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RESEARCH

A wideband multiple rectangular slotted patch antenna for 5G applications

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A microstrip antenna with four slots in the center of the patch for 5G applications focusing on enhancing bandwidth and other key metrics is presented. The proposed antenna with multiple rectangular slots and a partial ground structure intends to address the difficulties that arise from working with the millimeter-wave frequencies of the 5G network. Operating at a frequency of 28.082 GHz, the antenna exhibits remarkable characteristics that position it as a promising candidate for 5G communication systems. The antenna's design is based on optimization process that involves iterative modifications to its geometry and structure. The final configuration consists of a rectangular patch incorporated with four symmetric rectangular slots, providing the antenna with the capability to achieve a bandwidth of 2.585 GHz. Constructed on a Rogers RT 5858 with desirable electrical properties, the suggested design provides a radiation efficiency of 73.43%, making it well-suited for high-frequency operations. Simulation results obtained using the CST Microwave Studio suite prove the antenna's outstanding performance. The return loss curve demonstrates a value of approximately −32.395 dB, accompanied by a −10 dB return loss. Furthermore, the Voltage Standing Wave Ratio (VSWR) remains consistently below 2, indicating favorable impedance matching. With a gain of 5.904 dB and a directivity of 8.049 dB, the antenna exhibits excellent signal amplification and control over radiation patterns. At the frequency where resonance occurs, the antenna's three-dimensional radiation pattern demonstrates how effectively it can transmit signals with focus and direction.

Keywords: microstrip, patch, bandwidth, wideband, slot, 5G

Introduction

Today's wireless communication usage is heavily reliant on internet-based activities such as web browsing and social media applications. 5G is the fifth generation of mobile networks in telecommunications, following the previous generations of 2G, 3G, and 4G. With faster connection speeds, lower response times, and greater capacity, 5G technology (1) offers more reliable service than previous networks. While operating similarly to previous generations, 5G uses higher radio frequencies known as millimeter waves (mm waves) (2, 3) that are less congested, allowing data to transmit at faster rates. However, there can be challenges with sending data over long distances in higher frequency bands and there can also be penetration losses. To overcome this, 5G uses Multiple Input and Multiple Output (MIMO) antennas (4, 5) to enhance signal strength and capacity across the wireless network. But, the optimization of Envelope Correlation Coefficient and diversity gain becomes an issue in this type of antennas.

Microstrip patch antenna's (MPA) (6–8) design, one of the classic designs, plays a crucial role in antennas for wireless communication due to their small length, lightweight, modest value, and ease of fabrication. But these antennas offer limited frequency range and inefficient coverage. In the context of 5G, microstrip patch antennas that operate around the 28 GHz frequency range bear particular significance mandates specialized substrate materials endowed with tailored attributes to ensure optimal functionality as in (9–11). However, conventional 5G microstrip patch antennas designed at 28 GHz exhibit limitations that impede their seamless integration into the world of 5G. The challenges of limited bandwidth and suboptimal radiation efficiency restrict their efficacy in catering to the multifaceted demands of modern high-frequency applications, which presents a design challenge for the antenna designer to achieve broadband operation.

To overcome the bandwidth limitation, slot cutting on the antenna's surface has been proved as an effective technique in expanding the available bandwidth. Incorporation of different slot shapes in the patch's structure results in broader bandwidth capabilities. This approach, highlighted in the references (12), contributes to overcoming the limitations associated with narrow bandwidth in traditional antennas. The process of slot cutting introduces a mechanism for improving the antenna's capacity to transmit and receive a wider range of frequencies, thus aligning with the requirements of 5G applications where increased bandwidth is of paramount importance. However, despite its advantageous attributes, it's important to acknowledge the potential complexity introduced by this technique. The intricate nature of slot cutting can lead to an increased level of intricacy within the system.

Inspired by slotting techniques introduced in (10), this paper presents an innovative antenna design aimed at overcoming limitations and enhancing the performance of microstrip patch antennas for 5G applications. By integrating multiple rectangular slots and implementing an advanced partial ground structure, the proposed antenna defies conventional constraints, leading to a substantial enhancement in both bandwidth and radiation efficiency. This groundbreaking design achievement empowers the antenna to provide an impressive bandwidth of 2.585 GHz and a radiation efficiency of 73.43%. This newfound capability positions the proposed antenna as a promising solution to address the escalating demands of 5G communication systems. It effectively bridges the gap between conventional narrowband antennas and the exacting requirements of contemporary high-frequency. The subsequent parts of the work are coordinated as follows. In Section II, the design and structural analysis of the proposed concept are detailed. The simulation outcomes and their subsequent discussion are provided in Section III. Lastly, Section IV encapsulates the work's conclusions.

