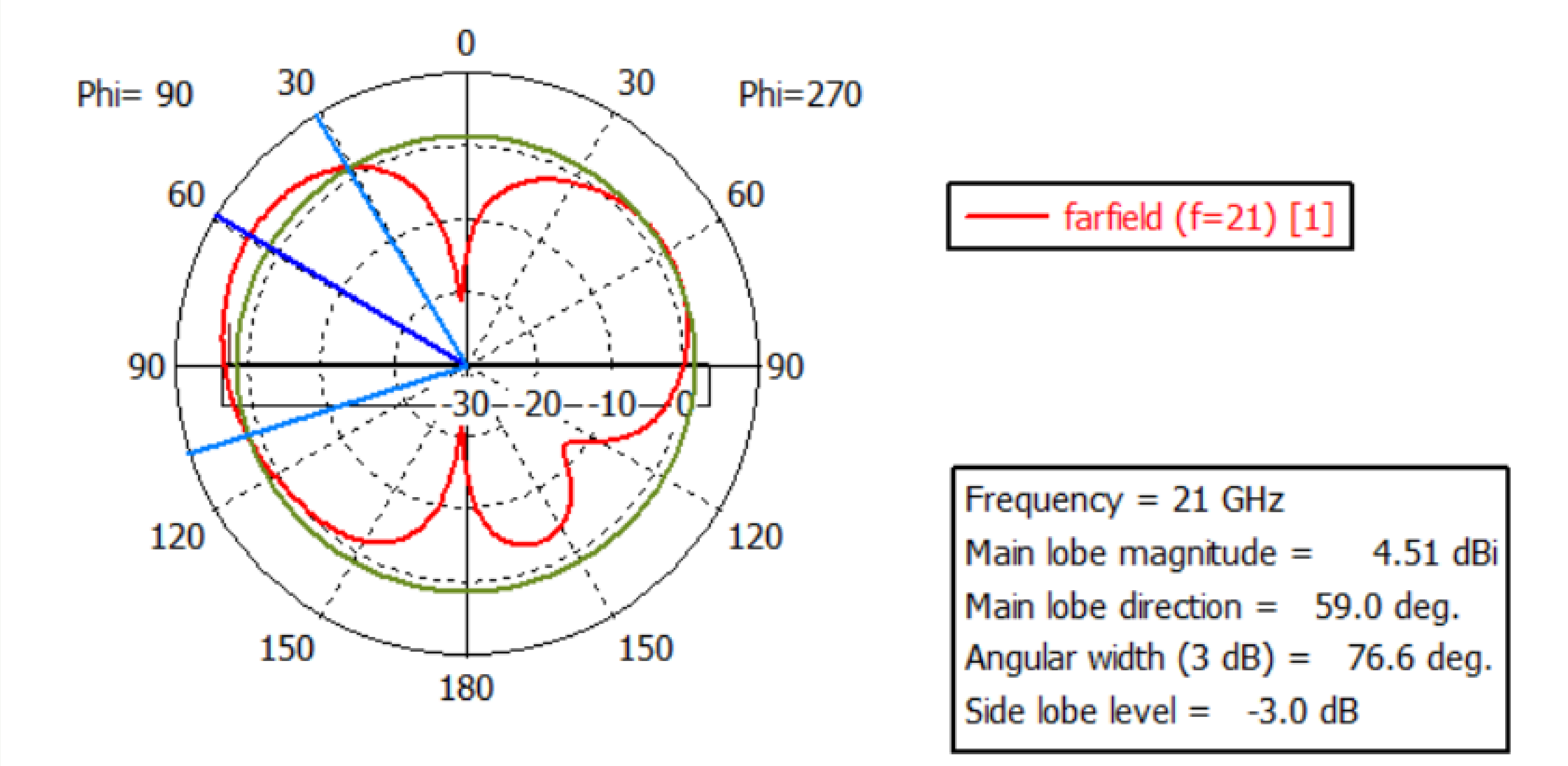
Key Observations

1. Polar Plot:
   - The main lobe magnitude is 5.45 dBi at 6.0°.
   - The angular width (3 dB beamwidth) is 98.6°, indicating the coverage range of the main lobe.
   - The side lobe level is -6.7 dB, **showing good suppression of unwanted radiation.**
2. 3D Radiation Pattern:
   - The antenna exhibits a maximum directivity of 5.448 dBi.
   - The total efficiency is -3.135 dB, and the radiation efficiency is -1.784 dB.
   - The pattern shows the **primary lobe directed outward with minimal back radiation.**

