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COMPACT SINGLE-LAYER MULTIBAND MICRO STRIP PATCH ANTENNA USING DUAL-CONNECTED T-SLOT AND PARASITIC ELEMENTS FOR IOT AND 5G APPLICATIONS

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ABSTRACT

A compact, single-layer multiband microstrip patch antenna is presented that attains six discrete resonances at 2.84, 3.93, 4.34, 5.38, 7.21, and 9.56 GHz on a low-cost FR-4 substrate. The radiator integrates a dual-connected T-slot and four parasitic elements optimized in ANSYS HFSS to achieve multiple resonant modes while retaining a simple single-feed topology. Measured results corroborate full-wave simulations: the best S11 reaches -37.6 dB and the antenna show a peak gain of 5.85 dBi with stable radiation patterns across the operating bands. Parametric studies reveal how slot length and parasitic-element spacing control the lower- and higher-frequency modes and the trade-off between bandwidth and peak gain. Compared with recent single-layer multiband designs, the proposed geometry delivers a higher number of usable bands with modest fabrication complexity, making it suitable for multi-standard wireless devices (IoT, wearable WBAN, and sub-6 GHz 5G). Full fabrication details, measured S-parameters, radiation patterns, and a discussion of practical limitations are included.



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I. INTRODUCTION

The fast advancement of Internet of Things tasks demonstrated the essential requirement for effective energy-saving strategies for devices with low power consumption. A notable obstacle encountered by these devices, particularly when utilized in isolated areas, is their dependence on conventional batteries that have predetermined power capacities and restricted durations of use. Conventional energy supply approaches limit the complete capabilities associated with Internet of Things applications because of the regular requirement for battery changes or recharging. This has led to an increasing demand for the exploration of other energy sources capable of delivering a consistent power supply to these devices over extended durations. Multiband microstrip patch antennas (MPAs) remain a thriving research area by virtue of their low profile, low cost, and easy integration with RF circuitry while meeting the growing demand posed by heterogeneous wireless standards — including sub-6 GHz 5G, millimeter-wave (mmWave), IoT/LoRa, satellite, and wearable/WBAN systems. Recent indexed works emphasize cost-effective single-layer designs, compact footprints, and a careful balance of bandwidth, gain, and radiation stability across multiple resonant bands—while minimizing fabrication complexity.

Slotting remains one of the simplest yet effective methods to induce multiple resonances. U-slots, E-slots, slits and asymmetric cuts introduce additional current paths on rectangular patches. For instance, Nahas (2025) presented a triple-band mmWave patch for 5G operating at 28 GHz, 32 GHz, and 38 GHz, with gains of 9.15 dBi, 7.48 dBi, and 12.08 dBi, achieved through multiple slot shapes on a single-layer rectangular patch [1]. Similarly, El Hachimi et al. (2025) designed a compact dual-band RFID antenna (2.45 GHz & 5.8 GHz) on FR-4 using slot techniques in both patch and ground, occupying just 28 × 26 mm² [2]. Springer's Umm Al-Qura University group (2025) proposed multiband broadband mm Wave patches using Rogers RO4450B substrates, achieving resonances at 29.26 GHz, 114.55 GHz, and 138.76 GHz, with efficiencies up to 94%, and another design extending continuous multiband coverage up to 335.5 GHz [3].

Another notable study by Nahas (2024) offered a dual-band slotted patch for 5G at 26 GHz and 28 GHz, using hammer slots to improve gain and radiation characteristics on a simple rectangular patch, demonstrating practicality for mobile devices [4]. Gopinath&Marichamy (2025) developed a multiband patch for wearable body area networks (WBAN) on FR-4 using slotting, partial ground plane, and band-gap structures. The patch measured 38×29.4 mm, showcasing multiband performance suitable for wearable integration [5]. RF-MEMS-controlled Minkowski fractal antennas (Microsystem Technologies, 2025) achieved dual-band reconfigurability, selectively activating fractal iterations for frequency agility without changing physical dimensions [6]. Earlier, fractal nested square ring designs (2023) supported multiple bands (C-, X-, Ku-bands) with a compact 24×24 mm² footprint and demonstrated ≈ 7.4 dBi gain with 60% efficiency [7].

Substrate choice remains critical. FR-4 is common for cost-sensitive sub-6 GHz applications but suffers losses at higher frequencies. For mmWave designs, low-loss Rogers substrates (e.g., RO4450B) are preferred to maintain efficiency [3]. Wearable and RFID applications also lean on FR-4 with clever slotting to preserve performance in tight area budgets [2], while WBAN designs still rely on FR-4 with slotting and ground-plane modifications [5]. Miniaturization tends to degrade radiation efficiency, and multiband designs often struggle to maintain stable gain and bandwidth across bands unless carefully tuned [1]–[3]. Though many studies rely on parametric sweeps, there is a growing—but still limited—emphasis on structured optimization methods. For example, the fractal and RF-MEMS hybrid design introduces re-configurability, yet analytical models or multi-objective optimization (MOO) frameworks remain underexplored [6]. Recent studies focus on multiband, miniaturized, and reconfigurable microstrip patch antennas, using techniques like RF-MEMS, parasitic elements, DGS, slots, and slits to enhance gain, bandwidth, and wireless communication performance. [8-11]

