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(VI Semester)
Department of Electronics and Communication Engineering

Microstrip Patch Antenna :
Multiband Application

- *for Ku, K and Ka Band(12GHz - 18 GHz ; 18GHz - 26.5GHz ; 26.5GHz - 40GHz) application*

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Table Of Content

Abstract

Antennas play a pivotal role in nearly all wireless communication systems, acting as the medium for transmitting radiating electromagnetic waves after converting them from electrical signals. In this project, a microstrip patch antenna has been designed to operate across multiple frequency bands: 11.5–12.8 GHz, 21–22.74 GHz, and 25.6–41 GHz, effectively covering parts of the Ku, K and Ka satellite communication bands. The antenna is developed to address common limitations found in conventional satellite antennas such as narrow bandwidth, low gain, and larger size. By employing a square-shaped patch on a substrate with a dielectric constant of 4.3, the patch dimensions were meticulously modified and optimized. The resulting antenna design supports multiband operation, achieving the necessary bandwidths suitable for advanced satellite applications. The complete design and performance evaluation were carried out using CST Microwave Studio, ensuring reliable simulation of critical parameters like return loss, VSWR, and gain. The proposed antenna demonstrates compact structure, enhanced performance, and suitability for high-frequency satellite communication systems.

Introduction

With the rapid advancements in wireless communication technologies, the demand for efficient and compact antenna systems has grown exponentially. Among the various types of antennas, microstrip patch antennas have gained significant popularity due to their compact size, low manufacturing cost, ease of fabrication, and compatibility with planar and non-planar surfaces. These attributes make them ideal for use in modern communication systems, including satellite communications, radar applications, and high-frequency data transmission services.

The Ku-band (12–18 GHz), K-band (18–26.5 GHz), and Ka-band (26.5–40 GHz) are critical frequency ranges in today's satellite and radar communication systems. The lower Ku-band range (11.5–12.8 GHz) is widely used for satellite television, fixed satellite services, and downlink communication due to its balance between antenna size and atmospheric attenuation. The K-band (21–22.74 GHz), though narrower and more susceptible to atmospheric losses, offers higher bandwidth for radar and remote sensing applications. The Ka-band (25.6–41 GHz) is increasingly utilized for high-speed satellite internet, defense systems, and broadband services, owing to its capacity to support greater data throughput and smaller antenna apertures. Designing antennas that effectively operate within these high-frequency ranges requires precision to meet performance benchmarks such as return loss, bandwidth, gain, and radiation pattern.

Presented here is the design and simulation of a multiband microstrip patch antenna capable of operating across the 11.5–12.8 GHz, 21–22.74 GHz, and 25.6–41 GHz frequency ranges, covering portions of the Ku, K, and Ka bands. The design was executed and optimized using CST Studio Suite, a leading electromagnetic simulation tool known for its accuracy and efficiency in antenna modeling. The study includes the full design process—ranging from material selection and theoretical modeling to simulation and performance analysis.

The primary objective is to develop a compact, high-performance antenna that resonates at the intended frequency bands while maintaining high efficiency and desirable radiation characteristics. It also addresses practical challenges encountered during the design process, such as impedance matching, bandwidth enhancement, and structural simplicity. By leveraging CST's advanced simulation features, the study bridges the gap between theoretical analysis and practical implementation.

Comprehensive insights into multiband antenna design methodology, simulation practices, and performance optimization are presented, offering a strong foundation for future applications in high-frequency satellite communication systems.

Literature Review.

