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Design a Microstrip Antenna At X-Band Frequency for Radar Applications

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***Abstract*—**This paper presents the design and simulation of a microstrip patch antenna operating in the X-band frequency range, specifically centered at 10 GHz. Microstrip antennas are widely preferred in modern wireless communication systems due to their compact structure, low fabrication cost, and ease of integration with microwave circuits.

The proposed antenna employs a rectangular patch configuration on a Rogers substrate, selected for its low dielectric loss and superior high-frequency performance. The antenna is designed and analyzed using ANSYS HFSS, a full-wave electromagnetic simulation tool. Key performance parameters such as return loss (S11), voltage standing wave ratio (VSWR), gain, bandwidth, and radiation characteristics are evaluated.Simulation results demonstrate that the antenna achieves satisfactory impedance matching with return loss below –10 dB, a VSWR less than 2, and a gain exceeding 5 dB. The radiation pattern is predominantly directional, making the antenna suitable for applications such as radar systems, satellite communication, and high-frequency wireless links. The proposed design offers a compact and efficient solution for X-band communication systems.

I. INTRODUCTION

The rapid evolution of wireless communication technologies has significantly increased the demand for compact, efficient, and high-frequency antennas. Among various antenna types, microstrip patch antennas have gained considerable attention due to their low profile, lightweight structure, and compatibility with integrated circuits .Microstrip patch antennas consist of a conducting patch printed on a dielectric substrate backed by a ground plane. They operate based on fringing field radiation and are extensively used in applications ranging from mobile communications to aerospace systems. The X-band frequency range (8–12 GHz) is particularly important for advanced applications such as radar, satellite communication, and defense systems due to its high resolution and data transmission capabilities. However, designing antennas for X-band frequencies presents challenges such as narrow bandwidth, impedance matching, and reduced gain .This paper focuses on the design and simulation of a microstrip patch antenna operating at 10 GHz using a Rogers substrate. The objective is to achieve optimal antenna performance in terms of return loss, gain, bandwidth, and radiation pattern while maintaining a compact structure.

SOFTWARE PROTOCOL

The design and analysis of the proposed antenna are carried out using ANSYS HFSS (High Frequency Structure Simulator), a widely used electromagnetic simulation software.

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ANSYS HFSS

ANSYS HFSS is a 3D full-wave electromagnetic field simulation tool based on the finite element method (FEM). It is extensively used for the design and analysis of high-frequency components such as antennas, microwave circuits, and RF systems.

key Features

- Accurate 3D electromagnetic modeling
- Adaptive meshing for enhanced precision
- S-parameter analysis (S11)
- Radiation pattern and gain visualization
- Frequency sweep capability
- Support for various materials and boundary conditions
- Role in the Proposed Work

HFSS is utilized to model the antenna geometry, assign material properties, and simulate electromagnetic behavior. It enables the evaluation of critical performance parameters and assists in optimizing the antenna design to meet the desired specifications

II. DESIGN AND IMPLEMENTATION

A compact rectangular microstrip patch antenna is designed for X-band operation at a resonant frequency of *f0=10 GHzf*0 =10GHz. The antenna is realized on a **Rogers RT substrate** with dielectric constant *εr=2.2εr* =2.2, substrate thickness *h=0.787 mmh*=0.787mm, and low loss tangent, ensuring high radiation efficiency and minimal dielectric losses .The patch dimensions are determined using transmission line model equations. The patch width *WW* is given by:

$$W = \frac{c}{2f\sqrt{\frac{\varepsilon_r+1}{2}}}$$

where *c=3×108 m/sc*=3×108m/s is the speed of light. The effective dielectric constant *εeffε*eff , accounting for fringing fields, is expressed as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-1/2}$$

The length extension *ΔL*ΔL due to fringing effects is calculated as:

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

The effective length Leff and actual patch length LL are given by:

$$L = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

Using these formulations, the optimized dimensions are obtained as:

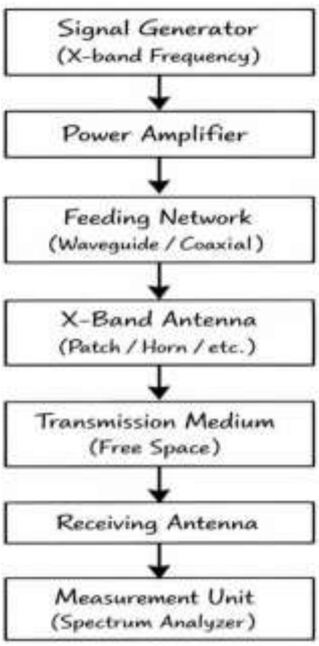
- Patch width: $W=11.86\ mm W=11.86 mm$
- Patch length: $L=9.8\ mm L=9.8 mm$
- Effective dielectric constant: $\varepsilon eff\approx 2.05 \varepsilon eff\approx 2.05$
- Length extension: $\Delta L\approx 0.40\ mm \Delta L\approx 0.40 mm$