II. DESIGN APPROACH FOR THE PROPOSED ANTENNA

II.1 FUNDAMENTAL RECTANGULAR PATCH ANTENNA DESIGN (DESIGN I)

This section presents the step-by-step design procedure adopted to develop the proposed antenna and achieve the desired operating frequency bands. To realize multiband characteristics, four different microstrip antenna configurations were designed and simulated using ANSYS HFSS. The proposed antenna has been designed by selecting different wireless communication frequencies in GHz. The theoretical formulation of the antenna model was carried out using standard design relations based on the resonant frequency (f), dielectric constant (ϵ_r), and substrate thickness (h) as described in . Furthermore, the classical equations provided were employed for the development of a conventional Rectangular Patch Antenna (RPA), considering the forementioned parameters. Equations (1)–(3) were utilized to estimate the patch length (L_p), patch width (W_p), and the feed line width (W_f). Subsequently, the antenna structure was modeled and simulated using Ansys HFSS, a FEM-based electromagnetic analysis tool. Minor adjustments in select design variables were performed to optimize the antenna's performance characteristics. The refined parameter values for the conventional RPA are compiled in Table 1, while the corresponding structure derived from these optimized parameters is depicted in Fig. 1 (Design I). The dimension of patch is given in table I.

II.2 RECTANGULAR PATCH WITH DUAL CONNECTED T SLOT (DESIGN II)

Since the desired frequency band is not achieved with this initial design, further structural modifications are necessary. The ground has remained the same, but the shape of the patch has unique slot design. This slot has been done using equations 7 and 8. Here we proposed the dual connected T slot patch. This novel patch design gives the desired frequency bands, but the gain of antenna is not desirable so further modification in patch design is required to enhance the gain. The S11 [dB] of design II is as shown in Fig. 2

II.3 RECTANGULAR PATCH WITH DUAL CONNECTED T SLOT AND 4 PARASITIC ELEMENTS (DESIGN III)

To have the targeted frequency band, and more gain on desired frequency bands we did slot using equations 7 and 8. Here we proposed the novel 4 parasitic elements design where parasitic elements placed on one side of the patch and other two are placed on the other side of the patch. This novel design along with dual connected T slot and 4 parasitic patch gives more accurate and desired results. The development of the proposed patch antenna is based on the subsequent formulae.

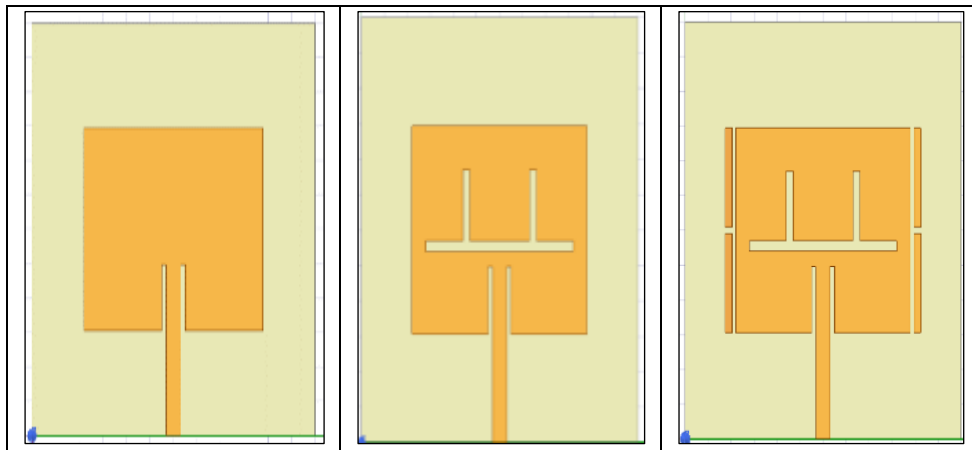


Figure 1: Geometry of novel antenna (a) Basic Patch (b) Patch With Dual Connected T Slot (c) Patch with Dual Connected T Slot and 4 parasitic elements.

Source: Authors, (2026).

Step 1: Determination of the Width (W)

$$W = \frac{c}{2f_0 \sqrt{\frac{(\epsilon_r + 1)}{2}}} \quad (1)$$

Step 2: The computation concerning the efficient Dielectric Constant. The parameters are determined by the dielectric constant and height associated with the dielectric material, and the determined width concerning the patch antenna.

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-1/2} \quad (2)$$

Step 3: Determination of the Patch Effective length

$$L_{\text{eff}} = \frac{c}{2f_0 \sqrt{\epsilon_{\text{eff}}}} \quad (3)$$

Step 4: Determination of the patch length extension ΔL

$$\Delta L = 0.412h \frac{(\epsilon_{\text{eff}} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{\text{eff}} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad (4)$$

Step 5: Determining the patch actual length

$$L = L_{\text{eff}} - 2\Delta L \quad (5)$$

Step 6: Determining the patch slot actual width

$$W_n = \frac{c}{4L_{\text{slot}} \sqrt{\frac{(\epsilon_r + 1)}{2}}} \quad (6)$$

Step 7: Determining the patch slot actual length

$$L_{\text{slot}} = l_s + w_s \quad (7)$$

Where, f_0 - Resonance Frequency, L - Patch length, W - Patch Width, h - thickness, ϵ_r - relative Permittivity related to the dielectric substrate, c - Speed of light which is 3×10^8 m/s

II.4 RECTANGULAR PATCH WITH DUAL CONNECTED T SLOT AND 4 PARASITIC ELEMENTS (DESIGN III)

To ensure optimal performance and impedance matching across desired bands, key geometrical parameters of the proposed antenna were optimized through parametric analysis using Ansys HFSS. Table 1 presents the finalized dimensions of the antenna's components, including the patch sizes, slot dimensions, inset feed, and ground plane as shown in figure 2.

