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Dual - Band Monopole Antenna for WLAN, Sub-6 GHz and IoT Applications

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Abstract:

This paper proposes a dual-band rectangular stub-loaded monopole antenna suitable for Sub - 6 GHz and IoT uses. The proposed antenna employs a rectangular radiating patch with two incorporated rectangular stubs and two rectangular slots to provide wideband impedance matching and dual-frequency operation. The antenna is fabricated on a Roger RO3003 substrate on compact dimensions of 50 × 50 × 1.524 mm³ along with a 50 Ω microstrip feedline to effect good impedance matching. The measured S_{11} results have shown two distinct operating band: 2.2GHz–2.6 GHz and 3.0GHz–4.9 GHz, with an exceptional return loss of –68.57 dB at 4.22 GHz, exhibiting excellent impedance matching. The suggested antenna exhibits a top gain of 2.72 dBi & total efficiency up to 97.8% that promises very good radiation performance. Due to its small size, high efficiency, and excellent impedance characteristics, the antenna is highly appropriate for IoT, WLAN, and Sub-6 GHz wireless communication systems.

Keywords:

Monopole antenna, dual-band, rectangular slot, partial ground plane, CST simulation.

10.22060/EEJ.2026.25184.5861

1. INTRODUCTION

The rapid growth of modern wireless communication systems has created an increasing demand for compact, cost-effective, and high-performance antennas that can use over multiple frequency band. Applications such as Internet of Things (IoT), without wire local area networks (WLAN), Bluetooth, and emerging 5G systems require antennas that provide stable radiation characteristics and reliable impedance matching in more than one frequency range. Conventional single-band antennas fail to meet these requirements due to their limited bandwidth and lack of frequency reconfigurability, which has motivated extensive research on dual-band and multiband antenna designs.

Recent studies have shown that introducing slots, stubs, defected ground structures, and partial ground planes on radiators can produce extra resonant modes, better impedance Matching, and increased overall bandwidth. The slot loading method is widely used to excite higher-order resonant modes in antennas. Stubs are used as tuning elements that help in adjusting the lower resonant frequency and minimize the antenna size. The Ground Plane variations have also been shown to improve the impedance stability and overall bandwidth of portable wireless communication systems [1], [2].

However, more complex designs involving phased - array integration, metamaterial loading, or shared aperture methods have been proposed. For example, [10] a low-cost multiband four-port phase array antenna for 5G systems in the sub-6 GHz band has shown improvements in gain and beam-forming performance. However, the design is more complex and requires more hardware. Likewise, [11] a metamaterial-loaded tri-band compact MIMO antenna for 5G IoT communication has been proposed. This design uses metamaterial structures for enhanced bandwidth and isolation. However, it results in more complex designs that are difficult to implement.

Other shared aperture and advanced designs for 5G IoT communication offer superior performance. However, these designs are large in size or more costly in terms of hardware implementation, making them more impractical for 5G IoT communication terminals [3]-[6].

10.22060/EEJ.2026.25184.5861

In contrast to above-mentioned designs, a broad upper band of bandwidth (3.104 – 4.900 GHz) with a very high return loss of –68.57 dB at 4.22 GHz is obtained. In view of a simple single-element design with a compact size of 50x50 mm², a monopole antenna with a slot, stub, and a partial ground plane is useful in providing a broad bandwidth, high efficiency, and a stable radiation pattern, suitable for use in IoT, WLAN, Sub-6 GHz, and other 5G communication systems.

In this work, a miniaturization dual-band monopole antenna is presented, designed on a Roger RO3003 substrate with a dielectric constant of 3.0 and Height of 1.5 mm. The antenna comprises a rectangular patch with two symmetrical rectangular slots and a rectangular stub, excited by a microstrip feedline. To further improve bandwidth performance, a partial ground plane is utilized. The simulated results confirm dual-band operation with resonances at 2.2–2.6 GHz and 3.0–5.0 GHz, so the design is suitable for IoT, WLAN, and 5G communication systems. Compared with existing designs, the suggested antenna has a simple structure, miniaturization size, and efficient dual-band operation and is thus a good Antenna to be integrated into portable and wireless devices.

2. DETAILS OF ANTENNA DESIGN

The suggested miniaturization antenna is design on a Roger RO3003 substrate having a dielectric constant (εr) of 3.0, a thickness of 1.5 mm, and an overall size of 50 × 50 mm². The top layer of the antenna having of a rectangular monopole patch integrated with a stub and two rectangular slots to achieve dual-band operation with enhanced impedance matching.

