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High-gain and broadband 1×4 rectangular microstrip antenna array for 28 GHz 5G applications

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ABSTRACT

Millimeter-wave (mmWave) communication systems at 28 GHz are key to fifth generation (5G) networks due to their high bandwidth and data rates. However, mmWave signals suffer from severe propagation losses, which demand antenna systems capable of providing high gain while maintaining a broad impedance bandwidth. This work presents a compact four-element rectangular microstrip antenna array fabricated on a Rogers RT5880 substrate (er=2.2, thickness=0.45 mm, and tan d=0.0009), designed to operate at 28 GHz. The antenna achieves approximately 14 dBi gain and an impedance bandwidth close to 1 GHz. Radiation patterns demonstrate stable directional performance and high efficiency. The results obtained highlight the suitability of the proposed antenna array as a compact and efficient solution for 5G mobile terminals and small-scale base station applications.

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1. INTRODUCTION

The fifth generation (5G) of wireless communication systems provides higher data rates, increased network capacity, and improved connectivity to support emerging applications, including the internet of things (IoT), intelligent transportation, and industrial automation [1]–[3]. To meet these requirements, millimeter-wave (mmWave) frequencies have attracted considerable attention because of their wide available bandwidths and potential for high-capacity wireless links. In particular, the 28 GHz band is a promising candidate for 5G communications [4]–[6]. However, significant propagation losses and sensitivity to obstacles make high-gain, directional antenna systems essential for improving link performance [7].

Microstrip patch antennas are widely used in wireless communications because of their low profile, lightweight structure, ease of fabrication, and compatibility with planar integration technologies [7]. Nevertheless, their impedance bandwidth and radiation gain may be limited. Various techniques, including optimized patch geometries, defected ground structures (DGS), and metasurfaces, have been investigated to improve antenna performance [8], [9]. Antenna arrays offer another effective solution by combining the electromagnetic fields radiated by multiple elements to increase directivity and gain [10]–[12]. However, array performance depends on element spacing, feeding network design, impedance matching, and mutual coupling, making the simultaneous optimization of gain, bandwidth, and structural complexity a significant design challenge.

Previous studies have investigated various antenna configurations for 5G and mmWave applications. Research has addressed massive multiple-input multiple-output (MIMO) configurations [13]–[15], rectangular microstrip patch antennas [16], and coplanar waveguide (CPW)-fed MIMO antennas [17]. Other studies have explored wideband Vivaldi antennas [18], high-gain and wideband MIMO structures [19], and dual-band

MIMO antennas operating at 28 and 38 GHz [20]. Alternative configurations include sinuous spiral antennas [21], stacked-patch antennas [22], and L-slotted microstrip patch antennas [23]. Metasurface-based antenna designs have also been investigated to improve radiation performance [24], while inset-fed microstrip antennas have been proposed for 5G applications [25]. In addition, analytical approaches have been developed to investigate microstrip antenna performance at mmWave frequencies [26]. These studies demonstrate the diversity of approaches to improving antenna performance. However, the choice of geometry, substrate, feeding configuration, and operating frequency remains critical to achieving the desired radiation characteristics.

In this context, this paper presents the design and full-wave simulation of a four-element rectangular microstrip antenna array operating at 28 GHz for 5G applications. The proposed structure uses a Rogers RT5880 substrate with a relative permittivity of 2.2, a thickness of 0.45 mm, and a loss tangent of 0.0009. A T-junction corporate-feed network is employed to distribute power among the radiating elements. The main contributions are the design and optimization of the antenna geometry and feeding network, together with a comprehensive evaluation of the reflection coefficient, impedance bandwidth, voltage standing wave ratio (VSWR), realized gain, radiation efficiency, and radiation patterns. The objective is to achieve a suitable combination of impedance matching, radiation gain, and bandwidth in a compact planar structure.

The remainder of this paper is organized as follows. Section 2 describes the antenna configuration and design methodology. Section 3 presents the simulation procedure. Section 4 discusses the simulated results and section 5 concludes the paper.

2. ANTENNA DESIGN AND METHOD

2.1. Rectangular antenna element geometry

As depicted in Figure 1, the basic radiating element consists of a rectangular microstrip patch fabricated on a 0.45 mm-thick Rogers RT5880 substrate. This substrate has a dielectric constant (εr) of 2.2 and a loss tangent (tan δ) of 0.0009. A quarter-wavelength transformer is utilized for impedance matching to ensure effective power delivery from the feed line to the patch. Initial dimensions were derived from transmission line model equations [7] and later refined via full-wave electromagnetic simulation to fine-tune the resonance to 28 GHz. The final optimized dimensions are listed in Table 1.

