International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 5; May 2025
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Design of a Single-Band Turtle-Shaped Patch Antenna for 5G mm-Wave Applications

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DOI: https://doi.org/10.52403/ijrr.20250519

ABSTRACT

The 5G mm-Wave antenna is designed to support high data rates and low-latency communication, addressing the needs of next-generation wireless networks. This paper introduces a single-band turtle-shaped antenna is designed for application of 28 GHz 5G mm-wave wireless communication. The suggested antenna is 36.12 mm x 36.12 mm by 0.8 mm and is constructed from Rogers RT5880 material. To reach its resonance frequency of 28 GHz, the antenna uses elliptical stubs that are placed exactly the same way inside the patch. At 28 GHz, the suggested antenna achieves a return loss of -38 dB, a VSWR of less than 2 within the band, and peak gains of 7.5 dBi. CST software is used to carry out the design and simulation results of the turtle-shaped antenna.

Keywords: *5G mm-wave, high data rates, low-latency, return loss, gain*

1. INTRODUCTION

In recent years, there has been an increasing amount of interest in fifth-generation (5G) wireless communication antennas [1]. Millimeter-wave (mm-W) antenna system is one of the vital components for the 5G communication due to its high-speed data transmission rate and low latency. Lots of researches focus on this topic and several mm-W antennas are also proposed [2]. Millimeter-wave frequency bands are increasingly explored by research societies worldwide, positioning them as strong contenders for the next generation of mobile communication [3]. Frequency bands such as 28 GHz, 38 GHz, 48 GHz, and 73 GHz are under consideration for the next generation of mobile communication [4]. Customers anticipate better connectivity, faster browsing, and possibly "unlimited" data with the fifth generation (5G) of wireless communications networks [5]. These features necessitate the system's utilization of millimeter-wave frequency bands and diverse coverage [6]. However, designing efficient antennas for 5G mm-wave systems presents unique challenges due to higher propagation losses, reduced penetration capabilities, and increased susceptibility to environmental blockages [7]. To address these issues, antennas must exhibit high gain, compact size, wide bandwidth, and beam-steering capabilities while maintaining low fabrication complexity and compatibility with integrated circuit technology [8]. This is supported by advances in nano-electronic devices and components that enable high processing power [9]. In this context, the lower frequency bands that are being exploited by various communication networks are becoming congested, forcing the industry stakeholders to investigate alternative pools of the spectrum [10]. The next Generation (5G) can be grounded using millimeter wave radio frequency [11]. The untapped 3GHz–300GHz spectrum of millimeter waves can be used to meet the demands of the next generation [12]. In the fifth generation (5G) of wireless communications systems, the consumers are looking forward to faster connectivity, faster browsing and even unlimited data [13]. These features necessitate the system's usage of millimeter-wave frequency bands and diverse coverage [14]. The proposed design focuses on optimizing key performance parameters, such as return loss, gain, and radiation pattern, while ensuring miniaturization and scalability for integration into modern communication devices [15]. Through comprehensive simulations and parametric studies, the antenna's performance is evaluated and validated, demonstrating its suitability for next-generation wireless networks [16].

This paper introduces a single-band turtle-shaped patch antenna designed for the application of 28 GHz 5G mm-wave wireless communication. The proposed antenna characterized by dimensions of 36.12 mm x 36.12 mm x 0.8 mm, is simulated Via micro strip feed excitation. The elliptical stubs are positioned identically within the patch, to achieve good return loss of -38dB at resonant frequency of 28 GHz.

2. ANTENNA DESIGN AND PROCEDURE

The millimeter wave turtle-shaped structure and analysis is shown in Figure 1. The proposed antenna is constructed on a SL ×SW, Rogers RT5880 material with 0.8 mm thickness, a dielectric constant $\varepsilon r = 2.2$ and loss tangent $\tan \delta = 0.0009$. The main radiator elements and plane are constructed using copper material, which has a thickness of 0.035 mm.

2.1 Antenna Optimization and Analysis

Extensive parametric experiments were conducted to further examine the effects of the primary antenna characteristics on performance. Table 1 lists the optimum values for the suggested design. For this investigation, three parameters were selected: the length of the ground plane, the feed position, and the kind of substrate used; these three parameters were deemed as the most sensitive ones in defining the desired frequency bands along with best impedance matching. Only one parameter was altered during each simulation; all other parameters remained constant. A CST EM simulator [CST-Computer Simulation Technology AG-2019] was used to help with the optimization analysis of the suggested antenna settings.

