Khulna University of Engineering and Technology

Dept. of Electronics and Communication Engineering

Project Title:

Design a dual band microstrip patch antenna operating at 11 GHz and 27GHz

Course Title: Antenna Engineering Laboratory
Course no: ECE-3208
Date of submission: 19-01-25

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Objective:

- To design a dual-band microstrip patch antenna operating at 11 GHz and 27 GHz.
- To calculate and optimize the antenna dimensions for dual-band performance.
- To simulate the antenna using CST Microwave Studio and compare simulation results with theoretical predictions.
- To analyze key performance metrics, including S-parameters, bandwidth, radiation pattern, gain, and directivity.

Introduction:

Wireless communications have experienced significant advancements in recent decades, with microstrip patch antennas becoming a cornerstone technology due to their unique structural and operational features. These antennas consist of a metallic patch on one side of a dielectric substrate and a ground plane on the other side. They have transformed modern wireless systems through their low profile, lightweight design, and cost-effective manufacturing process. The fundamental operation of a microstrip patch antenna relies on a resonant cavity effect, where the electric field is confined between the patch and the ground plane, allowing for efficient radiation through carefully designed patch geometries and feed configurations.

Dual-band microstrip patch antennas represent an advanced implementation that enables simultaneous operation at two distinct frequency bands. This is achieved through specialized design techniques such as multiple resonant structures, slot-loading, and modified ground structures. This capability is particularly important in the microwave frequency range of 11 GHz to 27 GHz, where applications include satellite communications, radar systems, and high-speed data transmission. Operating in dual frequency bands offers significant advantages, including reduced system complexity, minimized interference, enhanced bandwidth capabilities, and improved spectrum utilization, making these antennas essential components of modern wireless communication systems.

This project focuses on developing a dual-band microstrip patch antenna that operates within the frequency range of 11 GHz to 27 GHz, utilizing CST Studio Suite for design optimization and performance analysis. The design methodology includes theoretical analysis of resonant frequencies, optimization of patch dimensions, selection of substrate materials, and design of the feed network, followed by comprehensive simulation studies to achieve superior performance metrics. This work aims to advance dual-band antenna technology through detailed electromagnetic simulation and analysis, particularly in high-frequency applications, while providing valuable insights for researchers and engineers tackling similar challenges in wireless communication systems.

Motivation:

The advancement of wireless communication systems demands increasingly sophisticated antenna solutions, leading to the development of dual-band microstrip patch antennas that combine efficiency with multi-frequency operation. This project focuses on designing a dual-band microstrip patch antenna operating in the 11 GHz to 27 GHz frequency range, addressing the growing need for compact, multi-functional antenna systems in modern communications.

The significance of this research lies in its practical applications across satellite communications, radar systems, and high-speed wireless networks, where simultaneous operation at multiple frequencies is crucial. Through careful design and optimization using CST Studio Suite, the project aims to achieve efficient dual-band operation while maintaining the inherent advantages of microstrip patch antennas - low profile, lightweight construction, and cost-effective fabrication. This research contributes to the broader field of antenna design by demonstrating effective methods for achieving optimal performance in multi-band operations.

Design Methodology:

Software Utilization: CST Studio Suite 2022 was utilized for the design and simulation of the microstrip patch antenna. This software offers advanced electromagnetic modeling and analysis capabilities, ensuring accurate results.

Material Specifications: The antenna was designed using the following materials:

- **Substrate: FR4 epoxy**
  - Dielectric constant (εr) = 4.3
  - Substrate thickness (h) = 1.2 mm

- **Conductor: Copper**
  - Patch thickness (t) = 0.035 mm
  - Ground plane thickness = 0.035 mm

Target Frequencies:

- Lower band (f1) = 11 GHz
- Upper band (f2) = 27 GHz

Design the Patch:

- Patch Width: 27.7 mm
- Patch Length: 24.5 mm

Design Features: Specific design strategies were implemented to ensure dual-band operation:

- **Slot Incorporation**: Rectangular slots were added to the patch, enabling resonance at 11 GHz while maintaining the 27 GHz resonance.
- **Ground Plane Optimization**: Adjustments were made to the ground plane to enhance bandwidth and reduce losses.

Simulation Setup:

- **Boundary Conditions**: Open with Add Space.
- **Frequency Range**: 9 GHz to 29 GHz.
- **Solver**: Time domain solver with adaptive mesh refinement.