III. RESULTS AND DISCUSSION

The results first tested HFSS software for all proposed design. The detailed comparison of simulated and measured results will be discussed in the given section. After getting the desired results for gain and return loss and other important parameters the proposed novel antenna having dual T connected slot and 4 parasitic elements has fabricated as shown in figure 3. The antenna fabricated on FR4 substrate having dielectric constant of 4.4. FR4 has higher loss tangent due to that gain is reduced but cost of the material is very low, so fabricated antenna has low price with good results. The detailed results discussed in further sections.

Table 1: Finalized dimensions of the antenna's component.

Parameter	Dimensions (mm)
Width of the radiating patch element (W)	38
Length of the radiating patch element (L)	28
Width of the microstrip feed line (Wf)	1.8
Length of the microstrip feed line (Lf)	24.8
Length of the ground plane (Gl)	60
Width of the ground plane (Gw)	60
Width of the etched slot in the patch (ws)	28
Length of the etched slot in the patch (ls)	12
Length of each parasitic arm element (Lg1)	14.2

Source: Authors, (2026).

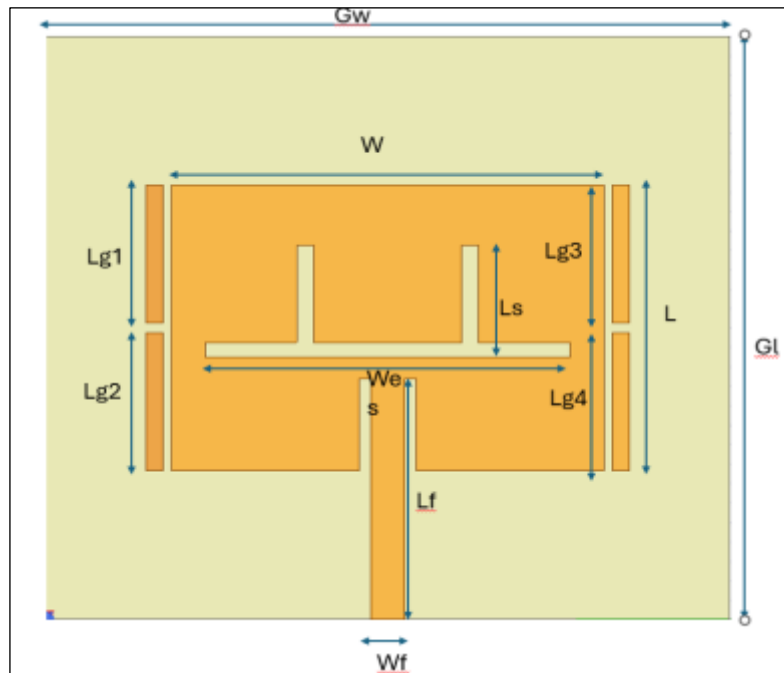


Figure 2: Top-View Representation of the Proposed Antenna with Ground and Substrate Parameters
Source: Authors, (2026).

