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Innovative Elliptical Patch Antenna Design with Bottom Strip for High-Performance Multiband Wireless Networks



Abstract: - This paper presents a comprehensive investigation of a novel elliptical patch antenna integrated with a bottom strip, designed for multiband operation in advanced wireless communication systems. Fabricated on an FR-4 substrate ($\epsilon_r = 4.4$), the antenna achieves a compact, cost-effective, and mechanically robust structure, while delivering stable radiation characteristics across multiple frequency bands. HFSS-based simulations reveal efficient performance over five distinct operating bands ranging from 5 GHz to 24 GHz, covering essential standards such as WLAN, WiMAX, 5G, and satellite communication. The antenna exhibits excellent impedance matching with return losses of -22.68 dB, -26.25 dB, -30.17 dB, $-18.00/-26.00$ dB, and -44.60 dB at resonant frequencies of 5.20, 6.26, 7.62, 10.14/11.64, and 17.60 GHz, respectively. Corresponding VSWR values remain well below the acceptable threshold of 2, indicating superior signal transmission and reduced reflection. The bandwidth enhancement, and 2D/3D radiation pattern analyses further validate the antenna's suitability for modern wireless networks. Comparative evaluation with existing designs confirms the proposed antenna's advantage in achieving wideband multi resonance behavior, thereby underscoring its potential in next-generation communication applications.

Keywords: Multiband, Return Loss, VSWR, HFSS, Radiation Pattern, 5G, WLAN, WiMAX

1. Introduction

The rapid evolution of wireless communication technologies has generated an increasing demand for compact, efficient, and multiband antennas capable of supporting diverse frequency bands. Contemporary wireless standards such as Wi-Fi, WiMAX, 5G, and the Internet of Things (IoT) necessitate devices that operate seamlessly across multiple frequency ranges, thereby reducing the need for multiple antennas, which in turn minimizes device size and manufacturing cost [1, 2]. Among the various antenna types, microstrip patch antennas are extensively favored for their low profile, lightweight construction, ease of fabrication, and compatibility with printed circuit board (PCB) technology [3]. However, these antennas inherently suffer from limitations including narrow bandwidth, modest gain, and susceptibility to substrate characteristics, which restrict their performance in multiband and broadband applications [4]. To overcome these challenges, significant research efforts have focused on innovative antenna geometries and structural modifications. Techniques such as fractal patch designs, defected ground structures (DGS), metamaterial-inspired configurations, and slot-loaded patches have been explored to enhance bandwidth and achieve multiband operation [5, 6]. For example, Paul et al. [7] demonstrated a tri-band slot antenna employing split-ring resonators, while Gupta and Shrivastava [8] proposed a dual circular slot antenna optimized for multiband functionality. More recently, the focus has shifted toward compact antenna designs tailored for 5G millimeter-wave (mmWave) applications [9], reconfigurable antennas suited for cognitive radio systems [10], and hybrid geometries combining elliptical and rectangular patch elements [11]. Despite these advancements, challenges persist in designing antennas that provide wide frequency coverage, robust impedance matching, and stable radiation patterns without increasing antenna profile or complexity. In this work, we propose

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a novel elliptical patch antenna augmented with a bottom strip to address these issues. The antenna is designed to operate across five key frequency bands spanning 5 to 24 GHz, targeting applications in WLAN, WiMAX, 5G, and satellite communication.

Table 1: compares the proposed antenna with representative designs from the literature on qualitative metrics.

Ref.	Technique/ Geometry	Bands / Type	Substrate	Size (relative)	Min S11 (dB)	Complexity	Remarks
[1]	Slot + SRR loaded	Tri-band	FR-4	Compact	-20	Medium	Good isolation via SRR
[4]	Dual circular slots	Tri-band	FR-4	Medium	-15	Low	Simple PCB process
[16]	Defected Ground (DGS)	Wideband	FR-4	Compact	-20	Medium	Impedance shaping via DGS
[17]	EBG/HIS backed	Broadband	FR-4	Medium	-15	High	Surface-wave suppression
[27]	EBG- integrated patch	Wideband	Rogers/F R-4	Medium	-18	High	Lower coupling
[28]	U-slot patch	Wideband	FR-4	Compact	-15	Low	Classic bandwidth extension
Proposed	Elliptical + bottom strip	Five bands (5–24 GHz)	FR-4	Compact (24×32×1. 6 mm ³)	-22 to -45	Low	Single-layer, PCB-friendly

The main contributions of this study include:

- The design and optimization of a novel elliptical patch antenna integrated with a bottom strip to achieve multiband performance.
- Comprehensive coverage of 5–24 GHz frequency bands relevant to modern wireless standards.
- Detailed simulation analyses of key performance metrics such as return loss, VSWR, gain, and radiation efficiency using HFSS software.
- A comparative performance evaluation against existing antenna designs documented in the literature.

