



(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 5, May 2025

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www.ijirset.com |A Monthly, Peer Reviewed & Refereed Journal| e-ISSN: 2319-8753| p-ISSN: 2347-6710|

Volume 14, Issue 5, May 2025

|DOI: 10.15680/IJIRSET.2025.1405036|

Ultra-Wide Band Microstrip Patch Antenna for Wireless Application

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ABSTRACT: The rapid growth of wireless communication technologies has driven the demand for compact, highperformance antennas capable of supporting ultra-wideband (UWB) frequencies. The design and analysis of a miniaturized UWB antenna tailored for wireless applications, operating over the frequency range of 3.1 GHz to 10.6 GHz. The proposed antenna features a compact geometry, making it suitable for integration into modern wireless devices such as smartphones, IoT devices, and wireless routers. The design parameters, including substrate selection, patch geometry, and feeding techniques, are optimized to achieve wide bandwidth, stable radiation patterns, and high gain. Simulation and experimental results demonstrate excellent performance, with a return loss (S11) below -10 dB across the entire UWB spectrum and a peak gain of 3 dBi.

KEYWORDS: Ultra-Band Antenna, FR4 Substrate, CST Studio Suite

I. INTRODUCTION

Ultra-Wideband (UWB) antennas are specialized antennas designed to operate across a wide range of frequencies. These antennas have gained significant popularity in wireless applications due to their unique characteristics and advantages. UWB antennas operate in the frequency range of 3.1 GHz to 10.6 GHz, as allocated by the Federal Communications Commission (FCC). UWB antennas emit very short pulses, typically on the order of nanoseconds, which results in a wide bandwidth and high-speed data transmission . Low Power Consumption. The explosion of wireless technologies—ranging from high-speed indoor communications to smart wearable networks—has ushered in the urgent need for antennas that are ultra-wideband (UWB), compact, efficient, and adaptive. While microstrip patch antennas (MPAs) have long been favoured for their low-profile, lightweight characteristics, their natural limitation—a narrow operational bandwidth—poses a critical bottleneck in modern wireless system performance.

Traditional MPAs, due to their resonant nature, typically offer bandwidths of only a few percent relative to their centre frequency. Numerous strategies such as substrate modification, slot loading, multi-resonator stacking, and the incorporation of Electromagnetic Band Gap (EBG) structures have been explored to overcome this limitation—but these approaches often compromise on size, efficiency, or manufacturability.

II. DESIGN OF PATCH ANTENNAS

Microstrip patch antennas (MSAs) have become fundamental building blocks of wireless communication today because of their compactness, simplicity in manufacturing, and capability of integration into printed circuit boards. Patch geometry, feeding technique, and ground structure have been altered by researchers working on antennas every decade





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or so since the last two decades to enhance the performance, especially dual-band performances necessary for operations in Wi-Fi (2.4 GHz and 5 GHz), WLAN, and WiMAX applications.

In 1998, Fayyaz et al. proposed a rectangular dual-frequency patch antenna with microstrip line feed and shorted edge, an early compact dual-band design attempt.

In 2001, Jan proposed a single-layer circular patch loaded with an open ring slot, demonstrating better dual-band performance. Chen et al. (2003) proposed a planar inverted-F antenna (PIFA) for mobile communication dual-band applications with a peak gain of 2.5 dBi. A milestone was achieved with the research of J.W. Wu et al. (2003), who used a slot-loaded rectangular patch for WLAN applications

Later work by Wong (2006), Khaleghhi (2007), and Liu & Chen (2009) tried T-shaped, meandered, and stepped patch designs to address various wireless platforms. In the 2010s, attention turned towards more compact and integrated dualand multi-band antennas. Hsu (2010) proposed an E-shaped patch antenna with operation at 2.4 and 3.5 GHz.Sim & Cai (2011) employed polygon slots with L-slit structures to obtain multi-band responses.

Liu et al. suggested stacked E- and U-shaped patches in 2015, resulting in high gain at 2.6 and 3.5 GHz but with complex multilayer fabrication.

