

Enhancement of Bandwidth of 5G Microstrip patch Antenna by using Defected Ground Structure

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Abstract— This paper presents the design and analysis of a low-profile microstrip patch antenna with a defected ground structure (DGS) for 5G millimeter-wave applications. The antenna uses Rogers RT 5880 substrate with a relative permittivity of 2.2, and is simulated with HFSS Ansys. The introduction of DGS improves the impedance matching and bandwidth of the antenna. The proposed antenna operates within the frequency range of 24.11 GHz to 31.15 GHz, providing a wide bandwidth of 7.03 GHz. It achieves a minimum return loss of -35.81 dB at the resonant frequency of 28.36 GHz. This compact antenna measures $20\text{ mm} \times 20\text{ mm} \times 0.79\text{ mm}$. Within its operating band, the antenna gains range from 3 dB to 6 dB, and its directivity varies between 5.1 dBi and 7.9 dBi. At the resonant frequency, the gain and directivity are 5.22 dB and 6.88 dBi, respectively. The voltage standing wave ratio (VSWR) stays between 1 and 2 across the entire operating band, indicating good impedance matching. Due to its compact size and improved performance, this antenna is ideal for future 5G wireless communication systems.

Index Terms—Antenna design, defected ground structure, fifth-generation systems, millimeter-wave communication, rectangular microstrip antenna

I. INTRODUCTION

With the continuous growth of wireless communication, mobile technology has progressed from the first generation (1G) to the fifth generation (5G). Each generation aims to meet the increasing need for faster data rates, better connectivity, and improved network performance. Compared to earlier generations, 5G provides massive connectivity, large channel capacity, and seamless integration with modern technologies such as the Internet of Things (IoT), radio frequency identification (RFID), and device-to-device communication. These features make 5G capable of supporting numerous connected devices with high data demands. Though 5G builds on

4G, it includes several key technological differences. 4G systems primarily use orthogonal frequency division multiplexing

orthogonality, an issue in 4G systems.

Therefore, while 4G requires strict frequency stability, orthogonal frequency division multiplexing (OFDM) is mainly used, whereas 5G employs advanced techniques such as non-orthogonal multiple access (NOMA) and NOMA-OFDM. The use of non-orthogonal subcarriers in 5G helps to reduce errors caused by loss of orthogonality, which is a major limitation in 4G systems. Additionally, 5G is more energy-efficient than earlier cellular technologies, which lowers operational costs. Another significant aspect of 5G is its use of millimeter-wave (mm-wave) frequency bands. These bands are less crowded and provide wider bandwidth compared to the frequencies below 3 GHz used in 4G. Given the rising demand for spectrum efficiency and cost optimization, researchers are focused on antenna designs that operate in the mm-wave range. Antennas for these frequencies must be compact, efficient, and capable of providing wide bandwidth and sufficient gain. Microstrip patch antennas are commonly used in wireless communication systems because they are low profile, lightweight, and easy to fabricate. However, traditional microstrip patch antennas often have limited bandwidth and low gain, especially at higher frequencies. To solve these issues, defected ground structures (DGS) are introduced. DGS alters the current distribution on the ground plane, improving the antenna's impedance matching, bandwidth, and radiation characteristics. Numerous antenna designs for 5G applications have been reported. Some designs provide wide bandwidth but occupy more space, while others achieve compactness with limited gain. Hence, there is still a demand for a compact antenna that offers wide bandwidth and acceptable gain for 5G

communication. This work focuses on designing a low-profile, wideband microstrip patch antenna that operates in the frequency range of 24.11 GHz to 31.15 GHz, targeting a resonance frequency around 28.36 GHz for 5G applications. Square-shaped defected ground structures are introduced to enhance the antenna's gain and directivity. The design is simulated using Ansys HFSS, and its performance is analyzed in terms of return loss, bandwidth, gain, radiation pattern, and efficiency. The rest of this paper is organized as follows. Section II describes the antenna design and simulation method. Section III presents the simulation results and performance analysis of the proposed antenna. Finally, Section IV concludes the paper with key findings and potential future improvements.