Parameter Values:

Optimized Parameters for 11 GHz and 27 GHz

Parameter	**Value (mm)**
Width of the ground plane (Wg)	13
Length of the ground plane (Lg)	10.8
Height of the ground plane (Hg)	0.035
Height of substrate (Hs)	1.2
Patch width (Wp)	8
Patch length (Lp)	6.3
Patch height (Hp)	0.035
Width of microstrip feed line (Wf)	2.2
Width of inset (Wi)	0.6
Lenth of inset(Li)	1.4
Width of Slot 1 (WS1)	5.4
Length of Slot 1 (LS1)	1.2

Calculations:

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Given Parameters:
- fr1 = 11 GHz = 11 × 10^9 Hz
- fr2 = 27 GHz = 27 × 10^9 Hz
- Dielectric constant (εr) = 4.3
- Substrate height (h) = 1.2 mm

STEP 1: PATCH WIDTH CALCULATION (Wp)
For fr1 = 11 GHz:
Wp1 = c / (2*fr1*√((εr + 1)/2))
Wp1 = (3 × 10^8) / (2 × 11 × 10^9 × √((4.3 + 1)/2))
Wp1 = (3 × 10^8) / (22 × 10^9 × √2.65)
Wp1 = 8.37 mm

 For fr2 = 27 GHz:
Wp2 = c / (2*fr2*√((εr + 1)/2))
Wp2 = (3 × 10^8) / (2 × 27 × 10^9 × √((4.3 + 1)/2))
Wp2 = (3 × 10^8) / (54 × 10^9 × √2.65)
Wp2 = 3.41 mm


 STEP 2: EFFECTIVE DIELECTRIC CONSTANT (εeff)
 For 11 GHz:
εeff1 = ((εr + 1)/2) + ((εr - 1)/2) * (1 + 12*h/Wp1)^(-0.5)
εeff1 = ((4.3 + 1)/2) + ((4.3 - 1)/2) * (1 + 12*1.2/8.37)^(-0.5)
εeff1 = 2.65 + 1.65 * (1 + 1.72)^(-0.5)
εeff1 = 3.65

For 27 GHz:
εeff2 = ((εr + 1)/2) + ((εr - 1)/2) * (1 + 12*h/Wp2)^(-0.5)
εeff2 = ((4.3 + 1)/2) + ((4.3 - 1)/2) * (1 + 12*1.2/3.41)^(-0.5)
εeff2 = 2.65 + 1.65 * (1 + 4.22)^(-0.5)
εeff2 = 3.37

STEP 3: LENGTH EXTENSION (ΔL)
 For 11 GHz:
ΔL1 = 0.412*h * ((εeff1 + 0.3)*(Wp1/h + 0.264)) / ((εeff1 - 0.258)*(Wp1/h +
0.8))
ΔL1 = 0.412*1.2 * ((3.65 + 0.3)*(8.37/1.2 + 0.264)) / ((3.65 -
0.258)*(8.37/1.2 + 0.8))
ΔL1 = 0.536 mm

 For 27 GHz:
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△L2 = 0.412*h * ((εeff2 + 0.3)*(Wp2/h + 0.264)) / ((εeff2 − 0.258)*(Wp2/h +
0.8))
△L2 = 0.412*1.2 * ((3.37 + 0.3)*(3.41/1.2 + 0.264)) / ((3.37 −
0.258)*(3.41/1.2 + 0.8))
△L2 = 0.497 mm
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 STEP 4: EFFECTIVE LENGTH (Leff)
For 11 GHz:
Leff1 = c / (2*fr1*√εeff1)
Leff1 = (3 × 10^8) / (2 * 11 × 10^9 * √3.65)
Leff1 = 7.15 mm
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For 27 GHz:
Leff2 = c / (2*fr2*√εeff2)
Leff2 = (3 × 10^8) / (2 * 27 × 10^9 * √3.37)
Leff2 = 3.02 mm
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STEP 5: PATCH LENGTH (Lp)
For 11 GHz:
Lp1 = Leff1 − 2*△L1
Lp1 = 7.15 − 2*0.536
Lp1 = 6.078 mm
```

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For 27 GHz:
Lp2 = Leff2 − 2*△L2
Lp2 = 3.02 − 2*0.497
Lp2 = 2.026 mm
```

Necessary Diagrams:

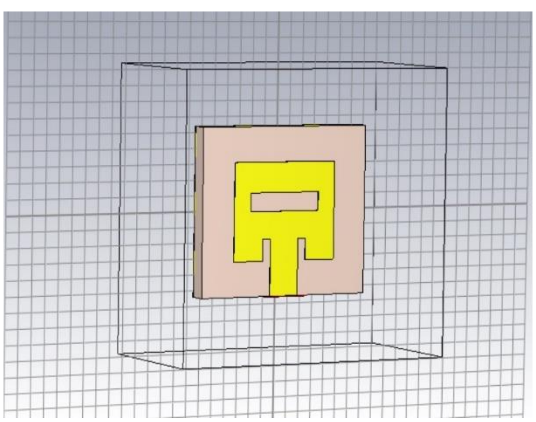

Fig1.1(a): Designed antenna(front view)

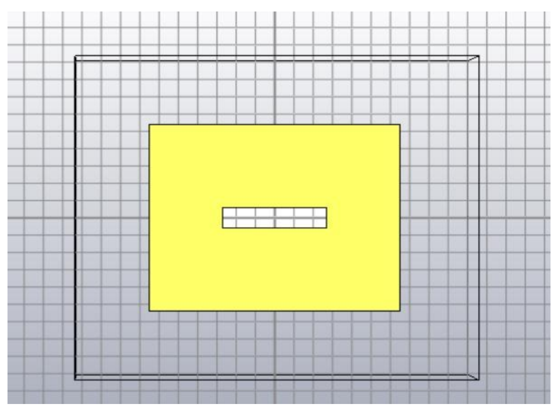

Fig1.1(b): Designed antenna(backview)