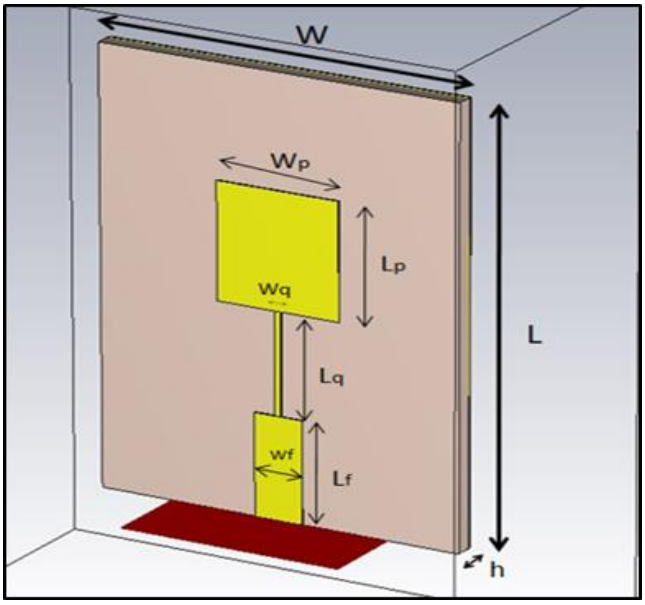


Figure 1. Structure of the single radiating patch

Table 1. Dimensions of the optimized rectangular patch

Parameters	W_p	L_p	W_q	L_q	W_f	L_f	W	L
Values (mm)	3.086	3.082	0.15	2.5	1.55	2.05	8.86	12.21

The patch width (W) and length (L) are determined using established microstrip design equations, as shown in (1) and (2) [7]:

$$W = c / (2fr) \times \sqrt{[2 / (\varepsilon r + 1)]} \quad (1)$$

$$L = c / (2fr \times \sqrt{\varepsilon eff}) - 2\Delta L \quad (2)$$

The effective dielectric constant ($\varepsilon_e$ff) and the length extension (ΔL) are given by (3) and (4):

$$\varepsilon eff = (\varepsilon r + 1)/2 + [(\varepsilon r - 1)/2] \times [1 + 12 \times (h/W)]^{\wedge}(-1/2) \quad (3)$$

$$\Delta L/h = 0.412 \times [(\varepsilon eff + 0.3) \times (W/h + 0.264)] / [(\varepsilon eff - 0.258) \times (W/h + 0.8)] \quad (4)$$

These relationships were used to compute the initial physical dimensions of the microstrip antenna before parameter tuning. The rectangular configuration was designed following the method outlined in [7], ensuring proper impedance matching and desired resonance characteristics at 28 GHz.

2.2. Configuration of the 1×4 antenna array

The 1×4 rectangular antenna array (Figure 2) is fed via a multi-stage T-junction corporate feed, ensuring uniform amplitude and phase across all elements. Two 1×2 sub-arrays are used to form the complete 1×4 array. The resulting optimized parameters are presented in Table 2.

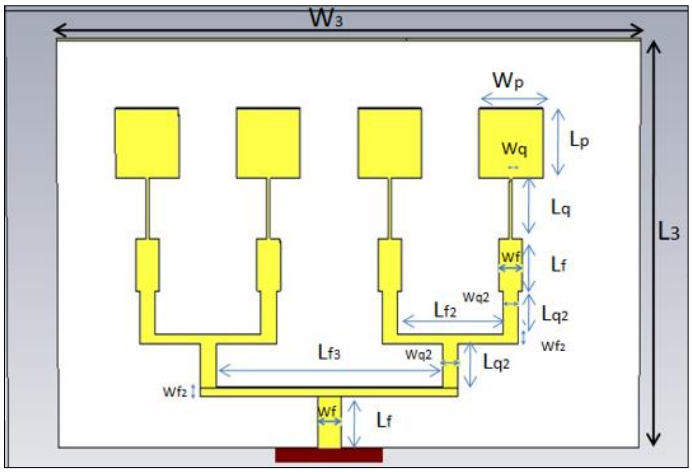


Figure 2. Geometrical configuration of the proposed 1×4 rectangular array

Table 2. Optimized dimensions of the 1×4 rectangular antenna array

Parameters	W_p	L_p	W_q	L_q	W_f	L_f	W_{q2}	L_{q2}	W_{f2}	L_{f2}	L_{f3}	W_3	L_3
Values (mm)	3.255	3.012	2.5	0.79	1.2	4.5	0.79	1.92	0.4	6.79	13.23	30.2	21.21