2-1- Design Methodology:

The proposed antenna is developed by step-wise evolution to achieve two distinct operating bands. First, a rectangular monopole patch is designed on a RO3003 substrate (εr = 3.0, tan δ = 0.001), which provides the fundamental resonance near 2.4 GHz. To extend the lower-band impedance matching from 2.2 GHz to 2.6 GHz, a rectangular stub is attached to the radiating patch. This stub increases the electrical length of the current path, thereby lowering the resonant frequency. Subsequently, two identical rectangular slots are etched on the patch to introduce an additional higher-order resonance.

10.22060/EEJ.2026.25184.5861

These slots perturb the surface current distribution and produce the second operating band covering 3.0 GHz to 4.9 GHz. Finally, a partial ground plane is employed to enhance impedance matching and hence bandwidth by controlling the fringing fields and tuning the input impedance. The combination of the effects of the stub, slots, and partial ground results in stable dual-band operation with wide impedance bandwidth. A 50 Ω microstrip feed line of width 2.9 mm and length 22 mm is used to excite a rectangular radiating patch, while ensuring that impedance matching is efficient. Two identical rectangular slots with dimensions 5 × 0.5 mm were symmetrically etched on the patch to develop additional resonant modes and hence broaden the bandwidth. A small rectangular stub of 5 × 0.5 mm is located at the junction of the feedline and patch to enhance impedance matching. A partial ground plane 16.3 mm long on the bottom side enhances the bandwidth and radiation efficiency due to capacitive coupling. An upper rectangular slot of 20 × 15.5 mm introduces higher-order resonance, enabling dual-band operation. Simulated using CST, the antenna exhibits $|S_{11}| < -10$ dB from 2.2GHz – 2.6 GHz and 3.0GHz – 4.9 GHz, with a extremely strong impedance matching of –68.57 dB indicates excellent impedance matching at 4.22 GHz, confirming excellent impedance matching suitable for Wi-Fi, WiMAX, and sub-6 GHz 5G applications.

The rectangular stub increases the electrical length of the antenna, enabling the lower frequency-band resonance, while the two rectangular slots create the more additional current paths responsible for the higher-band resonance. Together, they are ensure controlled dual-band behavior, improved the impedance matching, and increased the design flexibility.

The partial ground plane significantly improves impedance bandwidth and return-loss performance. For a shorter ground length, the fringing fields in the vicinity of the feedline become stronger and more consistent, hence decreasing capacitive reactance and improving input impedance matching. Consequently, both operating bands feature wider bandwidth and smoother S11 characteristics.

10.22060/EEJ.2026.25184.5861

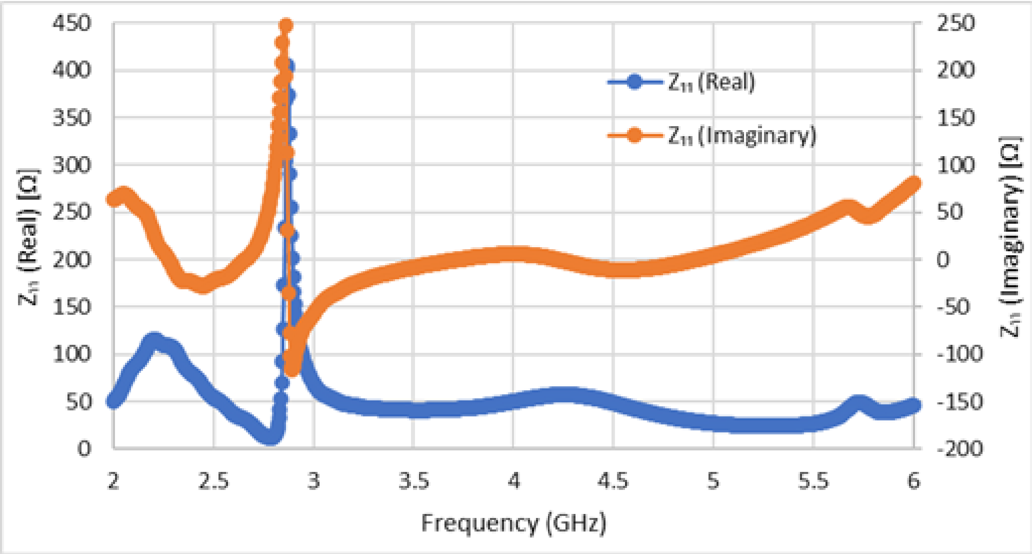


Fig. 1. Input Impedance of proposed monopole antenna.

The input impedance characteristics of the proposed antenna in Fig. 1. The simulated input impedance (Z_{11}) of the antenna was examined from 2–5 GHz to verify impedance matching. Therefore, in its vicinity, the real part stays close to 50 Ω, while the imaginary part approaches zero near resonance, confirming that matching with the feed line is proper. A strong resonance occurs at 4.22 GHz, where the impedance is nearly 49 Ω + j0 Ω, corresponding to a extremely strong impedance matching $|S_{11}|$ of –68.57 dB. The impedance behavior across both bands, namely, 2.2–2.6 GHz and 3.0–4.9 GHz, respectively, shows excellent matching and validates the effectiveness of the slot and stub structure in achieving wideband performance.