2.2 Simple Patch Antenna

In the first stage, A simple patch antenna with an elliptical body and a microstrip feed line is shown in Fig. 1(a). The ideal frequency is resonant at 28 GHz. But we didn't get our required resonance frequency band.

2.3 Patch Antenna with Elliptical Stubs

The designed simple patch antenna is further modified to get the better resonant frequency an elliptical stub, hereafter referred to as the 'head,' was integrated into the structure. The antenna achieved an operational frequency range of 26.8–28.5 GHz, centered at 27.5 GHz, with a measured return loss of –24.08dB. Shown in fig1(b)

In the subsequent design stage, additional elliptical stubs designated as ears, hands and legs were incorporated. This modification resulted in an operational frequency range of 27.8–28.96 GHz, centered at 28 GHz, with a return loss of –38.5dB. Shown in fig 1(c)

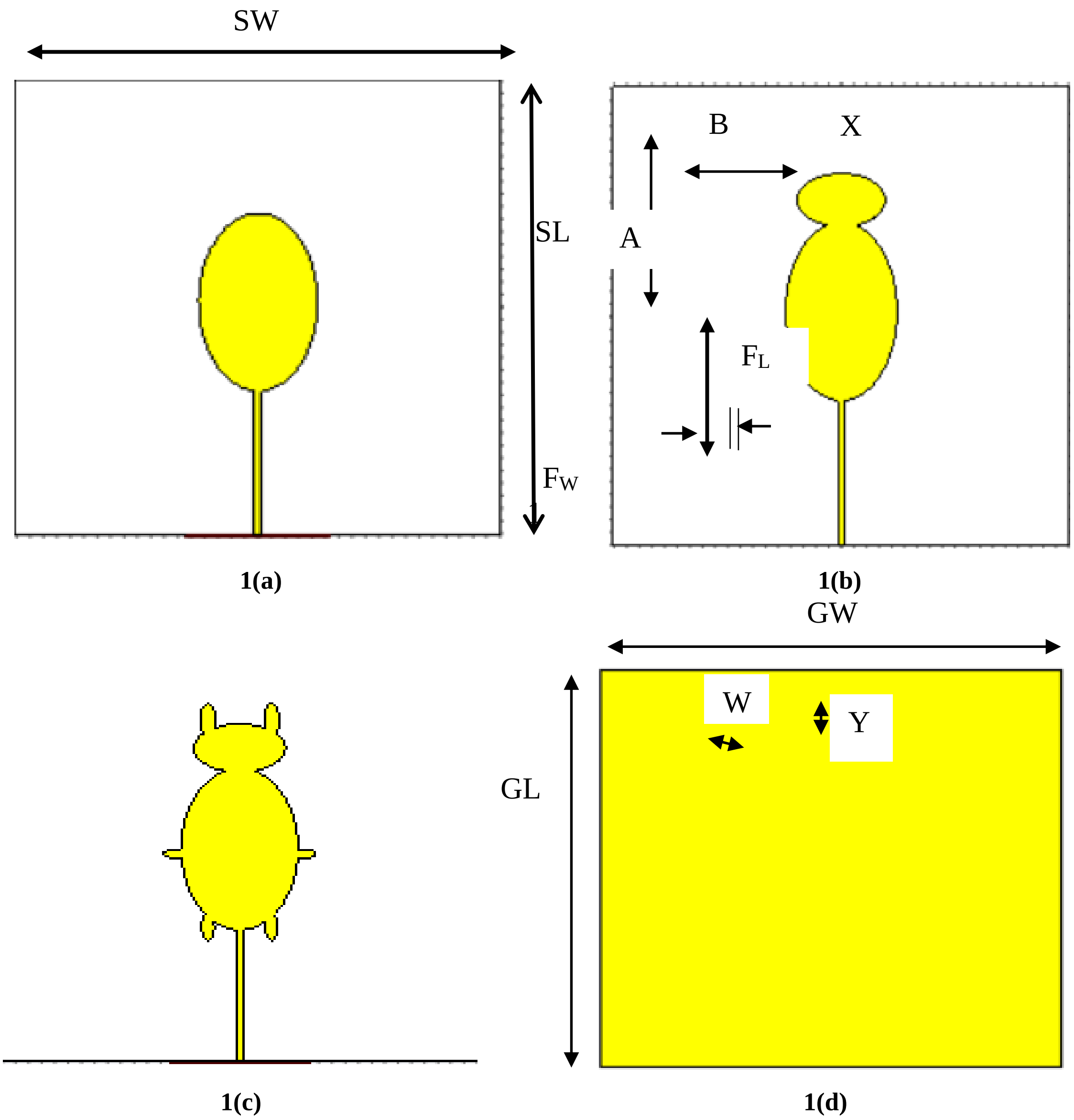


Fig.1: Proposed antenna Design (a) Simple elliptical patch. (b) Patch with head as a stub. (c) patch with more stubs like ears, legs and hands. (d) ground plane.

