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Multiple Input Multiple Output Antenna at 28 GHz Using Two Planar Inverted F Antennas

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Abstract

This study investigates a multiple-input-multiple-output (MIMO) antenna system comprising two planar inverted F antennas (PIFAs) designed for operation at 28 GHz. Each PIFA element has a compact size of $0.0106\lambda_0^3$, where λ_0 represents the free space wavelength at 28 GHz. The overall size of the two-element MIMO antenna system measures $0.0212\ \lambda_0^3$. Three different design approaches are explored for this system. In the first design, the two PIFAs are positioned side by side with their vertical metal walls aligned parallel. This configuration achieves an impedance bandwidth of 2.25 GHz, ranging from 26.92 GHz to 29.17 GHz, with a directivity of 6.6 dBi at 28 GHz. The isolation exceeds 16 dB, and the envelope correlation coefficient (ECC) remains below 0.01, with a diversity gain over 9.951 across the bandwidth. The radiation efficiency and total efficiency for this design are 72.15% and 70.25%, respectively, at 28 GHz. In the second design, the metal walls of the PIFAs are oriented at 90 degrees to each other to enhance isolation. This adjustment results in improved performance parameters, including an isolation increase of approximately 10 dB and a directivity of 8.27 dBi at 28 GHz. The radiation and total efficiencies rise to 75.72% and 75.68%, respectively, indicating a slight improvement over the first design. The ECC remains below 0.00024, and the diversity gain consistently exceeds 9.9988 throughout the entire 2.2 GHz bandwidth, which is slightly narrower than that of Design 1. The third design introduces a slot in the metal patch of each antenna element, further miniaturizing the MIMO system to $0.0195\ \lambda_0^3$. This configuration achieves a minimum isolation of 26.27 dB and a directivity of 8.06 dBi at 28 GHz. Although the bandwidth reduces to 1.78 GHz, the ECC stays below 0.00033, and the diversity gain remains above 9.9983. The efficiencies slightly decrease to 73.02% and 71.88%, respectively. The Channel Capacity Loss values at 28 GHz are 0.048 bits/s/Hz, 0.017 bits/s/Hz, and 0.007 bits/s/Hz for Designs 1, 2, and 3, respectively, all within the acceptable limits. The performance of the MIMO antenna system is evaluated through computer simulation and compared with similar antennas documented in recent literature.

Categories: Microwave and RF Engineering, Telecommunication Networks, Wireless Communication Systems
Keywords: multiple-input multiple-output antenna systems, antenna design, 5g millimeter-wave, planar inverted-f antenna, mimo antenna, two-port mimo antenna, wideband mimo antenna

Introduction

Advancements in wireless communication technology, particularly with the development of 5G and future networks, have increased the demand for extremely high data rates, often exceeding gigabits per second. These high data rates are crucial for modern wireless applications, including mobile communication, video streaming, multimedia transmission, and the Internet of Things (IoT). Recently, millimeter wave frequencies have gained prominence because they provide the broad bandwidth necessary for such high data rates [1-3]. As the wavelength decreases into the millimeter range, device sizes also become smaller, facilitating integration into compact circuits. However, millimeter wave signals have limited coverage areas because of higher propagation losses and are more vulnerable to obstructions such as buildings and trees. Various design strategies have been explored to enhance data rates, signal quality, and coverage, including the use of millimeter wave Multiple Input Multiple Output (MIMO) antenna technology [4-12]. MIMO employs multiple antennas for transmission and reception, transmitting the same data stream over multiple paths. This approach significantly increases the likelihood of faithful signal reception, even when some paths experience degradation due to interference or fading. In urban environments, multipath propagation caused by obstacles can be mitigated effectively using MIMO technology. Increasing the number of antennas in a MIMO system improves transmission and reception performance but also raises system complexity and spatial requirements.