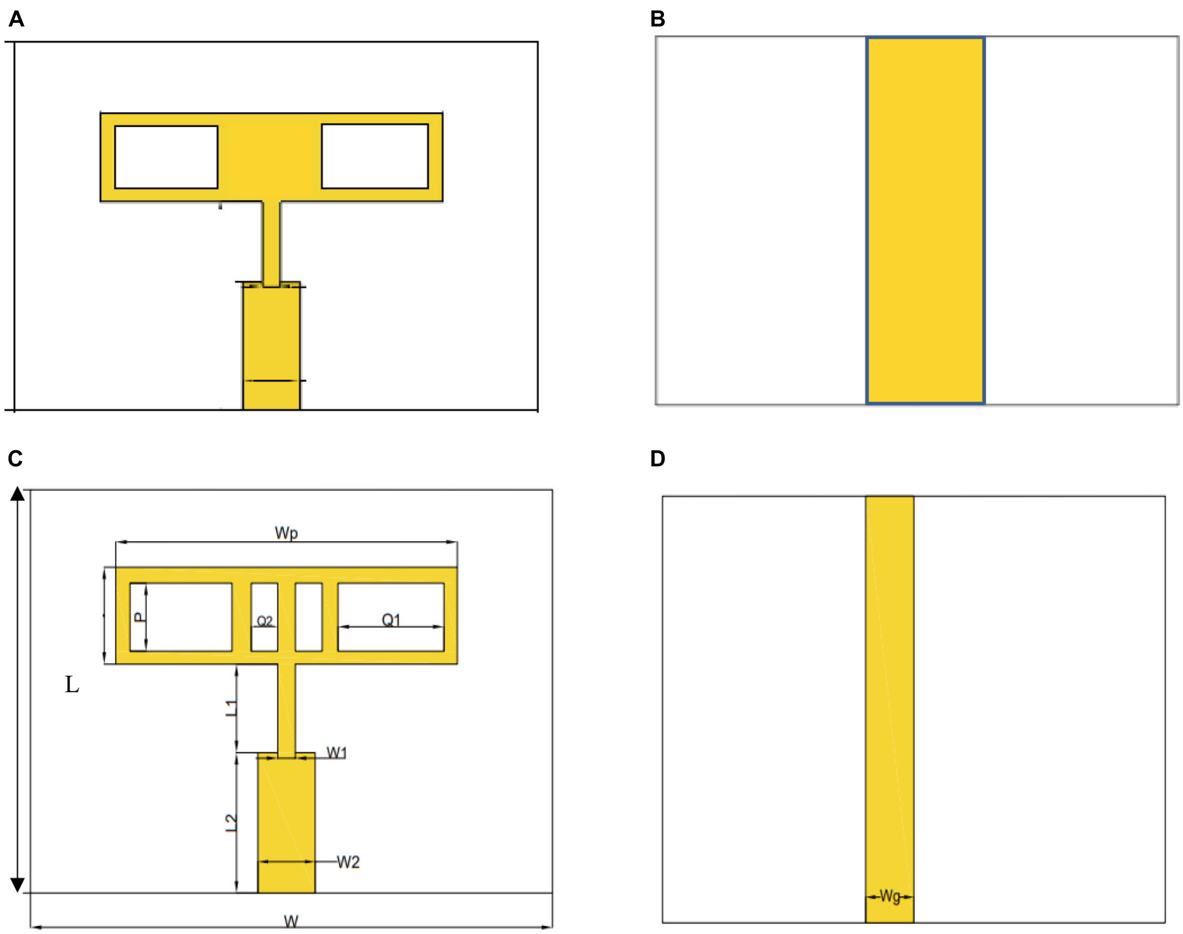

FIGURE 1 | Proposed antenna design **(A)** Initial design front view, **(B)** Initial ground structure, **(C)** Modified design front view, and **(D)** Modified ground structure.

TABLE 1 | Dimensions of the slotted antenna.