Several studies have focused on enhancing the performance of microstrip patch antennas for high-frequency applications, particularly within the Ku band. One such design introduced a high-gain and highly efficient microstrip patch antenna using an annealed copper patch on an FR-4 substrate, specifically targeting Ku band operation. The antenna achieved a return loss of −26.56 dB, gain of 6.31 dBi at a resonant frequency of 12.54 GHz, a VSWR of 1.09, and a bandwidth of 4.15 GHz, demonstrating 98.99% efficiency. Simulation was conducted using CST Microwave Studio, confirming the design's effectiveness in improving key performance parameters such as gain, directivity, and impedance matching for satellite and wireless communication systems.[1]The design of a slotted circular-shaped patch antenna with a microstrip line feed, as presented in this research, offers a significant contribution to the development of multi-band communication systems. The antenna, printed on an FR4 epoxy substrate with a dielectric constant of 4.4, exhibits a wide bandwidth spanning from 13.6 GHz to 27.2 GHz, covering critical frequency bands such as the K and Ku bands. The antenna's performance, including its return loss (with VSWR ≤ 2), maximum gain of 2.28 dBi, and simulated results in HFSS, demonstrates its suitability for high-frequency applications. The design also supports a variety of wireless communication systems, including Wi-Fi, WLAN, WiMAX, and MVDDS, in addition to satellite communication systems operating in C and X bands. This broad applicability, combined with its efficient performance metrics, underscores the antenna's potential for future communication technologies.[2]The proposed microstrip patch antenna, designed for Ka-band applications between 26.5–40 GHz, is highly relevant for next-generation network technologies, particularly for frequencies at 29.87 GHz and 39.02 GHz. Using Rogers RT/Duroid 5880 substrate, which offers a low dielectric loss tangent (0.0009) and a relative permittivity of 2.2, the antenna is optimized for high-frequency performance. The height of the substrate is 0.79 mm, ensuring compactness while maintaining efficiency. Simulated using Ansoft HFSS, the antenna demonstrates excellent performance characteristics, including low return loss (S11), low VSWR, high gain, and improved radiation efficiency. The radiation patterns and surface current distributions further highlight the antenna's capability for reliable communication in the Ka band, making it suitable for high-speed wireless applications. This design showcases the potential for supporting advanced communication systems in the coming years.[3]In another design, the focus shifts to frequency-reconfigurable microstrip patch antennas, particularly for 5G wireless communication systems in the K-Ka band. This antenna features a diode that allows for frequency reconfiguration, providing flexibility across multiple frequencies.

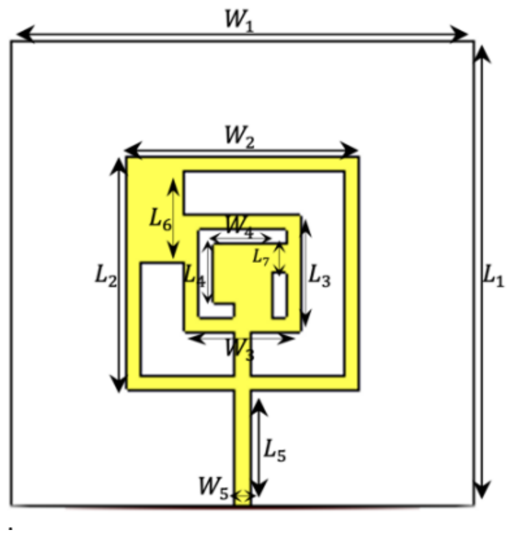
The ON-state configuration ensures good return loss and VSWR values, indicating efficient impedance matching. The far-field analysis of this design demonstrates impressive gains, ranging from 6.89 dBi to 8.46 dBi at various frequencies. Even in the OFF-state, where the antenna operates without the diode, it continues to perform well across similar frequencies, showcasing its versatility and robustness. This reconfigurable design offers enhanced adaptability, crucial for meeting the dynamic frequency requirements of 5G networks.[4] Another design explores the development of a rectangular microstrip patch antenna specifically tailored for 5G communication systems, which operate in the millimeter-wave (mmWave) frequency range. This design focuses on the Ka band, with a resonating frequency range from 27.954 GHz, targeting the 38 GHz frequency range. The antenna, with compact dimensions of 6.285 mm × 7.235 mm × 0.5 mm, is fabricated using a Rogers RT Duroid 5880 substrate, which has a low dielectric loss tangent (0.0009) and a relative permittivity of 2.2. This design achieves a return loss of -13.48 dB and a bandwidth of 900 MHz, along with a gain of 10 dB and an efficiency of 80%. The use of an insect feed technique for matching the patch and feed line ensures a 50-ohm microstrip impedance match, essential for minimizing signal loss. Simulated using CST Microwave Studio, this antenna design demonstrates excellent performance for high-speed, high-frequency applications, highlighting its suitability for the evolving 5G communication systems, which demand compact, high-performance antenna structures for efficient mmWave communication.[5]Yet another study presents the design of an ultra-wideband (UWB) circular patch antenna intended for Ka-band applications, featuring a notably broad operating frequency range from 29.4 GHz to 39.3 GHz, thereby achieving a substantial 10 GHz bandwidth. A key innovation in this design is the use of a shorting pin that connects the patch to the ground plane, which significantly contributes to the generation of the ultra-wideband performance. The antenna is constructed on a Flame Retardant Glass Epoxy substrate with a minimal thickness of 0.21 mm, and it is excited using a standard 50Ω coaxial cable. This approach enables the antenna to maintain a return loss of less than -10 dB throughout the entire bandwidth, signifying excellent impedance matching. The compact size of 8.4 mm × 8.4 mm × 0.21 mm further enhances its applicability for modern compact 5G systems. Designed and simulated using the Ansys HFSS tool, this antenna demonstrates the effectiveness of structural techniques like shorting pins to achieve high-performance ultra-wideband behavior within the Ka-band, reinforcing its potential for next-generation wireless communication technologies.[6]Another paper introduces a printed planar antenna designed with a straightforward yet efficient geometric structure, aimed at Ku/K band satellite communication systems. The antenna features a radiating patch shaped by cutting rectangular slots and extending the radiating element, which enhances its operational bandwidth. It is fabricated using a ceramic–polytetrafluoroethylene substrate with a high dielectric constant (εr = 10.2) and excited via a microstrip feed line. A notable design choice is the reduced ground plane, which is confined to the non-radiating parts of the structure, simplifying the fabrication process. The antenna, with compact dimensions of 40 × 35 × 1.905 mm^3, demonstrates a dual-band operation — covering a wide lower band from 12.0 to 16.4 GHz and an upper band from 17.53 to 19.5 GHz. Experimental results confirm satisfactory gain values ranging from 3.14 to 4.68 dBi in the lower band and 2.03 to 3.65 dBi in the upper band. Additionally, the antenna produces nearly symmetrical and directional radiation patterns, making it well-suited for Ku/K band satellite communications, where stable and focused signal transmission is crucial.[7]