This paper explores the design of a two-port MIMO antenna system at 28 GHz, balancing signal fidelity and system complexity. It investigates and analyzes three design approaches for a simple, low-profile two-port MIMO antenna utilizing two Planar Inverted F Antennas (PIFAs) [5,6] at or near 28 GHz. PIFAs are popular in wireless devices due to their simple design and compact form factor. The presence of a vertical metal wall at one end of the patch, extending through the substrate to the ground plane, allows for a smaller patch size compared to traditional rectangular or square antennas.

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Materials And Methods

The cross-sectional side view of the PIFA configuration is illustrated in Figure *1*. The discrete port and the thin metal wall, which extends perpendicular to the plane of the paper, form the two arms of an inverted letter "F."

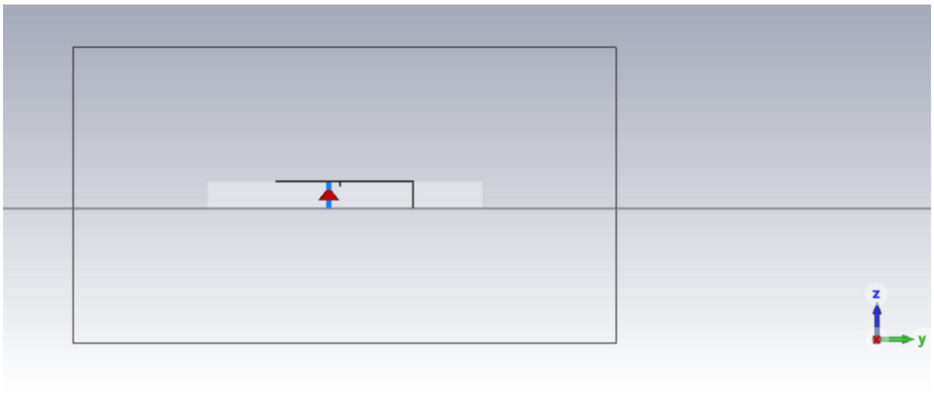

FIGURE 1: Schematic diagram of cross-sectional side view of PIFA

PIFA, Planar Inverted F Antenna

A PIFA designed for operation at 28 GHz features a square ground plane made of annealed copper, a square substrate of FR4, and a square radiating patch also constructed from annealed copper. A slender vertical wall, also of annealed copper, extends from the patch to the ground along one edge, with a width equal to half the side length of the patch. The design parameters for the single antenna are detailed in Table *1*.

Frequency of Operation (GHz)	Dimension of Substrate (Ls × Ws × h)	Dimension of Patch (Lp × Wp × t)	Dimension of Wall (Lw × h × t)	Dimension of Ground Plane (Lg × Wg × t)	Dielectric Constant of Substrate (□□)	Materials Used
28	5.13 mm × 5.13 mm × 0.5 mm	2.565 mm × 2.565 mm × 0.02 mm	1.2825 mm × 0.5 mm × 0.02 mm	5.13 mm × 5.13 mm × 0.02 mm	4.4	Copper (Annealed), FR-4 (Lossy)

TABLE 1: Design parameters of single PIFA element

PIFA, Planar Inverted F Antenna

Design 1

Two PIFAs are arranged side by side as shown in Figure *2* with the vertical metal walls of the PIFA elements oriented in parallel. The dimension of this two element MIMO is 10.22 mm × 5.11 mm × 0.5 mm.