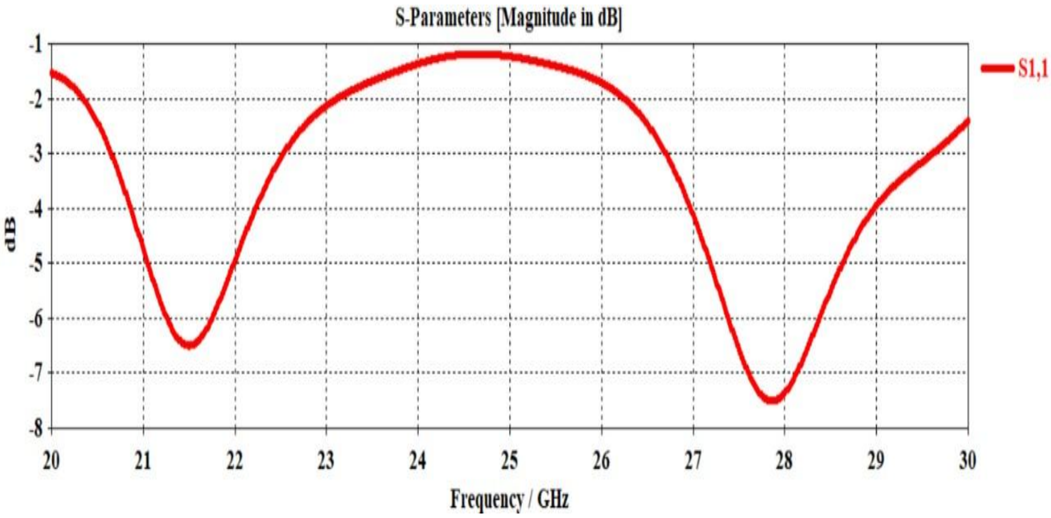
2.4 Parameters:

parameters	SL	SW	F_L	F_W	A	B
values	36.12	36.12	11.7	0.578	7.04	4.43
Parameters	GW	Z	W	X	Y	GL
values	36.12	1.45	0.58	3.48	2.09	36.12