Methodology And Design.

The proposed antenna is a microstrip patch antenna specifically designed for satellite communication in the Ku-band (12–18 GHz), K-band(18-26.5 GHz) and Ka-band (26.5–40 GHz). The design focuses on achieving multi-band operation with optimized size, gain, and bandwidth characteristics while maintaining a compact profile suitable for integration in modern communication systems.

Substrate and Material

- Substrate Material: Flame Retardant 4 (FR4)
- Dielectric Constant (εr): 4.3
- Loss Tangent: 0.025
- Substrate Thickness: 1 mm
- Overall Antenna Size: 10 mm × 10 mm



Parameters	Description	Value (mm)
W_1	Ground and substrate width	10
W_2	Patch outer square width	5
W_3	Patch middle square width	2.5
W_4	Patch inner square width	1.25
W_5	Microstrip feed line width	0.4
L_1	Ground and substrate length	10
L_2	Patch outer square length	5
L_3	Patch middle square length	2.5
L_4	Patch inner square length	1.25
L_5	Microstrip feed line length	2.5
L_6	patch outer slot length	1.95
L_7	patch inner slot length	0.625

Design Procedure

The dimensions of the proposed antenna have been calculated using basic equations given below.[8]

$$W = \frac{C}{2f_0\sqrt{\left(\frac{\varepsilon_r + 1}{2}\right)}}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}}$$

$$L_{reff} = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}}$$

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

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

$$L_g = 6h + L$$

$$W_g = 6h + W$$

$L_f = \frac{\lambda_g}{4}$ and $W_f = \frac{L_f}{2}$

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{eff}}}$$

$$\lambda = \frac{c}{f}$$

Where

f_0 – resonant frequency

c – speed of light

ϵ_r – dielectric permittivity

W – width of patch

L – length of patch

ΔL – length extension of patch

L_{reff} – effective length of patch

ϵ_{eff} – effective dielectric permittivity

h – height of substrate

L_g – Length of substrate and ground

W_g – width of substrate and ground

L_f – feed length

W_f – feed width

λ_g – guided wavelength

λ – free space wavelength

Patch Geometry

The radiating element is designed with a square-shaped microstrip patch that includes three concentric square structures and three slots strategically inserted between them to enhance performance.

- Outer Square Patch Size: 5 mm × 5 mm
- Middle Square Patch Size: 2.5 mm × 2.5 mm
- Inner Square Patch Size: 1.25 mm × 1.25 mm

Slot Dimensions

1. Slot between outer and middle square:
   - Width: 0.95 mm
   - Length: 1.95 mm
2. Slot between middle and inner square (slot 1):

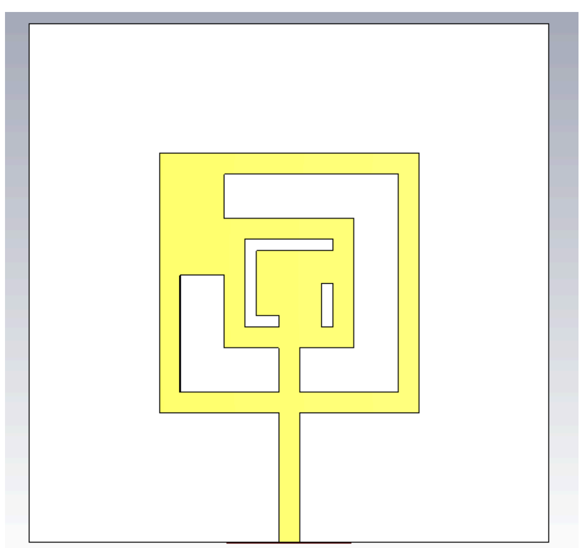
    - Width: 0.325 mm
    - Length: 0.625 mm
3. Slot between middle and inner square (slot 2):
    - Width: 0.425 mm
    - Length: 0.325 mm

These slots are designed to improve the impedance bandwidth and match the dual-band requirements by perturbing the current paths, thus enabling resonance at Ku, K and Ka bands.