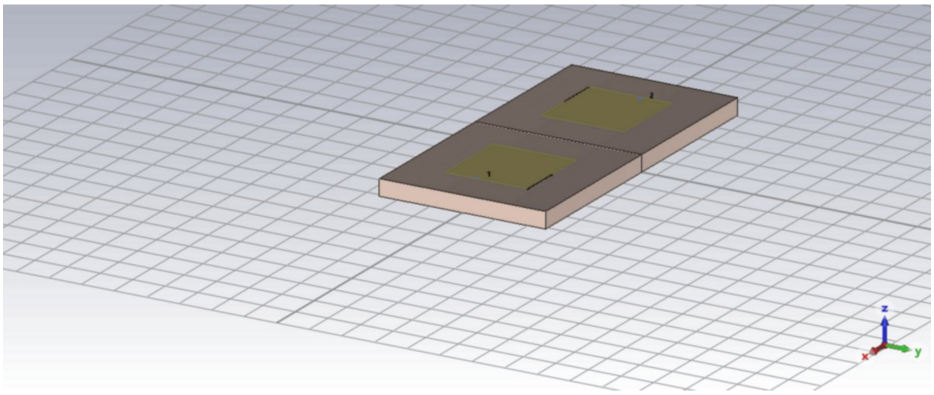

FIGURE 2: MIMO antenna of Design 1

MIMO, Multiple Input Multiple Output

Design 2

In order to enhance isolation between the two antennas, the metal walls of the PIFAs are oriented at 90 degrees to each other in the second design as shown in Figure *3*.

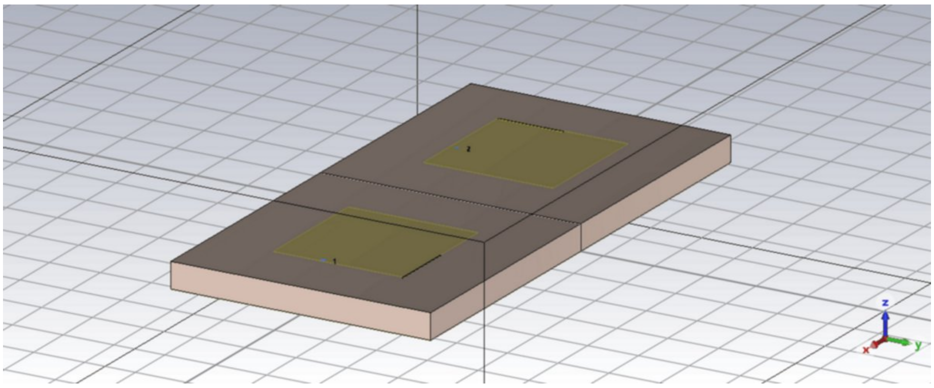

FIGURE 3: MIMO antenna of Design 2

MIMO, Multiple Input Multiple Output

Design 3

The third design features a MIMO antenna operating at 28 GHz, which has been further miniaturized by adding a slot to the metal patch of each antenna element. This modification reduces the overall size of the MIMO antenna to 9.8 mm × 4.9 mm × 0.5 mm, with the slot measuring 2.05 mm × 0.3 mm (Figure *4*).