This introduction also synthesizes foundational and contemporary research on multiband and broadband microstrip antennas, emphasizing geometry-driven techniques such as slotting and parasitic element integration, ground-plane engineering involving defected ground structures (DGS) and electromagnetic bandgap (EBG) surfaces, miniaturization approaches like shorting pins and meandered paths, and reconfigurability for cognitive and 5G systems [12–17]. Classical antenna theory and design principles, as presented in authoritative texts by Balanis [18], Pozar [19], Garg et al. [20], James & Hall [21], and Volakis [22], provide the theoretical underpinning for understanding the radiation, impedance, and bandwidth characteristics of printed antennas. To realize multiple resonances within a compact footprint, researchers have employed strategies such as resonant U- and E-shaped slots, fractal geometries, and parasitic elements to excite closely spaced modes and control current distribution [23]. The incorporation of DGS and EBG structures has proven effective in suppressing surface waves, improving input impedance matching, and enhancing bandwidth, often without significantly increasing antenna thickness [24, 25]. For mmWave 5G front-ends, elliptical, circular, and hybrid antenna topologies are increasingly favored due to their robust impedance characteristics over wide frequency sweeps, as well as ease of integration and packaging [26]. Representative works include tri-band and wideband designs utilizing split-ring resonators and slot loading [7], dual-/multislot patches aimed at WLAN and WiMAX applications [8], and U-slot or stacked patch configurations that extend bandwidth while maintaining planar form factors [27]. DGS-based

antennas have demonstrated improved impedance matching and radiation efficiency by perturbing ground currents [28], while EBG and high-impedance surfaces mitigate mutual coupling and surface-wave losses, critical for compact antenna arrays [22, 24]. In addition, system-level analyses for 5G/mmWave communications highlight the significance of stable antenna gain and beamforming capability in dynamic user scenarios [16–19]. For low-cost IoT and wearable devices, planar monopoles and patch antennas fabricated on FR-4 substrates remain attractive, although meticulous control of effective permittivity, dielectric loss tangent, and current distribution is essential to preserve radiation efficiency [15].

Compared to conventional designs, the proposed elliptical patch antenna with a bottom strip provides a compact, single-layer, PCB-compatible structure that ensures multiband performance while maintaining design simplicity. The hybrid geometry supports multiple current paths and modal excitations, which enables the antenna to achieve five distinct operating bands without relying on complex stacking techniques or active tuning mechanisms. Furthermore, the antenna consistently exhibits VSWR values below 2 at all resonant frequencies, confirming excellent impedance matching and efficient radiation [18-22].

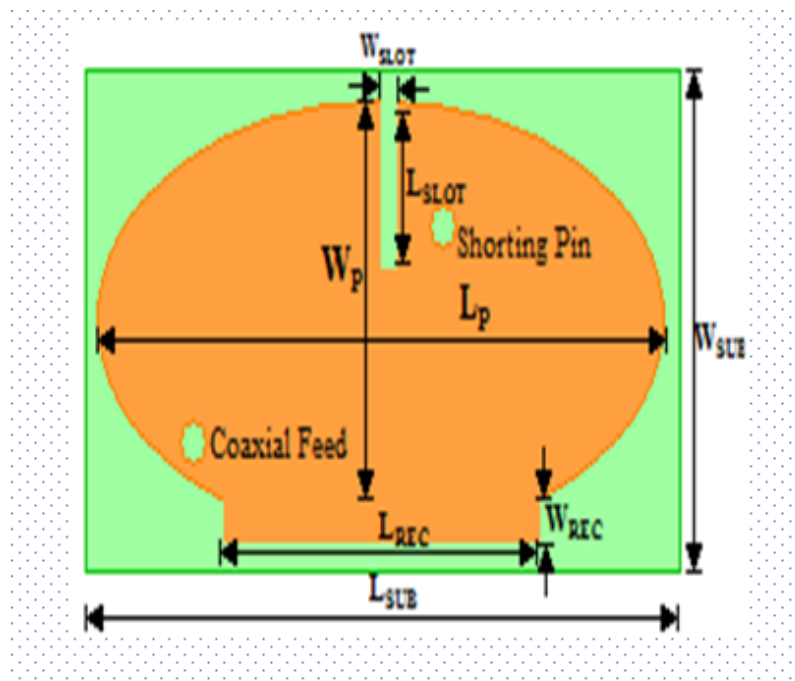
The multiband capability of the proposed antenna makes it suitable for a wide range of modern wireless applications, including:

- WLAN systems (5 GHz band)
- WiMAX and 5G New Radio (sub-6 GHz and mm-wave bands)
- X-band satellite communication
- Internet of Things (IoT) networks and smart device integration

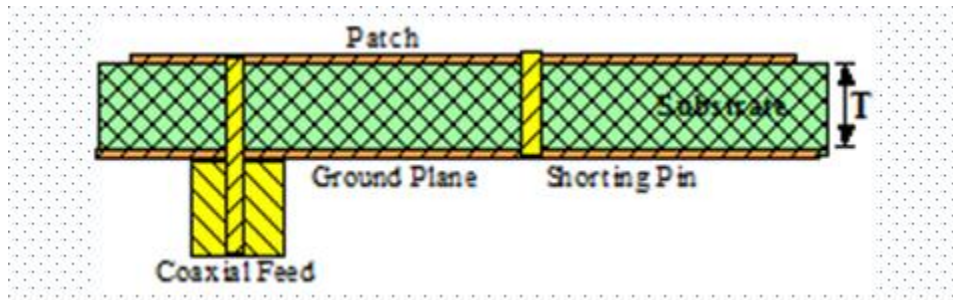
These features highlight the proposed antenna as a versatile, high-performance solution for emerging wireless communication technologies.

