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High-Performance Circularly Polarized MIMO Antenna for 5G mmWave n261 Band Using Asymmetric Stubs

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Abstract: This research presents the design and analysis of a circularly polarized MIMO antenna employing an inset-fed rectangular patch integrated with asymmetric stubs and slots. The antenna is specifically optimized for 5G millimeter-wave (mmWave) applications targeting the n261 band (27.50–28.35 GHz), with a center frequency of 28 GHz.The structure is fabricated on a Rogers RT/duroid 5880 substrate, characterized by a compact footprint of 19.64 × 30.25 × 0.79 mm³. The proposed design achieves operating bandwidth of 27.44 - 28.79 (1.36) GHz.based on the 2:1 VSWR and operating bandwidth of 1.28 GHz (27.46–28.74 GHz) based on the –10 dB return loss criterion.
Keywords: Asymmetric stubs, Circularly polarised, mmWave,MIMO, Slots.

I. INTRODUCTION

The advancement of modern wireless technologies has accelerated the global transition toward fifth-generation (5G) communication systems, characterized by ultra-fast data transmission, minimal latency, and highly reliable connectivity across a broad spectrum of intelligent applications. To meet the rigorous performance demands of 5G, particularly in terms of data capacity and spectral efficiency, Multiple-Input Multiple-Output (MIMO) antenna architectures have become indispensable. These systems leverage multiple transmitting and receiving elements to support parallel communication channels, resulting in enhanced link reliability and improved throughput [1].

One of the most promising frequency bands allocated for 5G is the millimeter-wave (mmWave) spectrum, especially the n261 band (27.50–28.35 GHz). Operating in this high-frequency range enables the exploitation of wide bandwidths necessary for high-speed data services. However, it also introduces challenges such as increased path loss, reduced penetration ability, and severe multipath effects, all of which require careful antenna design considerations to ensure system efficiency [2].

In this context, circularly polarized (CP) antennas have emerged as effective candidates for mitigating polarization mismatch and improving signal stability in dynamic and reflective environments. Unlike linearly polarized antennas, CP structures produce waves with a continuously rotating electric field vector, which is particularly advantageous in mobile or cluttered urban scenarios where signal orientation often changes. This property significantly reduces signal degradation due to polarization misalignment and enhances performance in multipath-rich conditions [3].

The integration of circular polarization with MIMO technology offers a robust solution for 5G antenna systems. This combination provides dual advantages: increased channel capacity through spatial multiplexing and reduced signal fading through polarization diversity. Such hybrid configurations enable better exploitation of the radio environment, improving overall signal quality and ensuring consistent performance under varying propagation conditions [4].

This study focuses on the design and development of a compact MIMO antenna system operating at 28 GHz, incorporating asymmetrically loaded stubs and slots to achieve circular polarization and enhanced isolation between ports. Through detailed analysis of key parameters such as impedance bandwidth, gain, axial ratio, and isolation, the proposed antenna aims to address the technical challenges associated with mmWave 5G communication. The outcomes contribute to the creation of resilient, high-performance antenna solutions vital for the realization of next-generation wireless networks [5].

The literature surveyed is discussed here, an 8×8 MIMO antenna array was developed on a Rogers RT/Duroid 5880 substrate with a partial ground plane, measuring 0.285λ × 0.11λ × 0.001λ at 28 GHz. The integration of metamaterial-inspired elements significantly enhanced gain, isolation, and axial ratio bandwidth. The antenna achieved an 18 GHz impedance bandwidth, axial ratio bandwidth of 13 GHz, peak gain of 20.5 dBi, and mutual coupling below –20 dB, effectively covering the 5G mmWave band from 25 to 29.5 GHz [6].