RADIATION PATTERN AT 21 GHZ (3D) :



RADIATION PATTERN AT 21 GHZ (1D) :



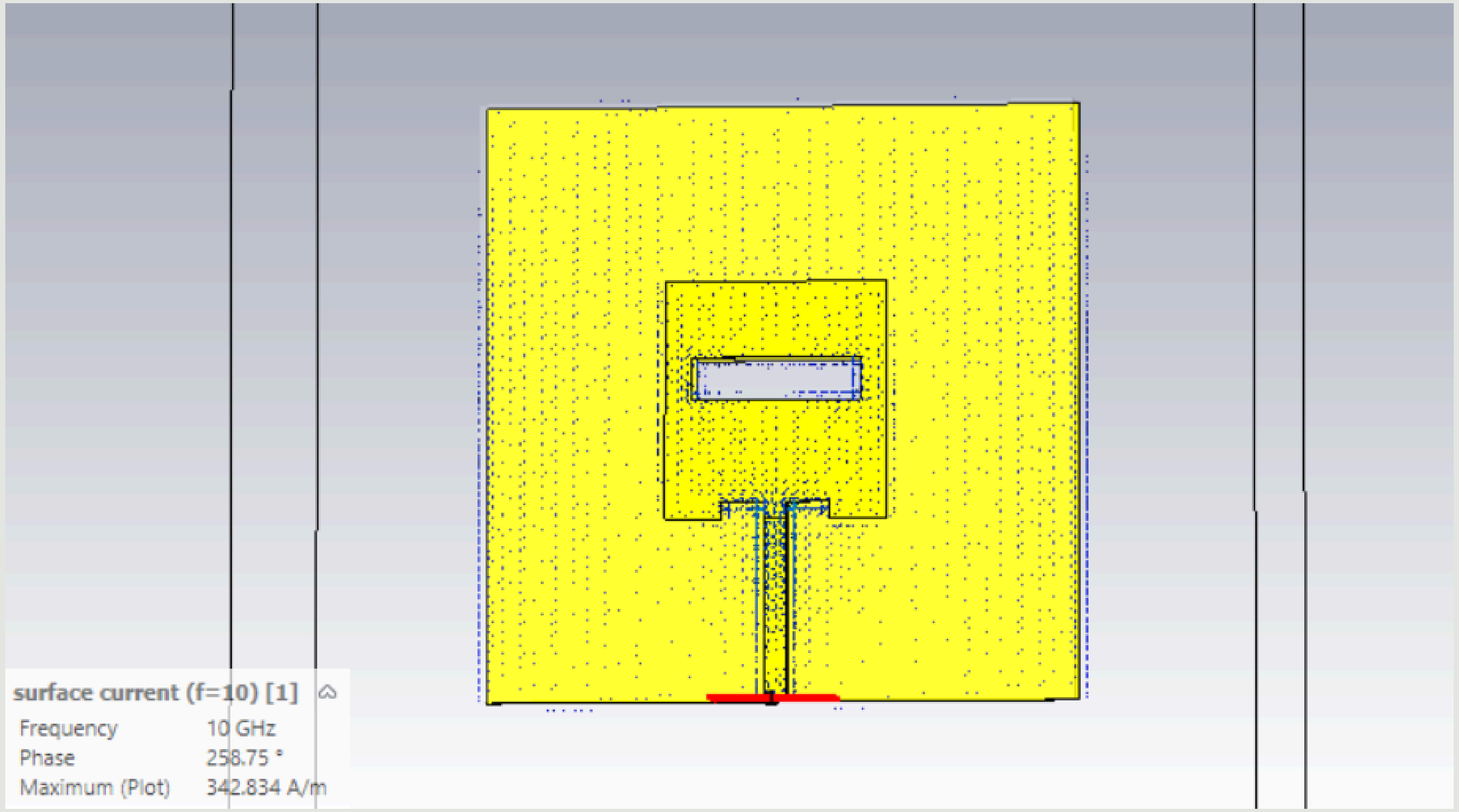
RADIATION PATTERN AT 10 GHZ :