II. DESIGN AND ANALYSIS

The proposed low-profile wideband microstrip patch antenna for 5G applications is designed using a commercially available Rogers RT 5880 substrate. This substrate is selected because of its low dielectric constant and low loss tangent, which are suitable for millimeter-wave antenna design. The relative permittivity of the substrate is 2.2, and the thickness of the substrate is chosen as 0.79 mm. The copper layer used for the patch and ground plane has a thickness of 0.035 mm. The overall size of the antenna is compact, measuring 20 mm × 20 mm, which makes it suitable for integration into modern wireless devices. The geometry of the radiating patch is designed using multiple horizontal and vertical metallic strips with different lengths and widths, as shown in Fig. 2(a). Two horizontal parallel strips of equal length ($W_1 = W_2 = 17.6$ mm) and narrow width are placed to improve impedance matching.

Similarly, two vertical strips with length $L_1 = 17$ mm are introduced. During the design process, it was observed that the horizontal strips mainly contribute inductive behavior, while the vertical strips introduce capacitive effects. By properly adjusting these elements, the overall input impedance of the antenna is well matched to the standard 50 Ω feed line. Additional strips with optimized dimensions (W_3 to W_7 and L_2 , L_3) are incorporated to enhance surface current distribution across the patch. From simulation observations, these modifications significantly improve the bandwidth and reduce return loss. Parametric analysis was performed by varying these

dimensions, and the final values were selected to achieve wideband operation with stable radiation characteristics. To further improve antenna performance, a defected ground structure (DGS) is introduced on the ground plane, as shown in Fig. 2(b). The ground plane is modified by etching Vertical rectangular slots are incorporated in the antenna structure to enhance the current distribution and improve impedance matching. The design includes two rectangular slots with dimensions 8 mm × 5 mm and 14 mm × 5 mm etched on the ground/radiating surface. In addition, multiple vertical slots with dimensions $x = 0.2$ mm, $y = 2$ mm, and $z = 0.035$ mm are introduced to further modify the surface current path. These slots increase the effective electrical length of the antenna and contribute to bandwidth enhancement and improved radiation characteristics. From simulation results, it was observed that these defects disturb the current distribution on the ground plane, which leads to improved impedance matching and enhanced operating bandwidth. The use of DGS also contributes to better gain and directivity compared to a conventional ground plane design. A three-dimensional view of the proposed antenna structure is shown in Fig. 2(c). All dimensional parameters of the antenna are summarized in Table I. The complete antenna design is modelled, simulated, and optimized using Ansys hfss. Through several design iterations, the proposed structure achieves wide band performance, compact size, and improved radiation characteristics, making it suitable for 5G millimeter-wave communication.

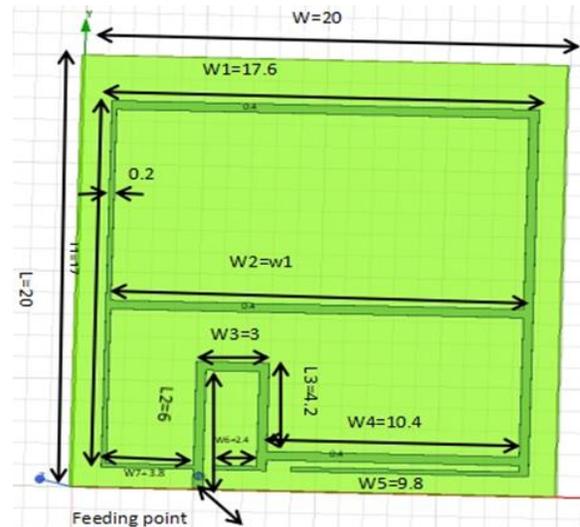


Fig1 (a) Front View (all the dimensions are in mm)