2. Antenna Design and Construction

The proposed antenna is designed on an FR-4 epoxy substrate with dimensions of $24 \text{ mm} \times 32 \text{ mm} \times 1.6 \text{ mm}$, a dielectric constant of 4.4, and a 0.035 mm copper cladding. FR-4 has been selected due to its wide availability, low fabrication cost, mechanical stability, and suitability for compact microwave and wireless applications. The radiating element employs a hybrid geometry, combining an elliptical patch with a rectangular bottom strip. The elliptical patch effectively supports multiple resonant modes by altering the surface current distribution along its major and minor axes, thereby enabling multiband operation over a broad frequency range.



(a)



(b)

Fig. 1: (a) Top view of the proposed antenna structure, and (b) side view illustrating the substrate and metallization details.

Table 2: Geometrical configuration and key dimensions of the antenna

Elements	Value (mm)
(Rectangular Bottom Strip Length) L_{REC}	15.5
(Rectangular Bottom Strip Width) W_{REC}	1.85
(Elliptical Patch Major Axis Length) L_P	29
(Elliptical Patch Minor Axis Width) W_P	10
(Slot Length) L_{SLOT}	10
(Slot Width) W_{SLOT}	0.5
Relative to Patch Center; Feed Location Affects Matching Feed Position (X, Y)	(-3, 5)
Relative To Patch Center; Position of Shorting Pin Position (X, Y)	(4, -11)

Meanwhile, the rectangular strip enhances impedance matching and improves radiation efficiency by ensuring efficient coupling between the feed and the patch. Collectively, these features yield a compact, versatile, and high-performance antenna tailored for modern multiband wireless communication systems. In the proposed antenna design, the structural parameters are defined as follows in table 2. The rectangular bottom strip has a length of $L_{REC}=15.5$ mm and a width of $W_{REC}=1.85$ mm. The main elliptical patch is characterized by a major axis length of $L_P=29$ mm and a minor axis width of $W_P=10$ mm. A narrow slot is introduced on the patch with a length of $L_{SLOT}=10$ mm and a width of $W_{SLOT}=0.5$ mm, which helps in generating additional resonances and improving impedance characteristics.

The feed point is located at $(-3, 5)$ mm relative to the patch center, ensuring proper impedance matching. Furthermore, a shorting pin is positioned at $(4, -11)$ mm relative to the patch center, which controls the effective electrical length and significantly influences the resonant frequencies of the antenna.

3. Results and Discussion

The proposed antenna design was simulated in ANSYS HFSS, which employs the finite element method (FEM) to solve Maxwell's equations. The simulation setup incorporated wave port excitation, radiation boundaries, and adaptive meshing to ensure reliable results. A frequency sweep ranging from 5 GHz to 25 GHz was performed to evaluate the antenna's performance. Key parameters such as return loss (S11), VSWR, operational bandwidth, gain, and radiation patterns were systematically analyzed. Furthermore, mesh convergence tests were conducted to confirm the accuracy and stability of the results, ensuring the robustness of the simulation. The performance of the proposed elliptical patch antenna integrated with a bottom strip has been thoroughly evaluated in terms of its operating frequency range, resonant frequencies, return loss, and VSWR demonstrated in table 3. The antenna achieves five distinct operating bands between 5.0 GHz and 24.0 GHz, thereby demonstrating its capability for multiband operation. In the first band (5.00–5.42 GHz), the antenna resonates at 5.20 GHz with a return loss of -22.68 dB and a VSWR of 1.3, indicating excellent impedance matching. The second band (6.00–6.54 GHz) resonates at 6.26 GHz, achieving an even better return loss of -26.25 dB with a VSWR of 1.2. Similarly, the third

band (7.30–7.90 GHz) exhibits resonance at 7.62 GHz, where a very low VSWR of 1.1 ensures minimal reflection. The fourth wideband (9.79–13.28 GHz) supports dual resonances at 10.14 GHz (−18.00 dB, VSWR 1.5) and 11.64 GHz (−26.00 dB, VSWR 1.4), confirming stable operation across a broad bandwidth.

