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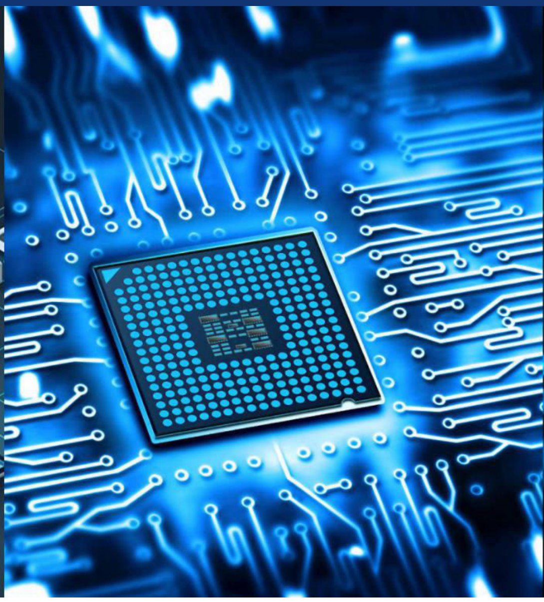


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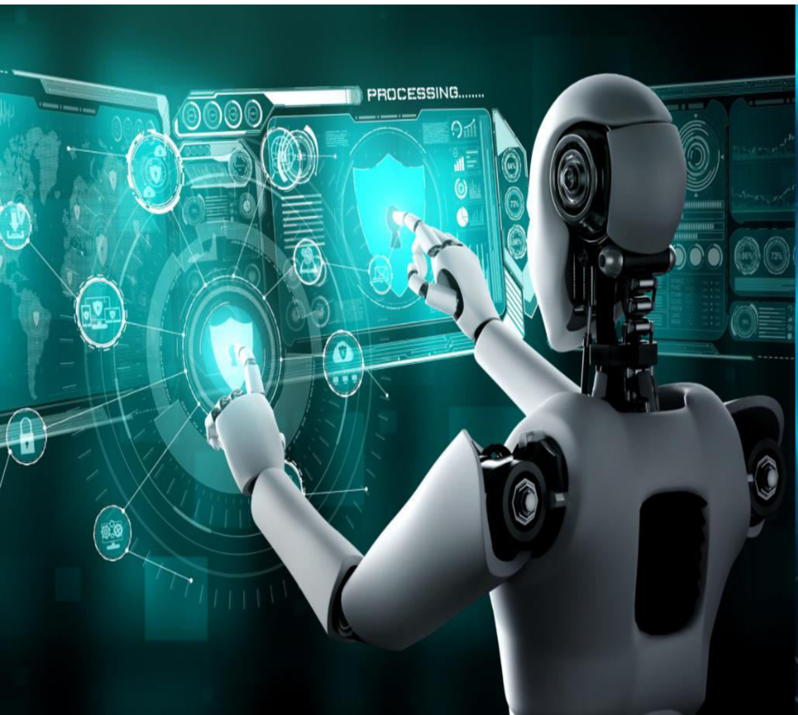