A 5G MIMO antenna employing complementary split-ring resonators and a defective ground plane was designed on a 40 × 40 × 0.8 mm³ FR4 substrate. The antenna consists of four orthogonally arranged rectangular patches with triangular cuts and inset feeds, enabling circular polarization with an axial ratio bandwidth of 1.5 GHz (27.25–28.75 GHz). It operates over a 7 GHz bandwidth (25.5–32.5 GHz) with a peak gain of 5 dBi and exhibits good impedance matching across the band [7].A mathematically inspired MIMO antenna for 1.8/1.9 GHz applications covers 1.5–2.1 GHz with 600 MHz bandwidth, –78 dB return loss, >17 dB isolation (improved by 7 dB via a parasitic element), ECC < 5×10^{-3}, >90% efficiency, and peak current density of 29.9 A/m² on a 40 × 81.76 mm² FR4 substrate [8].A low-profile CP metasurface antenna using CMA achieved 27.4% IBW, 10.1% ARBW, and 6.9 dBic gain at 4.4 GHz, with circular polarization enabled by 90° CA separation and performance improved by transmission line modification [9].A 4-port hexagonal MIMO antenna operating at 2.1 GHz was designed using CST-MWS for mobile applications. The design, fabricated on FR4, features low ECC (<0.08), diversity gain of 10 dB, and inter-port isolation >15 dB. It achieves a peak gain of 0.45 dBi, SAR < 0.5 W/kg, MEG of 3.0 dB, and CCL of 0.4 bits/s/Hz. The antenna radiates mainly at 190° (E-field) and 187° (H-field), with manifold arms aiding in decorrelation among ports [10].

II. CP MIMOANTENNADESIGN WITH ASYMMETRIC ELEMENTS

The design of the proposed MIMO antenna incorporating asymmetric stubs is carried out in five distinct stages. Initially, a single SISO antenna element—intended to serve as the building block for the MIMO configuration—is developed over the first four stages. In the final (fifth) stage, a MIMO structure is formed by duplicating the SISO element as its mirror image, thereby enhancing the overall performance characteristics of the antenna system. The front and back views of the final MIMO configuration are illustrated in Fig. 1 and Fig. 2, respectively.

The CST Microwave Studio (CST-MWS) optimized dimensions and design parameters for the proposed antenna are summarized in TABLE I. Fig. 3 presents the step-by-step evolution of the SISO design leading up to the complete MIMO configuration. The antenna is realized on a Rogers RT/Duroid 5880 substrate, with total dimensions of 19.64 × 30.25 × 0.79 mm³, while each individual SISO unit occupies 19.64 × 15.12 × 0.79 mm³. The spacing between the two antenna elements in the MIMO setup is maintained at 5.96 mm to ensure effective isolation and performance.

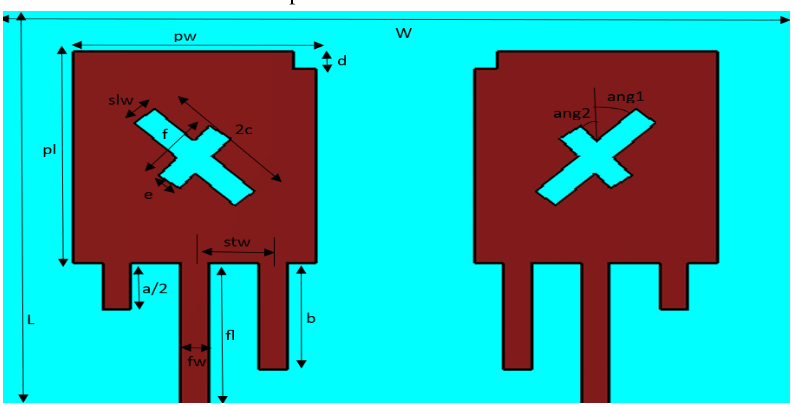

Fig. 1. Front side of proposed MIMO antenna with asymmetric stubs andslots

Fig. 2. Back side of proposed MIMO antenna with asymmetric stubs and slots

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TABLEI
OPTIMIZED DIMENSIONALVALUESOFVARIOUSSTEPS(mm)

Parameter	pw	pl	gh	sh
Value(mm)	9.16	10.41	0.0175	0.79
Parameter	W	L	fl	fw
Value(mm)	30.254	19.649	7.11	1.04
Parameter	a	b	c	d
Value(mm)	4.62	5.23	2.77	0.87
Parameter	e	f	stw	slw
Value(mm)	1.02	3.11	2.94	1.03
Parameter	ang1	ang2	-	-
Value(mm)	42.82	38.09	-	-