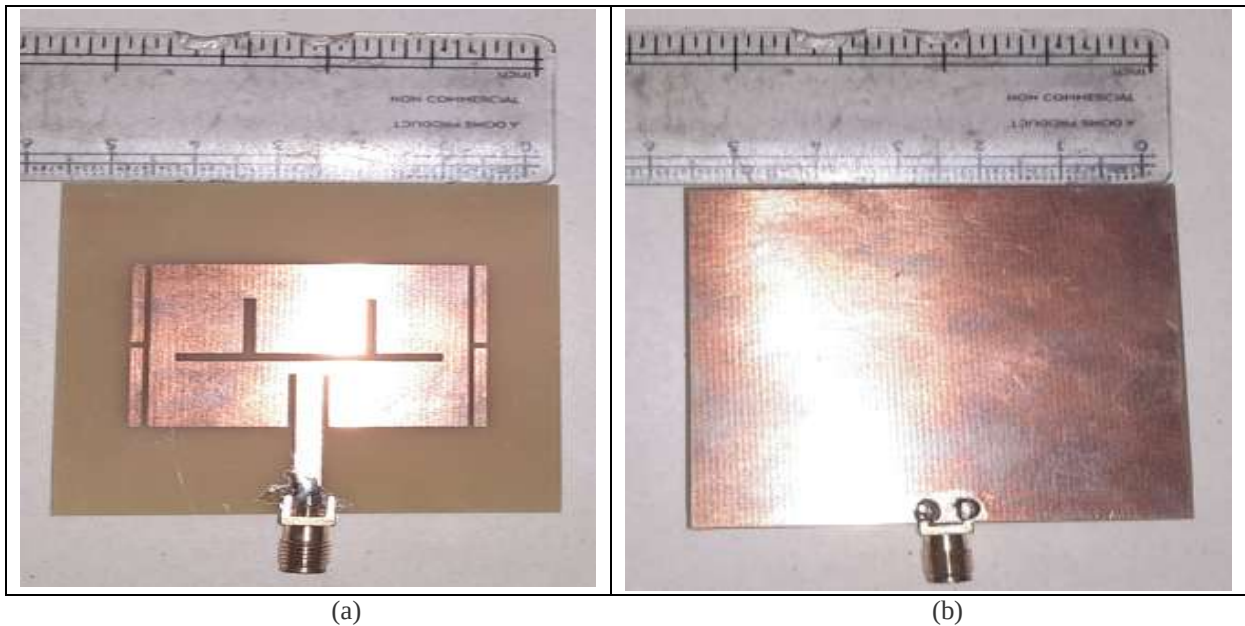


Figure 3: Design and parameters of the proposed antenna, with the top view illustrating the ground plane and substrate geometry
Source: Authors, (2026).

III.1 S11 SIMULATED RESULTS

The antenna has made with three different patch designs as shown in figure 1 and discussed in design section. The return loss compression of all designs is given in figure 4. The conventional rectangle insert field patch design gives the return loss of only 3 bands. To have more frequency band in the same design with same material a novel dual T connected slot design is proposed which gives more multiband frequency as respectively as shown in figure 4. Yet still scope of optimization and to have more frequency bands and better gain. The proposed novel Rectangular Patch with Dual Connected T Slot and 4 parasitic elements give 6 frequency bands along with more gain on radiating frequencies. The simulated S11 comparison between all the proposed antenna is shown in figure 4. The novel antenna radiates on 2.84 GHz, 4.34 GHz, 3.93 GHz, 5.38 GHz, 7.21 GHz and 9.56 GHz. The notch of the can be controlled by changing the value of L_s and w_s which is length and width of the slot given in table 1. The simulated results of S11 return loss notch is as shown in figure 5. The antenna has notch frequency of 4.42-5.28GHz, 5.53-6.39GHz, 6.50-7.12GHz, 7.32-7.64GHz and 7.82-9.49GHz. The notched return loss is as shown in figure 5. The antenna give four different notches which can used for frequency jammer.

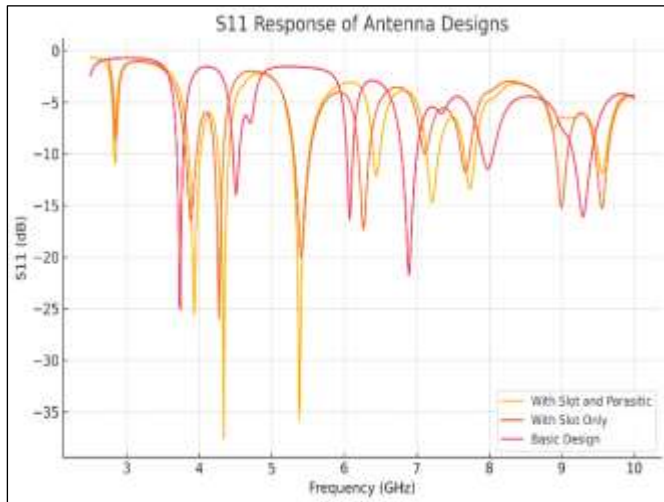


Figure 4: Return loss S11 associated with the proposed design.

Source: Authors, (2026).

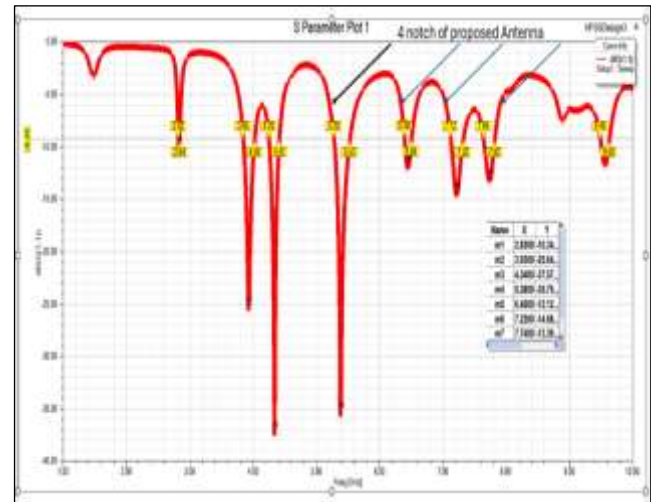


Figure 5: S₁₁ (dB) response of the proposed design illustrating the notch band.

Source: Authors, (2026).

III.2 SIMULATED AND MEASURED S11 RESULTS COMPARISON

As the detail comparison of S11 simulated for all proposed antenna has given in figure 4. The comparison shows that Dual Connected T Slot and 4 parasitic elements give better results for multiband as well as also gives good directional gain on radiating frequencies. So, from simulated results we fabricated the novel Dual Connected T Slot and 4 parasitic elements patch antenna. The antenna is fabricated on FR4 substrate which is low cost. The fabricated antenna top and bottom view is shown in figure 3. As shown in figure 5 the antenna was tested on VNA to measure the return loss S11. The measurement setup is shown in figure 7 where the fabricated antenna's S11 was tested on 2-18GHz VNA at Entuple Technology. The comparison of simulated and measured results of Dual Connected T Slot and 4 parasitic elements is shown in Fig 6. The results show more accurate match of simulated and measured on each frequency band. The measured result shows a minor mismatch and a little change in frequency, which could be caused by fabrication minor error and mismatch at the excitation port.