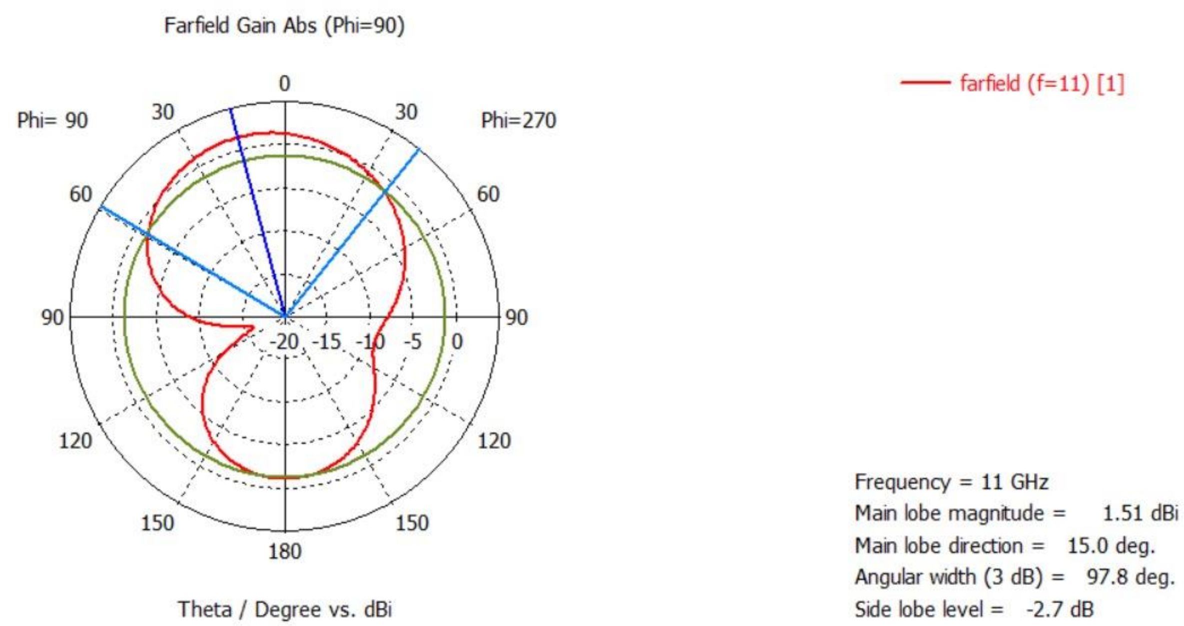

Fig 1.2: Farfield 1D plot for 11GHz of the designed antenna

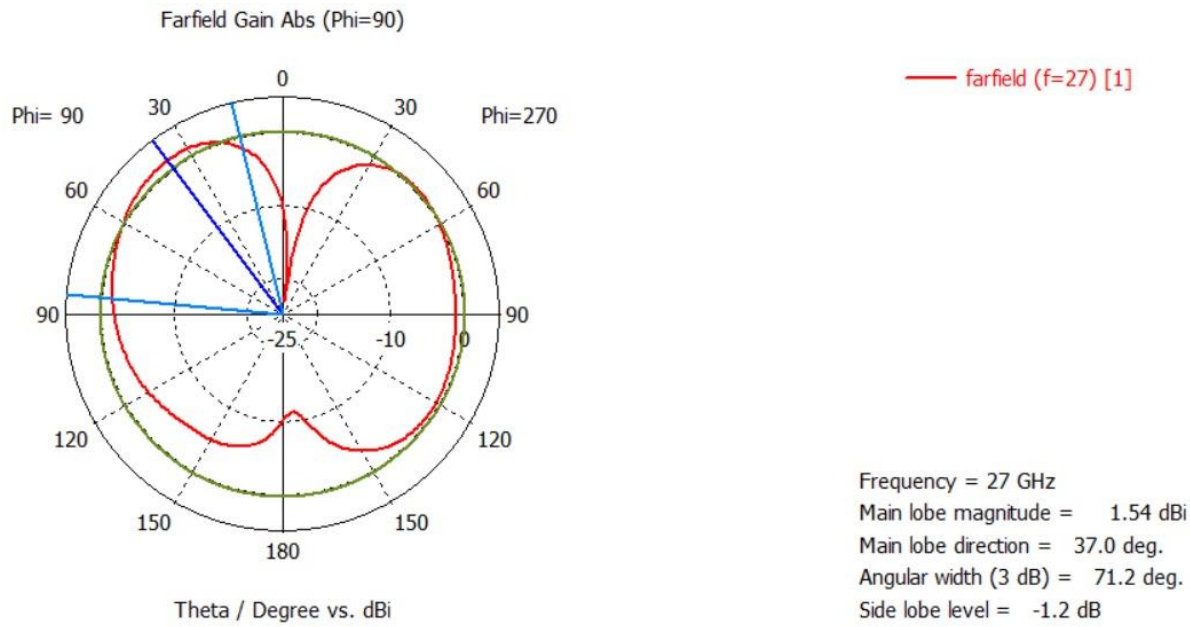

Fig1.3: Farfield 1D plot for 27GHz of the designed antenna

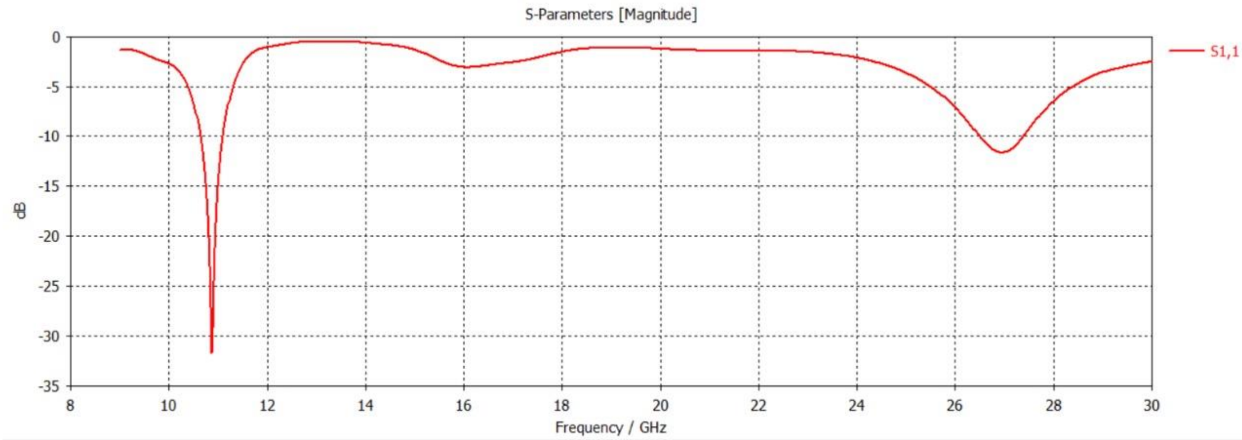