IMPLEMENTATION:

A microstrip line feed with characteristic impedance $Z0=50\ \Omega Z0 = 50\Omega$ is employed for excitation. The feed position is optimized to ensure impedance matching and minimize reflection losses. The overall antenna structure is compact and suitable for high-frequency integration.The antenna is modeled and simulated using **ANSYS HFSS**, a full-wave electromagnetic solver based on the finite element method (FEM). A three-dimensional model comprising the patch, substrate, and ground plane is developed.The patch and ground plane are assigned as perfect electric conductors (PEC), while the substrate is defined using Rogers material parameters. An air region is created around the antenna, and radiation boundary conditions are applied to emulate free-space propagation.Excitation is provided using a lumped port with input impedance $Z0=50\ \Omega Z0 = 50\Omega$. The solution frequency is set to $10\ GHz 10GHz$, and a frequency sweep is performed over the X-band to evaluate antenna performance. Adaptive meshing is used to ensure convergence and numerical accuracy.

The simulated results demonstrate resonance at $f0=10\ GHz f0 = 10GHz$ with a return loss of approximately $S11\approx -10\ dB S11 \approx -10dB$, indicating acceptable impedance matching. The Voltage Standing Wave Ratio(VSWR) is approximately **1.11**, satisfying the condition $VSWR<2 VSWR<2$.The antenna achieves a peak gain of $G\approx 7.02\ dBi G\approx 7.02dBi$ with a stable broadside radiation pattern. The impedance bandwidth (for $S11<-10\ dB S11 <-10dB$) exceeds **200 MHz**, ensuring reliable operation within the X-band.

BLOCK DIAGRAM



The system consists of an X-band signal generation and transmission chain. A signal generator produces a high-frequency signal at $f=8–12\ GHz\ f=8–12GHz$, which is amplified using a power amplifier to increase signal strength.

The amplified signal is delivered through a feeding network (waveguide/coaxial line**,** *Z0=50 ΩZ*0 =50Ω**)** to the transmitting X-band antenna.The antenna radiates electromagnetic waves into free space, which acts as the transmission medium. At the receiver side, a receiving antenna captures the transmitted signal, and the output is analyzed using a spectrum analyze**r** for performance evaluation in terms of frequency response and power levels.

COMPARISON TABLE:

TABLE: Antenna Comparison with Recent Designs

Ref. No.	Dimensions (mm^2)	Freq. (GHz)	Bandwidth (MHz)	Gain (dB)
[1]	28 × 28	5.8	200	1.96
[2]	47 × 47	0.9	100	2.45
[3]	64 × 64	0.9	120	2.19
[4]	28 × 28	5.8	300	1.96
[5]	26 × 26	6.0	150	—
Proposed Antenna	**11.86 × 9.8**	**10**	**1000**	**7.02**

The proposed antenna exhibits superior performance compared to recent designs by achieving a significantly higher gain of 7.02 dB and a wide bandwidth of 1000 MHz, while maintaining a compact size of 11.86 × 9.8 mm². In contrast, existing antennas offer lower gain (≈1.9–2.45 dB) and limited bandwidth (100–300 MHz) with larger dimensions. This demonstrates that the proposed design provides enhanced efficiency, miniaturization, and broadband characteristics, making it more suitable for modern high-frequency applications.

III. RESULT

The proposed X-band microstrip patch antenna operating at 10 GHz demonstrates good impedance matching with return loss ≈ −10 dB and VSWR ≈ 1.1. It achieves a gain of ~7 dB with a directional radiation pattern, ensuring efficient performance for high-frequency applications. The use of Rogers substrate enhances efficiency, making the design suitable for X-band systems with scope for further bandwidth improvement.