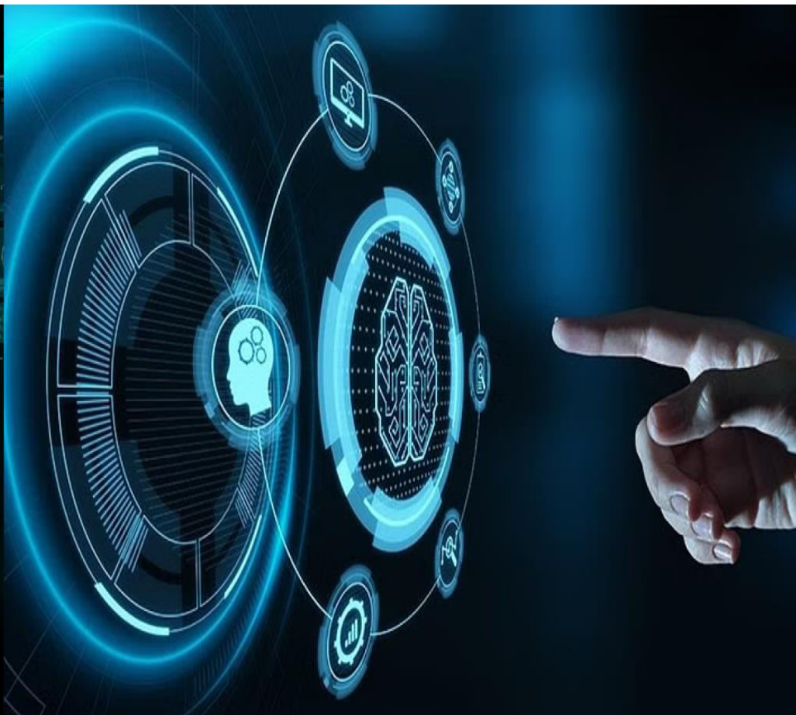

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Dual-Band Microstrip Patch Antenna for Wireless Application

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ABSTRACT: This paper presents the design and analysis of a compact dual-band microstrip patch antenna tailored for wireless router applications. The proposed antenna is developed on an FR4 substrate with a thickness of 1.6 mm, featuring a modified ground plane and dual microstrip feeding lines to optimize performance across two frequency bands. Simulation and measurement results demonstrate effective impedance matching, high radiation efficiency, and low envelope correlation between ports- attributes vital for multiple-input multiple-output (MIMO) configurations. The antenna achieves peak gains of 2.217 dBi at 2.95 GHz and 3.83 dBi at 5.07 GHz, with corresponding directivities of 2.52 dBi and 4.384 dBi, respectively. CST Studio Suite 2024 is employed for electromagnetic modeling and optimization. The design proves suitable for modern wireless communication systems, including radar and infrastructure monitoring, offering benefits such as dual-band operation, low cost, ease of integration, and compact dimensions.

KEYWORDS: Dual-Band Antenna, FR4 Substrate, **CST** Studio Suite

I. INTRODUCTION

The increasing need for wireless connectivity in a seamless manner has spurred considerable progress in the design of antennas, especially in the creation of microstrip patch antennas (MSAs). Due to their low-profile and compact configuration and simplicity in integration with planar circuitry, MSAs have emerged as a ubiquitous element of applications that extend from mobile communication and RFID to satellite systems and wireless networking. Among the changing needs in these systems is the capacity to handle multi-band operation, particularly the popular 2.4 GHz and 5 GHz Wi-Fi bands in today's routers and smart devices. Even with broad usage, traditional MSAs are frequently plagued by bottlenecks in bandwidth, gain, radiation efficiency, and polarization versatility. These issues call for on-going development in antenna design methodology to improve performance without sacrificing simplicity or miniature size. Researchers have investigated a number of strategies, such as slot-loading, stacked configurations, and ground plane adjustments, to mitigate these problems. Of particular interest, slot-based patch designs provide an easy method to obtain dual-band operation by creating multiple current paths, thereby allowing for separate resonances within one structure.

A dual-band microstrip patch antenna is considered in this study, specifically optimized for wireless routers. It was designed using a 1.6 mm thickness FR4 substrate and consists of a vertically slotted modified rectangular patch, a stepped feed architecture, and a notched ground plane. They are modifications incorporated to improve the impedance matching, increase the inter-band isolation, and enhance radiation characteristics. The antenna functions effectively in the 2.95 GHz and 5.07 GHz frequency bands, as required by 2.4/5 GHz Wi-Fi routers. Electromagnetic simulation is performed with CST Studio Suite 2024, and important performance parameters like return loss, VSWR, gain, directivity, and radiation patterns are studied. The designed structure realizes gain of 2.217 dBi and 3.83 dBi at the corresponding bands, proving its applicability for practical implementation.

This research helps to advance the development of miniaturized and low-cost antenna solutions for future wireless communication systems, providing a promising candidate for integration into IoT devices, smart routers, UWB systems, and other dual-band wireless platforms. It also paves the way for further improvement through material optimization, miniaturization, and adaptive reconfigurable antenna technologies.

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II. DESIGNS 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 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 dual- and 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 ($\varepsilon r = 4.4$, thickness = 1.6 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 cost-effectiveness-making it applicable for wireless routers, IoT devices, and consumer-grade wireless devices.

III. ANTENNA DESIGN METHODOLOGY

The computation of the proposed dual-band microstrip patch antenna design was undertaken in CST Studio Suite 2024. The antenna is designed to operate specifically at 2.95 GHz and 5.07 GHz, which closely correspond to the 2.4 GHz

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and 5 GHz bands of Wi-Fi communication devices. The approach involves a small structure size, low-cost materials, and easy fabrication process.