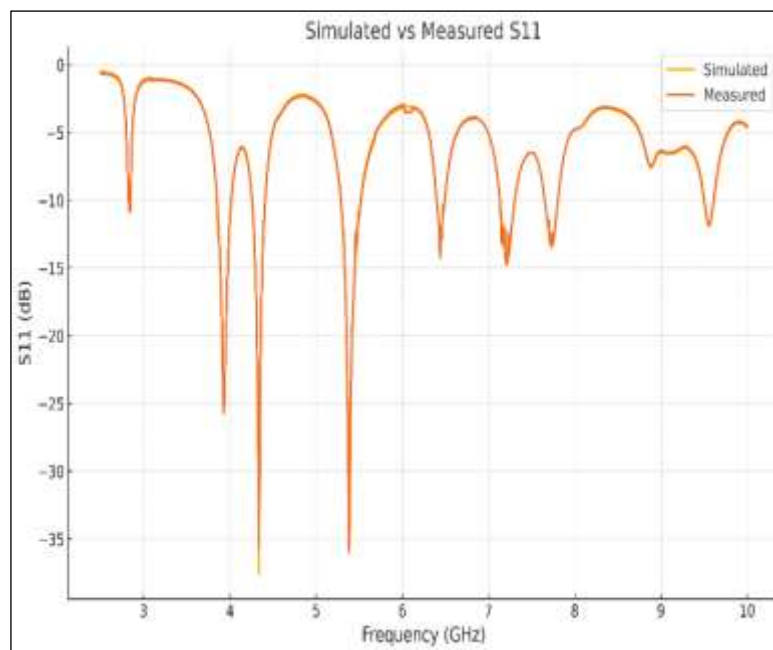


Figure 6: Return loss comparison of simulated and fabricated antenna

Source: Authors, (2026).

III.3 RADIATION PATTERN COMPARISON AND ELECTRIC FIELD DISTRIBUTION

Figure 8 presents the simulated radiation patterns and gain characteristics of the proposed antenna. The radiation patterns demonstrate stable and nearly omnidirectional behavior in the lower frequency bands, which is desirable for wide coverage applications, while at higher frequencies, the patterns exhibit slight distortions due to higher-order mode excitation and surface current variations. The antenna maintains good gain performance across all operating bands, with peak gains increasing progressively with frequency. These results confirm that the proposed design achieves efficient radiation with consistent gain levels and acceptable pattern stability across the multiband spectrum, making it suitable for modern wireless and communication applications.

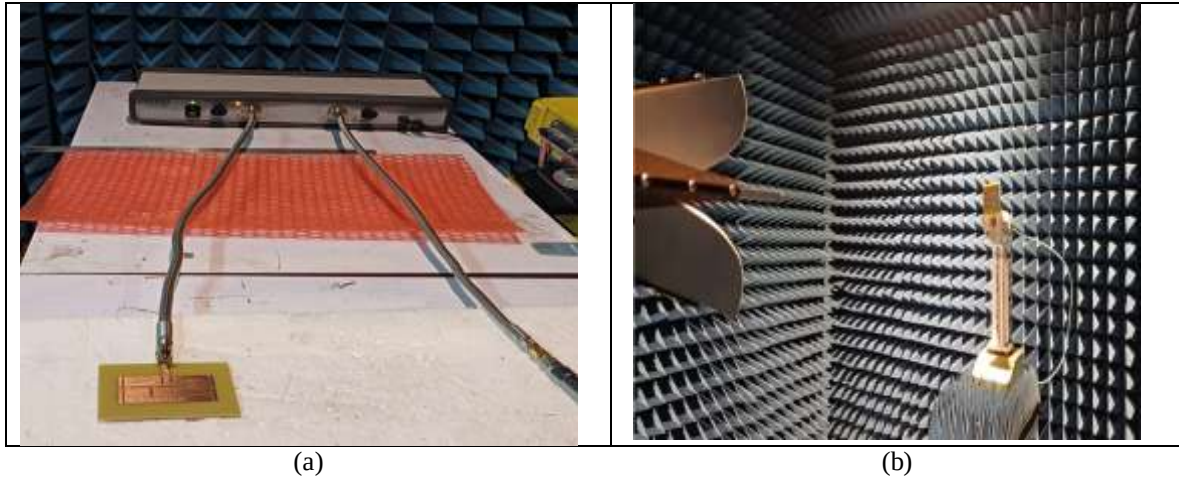
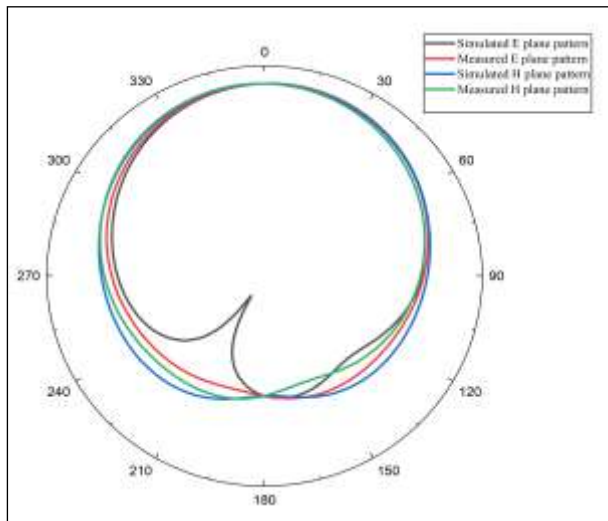
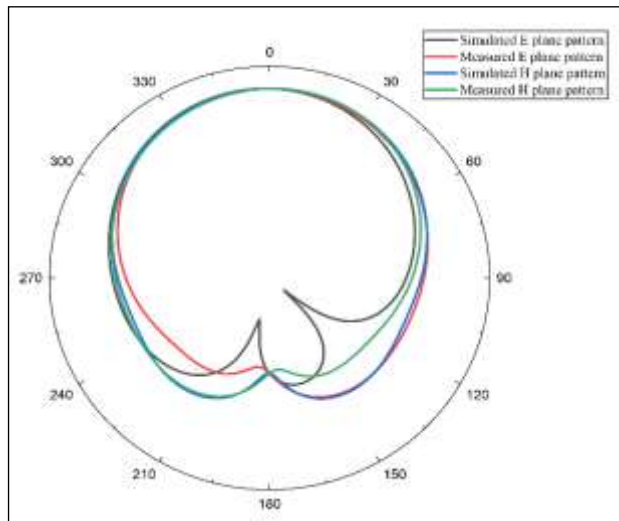