2-2- Antenna Geometry:

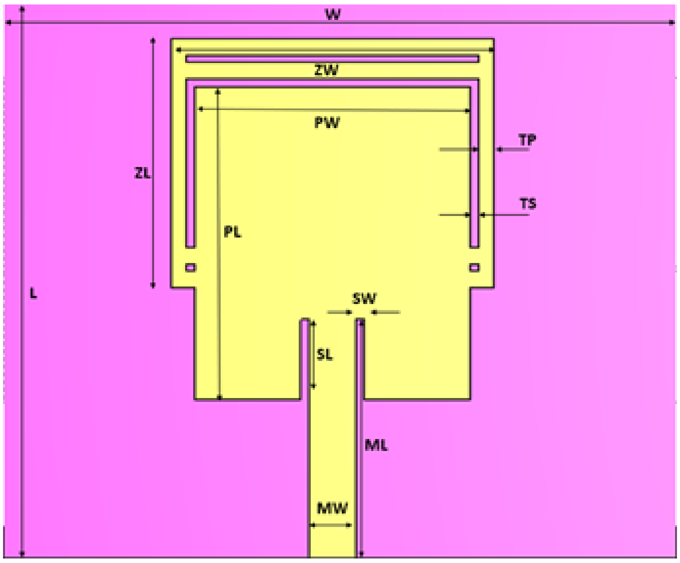
The suggested antenna is design on a Roger RO3003 substrate of size 50 × 50 × 1.5 mm³, having a dielectric constant of 3.0 and a loss tangent of 0.001. This comprises a rectangular radiating patch feding by a microstrip line which is width =2.9 mm and length = 22 mm to ensure impedance matching for 50 Ω. There are two symmetrical rectangular slots (5 × 0.5 mm) etched on the patch; a stub (5 × 0.5 mm) is attached between the patch and feedline to enhance bandwidth. Moreover, the antenna utilizes a partial ground plane of length 16.3 mm on the back side to enhance radiation efficiency. One more

10.22060/EEJ.2026.25184.5861

rectangular slot of 20 × 15.5 mm above the patch further supports dual-band resonance with stable impedance matching.

RO3003 is used instead of FR4 since its low dielectric loss of tan δ = 0.001 and stable permittivity enhance the radiation efficiency and reduce the signal attenuation at microwave frequencies. FR4 has relatively high losses at the frequency of 3–5 GHz, which results in poor gain, unstable bandwidth, and performance deterioration. In the low-power operation of IoT and WLAN devices, RO3003 provides more reliable and efficient operation.

10.22060/EEJ.2026.25184.5861



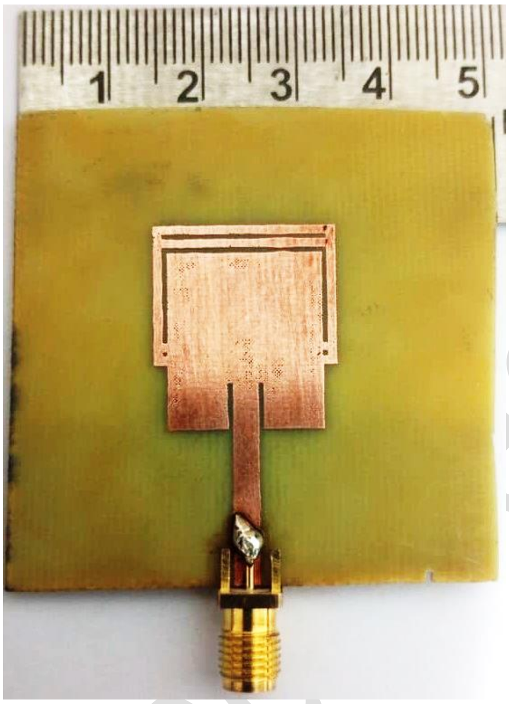


Fig. 2. Proposed monopole antenna Geometry.

10.22060/EEJ.2026.25184.5861

Table 1. The monopole antenna design parameters.