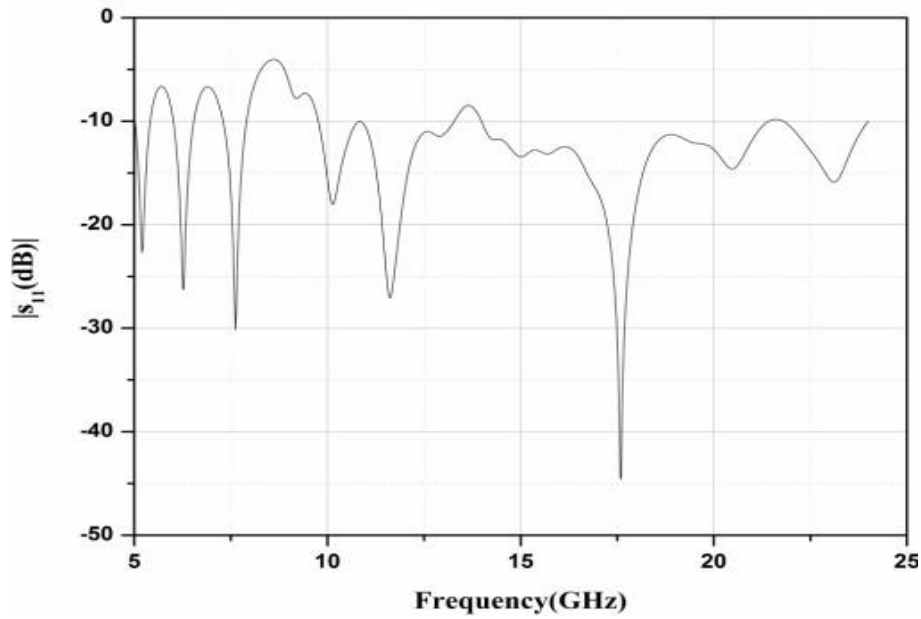


Fig. 2: Simulated return loss (S11) characteristics of the proposed antenna across the operating frequency range.

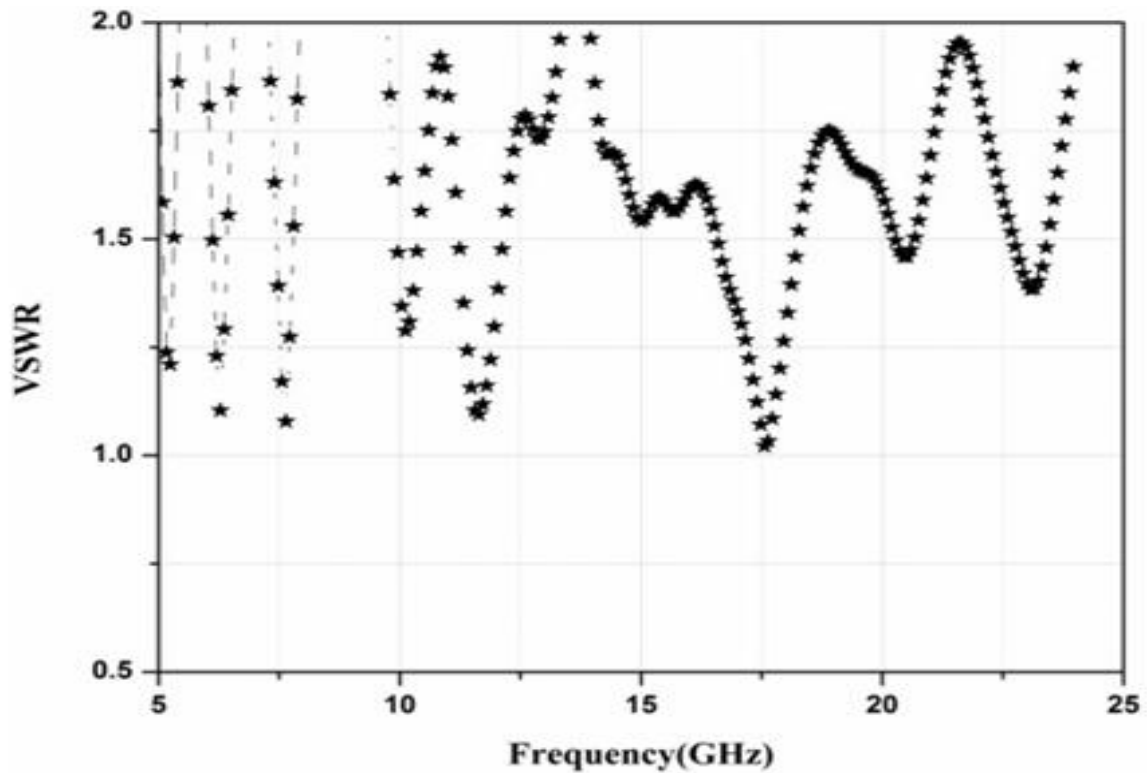


Fig. 3: Simulated VSWR characteristics of the proposed antenna over the operating frequency band.

Finally, the fifth band (14.00–24.00 GHz) resonates strongly at 17.60 GHz with the best return loss of –44.60 dB and a VSWR of 1.2, ensuring maximum power transfer and superior efficiency.