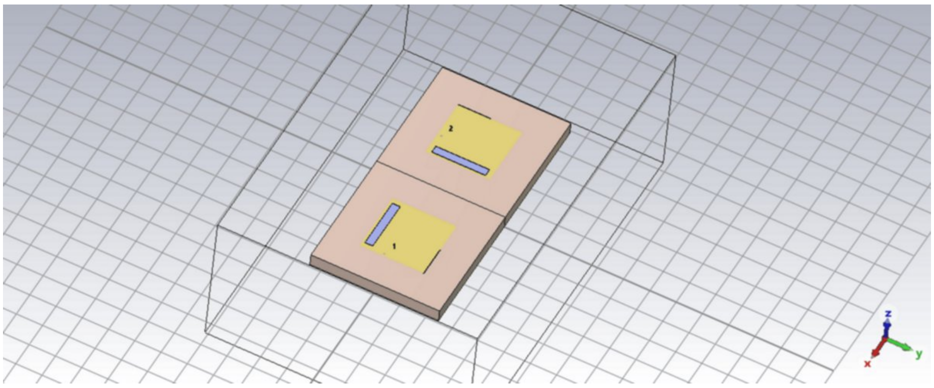

FIGURE 4: MIMO antenna of Design 3

MIMO, Multiple Input Multiple Output

Results And Discussion

MIMO antenna performance is assessed through several key parameters that reflect its effectiveness in wireless communication systems. These parameters include gain, bandwidth, radiation pattern, isolation, and diversity characteristics. Diversity performance is evaluated using metrics such as envelope correlation coefficient (ECC), diversity gain (DG), mean effective gain (MEG), and channel capacity loss (CCL). ECC measures the correlation between signals from different antenna elements; a lower ECC indicates better performance, with an ideal value of zero. DG represents the improvement in signal quality achieved through MIMO techniques compared to single-antenna systems; a higher DG, with an ideal value of 10, signifies better performance. MEG indicates the power received by the diversity antenna relative to an isotropic antenna, with acceptable values typically ranging from -3 dB to -12 dB. CCL quantifies the reduction in maximum achievable data rate caused by signal interference and channel impairments; lower CCL values, below 0.4 bits/s/Hz, are considered desirable for practical MIMO systems.

The performance of the proposed designs was evaluated using the Computer Simulation Technology environment. For Design 1, the impedance bandwidth at 10 dB spans from 26.92 GHz to 29.17 GHz, as shown in Figure *5*, indicating its operational frequency range. The isolation factor between the two antennas varies from 17 dB to 22 dB across the entire bandwidth, as depicted in Figure *6*, demonstrating reasonable isolation between the PIFA elements. The far-field pattern of the MIMO system for Design 1 at 28 GHz is illustrated in Figure *7*, with a directivity of 6.6 dBi at this frequency. The radiation efficiency and total efficiency for this design are 72.15% and 70.25%, respectively, at 28 GHz. Although the directivity is satisfactory, the efficiency values are moderate, primarily due to the lossy nature of the materials used. The ECC is below 0.016, indicating a minimal correlation between antennas. The DG exceeds 9.97, nearing the ideal value of 10, as illustrated in Figures *8* and 9.

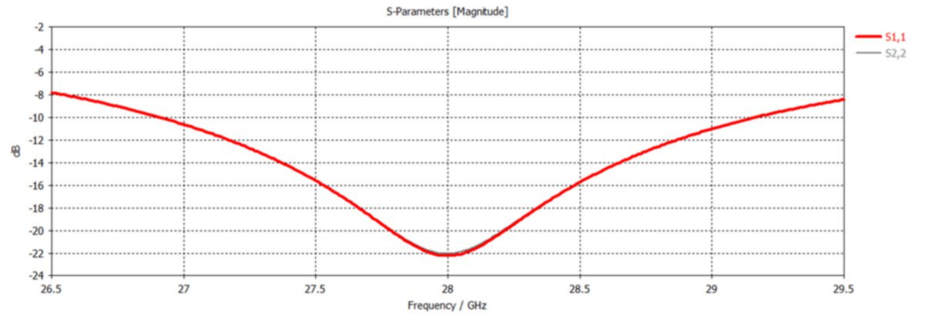

FIGURE 5: Reflection coefficient versus frequency of the MIMO antenna of Design 1

MIMO, Multiple Input Multiple Output

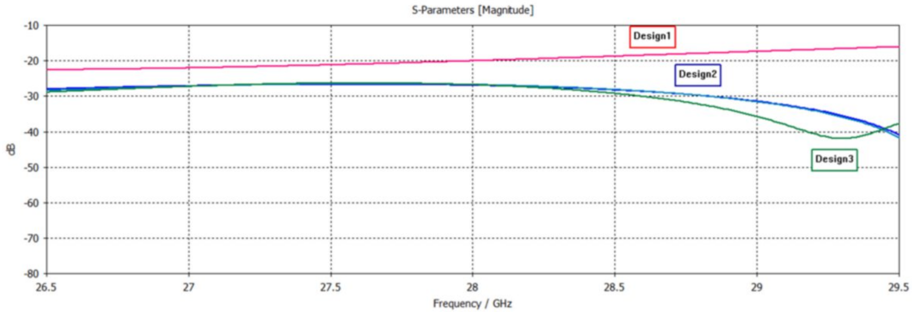

FIGURE 6: Transmission coefficients versus frequency plots of all the three designs