3. RESULTS AND DISCUSSION

3.1. Single antenna element

Figure 3 presents the reflection coefficient (S11) of the single patch antenna, which reaches a minimum value of −33 dB at the resonant frequency. The corresponding VSWR, shown in Figure 4, is very close to unity, confirming good impedance matching. The antenna achieves an approximately 1 GHz impedance bandwidth for S11<−10 dB. Regarding its radiation performance, the antenna provides a gain of approximately 6.37 dB, as shown in Figure 5. The radiation patterns presented in the E-plane (φ=0°, Figure 6) and H-plane (φ=90°, Figure 7) exhibit well-defined main beams, with half-power beamwidths (HPBW) of 95.7° and 78.5°, respectively.

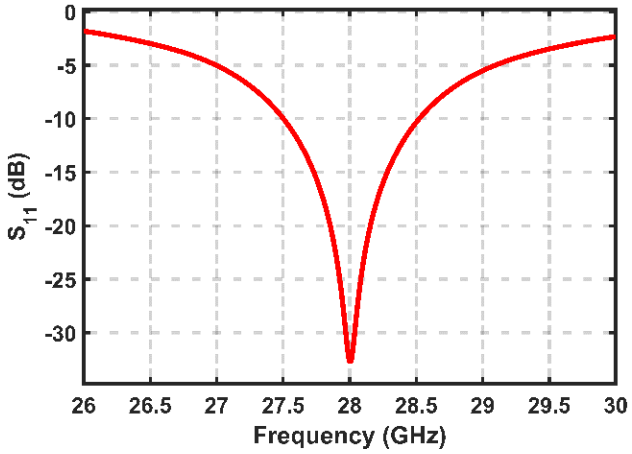


Figure 3. S_{11} frequency response of the proposed rectangular microstrip antenna, illustrating efficient impedance matching

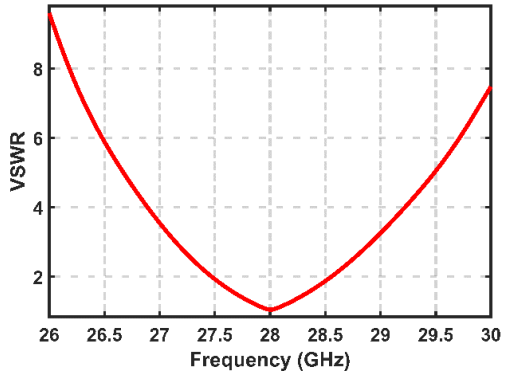


Figure 4. Frequency response of VSWR for the proposed rectangular antenna element

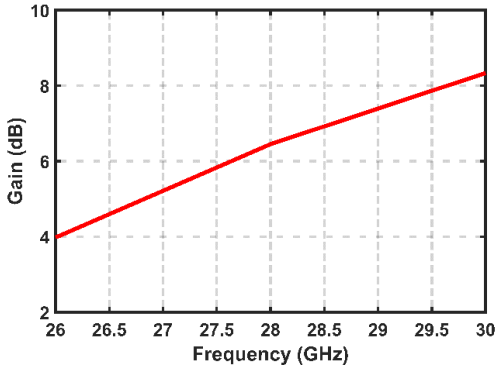


Figure 5. The simulated realized gain performance, achieving a maximum of 6.37 dB at the design frequency of 28 GHz

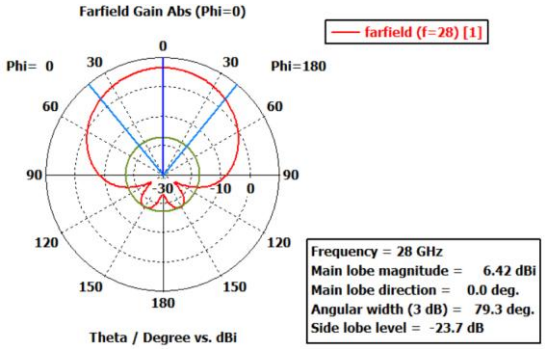


Figure 6. E-plane (φ=0°) radiation pattern of the proposed microstrip antenna at 28 GHz