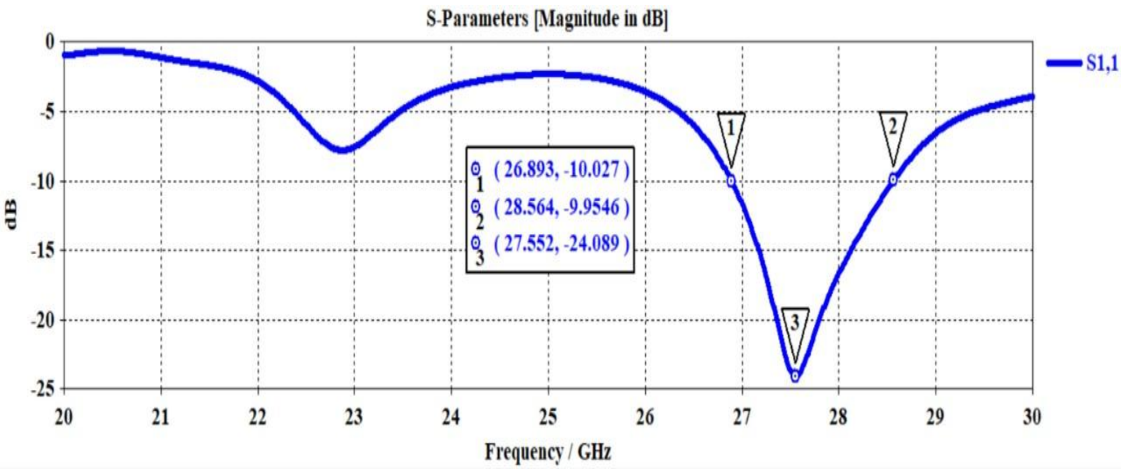
3. RESULT

3.1 S-parameters

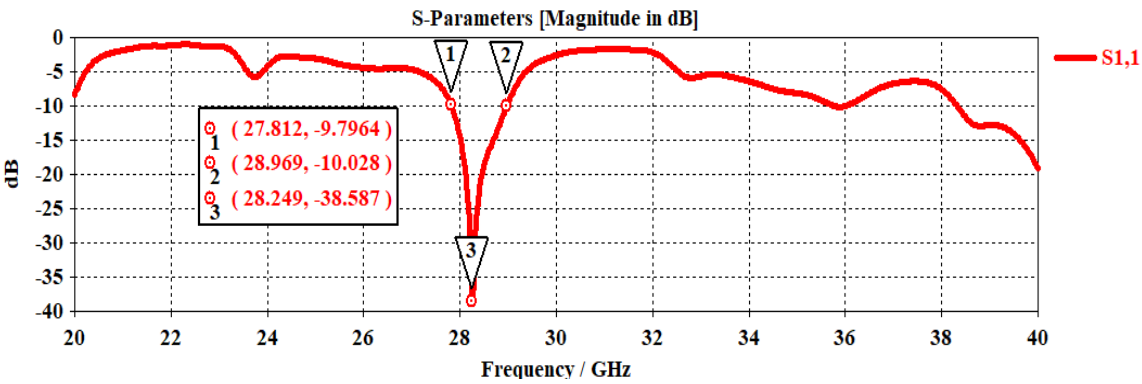
Fig.2(a) illustrates the simulated S-parameters of the conventional patch antenna without the incorporation of elliptical stubs. As observed, the design fails to exhibit any significant return loss within the targeted frequency band, indicating poor impedance matching and minimal resonance behavior. As depicted in Fig. 2(b), the conventional patch antenna with stubs resonates at 27.56 GHz, achieving a return loss of –24 dB, which indicates moderate impedance matching. To enhance the antenna performance, elliptical stubs designated as the head, ears, hands, and legs were strategically integrated into the radiating structure. The modified design, presented in Fig. 2(c), exhibits a resonant frequency shift to 28 GHz along with a significantly enhanced return loss of –38.5dB. This substantial improvement in return loss demonstrates the effectiveness of the stub-loading technique in optimizing impedance matching and minimizing reflection losses. The results clearly validate that the addition of stubs not only refines the impedance bandwidth but also improves the overall radiation performance, thereby making the proposed antenna a promising potential for millimeter-wave uses, especially in the 5G frequency ranges.



2(a)



2(b)



2(c)

Fig 2: S-Parameters of proposed antenna design (a) simple patch (b) patch with stubs (c) proposed design

3.2 VSWR (VOLTAGE STANDING WAVE RATIO)

The Voltage Standing Wave Ratio (VSWR) plot of the suggested antenna design with elliptical-shaped stubs is displayed in Fig. 3. The results indicate that the VSWR remains well below the critical threshold of 2 across the targeted frequency band, confirming good impedance matching between the antenna and the feed line. In particular, a minimum VSWR value indicates little signal reflection and effective power transfer, which is represented by the resonant frequency. The incorporation of elliptical stubs plays a key role in achieving this performance by fine-tuning the current distribution and enhancing the impedance characteristics of the radiating structure. A VSWR of less than 2 is typically considered acceptable for real-world antenna applications. The suggested design satisfies this requirement throughout the operating band, confirming its appropriateness for high-frequency and millimeter-wave communication systems.