Patch Shape and Dimensions:
The radiating patch is based on a rectangular shape, altered with three vertical slots to bring in extra current paths and achieve dual-frequency resonance.

The patch dimensions are about:
- Width: ~21 mm
- Height: ~14 mm
- Slot width: 1 mm
- Slot spacing: Spaced uniformly at 1 mm

The bottom edge of the patch has a stepped structure, which is involved in fine-tuning impedance and enhancing return loss.

Slot Configuration and Purpose:
Three narrow vertical slots are placed in the upper half of the patch. The slots:
- Change the surface current distribution
- Provide multiple resonant paths
- Make dual-band operation possible by providing coupling at both 2.95 GHz and 5.07 GHz frequencies

The slots provide compactness while keeping the desired frequency response without an increase in the size of the patch.

Ground Plane Structure:
The ground plane covers the whole base of the substrate (45 mm × 40 mm) but has a central triangular notch along its top edge. This adjustment serves to:
- Enhance impedance matching
- Regulate the surface wave propagation
- Increase bandwidth and return loss at target frequencies

The notch structure is one of the major contributors to the fine-tuning of resonant behavior.

Feed Mechanism:
The microstrip line feed is used to feed the antenna, and it is extended directly from the patch base. This technique:
- Provides ease of integration with conventional PCBs
- Ensures minimal loss of signal
- Provides a direct, low-complexity feed appropriate for commercial applications

The stepped extension at the patch base also serves as a matching section for smoother energy transition.

Substrate Properties:
The substrate material used here is FR-4 (Flame Retardant 4), commonly employed in PCB production owing to its cost-performance balance. Some of the important properties are:
- Relative permittivity (ε_r): 4.4
- Thickness: 1.6 mm
- Loss tangent ($\tan\delta$): ~0.02

FR-4 is used because of its low cost, easy availability, and compatibility with planar integration of circuits, resulting in an extremely manufacturable design.

Schematic Diagram:
The configuration of the given antenna consists of:
- A slot-loaded rectangular patch
- A feed line stepped out from the lower center of the patch
- A notched ground plane at the back of the substrate.

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All these components are simulated and modeled with CST Studio Suite 2024, which allows accurate measurement of return loss, VSWR, radiation pattern, and gain over the desired frequency ranges.

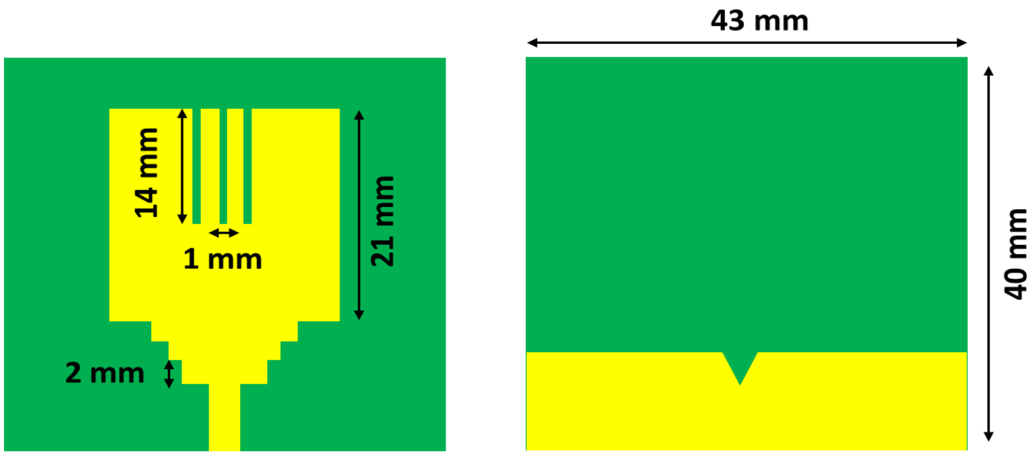

Fig.1.Proposed Antenna Design

IV. SIMULATION SETUP

The design and analysis of the dual-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 S-parameters.

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.