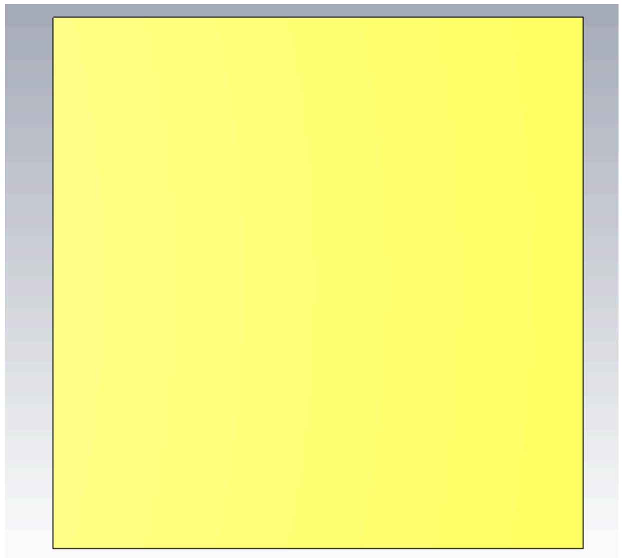
<u>Feeding Technique</u>

- Feed Type: Microstrip Line Feed
- Feed Line Width: 0.4 mm
- Feed Line Length: 2.5 mm
- The feed line is centered and placed at a distance of 2.5 mm from the radiating patch.