Key Observations

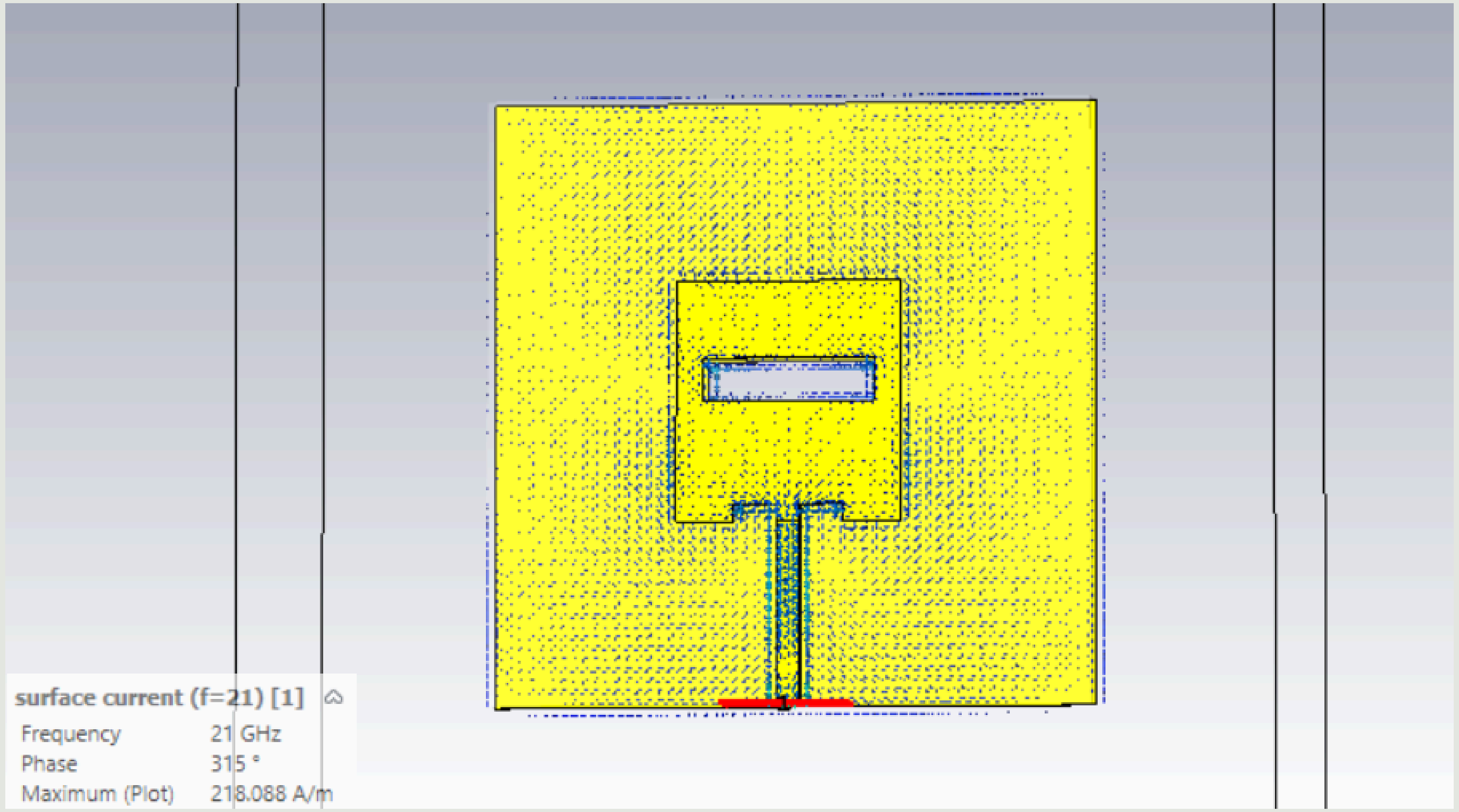
1. Polar Plot:
    - **The main lobe magnitude is 4.51** dBi at 59.0°.
    - The angular width (3 dB beamwidth) is 76.6°, indicating the main lobe's coverage range.
    - The side lobe level is -3.0 dB, **showing some side lobe radiation but still maintaining good directionality.**
2. 3D Radiation Pattern:
    - The antenna achieves a maximum directivity of 4.506 dBi.
    - The total efficiency is -1.687 dB, and the radiation efficiency is -1.686 dB.
    - The pattern shows **the main lobe radiating effectively, with some back and side lobes visible.**