Description	***Paramete r***	***Dimension (mm)***
Substrate width is	W	50
Substrate length is	L	50
Patch width is	PW	17
Patch length is	PL	19.5
Feedline width is	MW	2.9
Feedline length is	ML	22
Slot length is	SL	5
Slot width is	SW	0.5
Outer slot length is	ZL	15.5
Outer slot width is	ZW	20
Slot thickness is	TS	0.5
Gap between patch and slot	TP	1
Partial ground plane	GL	16.3

The distribution of the surface current of the proposed antenna at 2.5 GHz, 3 GHz, and 4.22 GHz is given in Fig. 3. At 2.5 GHz, strong currents appear along the feedline and lower patch edges, representing the fundamental mode. At 3 GHz, the current extends toward the slot edges, thus increasing coupling and impedance matching. At 4.22 GHz, one can observe dense currents around the upper slot and the feed transition, which involves higher-order mode excitation that is responsible for the extremely strong impedance matching level of −68.57 dB. These all verify that the antenna will be able to support multiple resonant modes for broadband operation.

Even though the surface current distribution is different compared to the classical monopole pattern due to these stub and slot perturbations, the far-field radiation behaves in a monopole-like omnidirectional

10.22060/EEJ.2026.25184.5861

fashion. The added features provide additional resonant paths with no detuning of the fundamental radiation mechanism.

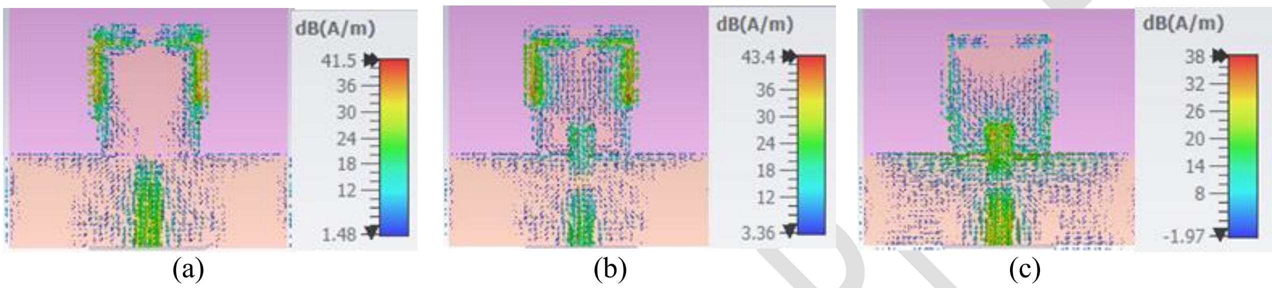
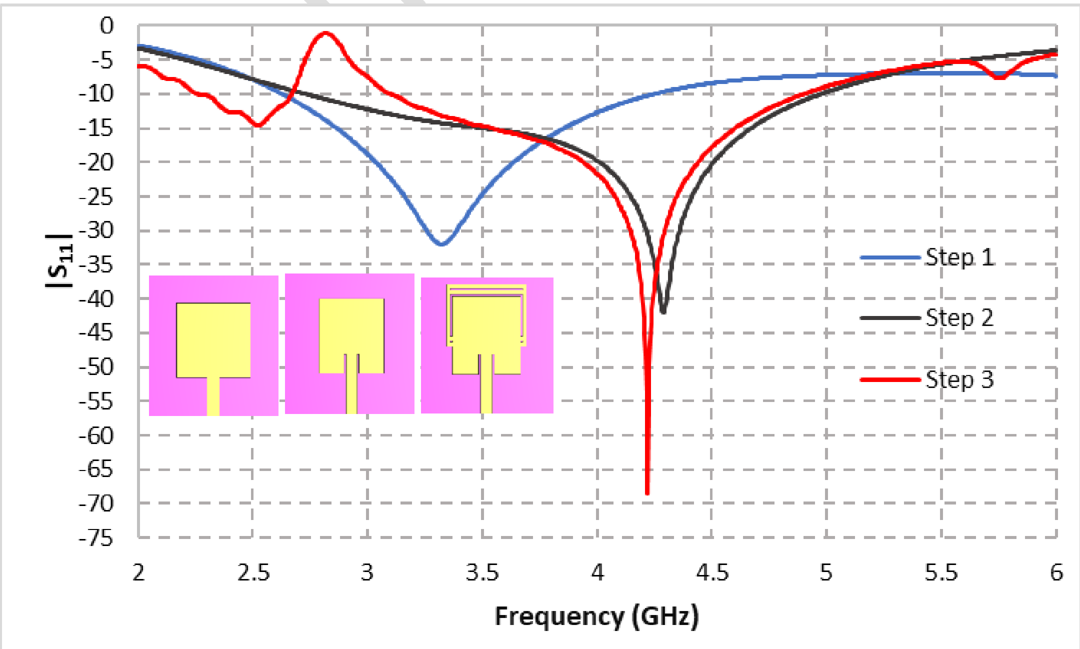


Fig. 3. Surface current distribution on patch and ground plane (a) 2.5 GHz, (b) 3 GHz, and (c) 4.22 GHz.