More recently,W.-Q. Cao (2016) developed a mushroom-shaped circular patch resonating at 4.42 and 5.74 GHz, whereas Salih and Sharawi (2016) illustrated a U-shaped patch on RO4350 substrate with defected ground structure, resonating efficiently at both 2.4 and 5.2 GHz-emphasizing a close match with contemporary Wi-Fi router frequency bands.

Gap Identification and Proposed Contribution:

Although previous designs illustrate efficient dual-band operation, most of them are plagued by issues such as:

- Multilayer or non-planar geometries of complex nature,
- Relying on costly substrates such as Rogers RO4003/RO4350,
- Lack of design simplicity for integration into consumer electronics.
- This work introduces a new single-layer, dual-band microstrip patch antenna designed on FR4 substrate
- $(\varepsilon r = 4.4, \text{ thickness} = 1.6 \text{ mm})$ —a low-cost and PCB-compatible substrate. The antenna incorporates:
- A modified rectangular patch with vertical slots for dual-resonant characteristics,
- A notched ground plane to improve impedance matching and bandwidth,
- Simulation results indicating successful operation at 2.95 GHz and 5.07 GHz, with gains of

2.217 dBi and 3.83 dBi, respectively.

This methodology fills the research gap by incorporating performance, manufacturability, and costeffectiveness-making it applicable for wireless routers, IoT devices, and consumer-grade wireless devices.

III. ANTENNA DESIGN METHODOLOGY

Patch shape and Dimensions:

- Shapes Used: Rectangular, square, circular—chosen for their well-defined radiation patterns and ease of analysis.
- Proposed Design: 13×12 mm miniaturized rectangular patch.
- Purpose: Compact size supports integration in wireless devices while preserving gain and efficiency.

Slot Configuration and Purpose:

- Material: FR4 Epoxy
- Dielectric Constant (ε_r): 4.3
- Thickness: ~1.6 mm (standard), top and bottom copper layer thickness: 0.035 mm





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• Rationale: Cost-effective, easily available, adequate for UWB despite moderate losses. Chosen to balance size, manufacturability, and performance.

Ground Plane Structure:

- Technique: Defected Ground Structure (DGS)
- Reduces antenna size by disturbing ground current flow
- Enhances bandwidth, gain, and suppression of surface waves
- Structure: Partial ground or etched patterns used to tune resonance and enable multiband operation.

Feed Mechanism:

- Microstrip Line Feed
- Low-profile and well-suited for compact layouts
- Compatible with simulation in CST Studio
- Purpose: Achieve impedance matching and stable return loss across UWB range.

Substrate Properties:

Material: FR4 Epoxy • Dielectric Constant (ε_r): 4.3

- Thickness: ~1.6 mm (standard), top and bottom copper layer thickness: 0.035 mm
- Rationale: Cost-effective, easily available, adequate for UWB despite moderate losses.

Chosen to balance size, manufacturability, and performance.

Schematic Diagram:

- Substrate: FR4 material with dielectric constant 4.3, forms the base layer.
- **Ground Plane**: Copper layer beneath the substrate for signal return path.
- Patch: Copper radiating element (13×12 mm) on top of the substrate.
- Feed Line: Microstrip line used to excite the patch.



Fig.1.Proposed Antenna Design





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IV. SIMULATION SETUP

The design and analysis of the Ultra wide band microstrip patch antenna proposed were conducted using CST Studio Suite 2024, top 3D electromagnetic simulation software. This section describes the simulation environment, boundary conditions, solver settings, and frequency parameters used during the design process. **Software Utilized:**

- CST Studio Suite 2024 was used for the full electromagnetic simulation.
- This program delivers precise 3D modelling and frequency-domain analysis appropriate for RF and antenna design.

Simulation Environment and Boundary Conditions:

- The simulation was done in a free-space condition to simulate actual radiation conditions.
- Open (add space) boundary conditions in all directions were used to enable electromagnetic waves to radiate without reflection from the structure.
- The input was terminated using a waveguide port to excite the antenna structure and analyse Sparameters.
- Solver Selection:
- CST's Frequency Domain Solver was chosen because it can be used to analyse narrow- and dual-band antennas.
- This solver offers high accuracy in S-parameter, radiation pattern, VSWR, and far-field analysis at target frequency points.