Table 3: Resonant frequencies, bandwidths, and VSWR performance of the designed antenna

Band No.	Operating Frequency Range (GHz)	Resonant Frequency (GHz)	Return Loss (dB)	VSWR
1	5.00 – 5.42	5.20	-22.68	1.3
2	6.00 – 6.54	6.26	-26.25	1.2
3	7.30 – 7.90	7.62	-30.17	1.1
4	9.79 – 13.28	10.14	-18.00	1.5
		11.64	-26.00	1.4
5	14.00 – 24.00	17.60	-44.60	1.2

Across all resonant frequencies, the VSWR remains consistently below 2, satisfying the condition for good impedance matching. Furthermore, the radiation patterns exhibit omnidirectional characteristics in the azimuth plane and stable elevation patterns, making the antenna highly suitable for wireless and satellite communication applications. A comparative assessment with existing literature highlights that the proposed design provides broader coverage and improved return loss performance than conventional patch and slot antennas, thereby confirming its effectiveness for modern multiband communication systems.

The radiation characteristics of the proposed elliptical patch antenna with a bottom strip were analyzed at different resonant frequencies to validate its suitability for multiband wireless applications. At 5.20 GHz (Fig. 4), the antenna exhibits a well-defined 2D radiation pattern at $\phi = 0^\circ$, which demonstrates stable performance with an almost omnidirectional distribution in the azimuth plane.

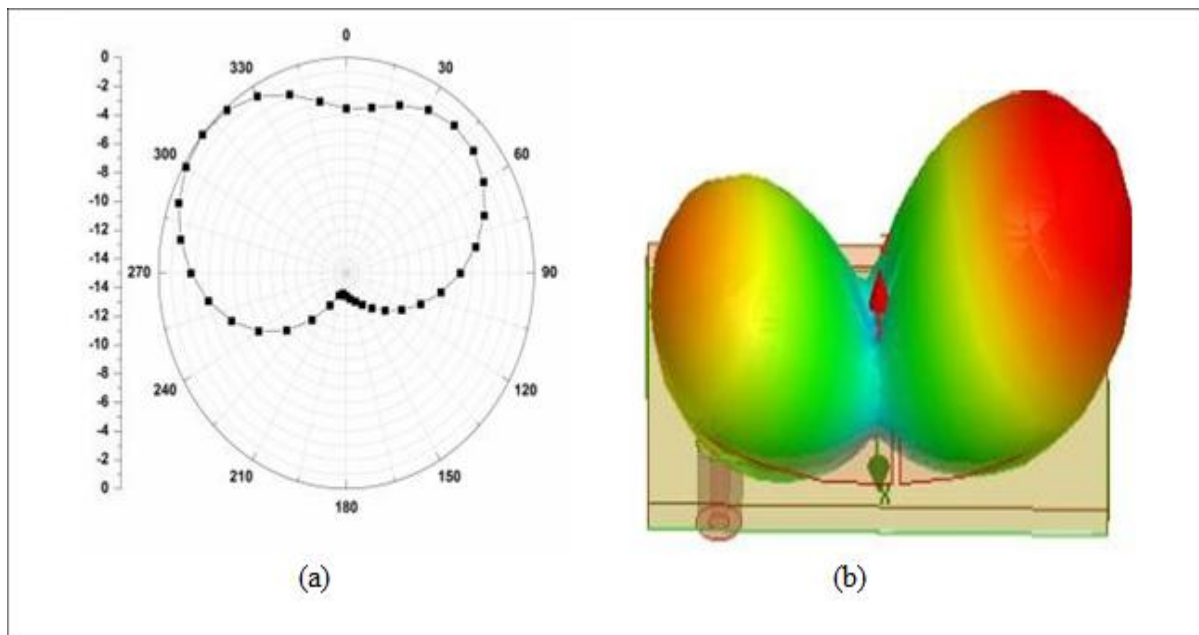


Fig. 4: Simulated radiation patterns of the proposed antenna at 5.20 GHz: (a) 2D radiation pattern at $\phi = 0^\circ$, and (b) 3D radiation pattern.