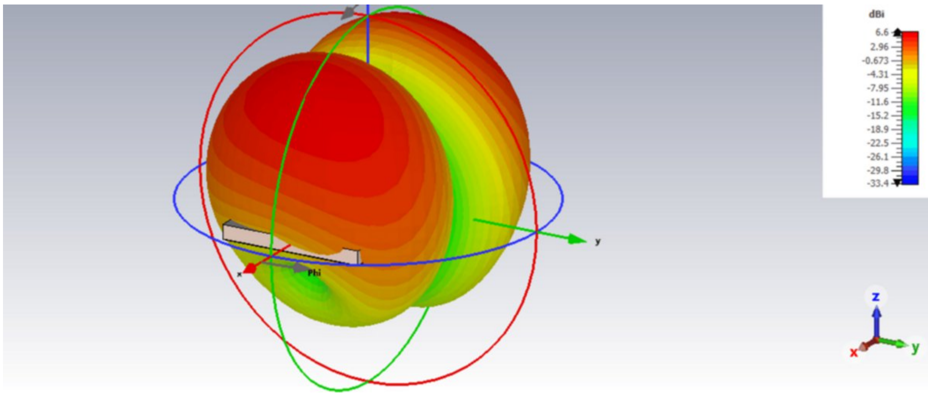

FIGURE 7: The 3D radiation pattern plot of the MIMO antenna of Design 1

MIMO, Multiple Input Multiple Output

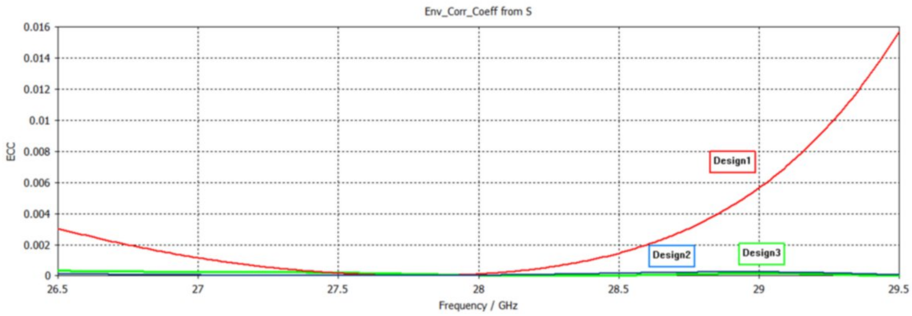

FIGURE 8: ECC versus frequency plots of the MIMO antennas of all the three designs

MIMO, Multiple Input Multiple Output; ECC, envelope correlation coefficient

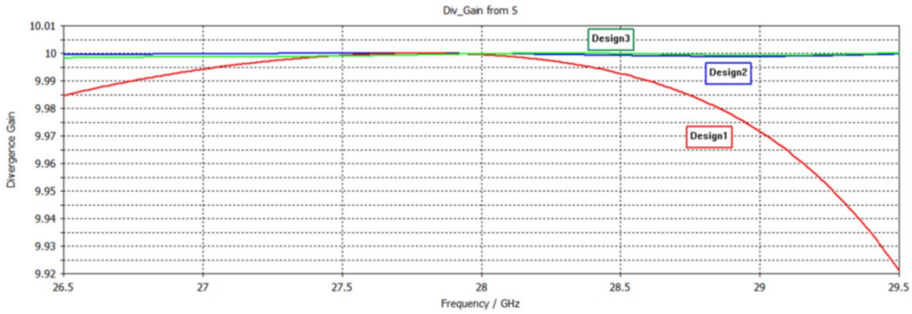

FIGURE 9: Diversity gain versus frequency plot of the MIMO antennas of all the three designs

MIMO, Multiple Input Multiple Output

Figure 6 illustrates an enhancement in the isolation factor between the antennas, surpassing 26 dB for Design 2. The return loss at 28 GHz is lower compared to Design 1, as depicted in Figure 10. The directivity at 28 GHz is measured at 8.27 dBi, exceeding that of Design 1, as shown in Figure 11. The ECC remains below 0.00024, and the DG consistently exceeds 9.995 across the entire bandwidth, as demonstrated in Figures 8 and 9. These results indicate that the performance parameters are enhanced for Design 2 across all evaluated aspects.