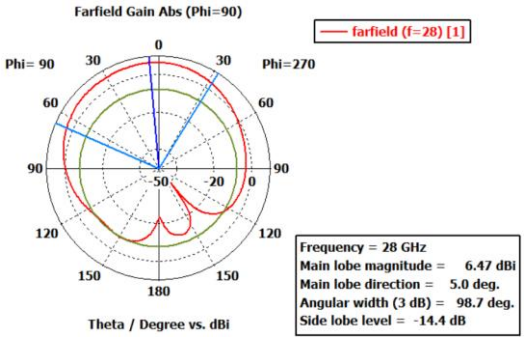


Figure 7. H-plane (φ=90°) radiation pattern of the proposed microstrip antenna at 28 GHz

3.2. 1×4 antenna array

The simulated results of the proposed 1×4 antenna array demonstrate a notable improvement in its overall performance. At 28 GHz, the array achieves a return loss of −19.18 dB, as shown in Figure 8. The corresponding impedance bandwidth, determined for a return loss below −10 dB, is approximately 1 GHz around the target frequency. As illustrated in Figure 9, the VSWR remains close to unity, confirming effective

impedance matching between the array and its feeding network. Moreover, the array provides a maximum realized gain of 14 dBi, as presented in Figure 10, demonstrating its suitability for mmWave 5G applications. The simulated far-field radiation patterns exhibit a pronounced directional behavior, with HPBW of 22.6° in the E-plane (φ=0°, Figure 11) and 27.9° in the H-plane (φ=90°, Figure 12), respectively.

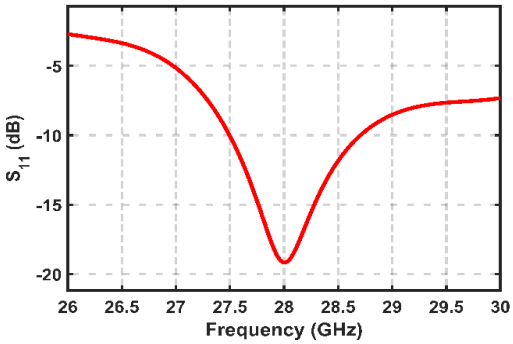


Figure 8. Frequency response of the reflection coefficient (S_{11}) of the 1×4 rectangular antenna array

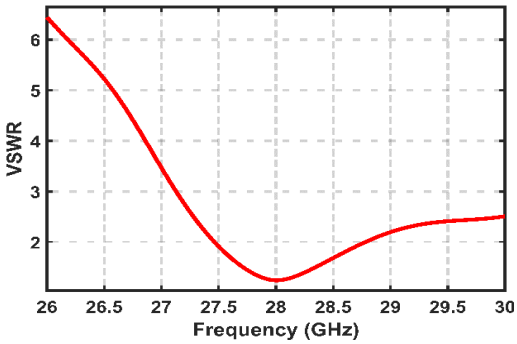


Figure 9. Frequency response of the VSWR of the 1×4 rectangular antenna array

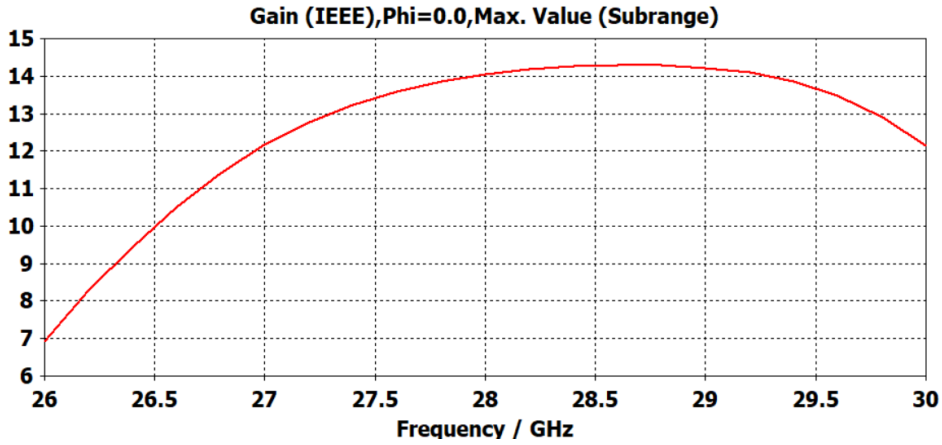


Figure 10. Frequency-dependent realized gain of the 1×4 rectangular antenna array, reaching a maximum value of 14 dBi at 28 GHz