Fig1.4: S-parameter of the designed antenna

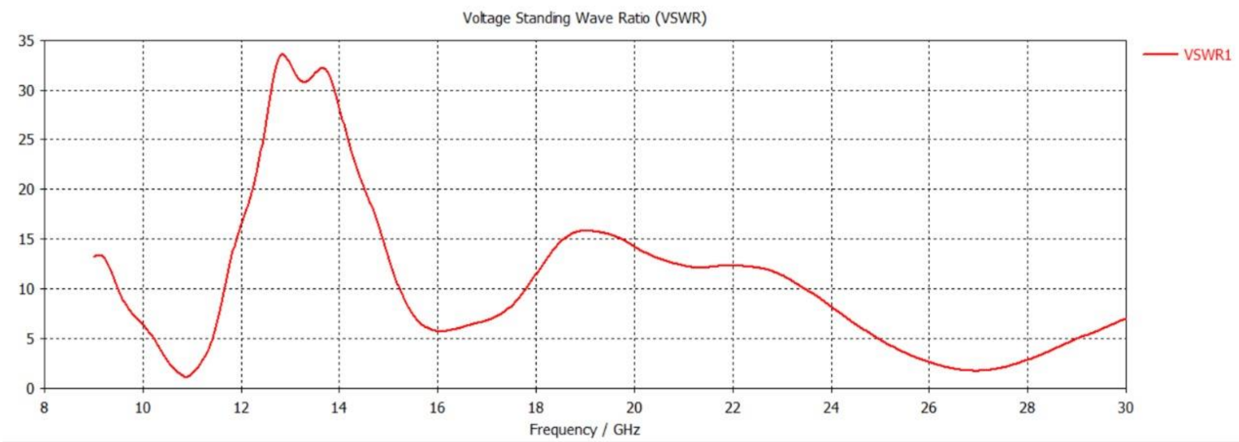

Fig1.5: VSWR of the designed antenna

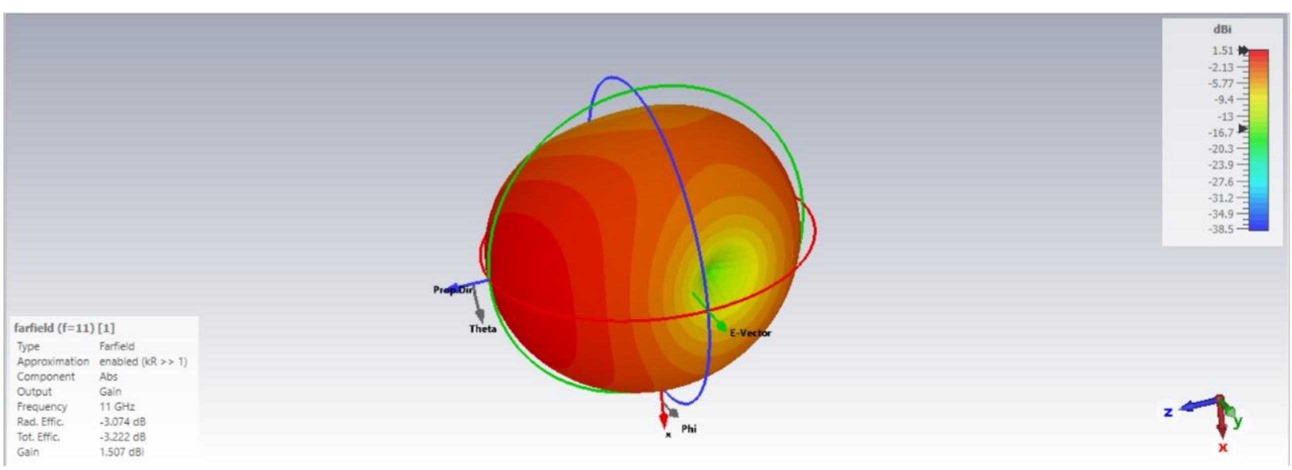

Fig1.6(a): Farfield 3D plot for 11GHz of the designed antenna