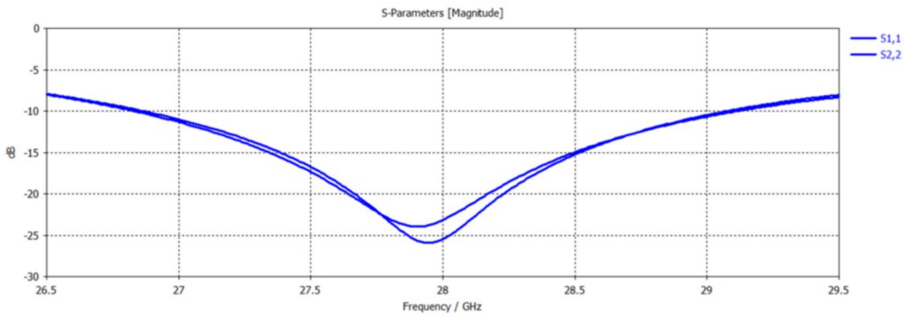

FIGURE 10: Reflection coefficient versus frequency plot of the MIMO antenna of Design 2

MIMO, Multiple Input Multiple Output

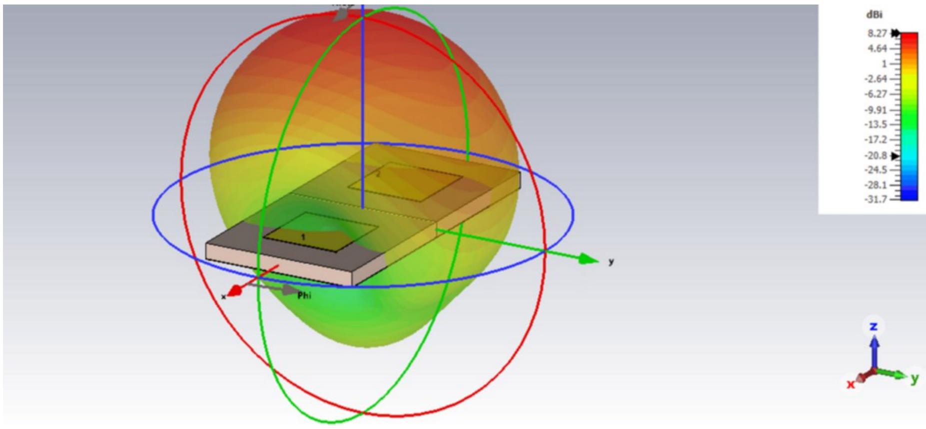

FIGURE 11: The 3D radiation plot of the MIMO antenna of Design 2

MIMO, Multiple Input Multiple Output

The third design exhibits a minimum isolation of 27 dB, a bandwidth of 1.78 GHz, and a directivity of 8.1 dBi at 28 GHz, as shown in Figures 6, 10, and 11. Although the bandwidth is narrower compared to previous designs, indicating a reduction in operating bandwidth, the envelope correlation coefficient remains below 0.0003 and the diversity gain consistently exceeds 9.998 across the bandwidth, as depicted in Figures 8 and 9, which is comparable to Design 2. Additionally, the radiation efficiency and total efficiency of the MIMO antenna experience slight decreases, reaching 73.02% and 71.88%, respectively, at 28 GHz. These MIMO antennas exhibit adequate efficiency given their simple designs, feeding methods, and the use of readily available materials. To improve performance, more advanced feeding techniques and higher-quality, lossless materials could be employed. Table 2 provides a comparative overview of the key parameters for these three configurations, highlighting a reduction in area in the third design while maintaining performance similar to that of Design 2. Furthermore, CCL is minimized in Design 3, indicating optimal performance for this parameter.