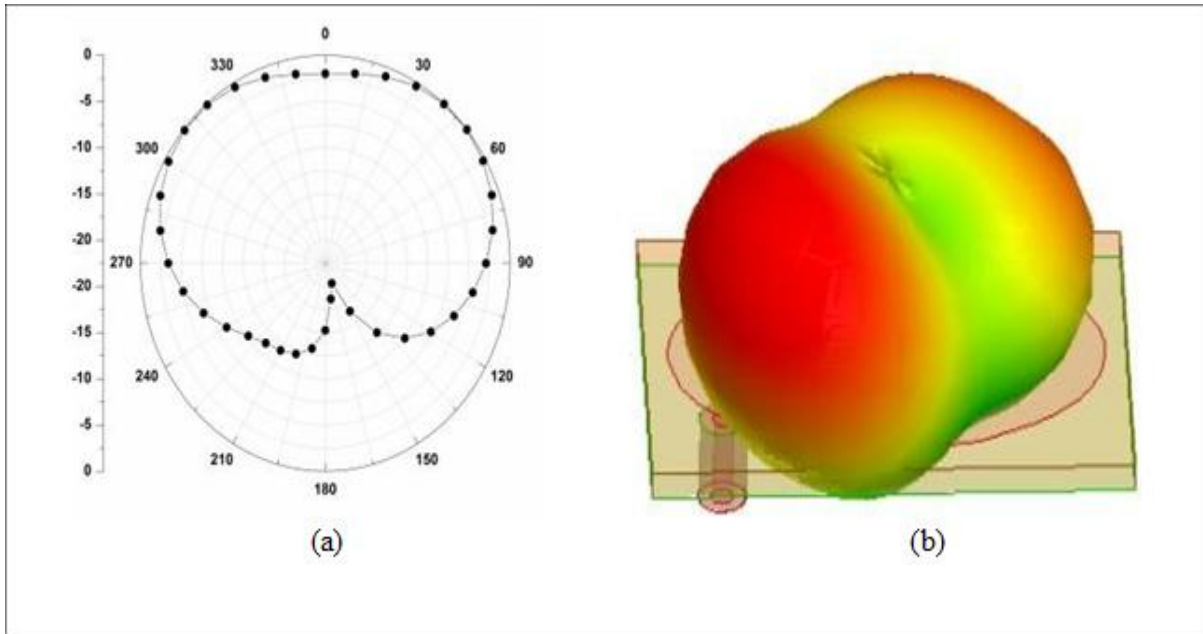


Fig. 5: Simulated radiation patterns of the proposed antenna at 6.26 GHz: (a) 2D radiation pattern at $\phi = 0^\circ$, and (b) 3D radiation pattern.

The corresponding 3D pattern confirms uniform radiation, indicating its effectiveness for low-frequency wireless communication. At 6.26 GHz (Fig. 5), both 2D and 3D radiation patterns maintain good stability, with the main lobe directed along the broadside, ensuring reliable coverage and minimal distortion. The radiation pattern at 7.62 GHz (Fig. 6) further validates the antenna's capability, where the 2D plot reveals controlled side lobes and the 3D pattern indicates enhanced gain characteristics suitable for mid-band communication systems.

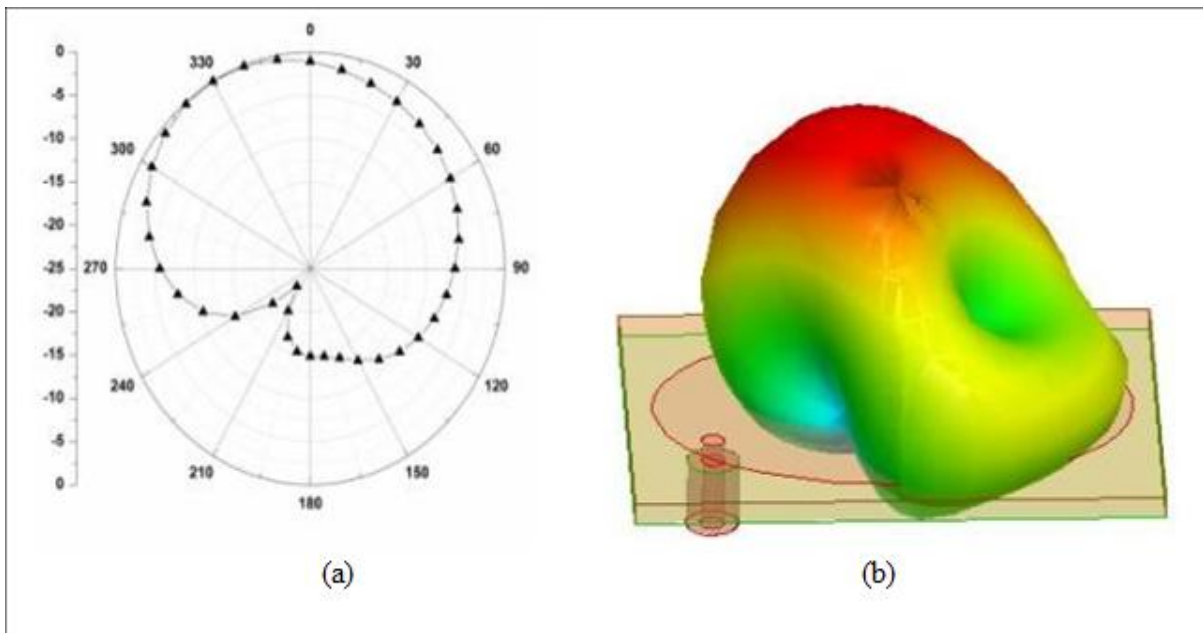


Fig. 6: Simulated radiation patterns of the proposed antenna at 7.62 GHz: (a) 2D radiation pattern at $\phi = 0^\circ$, and (b) 3D radiation pattern.