Frequency Range:

The antenna was simulated for a frequency range of 2 GHz to 6 GHz that includes:

- The lower Wi-Fi band with its center at 2.95 GHz
- The upper Wi-Fi band with its center at 5.07 GHz

This range will allow for precise analysis of return loss, bandwidth, and gain across the anticipated dual-band operation.

V. PERFORMANCE ANALYSIS

The designed dual-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 2.95 GHz and 5.07 GHz.

Return Loss (S11):
The return loss plot shows effective impedance matching at both target frequencies:
- At 2.95 GHz, the return loss goes below -10 dB, showing high resonance.
- At 5.07 GHz as well, the return loss goes below -10 dB, verifying the effective dual-band operation.

These values represent that the antenna radiates the input signal effectively at both bands with negligible reflection.

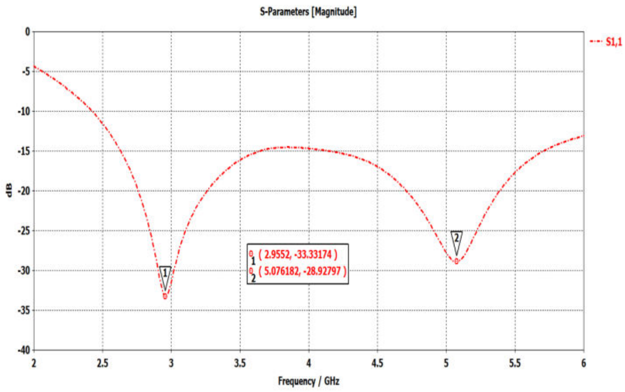

Fig.2.Return Loss (dB)

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.

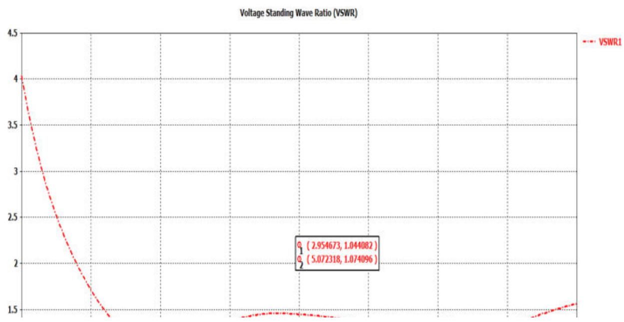

Fig.3.Voltage Standing Wave Ratio (VSWR)

Frequency / GHz

Gain and Directivity:

The simulated gain and directivity of the antenna at the resonant frequencies are as follows:

Parameter	2.95 GHz	5.07 GHz
Gain (dBi)	2.217	3.83
Directivity (dBi)	2.52	4.384

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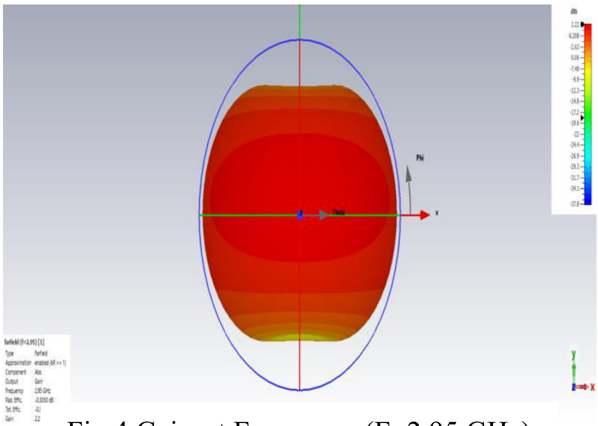