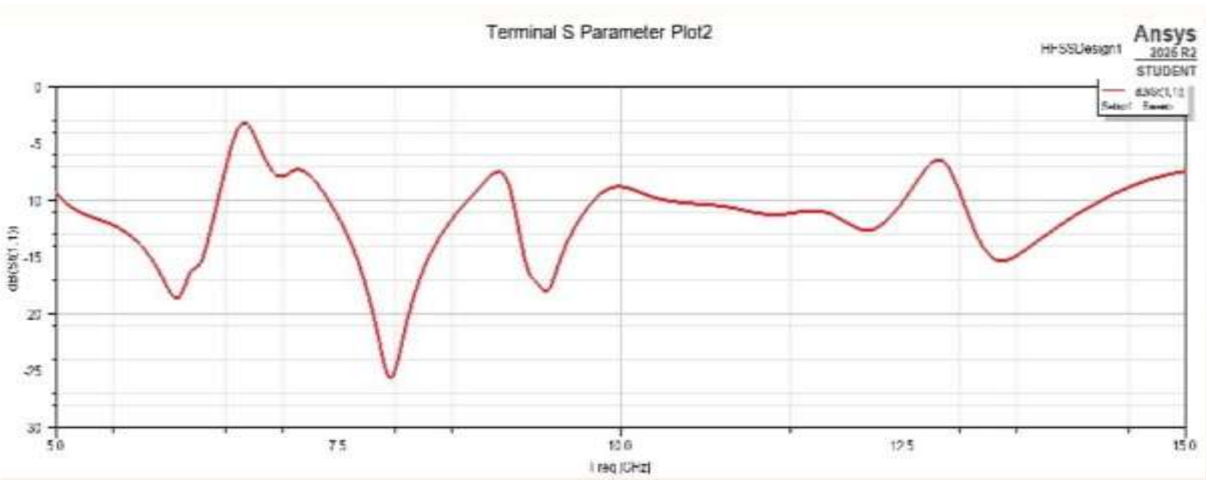


Fig .2: Simulated S11 Parameters

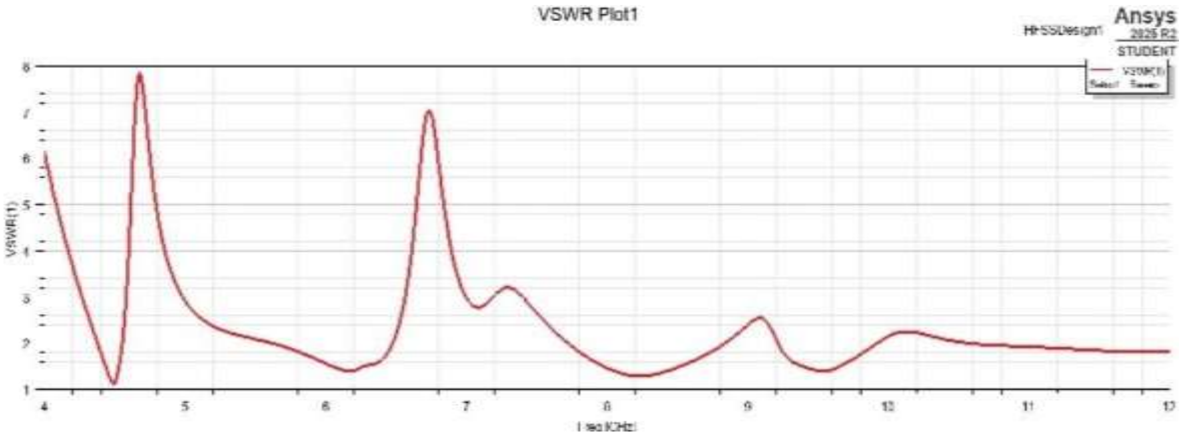


Fig.3: VSWR at 10GHZ

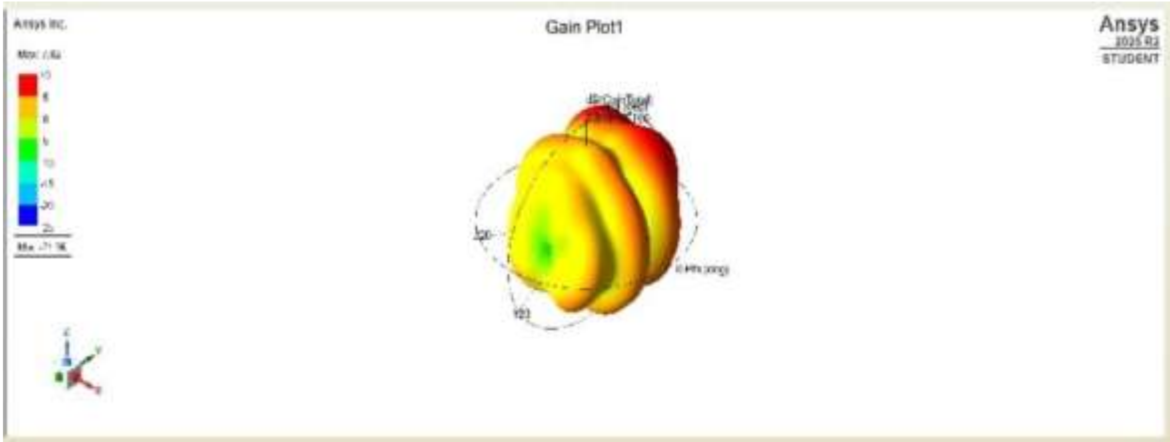


Fig.4: 3D Gain of antenna

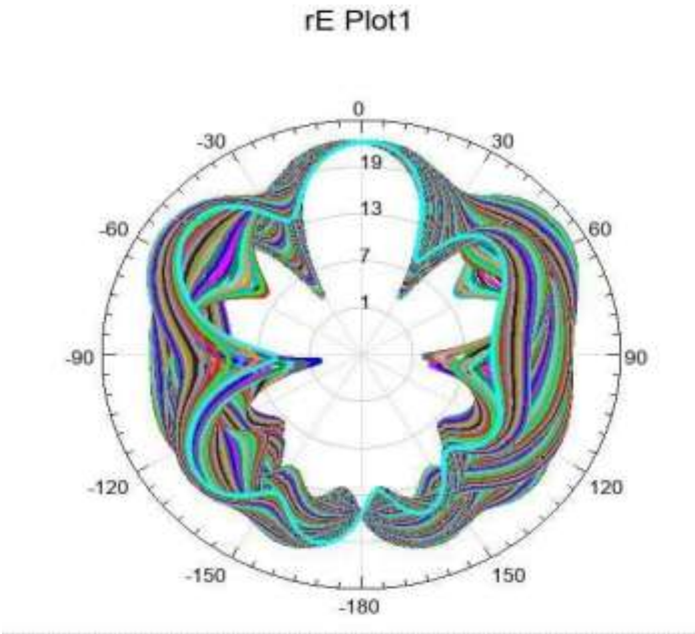


Fig .5:Radiation Pattern

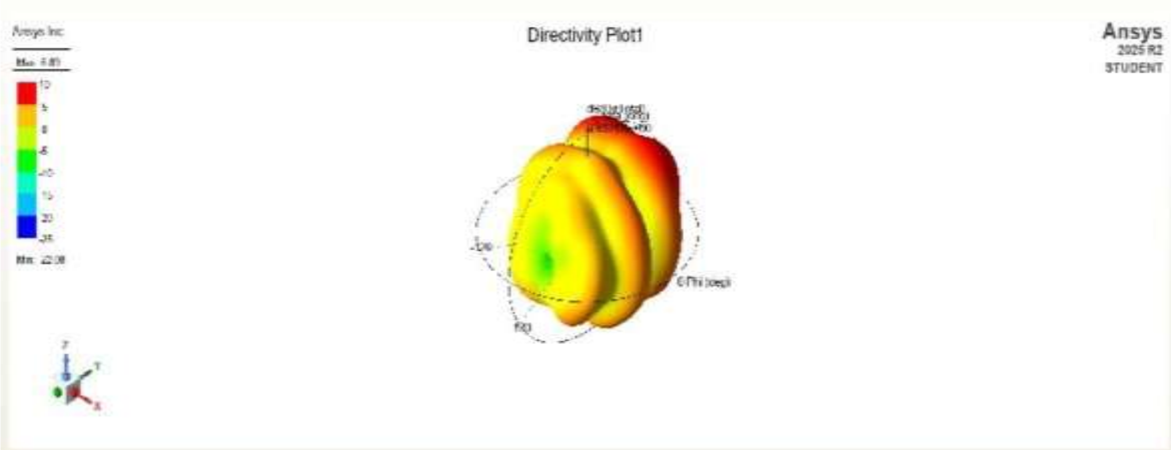


Fig.4: 3D Directivity of antenna

IV. CONCLUSION

This paper presents the successful design and simulation of a microstrip patch antenna operating at X-band frequency using a Rogers substrate. The antenna demonstrates satisfactory performance in terms of return loss, VSWR, gain, and radiation characteristics.

The simulated results indicate that the antenna achieves good impedance matching with return loss below –10 dB and a VSWR less than 2. The gain exceeds 5 dB, and the radiation pattern is directional, making it suitable for high-frequency applications such as radar and satellite communication systems. Despite inherent limitations such as narrow bandwidth, the proposed design provides a compact and efficient solution for X-band applications. Future work may focus on bandwidth enhancement, gain improvement, and the development of multiband or array configurations to further extend the antenna's applicability in advanced communication systems

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