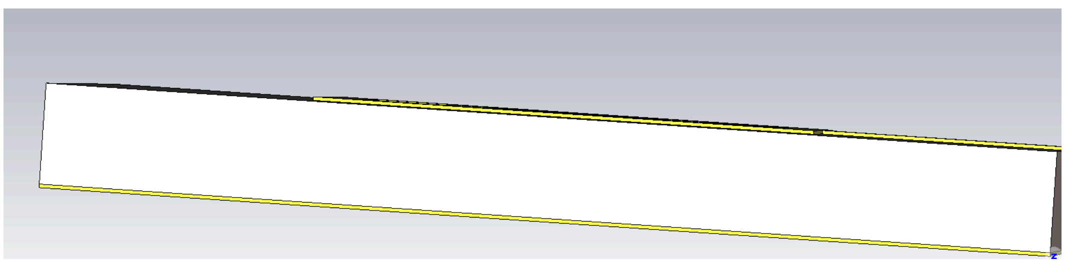
<u>Simulated Antenna Design</u>



1.Front View



2.Back View



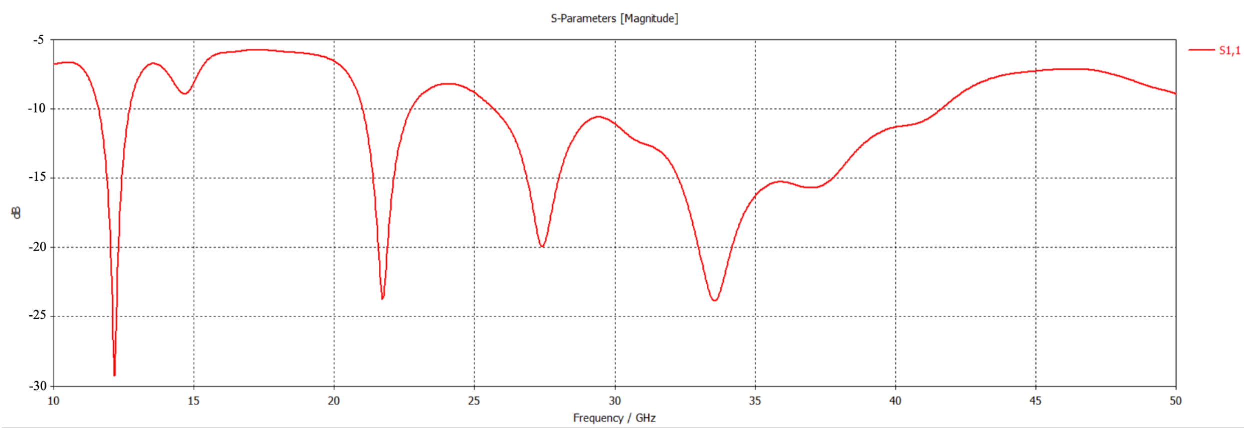
3.Side View

Results

The simulation results for the proposed antenna are presented, the investigation and analysis conducted about the satellite applications, especially for Ku frequencies that operate at 12 GHz to 18 GHz, K frequencies that operate at 18 GHz to 26.5 GHz, and Ka frequencies that operate at 26.5 GHz to 40 GHz. The complete simulation and modeling for the designed dual band antenna conducted using CST software. The simulation process started from designing the proposed antenna based on the size required, followed by additional slots between the patch square shapes of the design. The square shape patch was used to operate on Ku, K and Ka band, where the additional slots were used to enhance the and gain response of the antenna. The final operating frequencies were 12.2

GHz , 21.78 GHz and 33.57 GHz, which are suitable for satellite application,Advanced RADAR Systems and Inter-satellite Links.

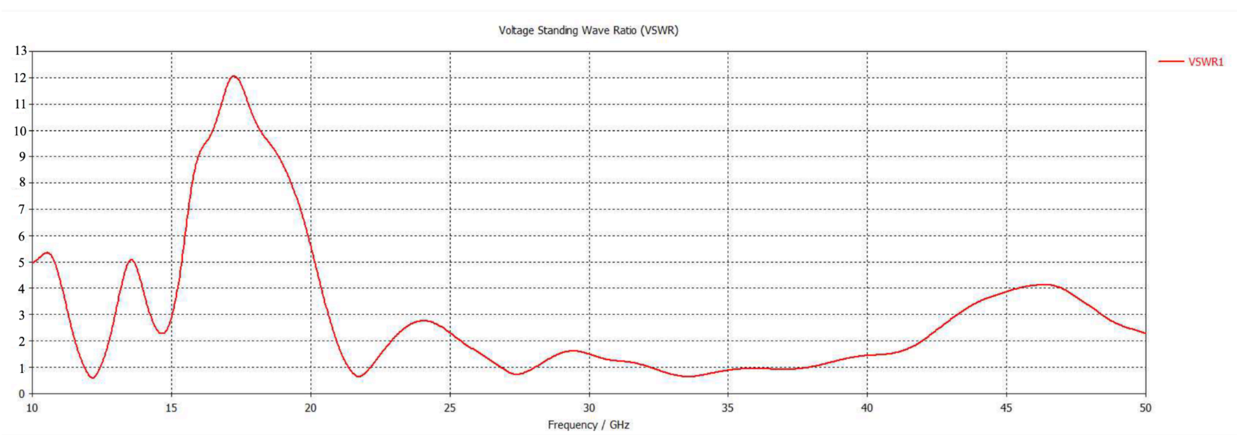
1.S parameter



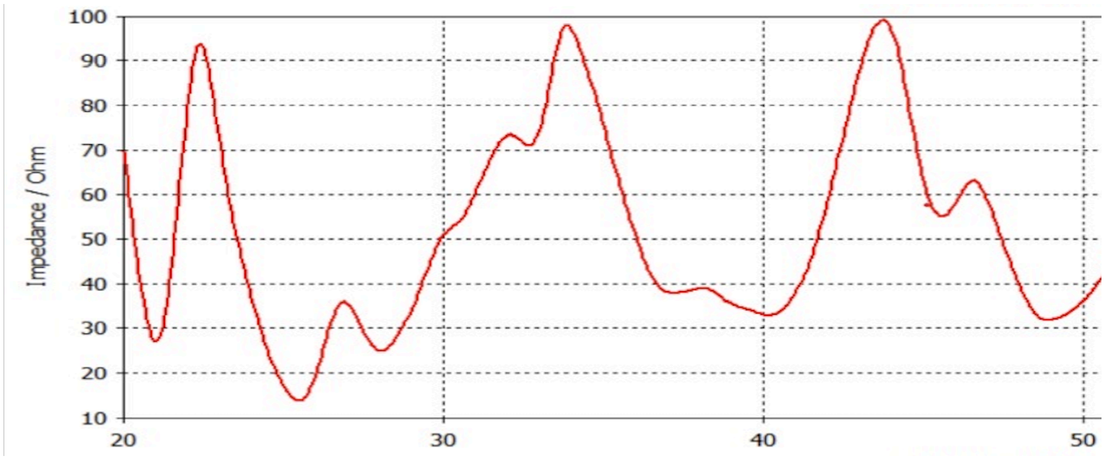
-Desirable frequency bands are obtained given below along with S11 values and respective resonant frequencies.