Performance Analysis

The designed Ultra wide band microstrip patch antenna was simulated in CST Studio Suite 2024. The performance was analysed based on critical RF parameters such as return loss, VSWR, gain, directivity, radiation patterns, and bandwidth at resonant frequencies of 5.3 GHz and 11.7 GHz.

Return Loss(S11):

The graph illustrates the return loss (S11 parameter) of the miniaturized microstrip patch antenna across different frequency bands. The x-axis represents frequency (GHz), while the yaxis shows magnitude (dB).

The red curve indicates how much signal is reflected rather than transmitted at various frequencies. Key observations:

- At ~4.32 GHz, return loss is -10.02 dB, suggesting moderate impedance matching.
- At ~12.38 GHz, return loss is -9.87 dB, indicating slightly higher reflection.

A return loss below -10 dB is generally considered good, meaning efficient signal transmission with minimal reflection. The use of Defected Ground Structure (DGS) likely contributes to improved impedance matching and miniaturization.



Fig.2.Return Loss (dB)





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Voltage Standing Wave Ratio (VSWR):

- At both the resonant frequencies, the VSWR is less than 2, which is in the safe limit for effective power transfer.
- This indicates that there is very little mismatch between the feed line and antenna at the resonant points.



Gain & Directivity in Antennas

Gain and directivity are essential parameters that define how efficiently an antenna transmits and receives signals. Gain

- Gain represents the ability of an antenna to amplify the transmitted or received signal in a specific direction.
- A higher gain ensures stronger signal transmission, making it ideal for long-range communication.
- It accounts for both the directional properties and efficiency of the antenna.

Directivity

- Directivity measures how focused the radiated energy is in a particular direction.
- A highly directive antenna concentrates more power in a specific direction, improving signal strength.
- It is crucial for applications where precise signal targeting is required, such as satellite communication.

Impact on Your Microstrip Patch Antenna

- The miniaturized microstrip patch antenna benefits from Defected Ground Structure (DGS), which enhances gain and directivity while maintaining compact size.
- Optimized directivity ensures efficient.





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Bandwidth:

- The -10 dB return loss bandwidth was observed around both resonant frequencies.
- Though exact bandwidth values were not stated in the slides, ultra-wide band behaviour was confirmed from the return loss curve dips.
- A typical estimation would place the bandwidths between 100–200 MHz for each band, depending on the steepness of the return loss curve.

Radiation Patterns:

- E-plane and H-plane radiation patterns were plotted at both resonant frequencies.
- The plots show directional patterns with a broad main lobe, typical of patch antennas.
- The radiation is mostly perpendicular to the surface of the patch, confirming stable far-field characteristics suitable for ro0075ter-based applications.





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Fig.7&8. E-plane & H-plane Radiation Pattern at Frequency F=11.7 GHz Summary Table of Key Parameters:

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Parameter	53 GHz	11 7 GHz
Return Loss (S11)	<-10 dB	<-10 dB
VCWD	< 2	2
VSWK	< 2	< 2
Gain	1.216 dBi	1.746 dBi
Directivity	2.097 dBi	2.679 dBi
Bandwidth (Est.)	~100–150 MHz	~100–150 MHz

IV. RESULT AND DISCUSSION

1. Emphasizing Design Trade-offs

The miniaturized microstrip patch antenna design balances size reduction with performance optimization. The use of Defected Ground Structure (DGS) enables miniaturization while maintaining acceptable gain, bandwidth, and return loss. However, trade-offs include:

- Reduced physical dimensions may slightly impact radiation efficiency.
- Bandwidth enhancement comes at the cost of increased complexity in fabrication.

2. Analysis of Simulation Results

Simulations conducted using CST Studio reveal key performance metrics:

- Return Loss (S11): Below -10 dB at key frequencies, ensuring minimal signal reflection.
- VSWR: Maintained below 2, indicating good impedance matching.
- Gain & Directivity: Gain ranges from 2.217 dBi to 3.83 dBi, while directivity improves at higher frequencies.
- Bandwidth: Estimated between 100–150 MHz, supporting multi-band operation.