RESULT & ANALYSIS

SURFACE CURRENT AT 10 GHZ :



SURFACE CURRENT AT 21 GHZ :



SURFACE CURRENT AT 10GHZ AND 21 GHZ :

1. **At 10 GHz:**
   - Frequency: 10 GHz
   - Phase: 258.75°
   - Maximum current density: 342.834 A/m
2. **At 21 GHz:**
   - Frequency: 21 GHz
   - Phase: 315°
   - Maximum current density: 218.088 A/m

These images display the behavior of the antenna's surface currents, showing how energy distribution varies at different resonance frequencies. The bright regions correspond to areas of higher current density, which align with resonant modes for efficient radiation.

DISCUSSION

Dual-Band Performance

The antenna successfully achieved dual-band operation at 10 GHz and 21 GHz, as demonstrated by the S-parameter results. The return loss at both frequencies was well below -10 dB, indicating efficient power transfer and minimal reflection. The Voltage Standing Wave Ratio (VSWR) values were close to 1 at these frequencies, further validating the impedance matching between the antenna and the feed line. This dual-band capability ensures the antenna's suitability for applications requiring communication over multiple frequency bands, such as satellite communication and 5G networks.

Radiation Characteristics

The farfield radiation patterns showed that the antenna exhibits directional radiation with significant gain and directivity at both frequency bands. At 10 GHz, the main lobe magnitude was 5.45 dBi with an angular width of 98.6°, while at 21 GHz, the gain was slightly lower at 4.51 dBi but with improved directivity, reflected by a narrower angular width of 76.6°. The directional patterns highlight the antenna's effectiveness in concentrating radiated energy, which is essential for high-frequency communication and radar systems.

Bandwidth and Impedance Matching

The impedance bandwidth achieved around the center frequencies was adequate for the intended applications. The wide bandwidth ensures reliable operation over a range of frequencies, allowing for flexibility in real-world usage. The optimized slot design contributed significantly to this performance by enabling the dual-band operation and improving impedance matching.

Challenges and Limitations

One of the challenges encountered was achieving optimal performance at 21 GHz, as evidenced by the slightly lower gain and wider side lobe levels compared to 10 GHz. This discrepancy can be attributed to increased losses and manufacturing tolerances at higher frequencies. Additionally, while the design successfully operated at dual bands, further miniaturization could be explored to meet the increasing demand for compact antennas in modern wireless devices.

CONCLUSION

- The dual-band microstrip patch antenna designed for 10 GHz and 21 GHz achieved efficient power transfer, low return loss, and directional radiation patterns. The use of rectangular slots enabled dual-band operation, while the FR4 substrate ensured practicality. The antenna demonstrated strong gain and directivity, making it ideal for satellite communication, radar, and 5G applications. Impedance bandwidth and VSWR results confirmed excellent performance and stability.

- Despite slightly reduced gain at 21 GHz, the results aligned with theoretical expectations. Future enhancements, such as advanced materials and optimization, can improve efficiency and expand applications. The design highlights the potential of microstrip antennas for high-frequency communication.

REFERENCE

1) A Study on Dual-band Microstrip Rectangular Patch Antenna for Wi-Fi

2) A circular microstrip patch antenna to operate in dual band for wireless communications

3) Dual Band Microstrip Patch Antenna and its Gain Enhancement for X Band and Ku Band Application Using Metamaterial

Thank You

For your attention