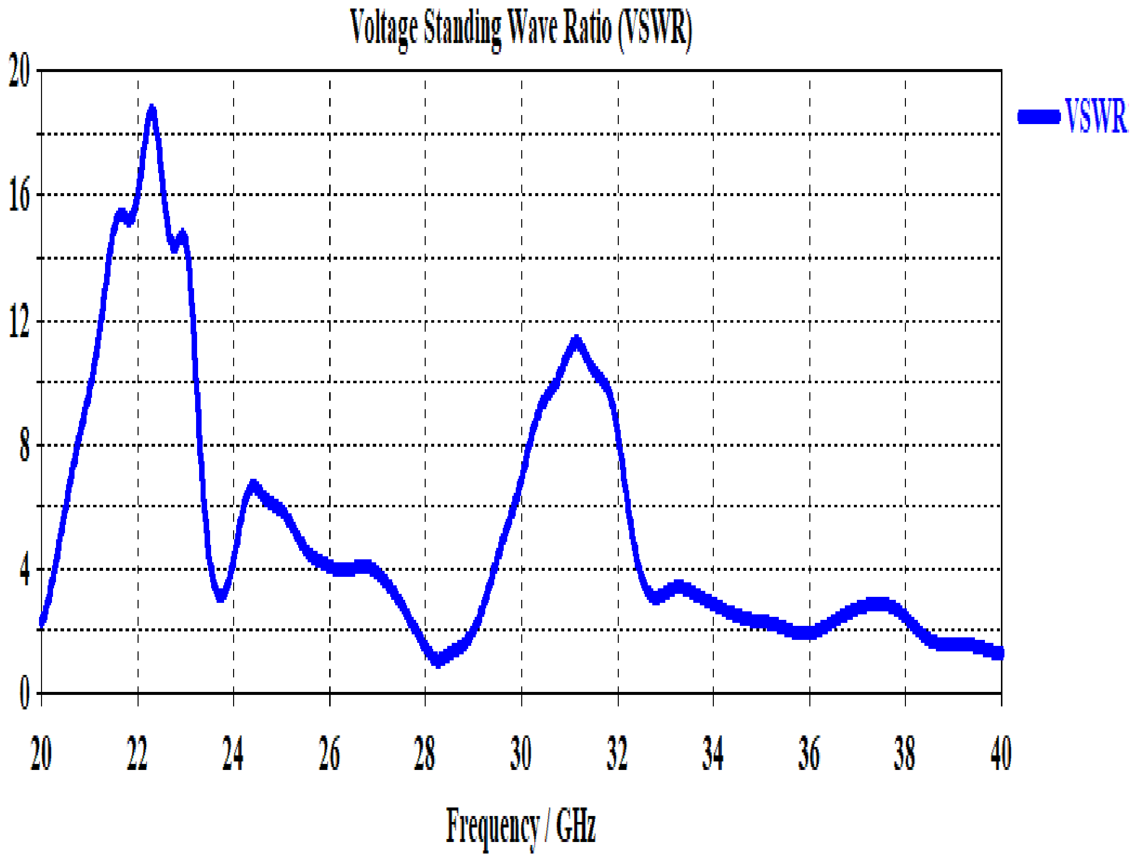


Fig 3: VSWR plot

3.3 Surface Current Distribution:

Fig. 4 illustrates the surface current distribution of the proposed antenna structure under excitation at the feed port. Upon excitation, the surface current initiates from the feed point and propagates along the radiating elements, including the elliptical-shaped stubs. A peak surface current density of approximately 5 A/m is observed near the feed region, confirming efficient excitation and strong electromagnetic coupling. The current distribution also highlights the role of the elliptical stubs in directing and enhancing current flow, which contributes to improved radiation characteristics and impedance matching. This distribution pattern supports the antenna's effectiveness in radiating energy at the desired frequency band and aligns with the resonant behavior observed in the S-parameter and VSWR results.

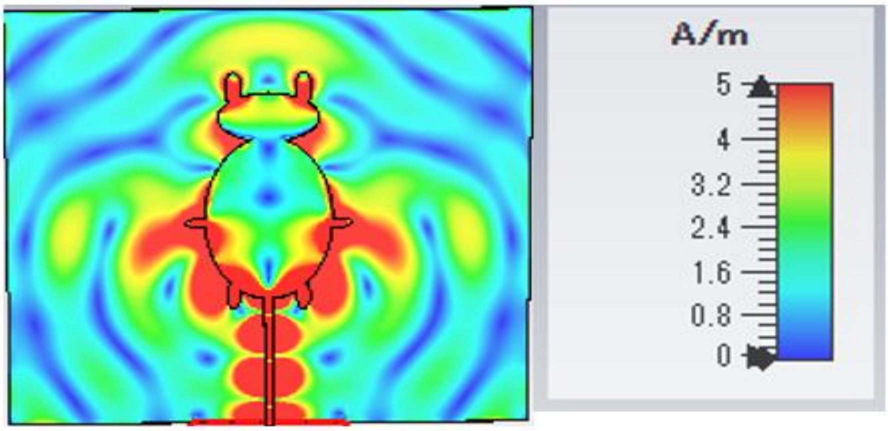


Fig.4: surface current distribution

3.4 Radiation Patterns:

Fig. 5(a) depicts the radiation patterns of the proposed antenna, with Fig. 5(b) showing the 3D polar plot. In the 2D radiation pattern, the red color represents the electric field (E-field), which exhibits a bidirectional radiation pattern, while the gray color corresponds to the magnetic field (H-field), which is omnidirectional. The antenna's directional radiation