Description	Symbol	Value (mm)	Description	Symbol	Value (mm)
Substrate length	L	30.0	Slot 1 Width	Q_1	4.0
Substrate width	W	40.0	Slot 2 Width	Q_2	2.0
Substrate thickness	H	1.575	Strip Length – 1	L_1	6.6
Patch length	L_p	6.0	Strip Length – 2	L_2	9.0
Patch width	W_p	26.0	Strip Width – 1	W_1	2.0
Metal thickness	t	0.035	Strip Width – 2	W_2	4.80
Slot length	P	7.0	Ground Width	W_g	5.0

Design analysis and structure of the proposed antenna

The structural configuration of the suggested antenna is depicted in Figure 1. Which is a multiple rectangular slotted antenna, featuring dimensions of (40 × 30 × 1.575) mm. The antenna patch comprises annealed copper and is placed on the top of a Rogers RT 5880 (lossy) with a thickness of 1.575 mm. The proposed antenna, which operates between 26 and 30 GHz, effortlessly covers the 28 GHz band, making it well suited for 5G applications. This design showcases commendable characteristics, boasting a gain of 5.904 dB and an expansive bandwidth of 2.585 GHz, effectively catering to the specific demands of 28 GHz 5G applications.

In the design process, an initial configuration employing a rectangular patch antenna featuring two slots, as portrayed in Figures 1(A, B), was initially explored to assess performance outcomes. However, the obtained results were deemed unsatisfactory. Subsequent modifications were made to the structure, primarily focused on reducing the ground width. A pivotal enhancement was introduced by incorporating four symmetric rectangular slots into the fundamental design, as visually represented in Figures 1(C, D). This strategic adjustment yielded notable improvements in bandwidth performance and other performance metrics, thereby corroborating the efficacy of the design enhancement strategy.

Table 1 shows the dimension parameters for the proposed design. The effectiveness of the design lies in this rigorous design strategy, which relies on changes to the structure and careful selection of parameters. This approach is appropriate for the requirements of today's high-frequency wireless communication.

Simulation results and discussion

The antenna design presented in this paper aims to address the limitations of conventional microstrip patch antennas in the context of 5G applications. These antennas have historically faced challenges such as narrow bandwidth and suboptimal radiation efficiency, which can hinder their performance in high-frequency communication scenarios, particularly in the vicinity of the 28 GHz frequency range where 5G operates. To overcome these limitations, the proposed antenna design employs an innovative approach that incorporates multiple rectangular slots and a partial ground structure. These design enhancements are strategically aimed at achieving two fundamental

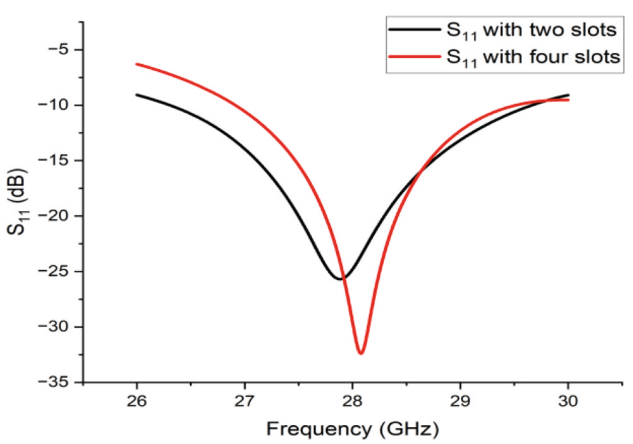

FIGURE 2 | Return loss of the proposed design.

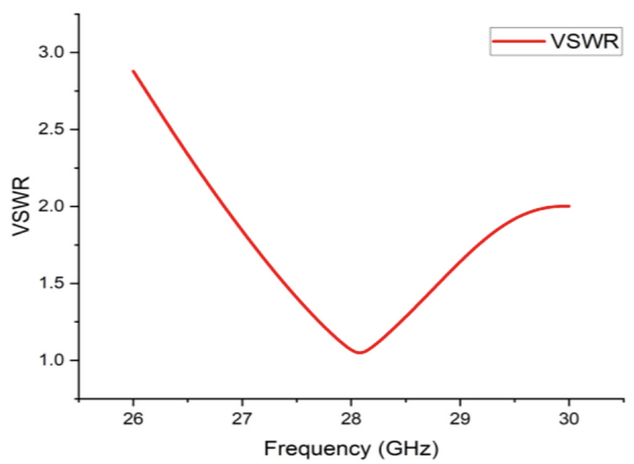

FIGURE 3 | Voltage Standing Wave Ratio (VSWR) of the proposed design.