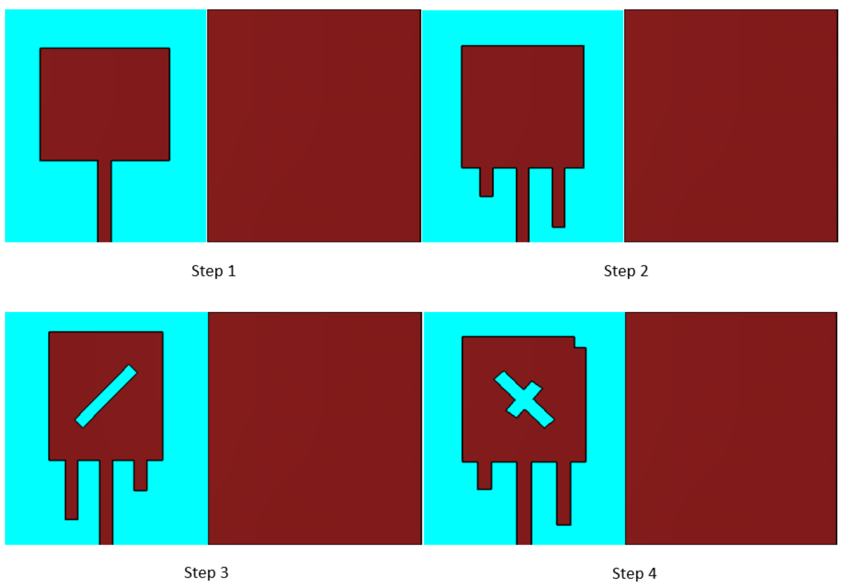

Fig. 3. Four design steps of SISO element

III. RESULTS AND DISCUSSION

The antenna design process begins with a basic rectangular patch structure fed by a microstrip line, serving as the initial configuration in Step 1. In Step 2, two asymmetric stubs of unequal lengths are introduced to influence the current distribution. Step 3 involves embedding a single tilted rectangular slot within the patch. In Step 4, a second tilted rectangular slot is added at an angle of 80.91° relative to the previous one, along with an additional rectangular slot positioned at the upper-right corner of the patch.

By Step 5, the evolved SISO design is transformed into a circularly polarized MIMO antenna through the mirrored arrangement of the SISO element. The inclusion of a cross-shaped aperture and asymmetric stubs in the final structure facilitates the excitation of orthogonal modes, effectively reducing the axial ratio and enabling circular polarization. These modifications also adjust the surface current path, introducing a phase delay between orthogonal components.

Throughout the progression from Step 1 to Step 4, the design gradually evolves toward achieving circular polarization. Moreover, both the impedance bandwidth and far-field gain show noticeable improvements from Step 2 through Step 5, confirming the effectiveness of each design enhancement.

The simulated S-parameters (S_{11}) corresponding to each of the five design stages are illustrated in Fig. 4 through Fig. 8, respectively.

The simulated S-Parameters of all the 5 design steps are compared with the help of a graph and are shown in Fig. 4and Fig. 5 show the S-parameters ($S_{11}$and S_{21}) for step 5.