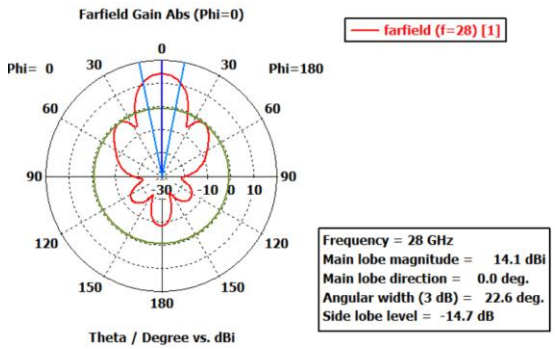


Figure 11. E-plane (φ=0°) radiation pattern of the proposed 1×4 rectangular antenna array at 28 GHz

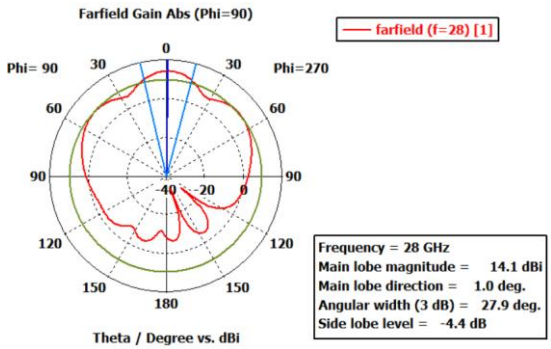


Figure 12. H-plane (φ=90°) radiation pattern of the proposed 1×4 rectangular antenna array at 28 GHz

4. ANALYSIS AND DISCUSSION OF THE SIMULATION RESULTS

The simulated results highlight the performance differences between the isolated rectangular patch antenna and the proposed 1×4 array employing a T-junction corporate-feed network. At 28 GHz, the isolated patch achieves a reflection coefficient (S_{11}) below −33 dB and a realized gain of 6.5 dBi, indicating excellent impedance matching and satisfactory radiation performance. The proposed array exhibits an S_{11} of −19 dB at 28 GHz, confirming satisfactory impedance matching despite the additional complexity of the feeding network and the possible electromagnetic coupling between elements. Its impedance bandwidth extends from 27.5 to 28.7 GHz for $S_{11} < -10$ dB, corresponding to a bandwidth of 1.2 GHz. In terms of radiation performance, the array achieves a maximum realized gain of 14 dBi, representing an improvement of 7.5 dB compared with the isolated patch. This enhancement results from the constructive superposition of the electromagnetic fields radiated by the four antenna elements, which increases the radiated energy in the desired direction and produces a more directive radiation pattern. The HPBW is 22.6° in the E-plane (φ=0°) and 27.9° in the H-plane (φ=90°), indicating a more directional radiation pattern suitable for mmWave 5G links. However, the side-lobe level (SLL) differs between the two planes, reaching −14.7 dB in the E-plane and −4.4 dB in the H-plane. These results indicate effective attenuation of the secondary lobes in the E-plane. Overall, the proposed 1×4 array provides a substantial gain enhancement and an impedance bandwidth of 1.2 GHz around 28 GHz. The improvement in gain is primarily attributed to the constructive superposition of the electromagnetic fields radiated by the individual antenna elements, which enhances the radiation in the main-beam direction. These results demonstrate the potential of the proposed array for mmWave 5G applications.

5. CONCLUSION

A compact 1×4 rectangular microstrip antenna array designed for 28 GHz 5G applications has been presented. The proposed configuration achieves a realized gain of approximately 14 dBi and an impedance bandwidth of nearly 1 GHz. Implemented on a Rogers RT5880 substrate, the antenna exhibits low-loss operation, stable directional radiation characteristics, and high radiation efficiency, making it a promising candidate for mobile terminals and compact base-station applications. Despite these promising results, the proposed design has some limitations, including its operation over a fixed frequency band and the lack of adaptive beam-steering and reconfigurable capabilities. Experimental measurements under practical propagation conditions would also be valuable for further validating the simulated performance. Future work will focus on incorporating reconfigurable and beam-steering functionalities, enhancing the operating bandwidth, and integrating beamforming networks to improve the suitability of the proposed antenna for advanced 5G and beyond-5G communication systems.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ghizlane Mounir	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jamal El Abbadi		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding authors on request.

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