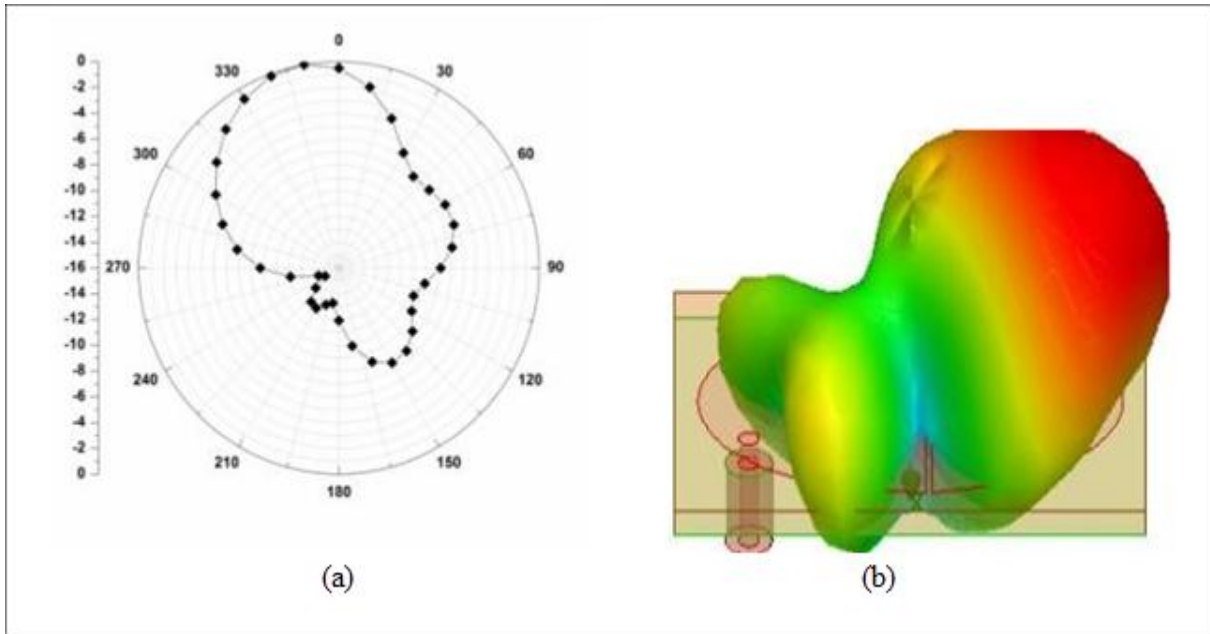


Fig. 7: Simulated radiation patterns of the proposed antenna at 10.14 GHz: (a) 2D radiation pattern at $\phi = 0^\circ$, and (b) 3D radiation pattern.

At 10.14 GHz (Fig. 7), the antenna continues to deliver stable radiation behavior with a broadside-directed main lobe. The 2D radiation pattern shows good symmetry, while the 3D view highlights effective power distribution. Similarly, at 11.64 GHz (Fig. 8), the radiation remains highly consistent, with the 2D radiation pattern at $\phi = 0^\circ$ confirming excellent impedance matching and radiation efficiency.