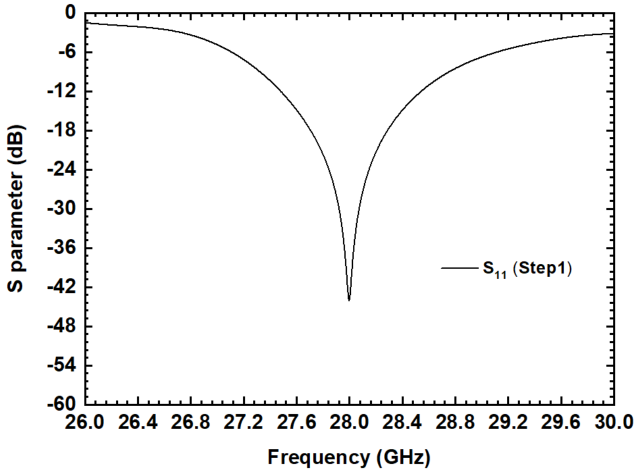

Fig. 4. $S_{11}$for step 1 for the proposed MIMO antenna

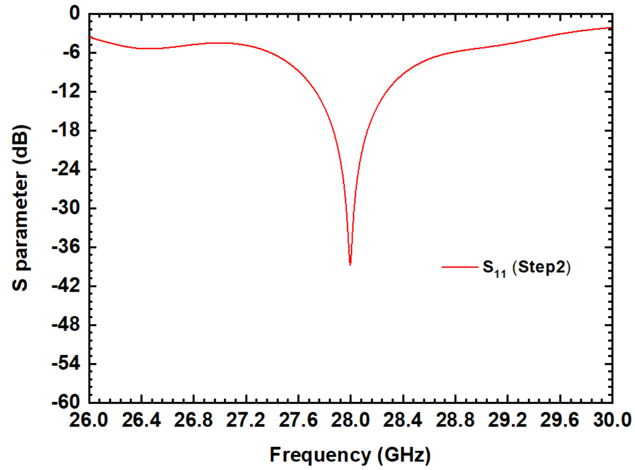

Fig. 5. $S_{11}$for step 2 for the proposed MIMO antenna

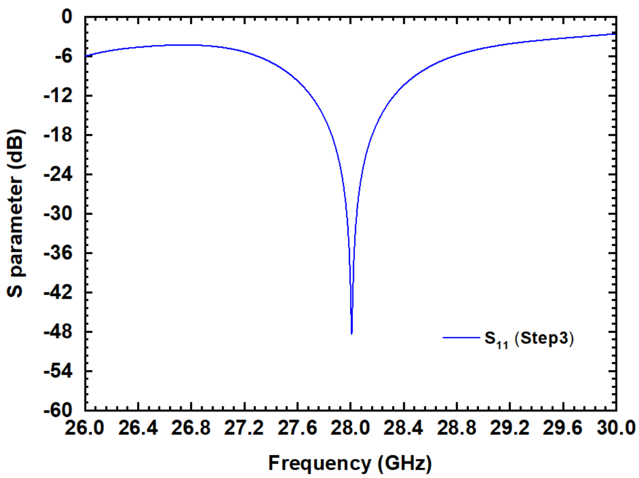

Fig. 6. $S_{11}$for step 3 for the proposed MIMO antenna

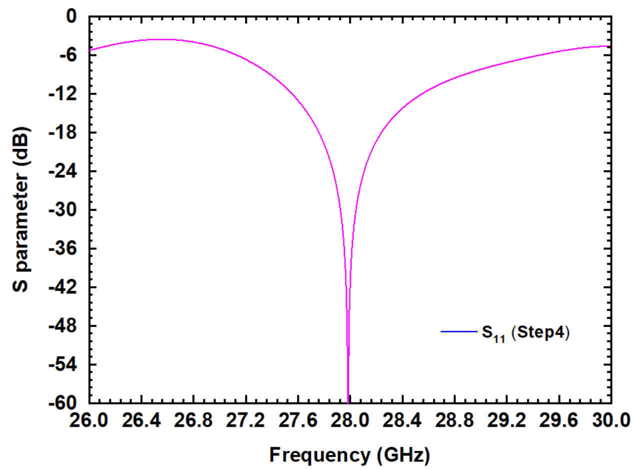

Fig. 7. $S_{11}$for step 4 for the proposed MIMO antenna

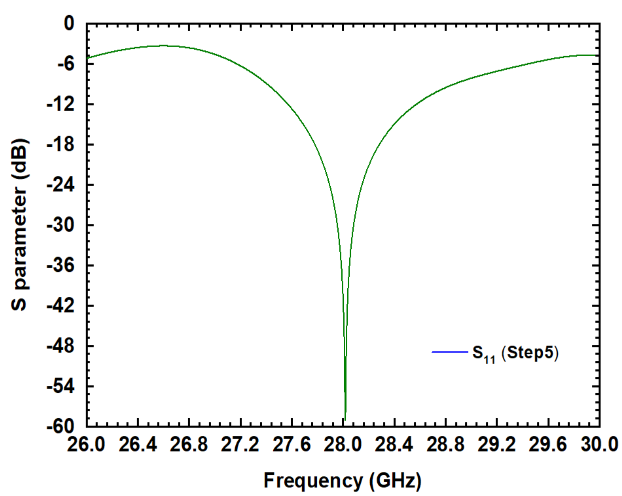

Fig. 8. $S_{11}$for step 4 for the proposed MIMO antenna

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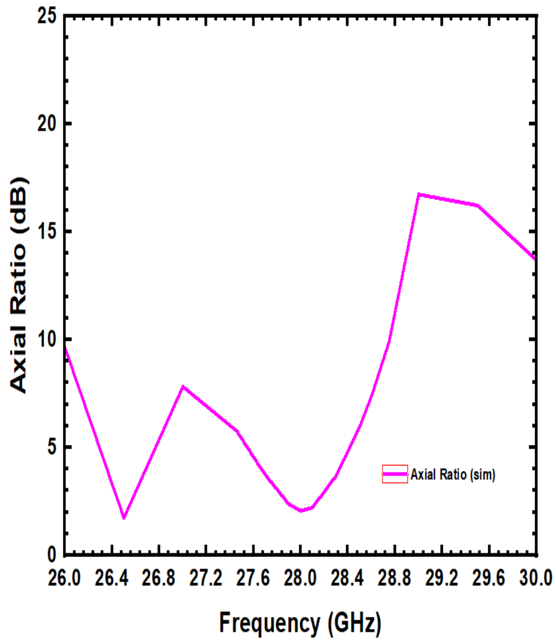
Axial Ratio (AR) indicates the polarization quality of an antenna, with AR ≤ 3 dB signifying circular polarization. Fig. 9 shows the AR curve of the proposed MIMO antenna, achieving a 0.4 GHz CP bandwidth.