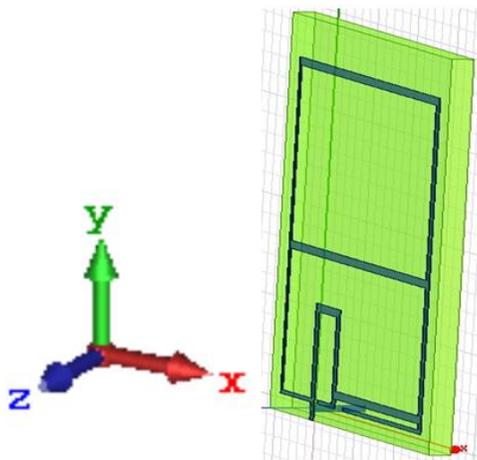
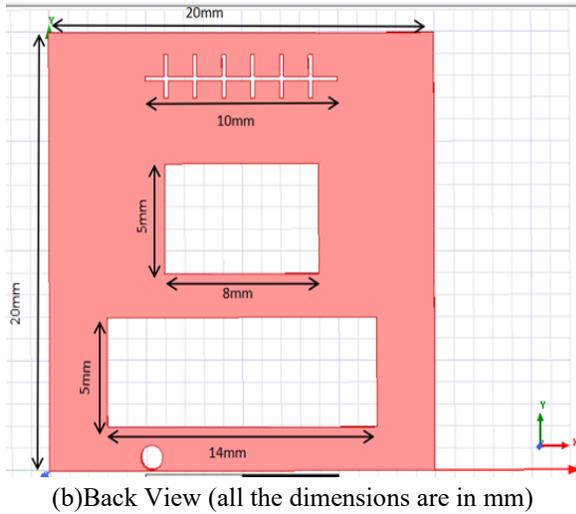


Fig. 2. Proposed 5G antenna with DGS

Table I: Design Summary of Microstrip Patch Antenna with Dgs for 5g.

Antennaparameters	Length inmm
W	20
L	20
W1=W2	17.6
W3	3
W4	10.4
W5	9.8
W6	2.4
W7	3.8
L1	17
L2	6
L3	4.2

III. RESULTS AND ANALYSIS OF PROPOSED ANTENNA

The performance of the proposed low-profile 5G antenna with defected ground structure is evaluated using simulation results obtained from the electromagnetic solver. The scattering parameter (S_{11}) of the antenna is shown in Fig. 3. From the S_{11} curve, it is observed that the antenna resonates at a center frequency of 28.36 GHz. At this frequency, the return loss is -35.81 dB, which indicates that very little power is reflected back and most of the input power is effectively radiated by the antenna. The bandwidth of the antenna is calculated by considering the -10 dB return loss criteria. The antenna operates over a wide frequency range from 24.11 GHz to 31.15 GHz, resulting in a bandwidth of 7.03 GHz. This wide operating bandwidth confirms that the proposed antenna can support upper millimeter-wave 5G applications, where high data transmission rates are required.

To further analyze impedance matching, the voltage standing wave ratio (VSWR) is examined. The simulated VSWR at the resonant frequency is found to be 1.032, which is very close to the ideal value of 1. Fig. 4 shows the variation of VSWR across the entire operating frequency band. It is observed that the VSWR remains between 1 and 2 throughout the bandwidth. This confirms that the antenna maintains good impedance matching over the complete operating range. From these observations, it is clear that the introduction of the defected ground structure plays a significant role in improving the impedance matching and bandwidth performance of the antenna. The obtained results demonstrate that the proposed antenna design is suitable for 5G millimeter-wave communication systems.