Fig.4.Gain at Frequency (F=2.95 GHz) is 2.217 dBi

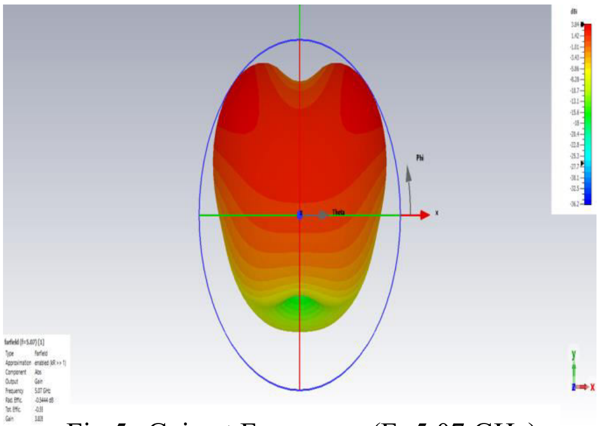

Fig.5. Gain at Frequency (F=5.07 GHz) is 3.83 dBi

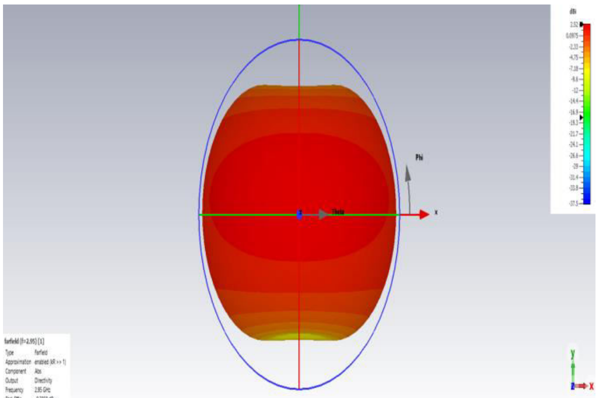

Fig.6. Directivity at Frequency (F=2.95 GHz) is 2.52 dBi

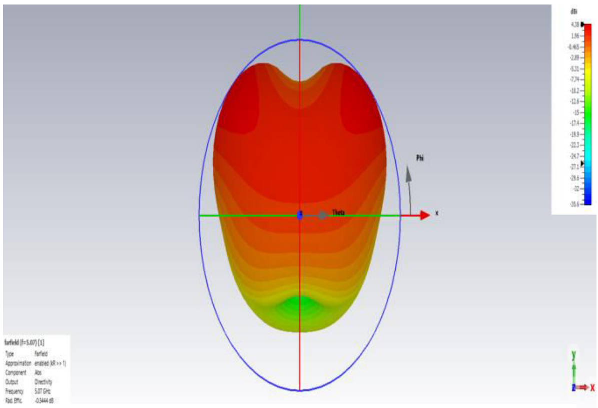

Fig.7. Directivity at Frequency (F=5.07 GHz) is 4.384 dBi

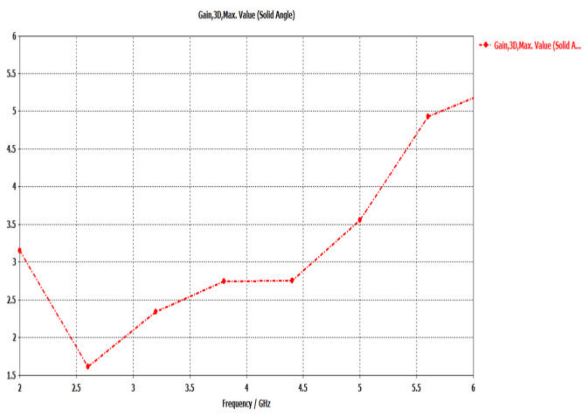

Fig.8. Simulated 3D Gain (Maximum Value)

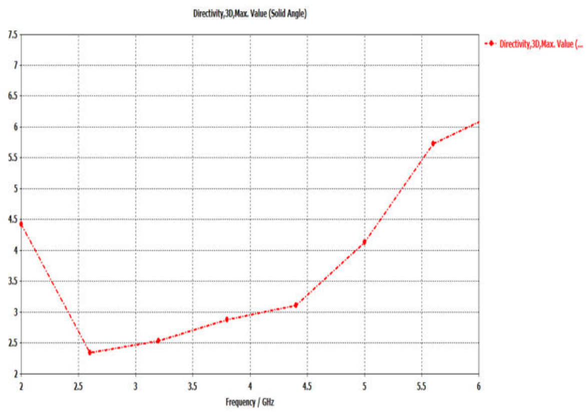

Fig.9. Simulated 3D Directivity (Maximum Value)

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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, dual-band behavior 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.