3. RESULTS AND DISCUSSIONS

Fig. 4. The simulated S-parameter (|S11|) of the proposed antenna shows excellent impedance matching characteristics at multiple frequency ranges. In fact, this antenna exhibits two separate operating bands, one from 2.2 GHz to 2.6 GHz and another from 3.0 GHz to 4.9 GHz, with |S11| values less than −10 dB. A extremely strong impedance matching of –68.57 dB at 4.22 GHz indicates extremely strong



10.22060/EEJ.2026.25184.5861

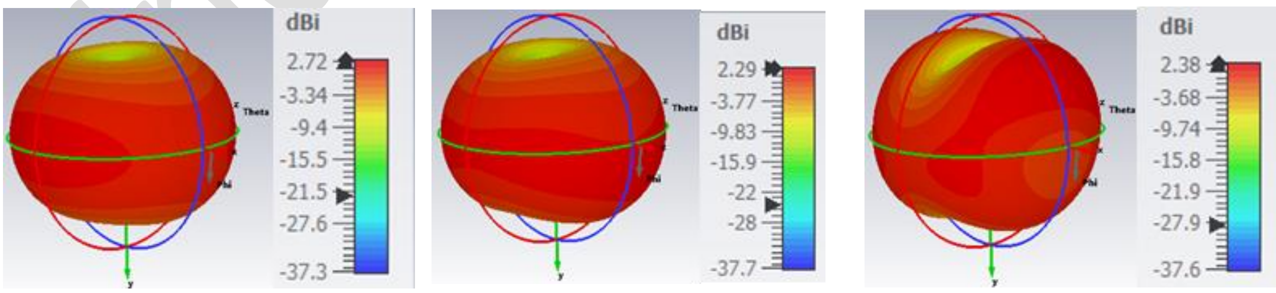
impedance matching between the antenna and the 50 Ω feed, confirming a well-established resonance, indicating that at this frequency, it has excellent impedance matching and thus very low signal

Fig. 4. S – Perameter of Proposed monopole antenna.

reflection. This good return loss indicates that there is efficient energy transfer between the feedline and radiating patch. Due to its multiband and high impedance matching characteristics, the proposed antenna is suitable for modern wireless communication systems like WLANs at 2.4 GHz, WiMAX at 3.5 GHz, and C-band applications from 4 to 8 GHz.

Fig. 5. The simulated 3D radiation patterns of the suggested monopole antenna were analyzed at three resonant frequencies: 2.5 GHz, 3.0 GHz, and 4.22 GHz. The maximum obtained gains are 2.72 dBi, 2.29 dBi, and 2.38 dBi, respectively. Over these frequencies, the radiation pattern shows an approximately omnidirectional characteristic, which is desirable for uniform coverage in realistic wireless communication environments. The stable radiation behavior along with consistent gain values is indicative of efficient radiation over the operating bands. Therefore, the proposed antenna proves to be reliably suitable for WLAN (2.4 GHz), WiMAX (3.5 GHz), and C-band (4–8 GHz) uses, as stated, when a moderate gain and wide coverage are necessary.

The proposed antenna, on the other hand, demonstrates linear polarization along the z-axis, as expected in common vertical monopole structures.



(a) (b) (c)

Fig. 5. 3-D radiation patterns of the suggested monopole antenna (a) 2.5 GHz, (b) 3 GHz, and (c) 4.22 GHz.

10.22060/EEJ.2026.25184.5861

Fig. 6 illustrates Gain and Realized Gain of the proposed antenna were analyzed over the frequency range from 2 to 6 GHz. The antenna shows fixed gain characteristics throughout the handling bands, though with a slight fluctuation in the regions outside the resonance. The top gain is about 2.86 dBi at the frequency of 2.6 GHz. It can also be seen that the maximum realized gain is 2.59 dBi at the same frequency, which indicates efficient radiation with very minimum losses. Within the major operating band (2.2GHz - 2.6 GHz and 3.0GHz - 4.9 GHz), the gain remains above 2 dBi, which confirms the effective impedance matching and radiating performance. Beyond 5.4 GHz, the gain and realized gain start to decrease gradually, indicating that this is according to the limits designed for bandwidth. Therefore, the reliability of the obtained gain behavior and the little difference between gain and realized gain validate the efficiency and suitability of the antenna for WLAN, WiMAX, and C-band communication systems.