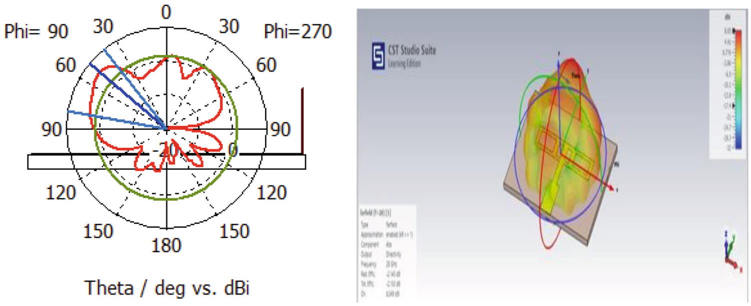

FIGURE 4 | Three-dimensional (3D) Radiation pattern of the proposed design at 28 GHz.

TABLE 2 | Comparison between proposed work with the literature.

Work	Size (mm)	Bandwidth (GHz)	Gain (dBi)	VSWR	Radiation efficiency (%)
[9]	47 × 39	1.046	7.587	1.023	98.214
[11]	94 × 38.4	NG	11	NG	NG
[12]	55 × 51.6	1.95	6.14	NG	NG
[15]	11 × 13	1	10	NG	NG
[16]	10 × 12	2.9	3.45	<2	88
[17]	$1.36\lambda_C \times 0.9\lambda_C$	650 MHz	5.83	NG	<85%
Proposed work					
Reduced ground width + slot	40 × 30	4.841	6.9	1.03	89.77
Reduced ground + Extra Slots	40 × 30	2.6	5.9	1.06	73.43

From the table, it is clear that the addition of slots and reduced ground width gives satisfactory performance in the case of 5G applications when compared to other results.

goals: expanding the available bandwidth and improving radiation efficiency.

The simulation results substantiate the efficacy of the design approach. The return loss graph (**Figure 2**) showcases a significant reduction in return loss, reaching approximately −32.395 Decibels, with a noteworthy return loss bandwidth of 2.605 GHz at −10 Decibels. This signifies that the proposed antenna is capable of both transmitting and receiving signals across a broader frequency range, contributing to improved connectivity and coverage.

Additionally, the voltage standing wave ratio (VSWR) magnitude of around 1.0681 (**Figure 3**) reinforces the antenna's strong impedance-matching characteristics. This is a crucial aspect for efficient signal transmission, as a low VSWR indicates that minimal signal power is reflected back to the source.

The antenna's gain of 5.904 Decibels and directivity of 8.049 Decibels, along with a radiation efficiency of 73.43%, reflect its capability to efficiently transmit and receive signals in a focused manner. These attributes are essential for maintaining strong communication links over extended distances.

Furthermore, the side lobe level measured at −4.4 Decibels and the half-power beam width of 41.8 degrees (**Figure 4**) underline the antenna's ability to concentrate its radiated energy in the desired direction, while minimizing unwanted radiation in other directions. This characteristic is crucial for optimizing signal strength and coverage in specific areas.

Comparing the outcomes of the proposed antenna with previous simulation outcomes and a reference design (as presented in the table), it is evident that the incorporation of slots and the reduction in ground width have contributed to improved performance, especially in center frequency, return loss, gain, VSWR, and, radiation efficiency. This comparison highlights the effectiveness of the design modifications in meeting the requirements of 5G applications. A comparison of the outcomes of the proposed antenna with the previous simulation results is shown in **Table 2**.

Conclusion

With 5G, one can now connect to the world faster, gain more experience and learn better due to the improved network capabilities. In this paper, a microstrip patch antenna with multiple rectangular slots is designed to fulfill the demands of 5G applications. Substantial performance factors, including wider band widths, enhanced gain, and a great impedance match, were achieved by the suggested antenna. At a frequency of 28.08 GHz, the antenna provides a return loss of −32.38 dB and a VSWR of 1.0681, while also offering a wide bandwidth of 2.605 GHz. This makes it a strong contender for next-generation 5G applications at 28 GHz.

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