Design	Overall volume of MIMO mm^3	Operating frequency GHz	10 dB impedance BW GHz	Directivity dBi	Isolation dB	ECC	DG	CCL Bits/s/Hz	MEG1, MEG2 dB
Design 1	10.22 × 5.11 × 0.5	28	2.25	6.6	>17	<0.015	>9.97	0.048	-3.08, -3.08
Design 2	10.22 × 5.11 × 0.5	28	2.2	8.27	>26.5	<0.00024	>9.9998	0.017	-3.03, -3.24
Design 3	9.8 × 4.9 × 0.5	28	1.78	8.06	>27	<0.00033	>9.9983	0.007	-3.02, MIMO-3.02

TABLE 2: Comparison of the performance parameters of the three designs of the proposed MIMO antenna

MIMO, Multiple Input Multiple Output; ECC, envelope correlation coefficient; DG, diversity gain; CCL, channel capacity loss; MEG, mean effective gain

Table 3 provides a comparison of key performance parameters for the proposed configurations with those documented in recent literature on two-port MIMO antennas operating near 28 GHz. The evaluated parameters include efficiency, diversity gain, channel capacity loss, and mean effective gain. Notably, some of these parameters are not assessed in the references cited in Table 3.

Design	Size of MIMO mm^2	Operating frequency GHz	10 dB impedance BW GHz	Directivity dBi	Isolation dB	ECC	DG	CCL Bits/s/Hz	MEG1, MEG2 dB
[11]	11.4 × 5.3	27.9–28.9	1.0	6	>36	0.001	--	--	--
[9]	10.8 × 19.64 27–28.16 >25 4.8 0.01	27–28.16	1.16	4.8	>25	0.01	-	-	-
[4]	30 × 15	25.5–30 35–40	4.5 5	5.7 6.9	>32.3 >36.7	0.001 0.001	-	-	-
[12]	26 × 14.5	26–28.6 36.3–40	2.6 3.7	5.2 5.5	>39 >38	0.0001	-	--	-
Design 1	10.22 × 5.11 × 0.5	28	2.25	6.6	>17	<0.015	>9.97	0.048	-3.08,-3.08
Design 2	10.22 × 5.11 × 0.5	28	2.2	8.27	>26.5	<0.00024	>9.9998	0.017	-3.03,-3.24
Design 3	9.8 × 4.9 × 0.5	28	1.78	8.06	>27	<0.00033	>9.9983	0.007	-3.02,-3.02

TABLE 3: Performance comparison with the recently published works

MIMO, Multiple Input Multiple Output; ECC, envelope correlation coefficient; DG, diversity gain; CCL, channel capacity loss; MEG, mean effective gain

Conclusions

The analysis examines three design approaches for a two-port MIMO antenna system utilizing PIFA technology. It has been observed that the orthogonal orientation of the vertical metal walls in PIFA elements improves overall performance compared to Design 1 across most parameters, as detailed in Table *2*, except for bandwidth. Additionally, Design 3 provides performance comparable to Design 2 but with reduced dimensions, although it exhibits a narrower bandwidth than the other two designs. From the comparison in Table *3*, it is evident that the sizes of all proposed antennas are smaller, and their directivity surpasses that of other antennas in the 28 GHz band. The bandwidth of these designs is similar to or greater than that of other antennas, except for antenna “h,” which has a larger size than the proposed designs. The isolation of Designs 2 and 3 is lower than that of all other antennas, except one, while the ECCs of these designs outperform all others. Not all performance parameters are considered in previous studies. In conclusion, all three designs show potential for wireless applications at 28 GHz.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Sukla Basu

Acquisition, analysis, or interpretation of data: Sukla Basu

Drafting of the manuscript: Sukla Basu

Critical review of the manuscript for important intellectual content: Sukla Basu

Supervision: Sukla Basu

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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