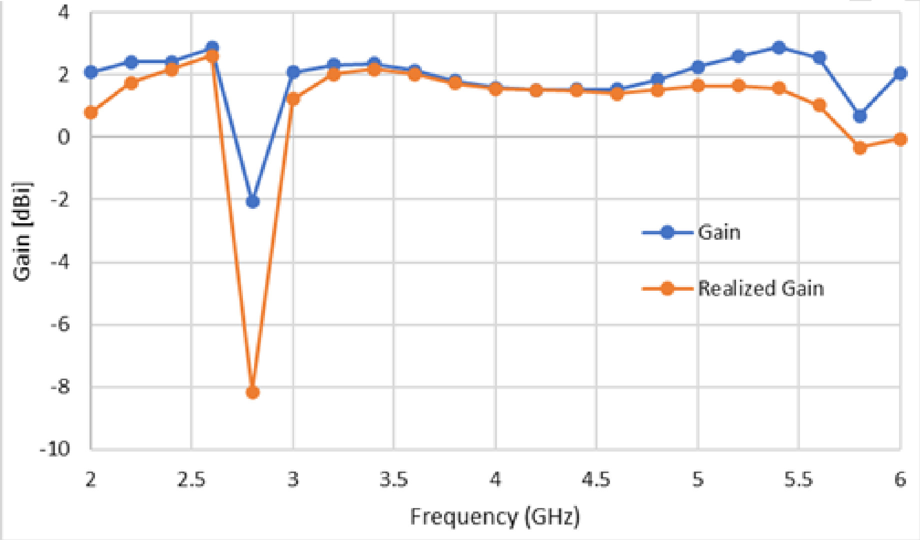
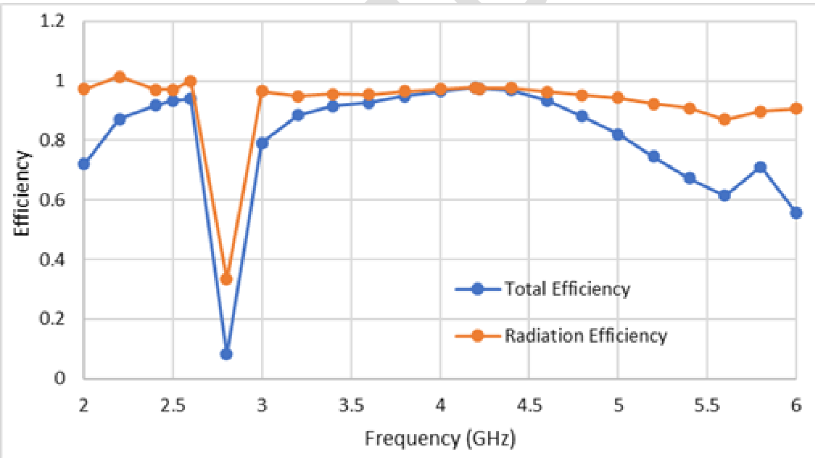


Fig. 6. Gain and Realized Gain of the suggested monopole antenna.

AUT Journal of Electrical Engineering
10.22060/EEJ.2026.25184.5861

Fig. 7 shows the simulated total and radiation efficiencies of the suggested antenna over the frequency range of 2–6 GHz. The antenna exhibits high total efficiency above 90% in the main operating bands of 2.2GHz –2.6 GHz and 3.0GHz –4.9 GHz, with the maximum value of 94% at 2.6 GHz. In addition, the radiation efficiency is above 95% within these bands, reaching almost unity, 0.99, at 2.6 GHz and 4.22 GHz. Relatively low efficiency beyond 5 GHz is due to increased surface wave losses and impedance mismatches at higher frequencies. Generally, the high and stable values of efficiency confirm the low-loss antenna performance, which is appropriate for energy-efficient WLAN, WiMAX, and C-band communication systems.

The maximum simulated radiation efficiency reaches approximately 94–97%, dependent upon the frequency band considered. The variation arises from the various surface current strengths and dielectric losses across the bands, which corresponds well with the RO3003 material characteristics.



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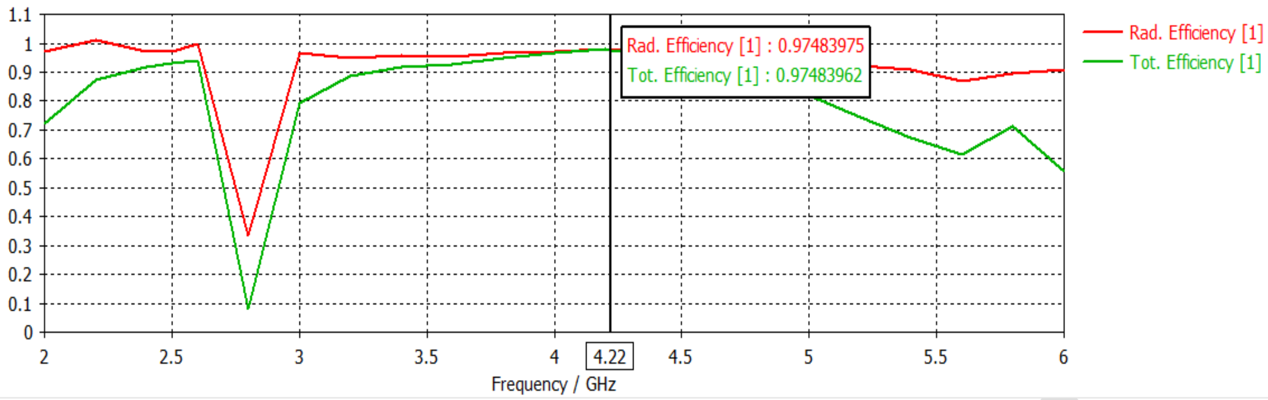

Fig. 7. Total Efficiency and Radiation Efficiency of the suggested monopole antenna.