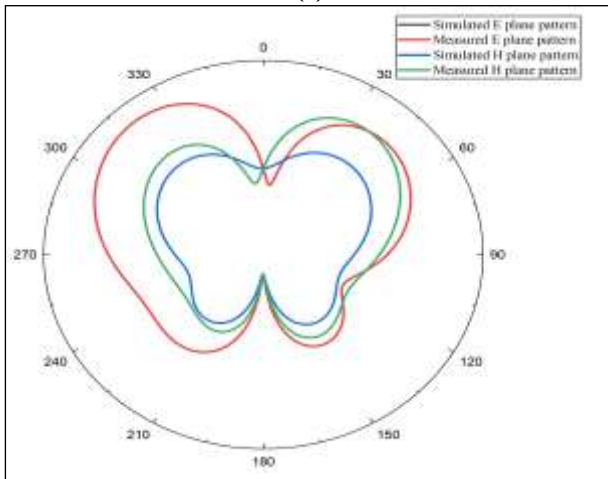
Figure 7: (a) Measurement of S11 on VNA (b) Measurement of the radiation pattern in anechoic chamber
Source: Authors, (2026).



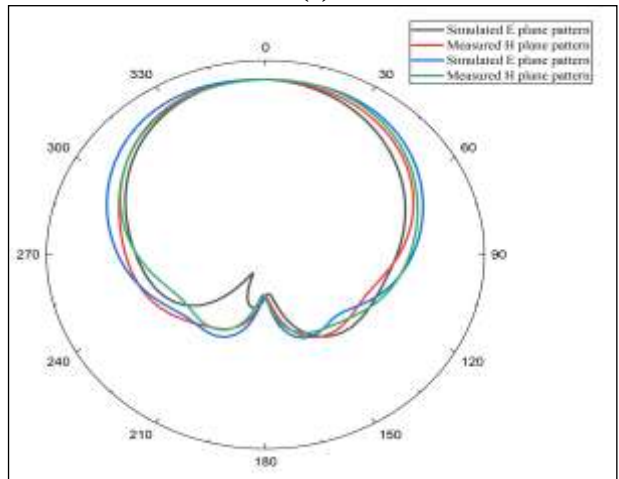
(a)



(b)



(c)



(d)