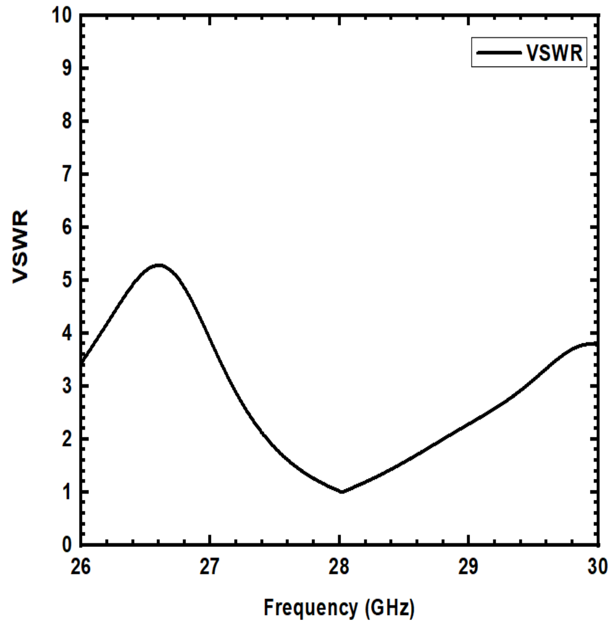
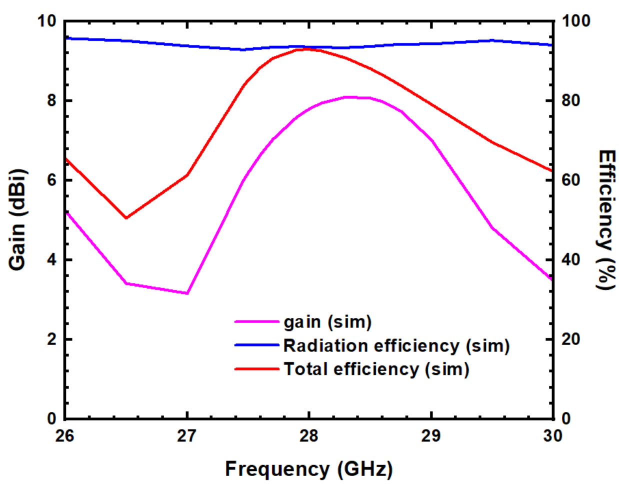


Fig. 9Axial ratio for the proposed MIMO antenna Fig. 10.VSWR for the proposed MIMO antenna

Figure 10 presents the simulated Voltage Standing Wave Ratio (VSWR) characteristics for the proposed circularly polarized MIMO antenna design. The antenna achieves a VSWR bandwidth corresponding to the standard 2:1 criterion within the frequency range of 27.44 GHz to 28.79 GHz, resulting in an effective bandwidth of 1.36 GHz.
Far-field gain is evaluated using the substitution method in CST, and the radiation, gain, and total efficiencies across 26–30 GHz are presented in Fig. 11.