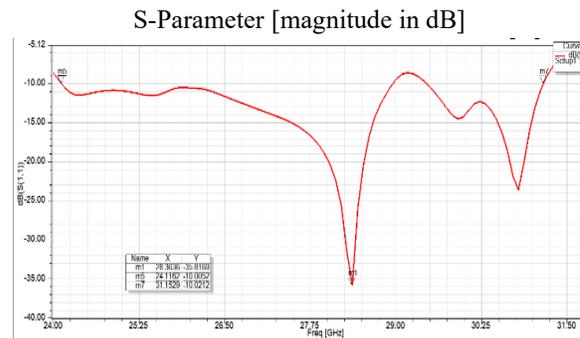


Fig. 3. S_{11} curve of the 5G antenna

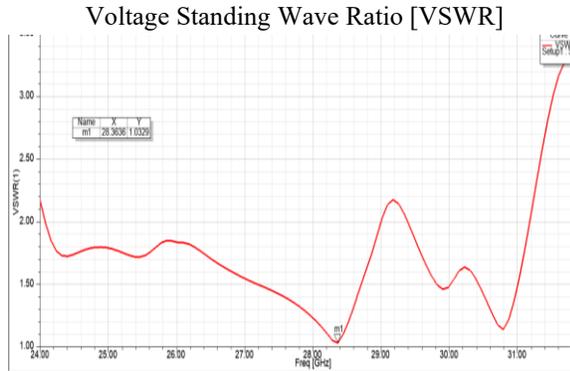
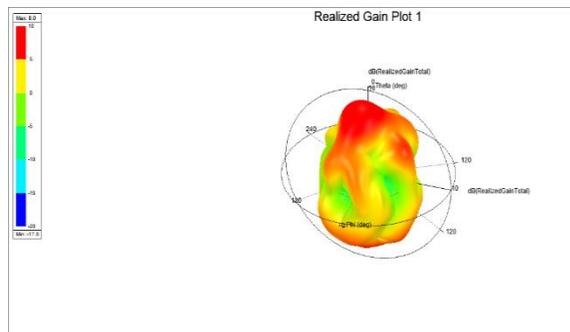
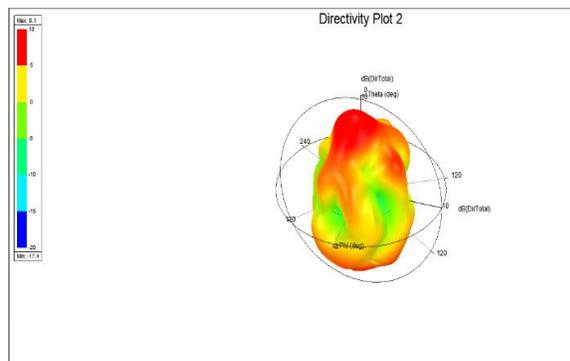


Fig. 4. VSWR of the 5G antenna.

Figure 5(a) and 5(b) illustrate the three-dimensional gain and directivity patterns of the proposed 5G antenna. At the operating frequency of 27.26 GHz, the antenna exhibits a peak gain of 5.29 dB and a directivity of 7.38dBi, indicating good radiation performance at the target frequency.



(a) 3D Gain at 28.36GHz

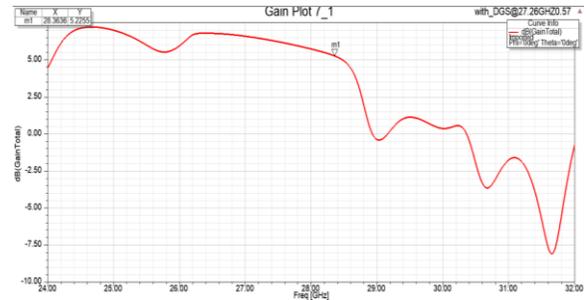


(b) 3D Directivity at 28.36 GHz

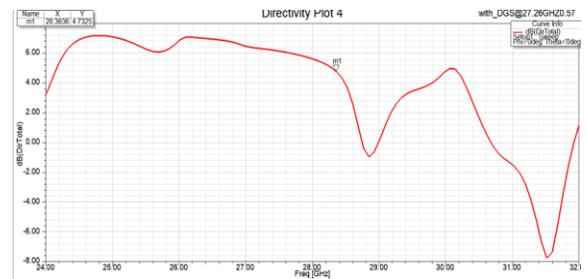
Fig. 5. Gain and Directivity of the 5G antenna at 28.32GHz.