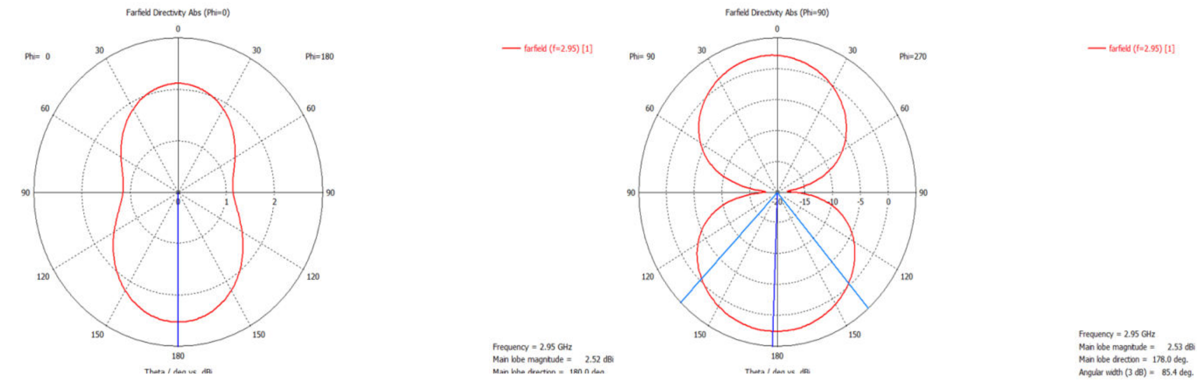

Fig.10. E-plane & H-plane Radiation Pattern at Frequency F=2.95 GHz

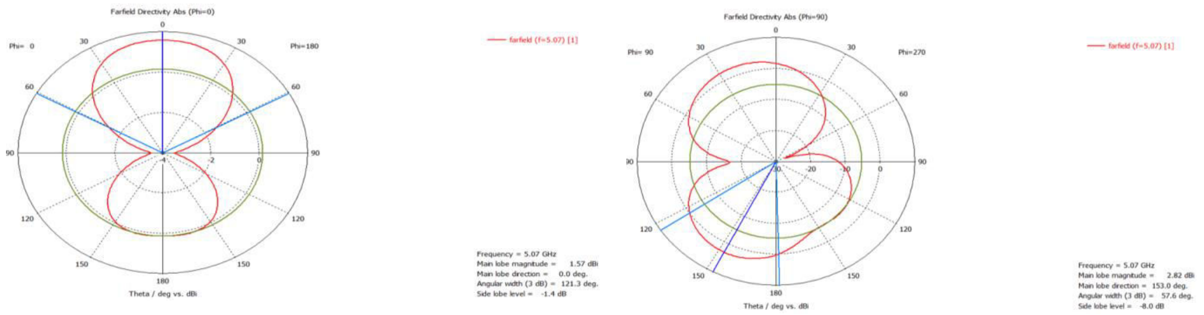

Fig.11. E-plane & H-plane Radiation Pattern at Frequency F=5.07 GHz

Summary Table of Key Parameters:

Parameter	2.95 GHz	5.07 GHz
Return Loss (S11)	< –10 dB	< –10 dB
VSWR	< 2	< 2
Gain	2.217 dBi	3.83 dBi
Directivity	2.52 dBi	4.384 dBi
Bandwidth (Est.)	~100–150 MHz	~100–150 MHz
Radiation Pattern	Stable (E/H)	Stable (E/H)

VI. RESULTS AND DISCUSSION

Simulation and Performance Analysis:
The proposed dual band microstrip patch antenna, simulated using CST Studio Suite 2024, targets Wi-Fi applications at 2.95 GHz and 5.07 GHz.

Key Simulation Results:

- Return Loss (S11):
  - Strong resonances at both 2.95 GHz and 5.07 GHz with S11 < –10 dB.
- VSWR:
  - Less than 2 at both bands, indicating effective impedance matching.
- Gain & Directivity:
  - At 2.95 GHz: Gain = 2.217 dBi, Directivity = 2.52 dBi
  - At 5.07 GHz: Gain = 3.83 dBi, Directivity = 4.384 dBi
- Radiation Patterns:
  - Stable, omnidirectional in both E- and H-planes.
- Bandwidth:
  - Adequate for Wi-Fi bands, based on S11 < –10 dB.

Comparison with Theoretical Expectations and Existing Designs:

- Matches theoretical performance for slot-modified patches.
- Unlike stacked or T-slot designs, it achieves dual-band operation with a simple, single-layer structure.
- Compared to RO4003/RO4350-based antennas, FR4 use lowers cost while delivering sufficient radiation characteristics.
- Slightly lower directivity, but suitable for typical router and IoT needs.