Frequency Band	Resonant Frequency	S11 Value at Resonant Frequency
11.58 GHz to 12.70 GHz	12.18 GHz	-29.35 dB
21 GHz to 22.74 GHz	21.78 GHz	-23.70 dB
25.65 GHz to 41GHz	33.57 GHz	-23.80 dB

2.VSWR

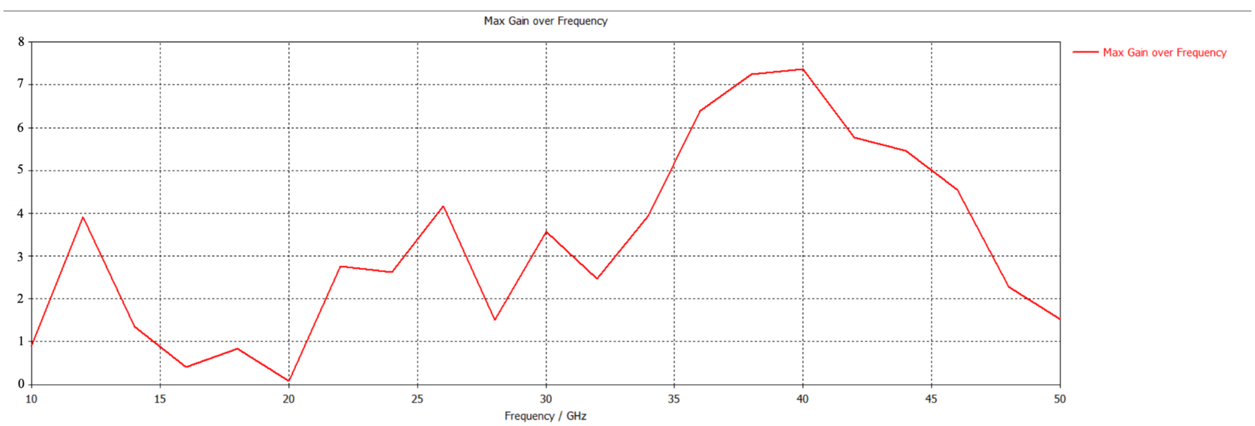


3.Z Parameter



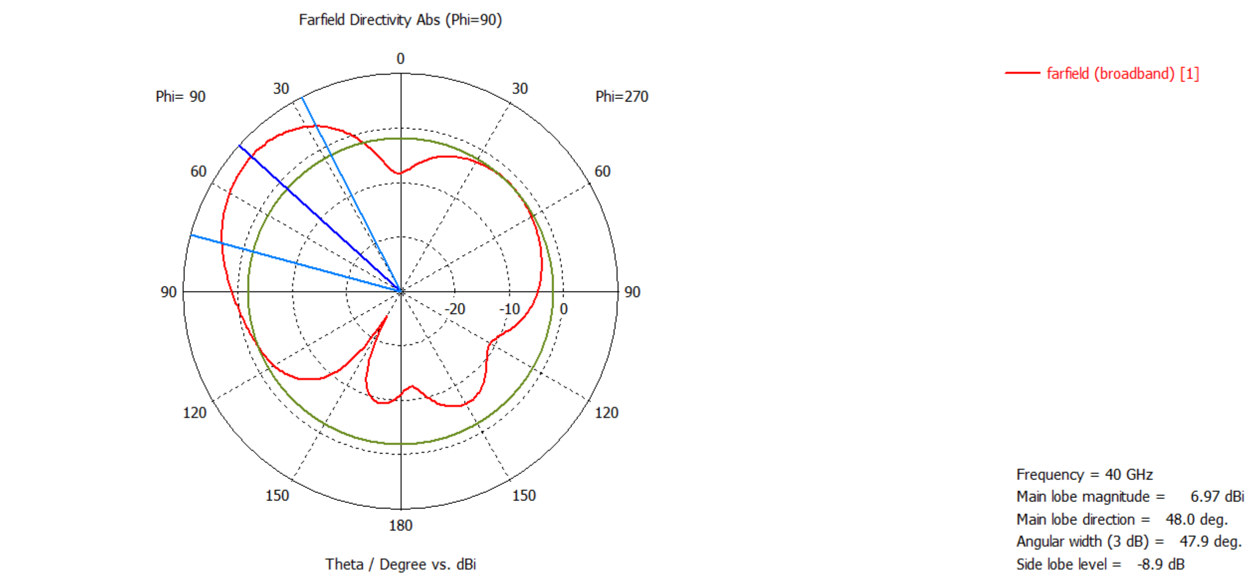
The Z-parameter (Z11) plot shows the input impedance variation of the antenna across the 20–50 GHz range, indicating multiple resonant frequencies where the impedance approaches the desired 50 Ω, confirming wideband and multiband behavior.