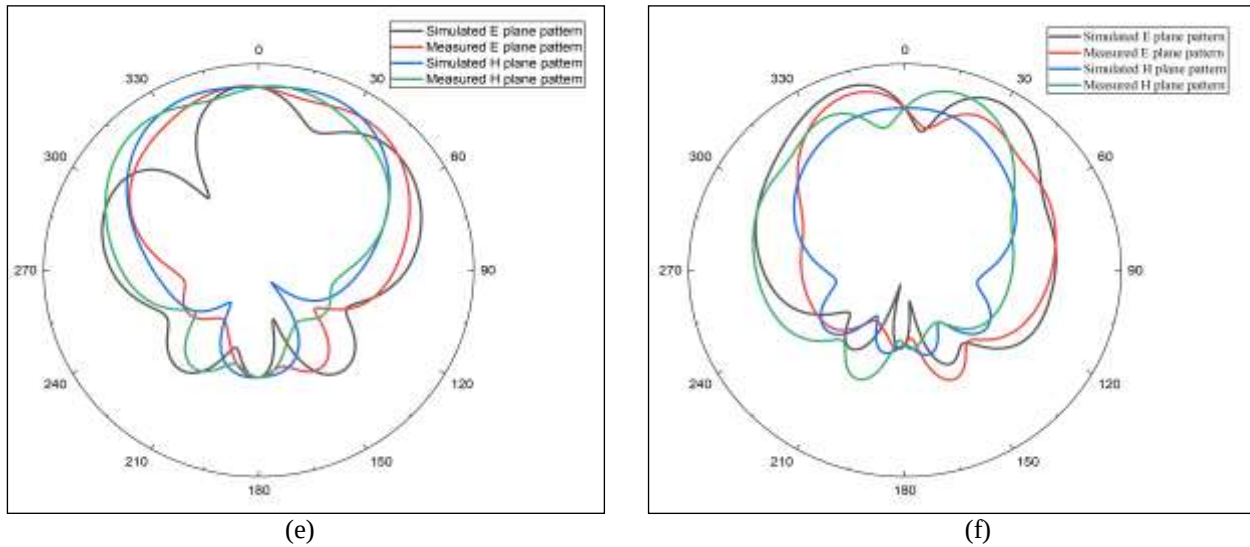


Figure 8: Radiation pattern and gain of proposed antenna at radiating frequencies (a) 2.84 GHz (b) 4.34 GHz (c) 3.93 GHz (d) 5.38 GHz (e) 7.21 GHz (f) 9.56 GHz
Source: Authors, (2026).

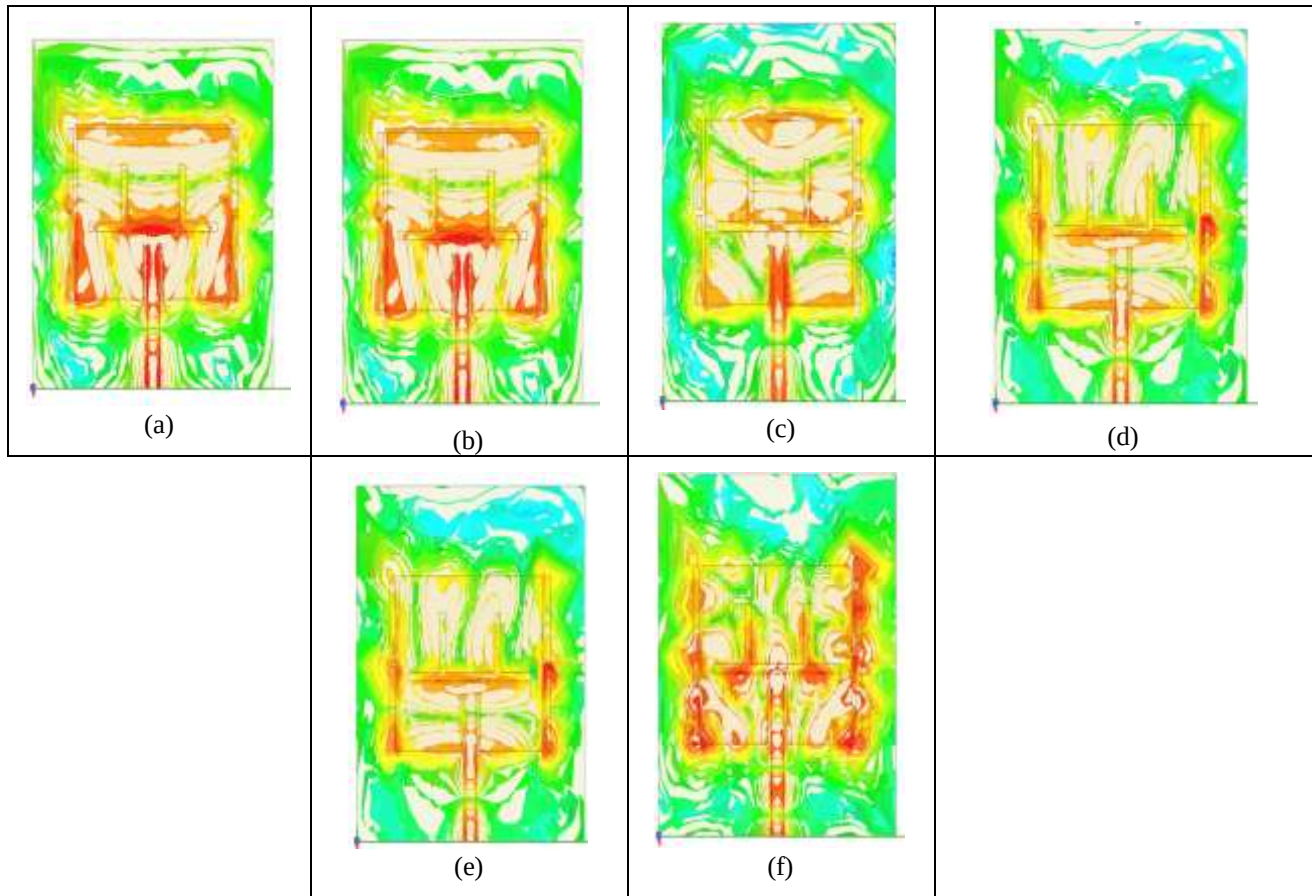


Figure 9: Simulated electric field distribution at various resonant frequencies a) 2.84 GHz (b) 4.34 GHz (c) 3.93 GHz (d) 5.38 GHz (e) 7.21 GHz (f) 9.56 GHz
Source: Authors, (2026).