Addressing Key Design Challenges:

- Small Size: Achieved using a slot-loaded rectangular patch.
- Dual-Band Operation: Covers both 2.95 GHz and 5.07 GHz Wi-Fi bands.
- Ease of Integration: Planar, single-layer layout is PCB-friendly.
- Low-Cost Fabrication: FR4 substrate ensures economic production.

Emphasizing Design Trade-offs:
As the antenna design maximizes compactness and dual-band performance, some trade-offs are noted:

- Gain vs. Size:
  - The small patch size and FR4 restrict peak gain over larger or multi-layer antennas.
- Bandwidth vs. Efficiency:
  - While adequate bandwidth is realized, FR4's increased loss tangent has a slight effect on radiation efficiency, particularly at higher frequencies.

However, for consumer applications such as Wi-Fi routers, these compromises are tolerable and provide the best possible balance between performance, price, and manufacturability.

VII. APPLICATIONS

Application Suitability:
The designed dual-band microstrip patch antenna demonstrates strong performance, compact size, and low-cost fabrication—making it highly suitable for various modern wireless systems.

Wi-Fi Routers (2.4 GHz and 5 GHz Bands):
Optimized for operation at 2.95 GHz and 5.07 GHz, aligning closely with standard Wi-Fi bands. Its planar, compact design fits easily onto router PCBs.

Why Ideal:

- Supports simultaneous dual-band operation, boosting data throughput.
- Compact form factor fits small router enclosures.
- Cost-effective, using FR4 substrate.

Smart IoT Systems:
Perfect for IoT devices needing compact, dual-band antennas for reliable wireless communication in smart homes and industrial environments.
Why Ideal:

- Lightweight and low-profile, suitable for embedded systems.
- Provides sufficient gain and directivity for indoor use.
- Ensures efficient, dual-band connectivity for cloud and local networks.

Compact Wireless Modules:
Suitable for space-constrained applications such as USB adapters, sensors, and wearables.
Why Ideal:

- Enables seamless integration into compact and portable devices.
- Offers good impedance matching and consistent performance.
- Dual-band operation enhances connectivity in dense wireless environments.

VIII. CONCLUSION

This paper introduced the design and simulation of an optimized dual-band microstrip patch antenna for wireless communication applications, i.e., Wi-Fi routers operating at 2.4 GHz and 5 GHz bands. The antenna was designed using CST Studio Suite 2024 and fabricated on FR4 substrate material with a thickness of 1.6 mm, providing a low-cost, compact, and easily integratable solution.

The antenna under consideration has a vertically slotted modified rectangular patch and notched ground plane, which provides effective dual-frequency resonance. Simulation has shown that the antenna had good impedance matching with return loss (S11) less than –10 dB at both frequencies. Major findings are as follows:

- Getting gain values of 2.217 dBi and 3.83 dBi at frequencies 2.95 GHz and 5.07 GHz, respectively.
- Demonstrating directivity of 2.52 dBi and 4.384 dBi at respective frequencies.
- Having a VSWR value lower than 2 in both resonant bands.
- Robust and preferred E-plane and H-plane radiation patterns for wireless communication coverage.

The proposed antenna has some important advantages compared to traditional designs:

- Compact dimensions, easy integration into space-limited devices.
- Easy single-layer structure, avoiding the complexity of multilayer or stacked configurations.
- Low cost of fabrication, using the readily available FR4 substrate.
- Good dual-band performance, without compromising gain or radiation stability.

IX. FUTURE SCOPE

Although the existing design effectively addresses the requirements of dual-band wireless applications, the following improvements could be investigated:

Reconfigurable designs: Incorporating tunable slots or varactor diodes to switch dynamically between various frequency bands.
Improved substrate materials: Employing low-loss substrates like Rogers RO4003 to enhance radiation efficiency at higher frequencies.

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Prototype fabrication and testing: Measurement of S-parameters, gain, and radiation patterns in real-world devices to confirm the simulated results.
Miniaturization methods: Continuing to miniaturize the antenna footprint with minimal loss of performance using met materials or innovative feeding structures.

The presented antenna offers a solid foundation for the development of compact, high-performance wireless communication systems in the future, especially in Wi-Fi routers, IoT modules, and smart devices.

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