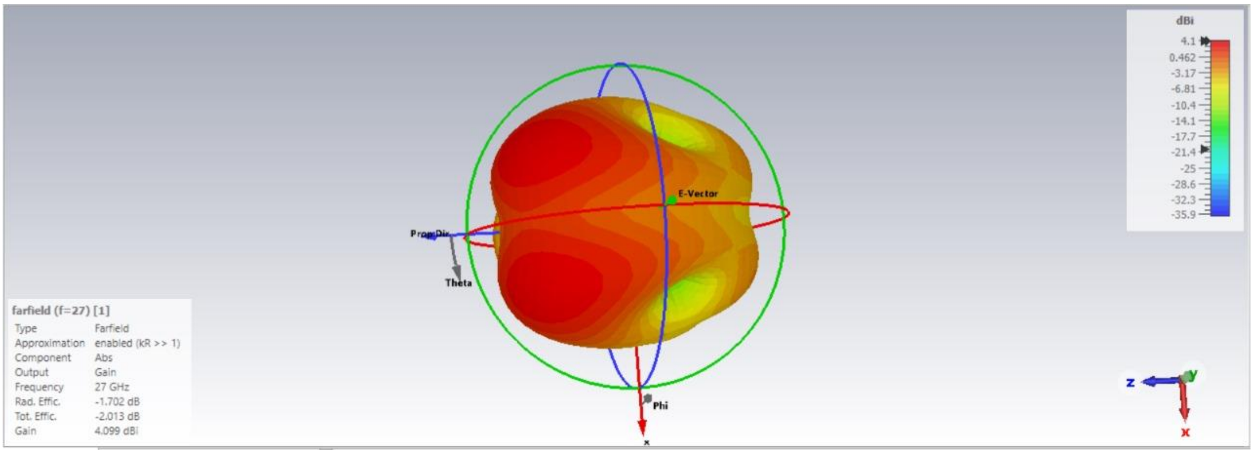

Fig1.6(b): Farfield 3D plot for 27GHz of the designed antenna

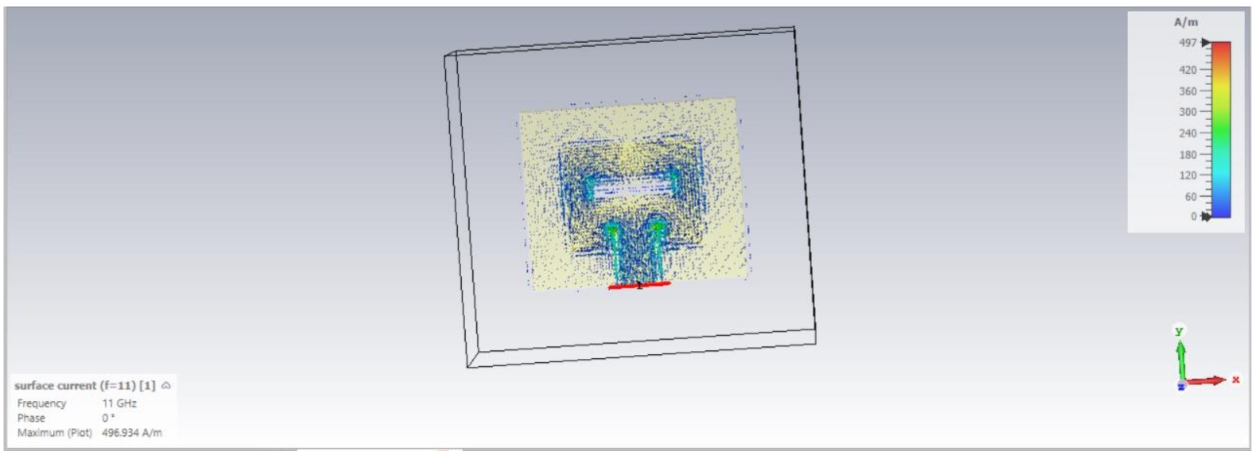

Fig1.7(a): Surface current (11GHz)

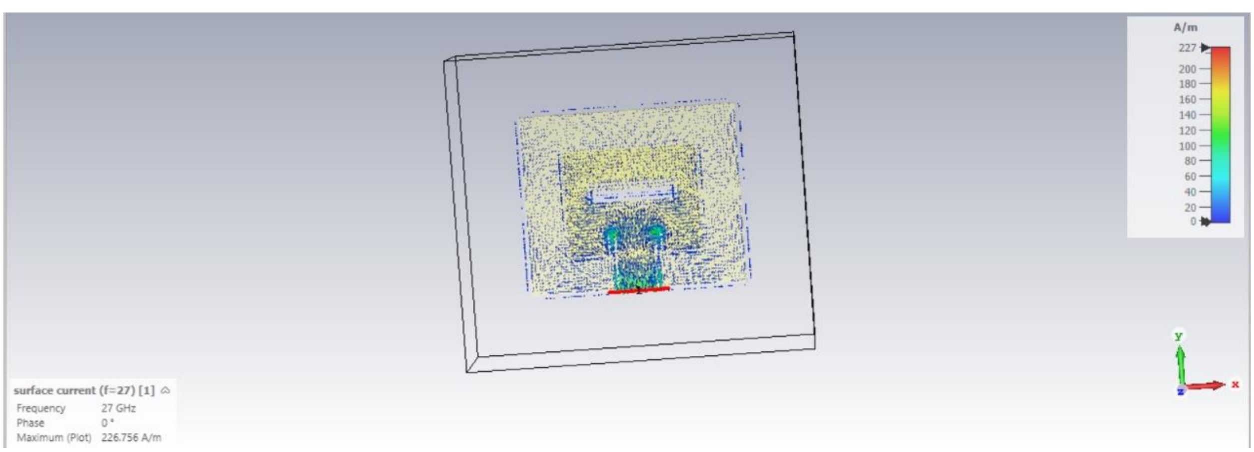

Fig1.7(a): Surface current (27GHz)