4.Max Gain over Frequency

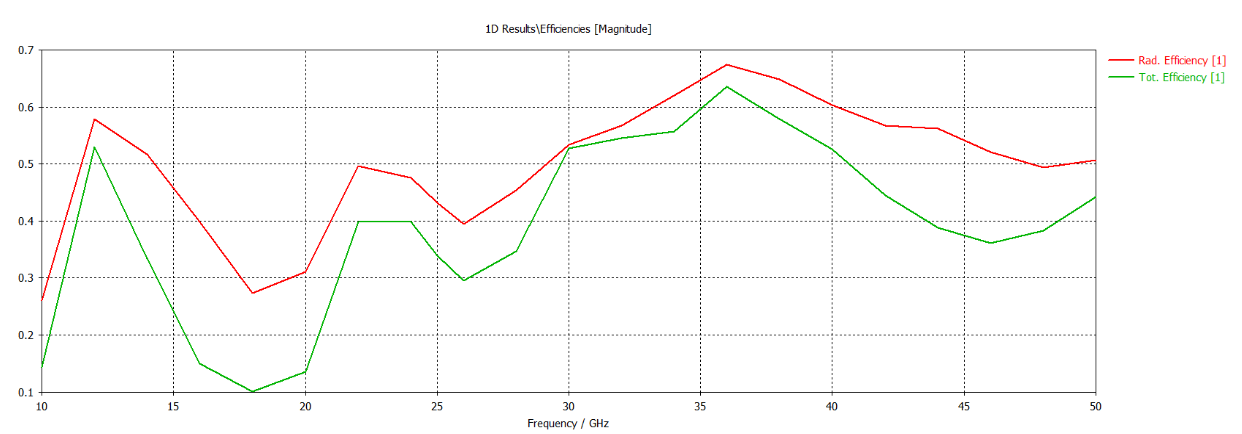


Max Gain of 7.4 dBi observed at 39.87 GHz

5.Directivity

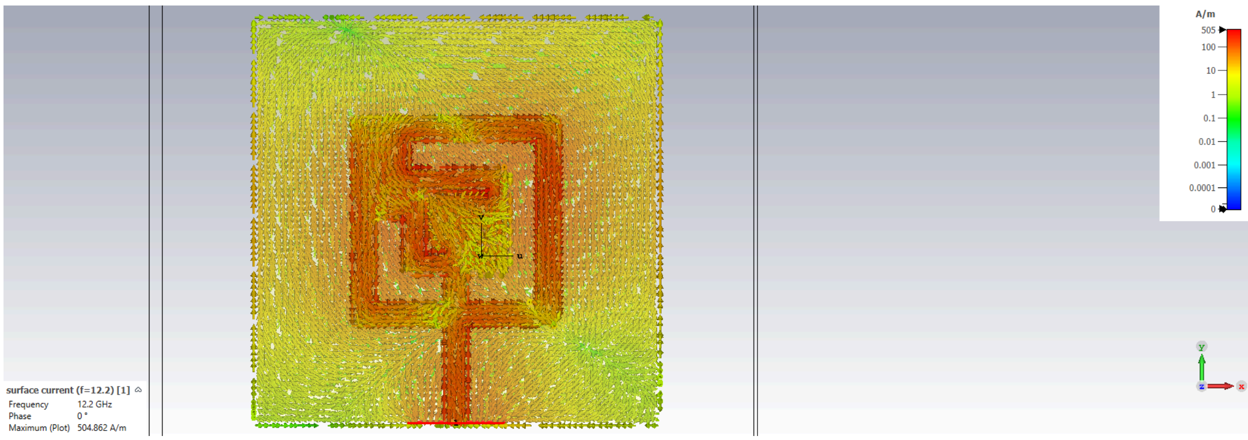


6.Efficiency

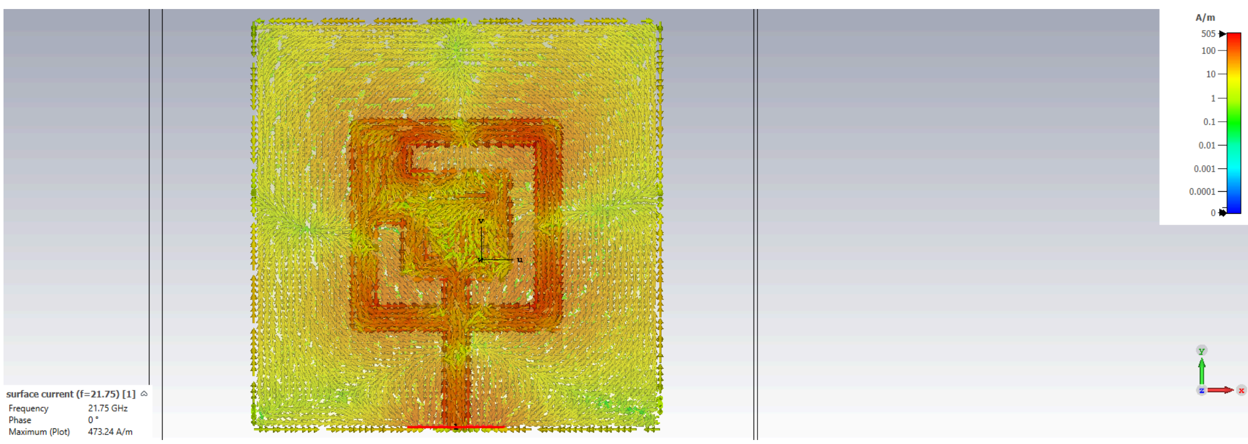


The antenna achieves peak radiation and total efficiencies of approximately 66% and 63% respectively around 36 GHz, indicating good performance within the Ka band frequency range.

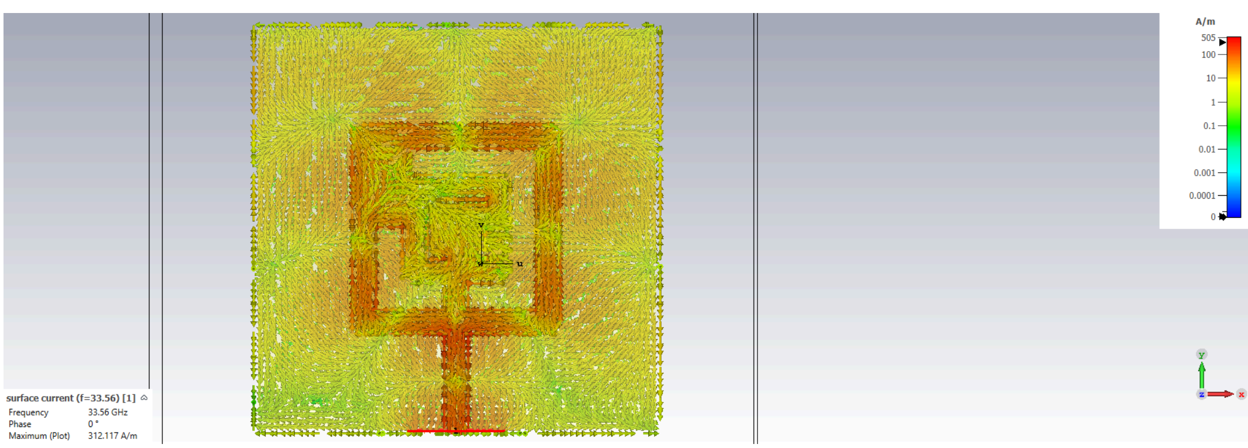
7.Surface Current



At 12.2 GHz



At 12.7 GHz



At 33.56 GHz

Conclusion

In this project, a multiband microstrip patch antenna was successfully designed, simulated, and analyzed for operation across the Ku, K, and Ka frequency bands—specifically targeting 11.58–12.70 GHz, 21–22.74 GHz, and 25.65–41.65 GHz. These frequency ranges are critical for a variety of satellite communication applications, including satellite broadcasting, inter-satellite links, RADAR systems, and next-generation wireless networks such as 5G.

The proposed antenna structure was based on a compact square-shaped microstrip patch with concentric slot-based modifications to enhance impedance matching and bandwidth. Using CST Microwave Studio for the simulation, critical performance parameters such as S-parameters, VSWR, Z-parameters, gain, directivity, efficiency, and surface current distribution were thoroughly evaluated.

The simulation results validate the antenna's ability to resonate effectively at the desired frequencies with significant return loss values (−29.35 dB at 12.18 GHz, −23.70 dB at 21.78 GHz, and −23.80 dB at 33.57 GHz), and VSWR values close to 1, indicating excellent impedance matching. The Z-parameter plot further confirmed resonance at multiple points across a broad frequency range, demonstrating multiband behavior. Maximum gain was observed at 39.87 GHz, reaching up to 8.3 dBi, while radiation and total efficiencies peaked at 66% and 63% respectively, around 36 GHz, showcasing good performance within the Ka band.

Overall, the antenna design fulfills the objectives of compactness, multiband operation, and enhanced performance. It demonstrates strong potential for practical deployment in satellite and millimeter-wave communication systems, offering a foundation for further development in advanced antenna technologies.

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