Figure 6 presents the variation of gain and directivity with frequency for the proposed 5G antenna. Throughout the operating band, the gain varies between 3 dB and 6 dB, and the directivity ranges from

5.1 dBi to 7.9 dBi. At the centre frequency of 28.36 GHz, the antenna shows a gain of 5.22 dB and a directivity of 6.8 dBi, demonstrating stable radiation performance across the band.



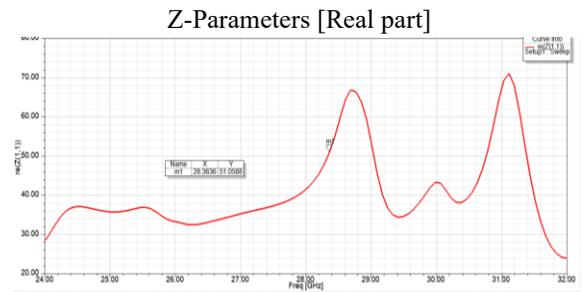
Gain at 28.36 GHz



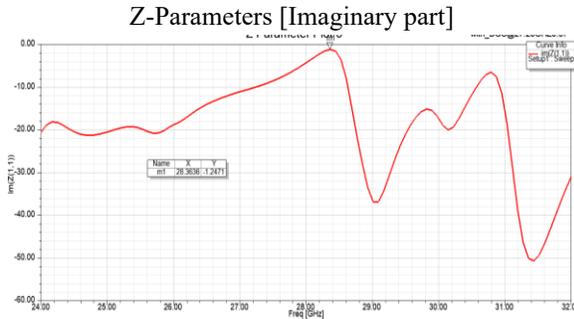
Directivity at 28.36 GHz

Fig.6 Gain and Directivity Vs Frequency

The antenna impedance is well matched with the port impedance, indicating proper impedance matching. The overall performance parameters of the antenna are summarized in Table II. Figure 8 shows the Z-parameters of the low-profile antenna, where the real part of the impedance is close to 50 Ω and the imaginary part is nearly zero at the operating frequency of 28.36 GHz. This confirms good impedance matching at the target frequency. The comparison presented in Table III demonstrates that the designed antenna is compatible with existing reported designs.



(a) Real part



(b) Imaginary part

Fig. 8. Z – Parameters (a) Real part and (b) Imaginary part

Table III: Comparison Table.

Parameter	Ref-14	Ref-16	Ref-17	Existing result	Proposed -results
Size (LxW)	4x9.45	5x5	35x36	20x20	20x20
Substrate material	$\epsilon_r=4.4$	Roggers RT 5880	Teflon	Roggers RT 5880	Roggers RT 5880
Frequency range (GHz)	25.2-34.3	20-42	28.1-28.91	25.52-31.37	24.11-31.15
Center frequency	27.4	38	28.49	27.26	28.36
Return loss(dB)	-30	-43	-39.55	-35.35	-35.81
Gain(dB)	2.3	4	8.841	5.11	5.22
Bandwidth	9.1	2.2	0.841	5.85	7.03

IV.CONCLUSION

In this work, a compact microstrip patch antenna with a defected ground structure (DGS) has been designed and analyzed for 5G communication applications. Introducing defects in the ground plane improves the flow of surface current, which helps in enhancing the radiation behavior and overall antenna performance. The proposed antenna operates over a wide bandwidth of 7.03GHz, covering frequencies from 24.11 GHz to 31.15 GHz, making it suitable for 5G millimeter-wave bands. The return loss (-35.39dB) and VSWR values across this frequency range indicate very good impedance matching. The VSWR remains between 1 and 2 throughout the operating band and reaches a minimum value of 1.032 at the resonant frequency of 28.36 GHz, confirming efficient power transfer. Additionally, the antenna achieves a directivity of 6.88 dBi, a gain of up to 5.22 dB, and a radiation efficiency of above 90%, which are acceptable and reliable values for practical 5G applications. Due to its compact size of 316 mm³, low profile, and enhanced performance achieved using the defected ground structure, the proposed antenna can be considered a strong and suitable candidate for future 5G wireless communication systems.

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