Figure 9 illustrates the simulated electric field distributions of the proposed antenna at its various resonant frequencies: (a) 2.84 GHz, (b) 4.34 GHz, (c) 3.93 GHz, (d) 5.38 GHz, (e) 7.21 GHz, and (f) 9.56 GHz. The field distributions reveal how the surface current and electric field intensities are concentrated over different regions of the radiating patch and ground plane at each resonance, indicating the excitation of distinct resonant modes. At lower frequencies, the field is primarily distributed over the entire patch, corresponding to the fundamental mode, whereas at higher frequencies, multiple localized field maxima are observed, signifying the presence of higher-order modes and complex coupling effects. These variations confirm the antenna's capability to support multiband operation with efficient radiation characteristics across the designated frequency bands.

Table 2: Comparison of different antenna on different frequency and application

Ref.	Design Approach	Bands Covered	Substrate / Size	Peak Gain / Eff.	Application
[1]	Multi-slot rectangular patch	28, 32, 38 GHz	Single-layer FR-4, compact	9.15, 7.48, 12.08 dBi	5G mmWave devices
[2]	Slotted patch + ground	2.45, 5.8 GHz	FR-4, 28×26 mm ²	~2.1 dBi, compact	RFID readers/tags
[3]	Broadband multi-slot mmWave	29.3, 114.6, 138.8 GHz (also 19–335 GHz)	Rogers RO4450B	Eff. up to 94%	5G/6G mmWave& THz
[4]	Dual hammer-slot patch	26, 28 GHz	FR-4	8.92 & 9.71 dBi	5G smartphones
[5]	Slotting + partial ground + EBG	Multiband (WBAN/ISM)	FR-4, 38×29.4 mm ²	~3–4 dBi	Wearable WBAN
[6]	RF-MEMS reconfig. Minkowski fractal	Dual-band reconfigurable	FR-4 + RF-MEMS	Switchable bands, ~3 dBi	Cognitive / reconfig.
[7]	Fractal iterations (nested rings)	C, X, Ku bands	FR-4, 24×24 mm ²	7.4 dBi, 60% eff.	Multiband wireless
Proposed Antenna	Dual Connected T Slot and 4 parasitic elements	2.84, 3.93, 4.34, 5.38, 7.21, 9.56 GHz	Single-layer FR-4, compact	5.85dB	Multiband wireless

Source: Authors, (2026).

The proposed novel antenna gives 6 radiating frequency bands has -10.34 dB, -25.64 , -37.57 dB, -35.75 dB, 14.68 and -11.67 dB reflection coefficients at 2.84 GHz, 3.93 GHz, 4.34 GHz, 5.38 GHz, 7.21 GHz and 9.56 GHz. This solution has a return loss of -37.57 dB, which matches impedance better than current works in the 2.4 GHz band [1–7]. The antenna has peak gain of 5.85dBi and maintain the high gain throughout the three working bands, these comparisons show that the Dual Connected T Slot and 4 parasitic elements shape is unique and performing, making it a promising multiband wireless communication systems.

IV. CONCLUSION

This work introduced a compact, single-layer FR-4 micro strip patch antenna employing a dual-connected T-slot and four parasitic elements to realize six resonances at 2.84, 3.93, 4.34, 5.38, 7.21, and 9.56 GHz. Simulations and measurements align closely: the prototype achieved a best measured S11 of -37.6 dB and a peak gain of 5.85 dBi, confirming the efficacy of the slot–parasitic combination for dense multiband operation. The main contribution is a practical, fabrication-friendly single-feed single-layer geometry that increases the number of resonances without resorting to stacked substrates or overly complex feeds. Limitations include elevated dielectric loss and slightly reduced efficiency at the highest band due to the FR-4 substrate and observed small shift in resonant frequency from fabrication tolerances. The antenna's compact size and measured performance recommend it for multi-standard embedded wireless modules. The following prioritized future work aims to address reconfigurability, array integration, robustness, and system-level validation to extend applicability to dynamic multi-band systems.

V. FUTURE WORK AND EXPERIMENTAL VALIDATION

Reconfigurability (short-term, high priority): Integrate RF-MEMS or PIN-diode switching within the T-slot network to enable dynamic band selection. Quantify insertion loss, switching speed, linearity, and on-state/off-state isolation in measurements (see recent RF-MEMS reconfigurable antenna work).

Array integration & mutual coupling (short-term): Build a 2×2 or 4×4 array based on the element to study coupling, beam-forming capability, and MIMO metrics (ECC, DG) via measured S-parameters and pattern scans. Evaluate element spacing trade-offs and feed network design. Multi-objective optimization & tolerance analysis (medium-term): Apply NSGA-II or similar multi-objective methods to jointly optimize bandwidth, gain, and footprint; run Monte-Carlo / tolerance analysis for realistic PCB fabrication variability. System-level validation (medium-term): Use 3GPP channel models and link-level simulations to estimate BER/throughput when the antenna is used in target scenarios (IoT/WBAN/sub-6 GHz NR). If feasible, perform over-the-air tests with a small transceiver.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Shahid S. Modasiya, Balvant J. Makwana, Komal D. Anadkat³ and Mitul Patel

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Investigation: Shahid S. Modasiya, Balvant J. Makwana, Komal D. Anadkat³ and Mitul Patel.

Discussion of results: Shahid S. Modasiya, Balvant J. Makwana, Komal D. Anadkat³ and Mitul Patel.

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Approval of the final text: Shahid S. Modasiya, Balvant J. Makwana, Komal D. Anadkat³ and Mitul Patel.

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