Fig. 8. illustrates the simulated VSWR response of the proposed antenna in the frequency band from 2 to 6 GHz. It can be noted from the VSWR curve that within the operating frequency bands of 2.20-2.60 GHz and 3.00-4.90 GHz, VSWR remains under 2 units, thereby verifying the impedance matching with the standard 50 Ω feed line. The minimum VSWR value reaches approximately 1.18 at 4.22 GHz and corresponds to the deeper return loss in the S_11 response with prominent resonances being noticed. Beyond the operating frequency bands, the VSWR drastically rises and thereby excellent band selectivity is achieved with the proposed design and validates the impedance matching with the standard 50 Ω feed line for the slot and stub-loaded monopole antenna with a partial ground plane to be applicable to various IoT and sub-6 GHz 5G technologies.

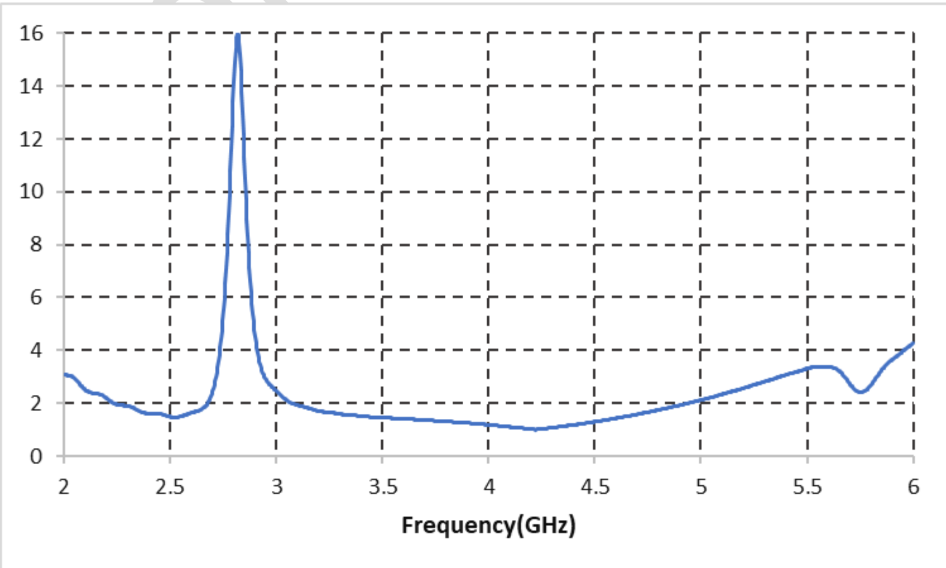

Fig. 8. Simulated VSWR response of the suggested monopole antenna.

Table 2. presents the comparison between the suggested antenna and various recently reported designs from the literature dating from 2019–2024. The presented antenna offers a wide dual-band operation in the frequency range of 2.20 GHz –2.60 GHz and 3.00 GHz –4.90 GHz, with extremely strong impedance matching $|S_{11}|$ of –68.57 dB, peak gain of 2.86 dBi, and 97 % total efficiency. In contrast with other antennas that use complex structures such as DGS or FSS, the proposed design has achieved higher efficiency, along with competitive bandwidth, using a simpler and more compact geometry, which makes it superior for sub-6 GHz wireless and IoT applications.

Table 2. COMPARISON OF PROPOSED ANTENNA TO SIMILAR ANTENNAS

Ref.	**Year**	**T_Q**	**D_V**	**BW**	**F_{BW}(%)**	**P_G**	**E_f**
[9]	2025	microstrip Rectangular patch monopole antenna	75.5 ×53.13×1.6	2.27 – 2.34	3.0%	2.6	~88
[3]	2023	Rectangular patch with FSS and top-hat stub	30 × 130 × 0.5	1.60–2.10 ,2.40–2.85	27.2%, 16.7%	5.2	~89
[5]	2024	Dual-band monopole with rose-shaped slots	25.7 × 50 × 1.52	2.00–3.71 ,5.90–7.54	60.6%, 24.1%	3.8	~96
[8]	2021	Widebeam composite microstrip-monopole antenna	60×60× 1.5	4.31 – 4.5	4.3%	3	~90