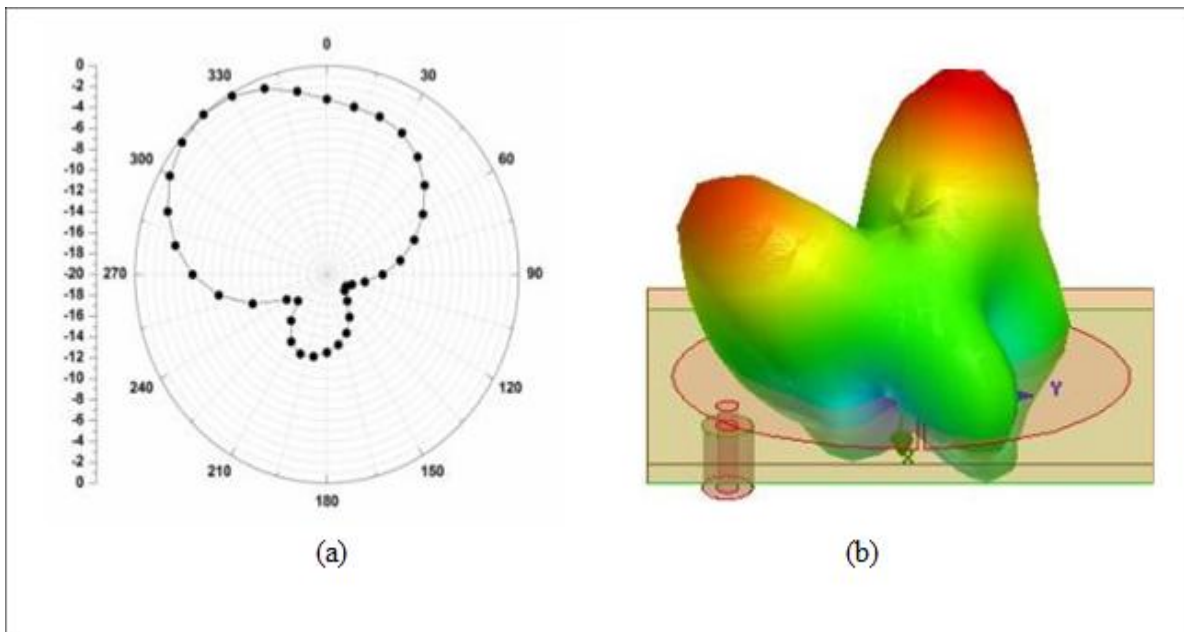


Fig. 8: Simulated radiation patterns of the proposed antenna at 11.64 GHz: (a) 2D radiation pattern at $\phi = 0^\circ$, and (b) 3D radiation pattern.

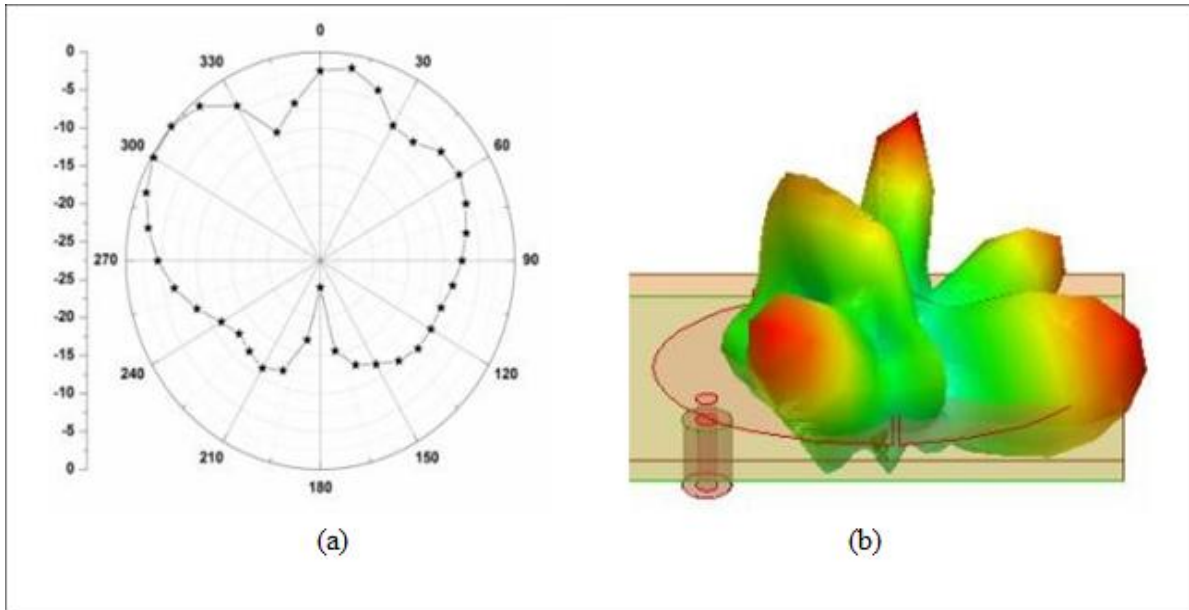


Fig. 9: Simulated radiation patterns of the proposed antenna at 17.60 GHz: (a) 2D radiation pattern at $\phi = 0^\circ$, and (b) 3D radiation pattern.

Finally, at the higher frequency of 17.60 GHz (Fig. 9), the antenna demonstrates a strong and concentrated main lobe, with the 3D radiation pattern depicting improved directivity and higher gain, making it well-suited for high-frequency multiband applications such as satellite and radar systems. Overall, across all analyzed frequencies, the proposed antenna maintains omnidirectional or stable radiation in the azimuth plane, while the elevation patterns remain robust and well-structured. This confirms its versatility, efficiency, and effectiveness in supporting multiband wireless communication systems with reliable performance.

4. Conclusion

This work presents the design and performance evaluation of an elliptical patch antenna integrated with a bottom strip, optimized for multiband operation. The antenna successfully covers five distinct frequency bands (5–24 GHz) while maintaining a return loss below -10 dB, $VSWR < 2$, and stable radiation patterns, thereby ensuring efficient impedance matching and reliable performance across the operating spectrum. The proposed single-layer, PCB-compatible design offers a compact, low-complexity, and cost-effective solution for modern wireless communication systems such as WLAN, WiMAX, 5G, X-band satellite, and IoT applications. Future work will focus on prototype fabrication and experimental validation to confirm the simulated results. Additionally, further improvements can be explored through the use of advanced substrates (e.g., Rogers) or metamaterial layers, which may enhance bandwidth, gain, and overall antenna performance, broadening its applicability to next-generation wireless and satellite systems.

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