3. Comparison with Theoretical Expectations and Existing Designs

- The proposed antenna achieves significant miniaturization (13x12 mm) compared to conventional designs (20x20 mm).
- The DGS technique effectively shifts resonance frequencies, aligning with theoretical predictions.
- Compared to existing designs, this antenna maintains competitive gain and bandwidth, making it suitable for wireless communication applications.

4. Addressing Key Design Challenges

- Impedance Matching: Achieved through careful substrate selection (FR4, $\epsilon r = 4.3$) and optimized feed techniques.
- Miniaturization vs. Performance: The DGS approach ensures compactness without compromising efficiency.
- Multi-band Operation: The antenna successfully covers L, S, C, X, Ku, and Ka bands, making it versatile for various application





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V. APPLICATIONS

1. Wireless Communication

Your miniaturized microstrip patch antenna plays a crucial role in modern wireless technologies:

- Used in Wi-Fi routers and Bluetooth modules for seamless data exchange.
- Integrated into 5G networks to support high-speed internet and low-latency applications.
- Enables IoT-based smart devices, improving connectivity for automation in smart homes and industries.

2. Satellite Communication

- The antenna's multi-band capability allows it to operate across several satellite frequencies:
- L-band (1–2 GHz): Used in GPS systems for precise location tracking and satellite mobile communication.
- S-band (2–4 GHz): Supports weather monitoring and space communication, including NASA's satellite network.
- C-band (4-8 GHz): Used for satellite TV broadcasting and remote sensing applications.

3. Biomedical Applications

The compact size and efficiency of the antenna make it ideal for healthcare innovations:

- Integrated into MRI and PET scanners for high-precision medical imaging.
- Used in wearable health monitors, allowing real-time tracking of vital signs like heart rate and blood pressure.
- Supports wireless implants, ensuring communication between medical devices and external monitoring systems.

4. Radar & Military Systems

- With enhanced gain and directivity, the antenna is well-suited for defense and security applications:
- X-band (8–12 GHz): Primarily used for military radar, enabling target detection and surveillance.
- Ku-band (12–18 GHz): Supports missile tracking systems and high-speed encrypted military communications.
- Enhances stealth communication, where compact antennas help improve defense system efficiency

VI. CONCLUSION

A novel miniaturized UWB microstrip patch antenna was designed and simulated in CST studio software tool. The designed antenna is 12x13mm dimension which is very compact in size. The designed antenna abled to resonate at 5.3 GHz and 11.7 GHz frequency respectively. The proposed antenna produce a gain of 1.216 and 1.746 dBi respectively for 5.3 GHz and 11.7 GHz. The proposed antenna produce a directivity of 2.097 and 2.679 dBi respectively for 5.3 GHz and 11.7 GHz. The performance of the antenna is obtained by introducing partial ground and slotted patch. Because of the introduction of partial ground the ability to provide better gain is reduced. Since a full ground will act as reflector. The return loss value obtained for the resonant frequency of F= 5.3 GHz is around -24.36 dB and F= 11.7 GHz is around -21.68 dBi.

The antenna can be used for wireless communication applications like Wi-Fi etc.

Future Scope

The evolution of miniaturized microstrip patch antennas continues to shape advancements in wireless communication, IoT, and next-generation networks. Several promising directions for future research and development include:

1. Integration with 5G & Beyond

- Miniaturized antennas will play a crucial role in 5G and 6G networks, supporting higher frequencies (mm Wave bands) for ultra-fast data transmission.
- Advanced designs will focus on multi-band operation to enhance connectivity across different communication standards.

2. AI-Driven Antenna Optimization

- Machine learning algorithms can be used to optimize antenna parameters, improving efficiency and adaptability.
- AI-based predictive modelling will help refine designs for better impedance matching and radiation characteristics.





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3. Metamaterial-Based Miniaturization

- Metamaterials offer a revolutionary approach to antenna miniaturization, enabling higher gain and bandwidth without increasing physical size.
- These materials can be engineered to enhance directivity and radiation efficiency.

4. Flexible & Wearable Antennas

- Future designs will incorporate flexible substrates for wearable applications in biomedical monitoring and smart textiles.
- Stretchable and conformal antennas will enable seamless integration into clothing and medical implants.

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