10.22060/EEJ.2026.25184.5861

Prop.	**-**	**Rectangular patch with rectangular stub and two rectangular slots (no DGS)**	**50 × 50 × 1.5**	**2.20–2.60, 3.00–~5.0**	**17.4%, 48.4%**	**2.86** (at 2.6 GHz)	**~97**

T_Q = Antenna Technique, D_V = Dimension (mm³), BW = Bandwidth ($|S_{11}| < -10$ dB) (GHz), F_{BW} = Fractional BW [Fractional BW= $(f_H - f_L) / f_C \times 100\%$], P_G = Peak Gain (dBi), E_f = Total Efficiency (%).

4. CONCLUSION

A small dual-band rectangular microstrip antenna has been designed and analyzed successfully. The proposed antenna, consisting of two rectangular stubs and slots, exhibits excellent impedance matching with a minimum $|S_{11}|$ of –68.57 dB and operates efficiently within 2.20–2.60 GHz and 3.00–4.90 GHz bands. Its excellent performance is shown in the measured top gain of 2.86 dBi and total efficiency of 97%. Owing to its simple structure, wide bandwidth, and high radiation efficiency, the suggested antenna is highly acceptable for modern wireless and IoT uses operating in the sub-6 GHz range.

The antenna is well-suited for IoT and WLAN applications because it covers both the 2.4 GHz ISM band and the 3-5 GHz sub-6-GHz spectrum used for Wi-Fi, BLE, Zigbee, and emerging IoT standards. Its moderate gain of 2.3-2.8 dBi, compact size, stable radiation pattern, and high efficiency (>94%) make it ideal for low-power short-range wireless communication nodes.

References:

[1] Benkhadda, O., Saih, M., Chaji, K., Ahmad, S., & Reha, A. (2023). A novel miniaturized dual band slotted monopole antenna for wlan and wimax applications. Progress In Electromagnetics Research C, 133, 167-179.

[2] Lin, Chun-Cheng. "Dual-band folded monopole antenna with slotted ground plane for WLAN applications." Progress In Electromagnetics Research Letters 15 (2010): 53-60.

[3] Danuor, P., Moon, J. I., & Jung, Y. B. (2023). High-gain printed monopole antenna with dual-band characteristics using FSS-loading and top-hat structure. Scientific Reports, 13(1), 9982.

10.22060/EEJ.2026.25184.5861

[4] Bhadravathi Ghouse, P. S., Kumar, P., Mane, P. R., Pathan, S., Ali, T., Boulogeorgos, A. A. A., & Anguera, J. (2024). Dual-Band Antenna at 28 and 38 GHz Using Internal Stubs and Slot Perturbations. Technologies, 12(6), 84.

[5] Iriqat, S., Yenikaya, S., & Secmen, M. (2024). Dual-band 2× 1 monopole antenna array and its MIMO configuration for WiMAX, sub-6 GHz, and sub-7 GHz applications. Electronics, 13(8), 1502.

[6] Chowdhury, M. Z. B., Armghan, A., Islam, M. T., Hossain, I., RAHMAN, M. N., Moniruzzaman, M., ... & Samsuzzaman, M. (2023). A dual band Y-shape monopole antenna for 5G wireless application. Journal of Optoelectronics and Advanced Materials, 25(May-June 2023), 248-257.

[7] Balanis, C. A. (2016). Antenna theory: analysis and design. John wiley & sons.

[8] Sun, K., Liu, S., Chen, Y., Zhao, Y., & Yang, D. (2021). Design of Composite Microstrip-Monopole Antenna With 180$^\circ $1 dB Beamwidth Based on Complementary Sources Concept. IEEE Antennas and Wireless Propagation Letters, 20(8), 1577-1581.

[9] Güzeltaş, M. B., & Bozkurt, Y. T. (2025, June). Design and Analysis of Microstrip Patch Antenna at 2.3 GHz Frequency for S-Band Applications. In 2025 9th International Symposium on Innovative Approaches in Smart Technologies (ISAS) (pp. 1-7). IEEE.

[10] Zakeri, H., Azizpour, R., Khoddami, P., Moradi, G., Alibakhshikenari, M., See, C. H., ... & Limiti, E. (2024). Low-cost multiband four-port phased array antenna for sub-6 GHz 5G applications with enhanced gain methodology in radio-over-fiber systems using modulation instability. IEEE Access.

[11] Rahman, M. A., Al-Bawri, S. S., Larguech, S., Alharbi, S. S., Alsowail, S., Jizat, N. M., & Islam, M. T. (2025). Metamaterial based tri-band compact MIMO antenna system for 5G IoT applications with machine learning performance verification. Scientific Reports, 15(1), 22866.