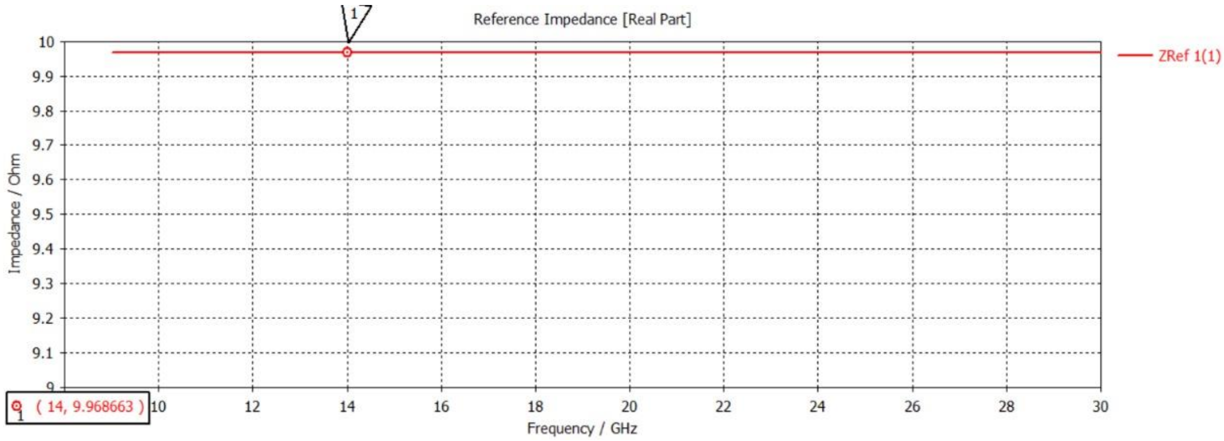

Fig 1.8: Impedence of patch antenna

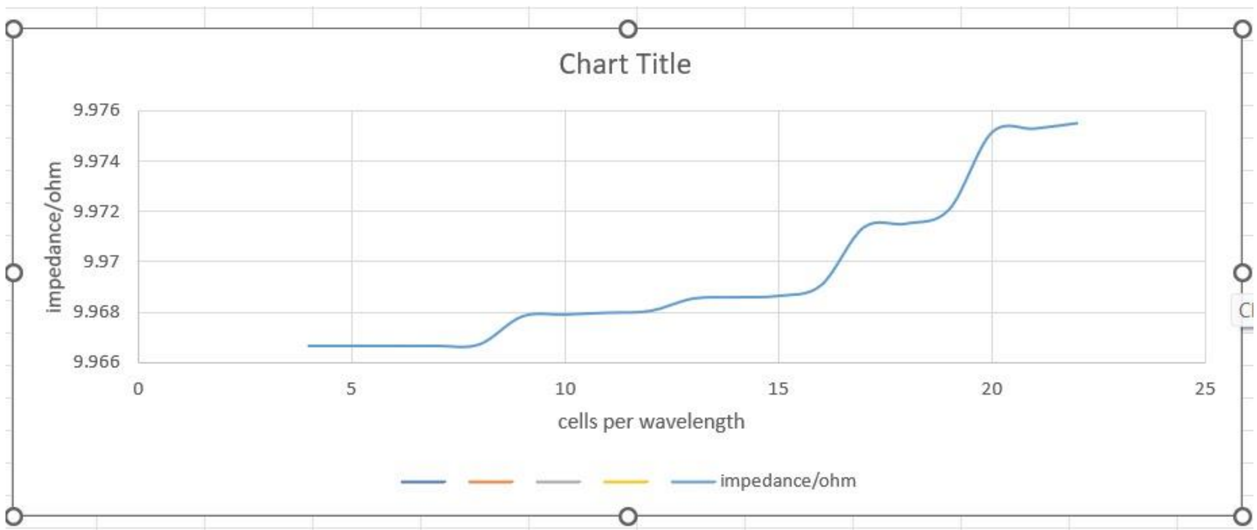

Fig1.9: Mesh convergence of patch antenna

Results and Analysis:

S Parameter (Return Loss)

The S-parameter (S11) analysis of the dual-band microstrip patch antenna shows successful operation at both 11 GHz (-32 dB) and 27 GHz (-12 dB) which can we observe at figure no 1.4 . Return loss values below -10 dB indicate that over 90% of the input power is being effectively transmitted by the antenna rather than being reflected back, with -10 dB meaning 90% transmission and 10% reflection. The deeper dip at 11 GHz (-32 dB) demonstrates particularly efficient power transfer at this frequency, while the -11 dB at 27 GHz represents acceptable but less optimal performance. These results confirm effective dual-band functionality with good impedance matching at both operating frequencies.

Also analysis the figure no 1.4 :

First Band:

- **Center Frequency**: Around 11 GHz (where the first deep dip is observed).
- **-10 dB Points**: Approximately 10 GHz and 12 GHz.
- **Bandwidth:** 12GHz−10GHz= 2GHz 12GHz−10GHz= 2GHz.

Second Band:

- **Center Frequency**: Around 27 GHz (where the second deep dip is observed).
- **-10 dB Points**: Approximately 26.5 GHz and 28 GHz.
- **Bandwidth:** 28GHz−26.5GHz= 1.5GHz 28GHz−26.5GHz= 1.5 GHz.

Radiation Characteristics

The radiation pattern analysis of the proposed antenna at 11 GHz and 27 GHz provides key insights into its performance. At 11 GHz, the antenna demonstrates an HPBW of 97.8 degrees with a main lobe magnitude of 1.51 dBi, indicating good directivity and efficiency. Similarly, at 27 GHz, the antenna exhibits an HPBW of 71.2 degrees and a main lobe magnitude of 1.54 dBi, showcasing effective performance at this frequency. The side lobe levels are -2.7 dB and -1.2 dB for 11 GHz and 27 GHz, respectively, ensuring minimal interference. These parameters, along with FNBW and minor lobe details, highlight the antenna's suitability for dual-band operation.

Gain :

Key performance metrics such as the antenna’s gain and efficiency were analyzed during the simulation:

• Gain at 11 GHz: 1.34 dBi
• Gain at 27 GHz: 2.57 dBi

VSWR

The VSWR results indicate good impedance matching for the dual-band antenna, with values of approximately 1.5 at 11 GHz and 2.0 at 27 GHz by reference of figure no 1.5 , suggesting efficient power transfer at these frequencies. VSWR, which measures impedance mismatch between the antenna and transmission line, is optimal when closer to 1.0, indicating minimal power reflection. Values below 2.0 are generally acceptable for wireless communications, confirming that the antenna operates effectively at the intended frequencies while showing high VSWR peaks at other frequencies, where performance is suboptimal.

Discussion:

The design and simulation of the dual-band microstrip patch antenna operating at 11 GHz and 27 GHz demonstrated promising performance characteristics despite some dimensional variations from calculated values. The antenna achieved satisfactory return loss (S11) below -10 dB at both frequencies, indicating effective impedance matching and minimal power reflection. Analysis of radiation patterns showed expected directional characteristics, though with some pattern distortion at 27 GHz and slightly lower gain than theoretically predicted. This performance variation can be attributed to several factors including manufacturing tolerances, substrate material properties, and coupling effects between the dual-band elements. Despite these challenges, the antenna maintained adequate bandwidth and radiation efficiency for practical wireless communication applications, demonstrating a reasonable balance between size reduction and performance. The results suggest that while there is room for optimization in terms of gain enhancement and manufacturing precision, the current design represents a viable solution for dual-band operations in modern communication systems.

Conclusion:

This project successfully developed and simulated a dual-band microstrip patch antenna operating at 11 GHz and 27 GHz using CST Studio Suite. The simulation results validated the design methodology, demonstrating favorable return loss characteristics below -10 dB at both operating frequencies, indicating effective impedance matching. While the antenna's gain was lower than the theoretical maximum, the achieved performance metrics including radiation patterns, efficiency, and bandwidth were suitable for practical wireless communication applications. The dimensional optimization and feeding technique implementation proved effective in achieving dual-band operation, though there remains potential for further enhancement through advanced manufacturing techniques and material selection. Overall, the project demonstrated that the proposed antenna design represents a viable solution for modern wireless communication systems requiring dual-band functionality in a compact form factor.

Reference:

http://www.researchgate.net/publication/339702806_Review_Dual_Band_Microstrip_Antennas_for_Wireless_Applications