Fig. 5(a) depicts the radiation patterns of the proposed antenna, with Fig. 5(b) showing the 3D polar plot. In the 2D radiation pattern, the red color represents the electric field (E-field), which exhibits a bidirectional radiation pattern, while the gray color corresponds to the magnetic field (H-field), which is omnidirectional. The antenna's directional radiation characteristics are depicted in the 3D polar plot by the red hue, which denotes regions of higher radiation intensity. The total radiated power for the 3D model is calculated as -0.3866 dB, whereas the radiated power of the designed antenna is slightly higher at -0.3788 dB, demonstrating a marginal improvement in radiation efficiency.

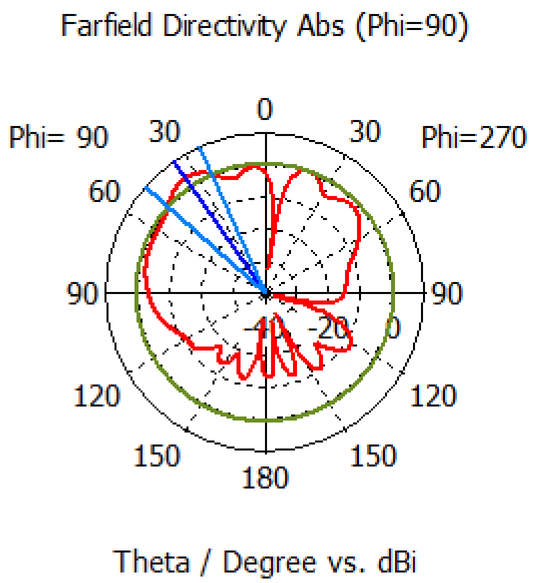


Fig. 5(a): 2D plot (E-field and H-field)

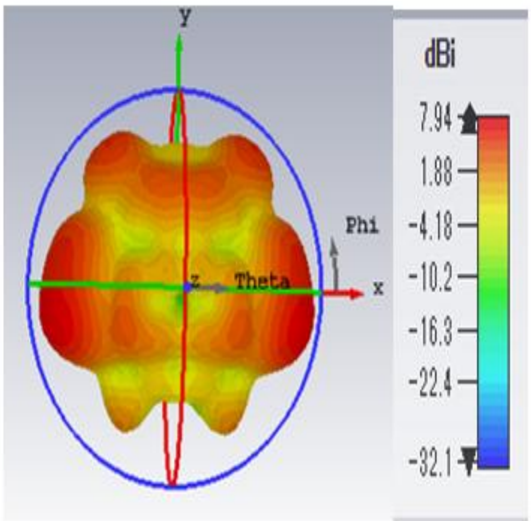


Fig. 5(b): 3D polar plot

4. CONCLUSION

In this work, a single-band turtle-shaped patch antenna operating at 28 GHz for 5G millimeter-wave applications has been successfully designed and analyzed. Using Rogers RT5880 substrate material, the antenna achieved an excellent return loss of -38 dB, a VSWR below 2, and a peak gain of 7.5 dBi at the target frequency. The incorporation of elliptical-shaped stubs within the patch significantly enhanced the antenna's performance by improving impedance matching and ensuring operation within the desired frequency band. Parametric studies confirmed that design optimizations, such as stub positioning and ground plane modifications, play a critical role in tuning antenna characteristics. Simulation results, including S-parameters, surface current distribution, and radiation patterns, validate the proposed antenna's suitability for 5G mm-wave wireless communication systems, offering a compact, high-gain, and efficient solution for next-generation networks.

Declaration by Authors

Acknowledgement: None
Source of Funding: None
Conflict of Interest: No conflicts of interest declared.

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How to cite this article: G. Kalyani, G. Srinivasa Rao, K. Deepika, P. Sai Alekhya, Ch. Pravallika. Design of a single-band turtle-shaped patch antenna for 5G mm-wave applications. *International Journal of Research and Review*. 2025; 12(5): 154-161. DOI: *https://doi.org/10.52403/ijrr.20250519*

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