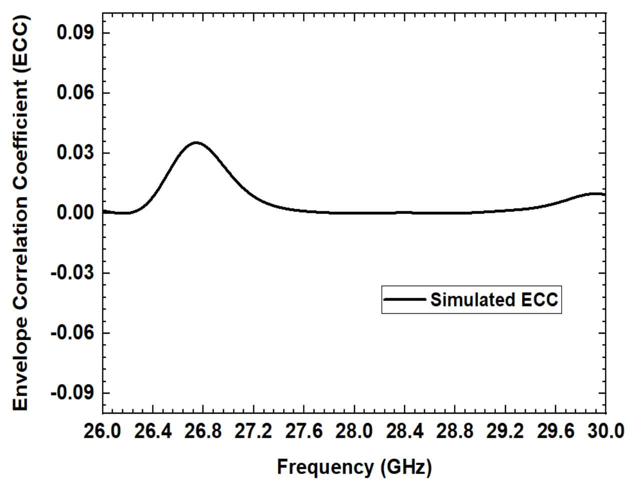


Fig. 11. Gain, radiation efficiency and total efficiency for the proposed MIMO antenna

Fig. 12.ECC for the proposed MIMO with asymmetric stubs and
Slots

ECC measures the radiation pattern correlation between MIMO elements, with values near zero indicating high diversity. As shown in Fig. 12, the proposed CP MIMO antenna achieves a low ECC of 0.0022, confirming excellent isolation and performance.

A comparison table is prepared for various reference researchpapersandproposeddesignwhich iscomparedinTABLEII.

TABLEII
COMPARISONOFVARIOUSREFERENCEANTENNASWITHPROPOSEDANTENNA

Ref.	Antenna size (mm^3)	Spectrum Coverage (GHz)	Axial Ratio Bandwidth (GHz)	Max Gain (dBi)	Min.Rad. Eff..	ECC	Polarization
[1]	34×34×0.49	24.26-30.2 (5.94)	NA	6.48	92.4	0.003	LP
[5]	51.75×17.02×0.79	24.96 – 29.5 (4.54)	0.46	5.58	82.61	0.0005	CP
[7]	40×40×0.8	25.5-32.5 (7)	1.5	5	80	0.12	CP
[17]	51.44×18.34×0.79	27.06-28.35 (1.29)	NA	16.07	93	NA	LP
[19]	12.82×33.56×0.79	12.33 (17.58-29.92)	NA	6.16	95	0.02	LP
[20]	48×55×0.79	1.37 (27.42–28.79)	NA	9.05	81	0.04	LP
[21]	60.6×31.8×0.508	1.53	NA	12.5	89	0.1	LP
[22]	15.2×7.3× 1.524	8.63 (21.06-29.7)	NA	6.38	72	0.05	LP
Prop.	19.64 ×30.25 × 0.79	27.46-28.74 (1.28)	0.4	8.09	92.87	0.0022	CP

IV. CONCLUSION

A compact circularly polarized MIMO antenna integrating asymmetric stubs and tilted slots has been developed, operating within a –10 dB impedance bandwidth of 1.28 GHz (27.46–28.74 GHz). The antenna achieves a circular polarization (CP) axial ratio bandwidth of 0.4 GHz (27.8–28.2 GHz). Simulated performance shows high radiation efficiency ranging from 92.87% to 94.23% and total efficiency between 83.9% and 92.93%. The realized gain spans from 6.04 to 8.09 dBi across the band. The design also demonstrates strong isolation of 22 dB at the 28 GHz resonant frequency and maintains a low ECC, with a peak value of only 0.035, indicating excellent diversity performance. These results confirm that the proposed asymmetrically loaded and slotted MIMO antenna delivers efficient performance with a compact footprint. The design approach also offers potential for future extensions to multiband or reconfigurable circularly polarized antenna systems.

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