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Single-Element 2-Port MIMO DRA for 5G mm-Wave n257 Band

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Abstract: This study presents a single-element 2-port multiple-input multiple-output (MIMO) Dielectric Resonator Antenna (DRA) with enhanced bandwidth. By introducing a central notch and side cutouts in the DRA structure, the antenna achieves an impedance bandwidth of 27.4-29.8 GHz, effectively covering the n257 (28 GHz) band. Orthogonal excitation and a metallic via inside the DRA ensure an isolation level greater than 15.6 dB across the entire operational bandwidth. The antenna delivers a peak gain of 5 dBi with a radiation efficiency of up to 96%. The MIMO performance metrics fall within acceptable limits, making the design highly suitable for mm-wave 5G applications. Its single-element configuration and aperture feeding contribute to a compact and straightforward design.

Keywords: MIMO, DRA, mm-wave, single-element

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1. INTRODUCTION

The increasing demands of modern wireless communication have spurred the advancement of fifth generation (5G) wireless technology. Initially, 5G networks were deployed in the sub-6 GHz spectrum. However, as the demand for data rates exceeding 1 Gbps and bandwidths greater than 1 GHz grows, the focus has shifted toward utilizing the millimeter-wave (mm-wave) spectrum to meet these requirements [1]. Many countries have now allocated the 28 GHz band specifically for 5G deployment, enabling faster, more reliable communications.

To address the high data throughput and increased capacity needs of 5G, multiple-input multiple-output (MIMO) antenna systems are employed. MIMO technology improves both signal reliability and channel capacity by leveraging multiple antennas. However, as MIMO antennas are integrated into compact devices, challenges such as minimizing antenna size and reducing electromagnetic field coupling become more pronounced [2]. Dielectric Resonator Antennas (DRAs) are gaining popularity for these applications, as their ceramic, non-metallic composition allows them to offer higher radiation efficiencies at elevated frequencies without suffering from the metallic losses typical of conventional printed antennas [3].

A variety of MIMO-based DRAs have been developed for different 5G frequency bands, incorporating various decoupling techniques to enhance performance [4]. Advanced techniques such as electromagnetic bandgaps (EBGs) [5], frequency selective surfaces (FSS) [6], metamaterials [7], and metasurfaces [8] have been employed to achieve high isolation between antenna elements. However, these approaches often introduce added complexity and require additional spacing between antennas, which can increase the overall size of the system. Alternatively, simpler isolation techniques—such as pattern, polarization, and spatial diversity—are frequently used, but they, too, can increase the size of the antenna structure [9-16].

Other strategies involve exciting higher-order modes within the DRA, eliminating the need for additional decoupling elements [17]. While this approach effectively mitigates coupling, it can also lead to an increased antenna profile, which may not be desirable for compact designs. Some solutions, such as inserting metallic sheets [18] or vias [19], allow for a more compact configuration, but they often come at the cost of reduced bandwidth and efficiency. Metal strips placed along the DRA walls can also enhance isolation in a compact design, though they may restrict the bandwidth [20, 21].

Considering the various MIMO DRA configurations and decoupling methods available, an ideal solution for mm-wave 5G applications would be a single-element MIMO design that incorporates an effective decoupling mechanism without requiring additional space, ensuring both compactness and performance in next-generation wireless systems.

2. ANTENNA GEOMETRY

The proposed design, illustrated in Figure 1, features a single-element rectangular Dielectric Resonator Antenna (DRA) composed of ECCOSTOK HiK ceramic, characterized by a relative permittivity (ε_r) of 10 and a loss tangent (tanδ) of 0.002. This DRA is positioned on top of the ground plane and excited by two orthogonal feedlines printed on the bottom side of the substrate, coupling energy to the DRA through rectangular slots. A central section of the DRA is strategically removed and a metallic via is inserted in the center that extends from the cut-out portion to the ground plane. This via serves to enhance isolation and improve performance. Additionally, portions from two sides of the DRA are cut out to further improve the bandwidth.

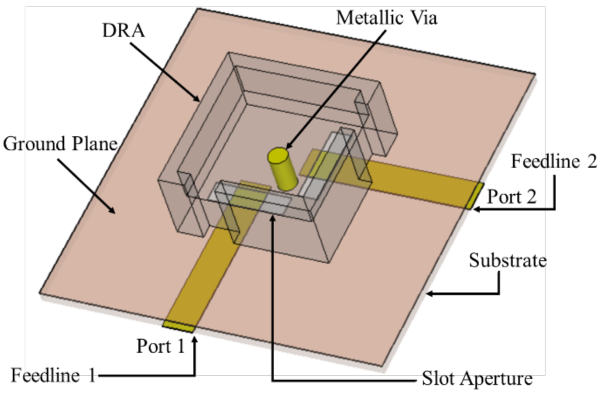

Figure 1. 3-D illustration of the proposed design

Figure 2 exhibits the top and side view of the proposed design with all the dimensions given in the figure caption.

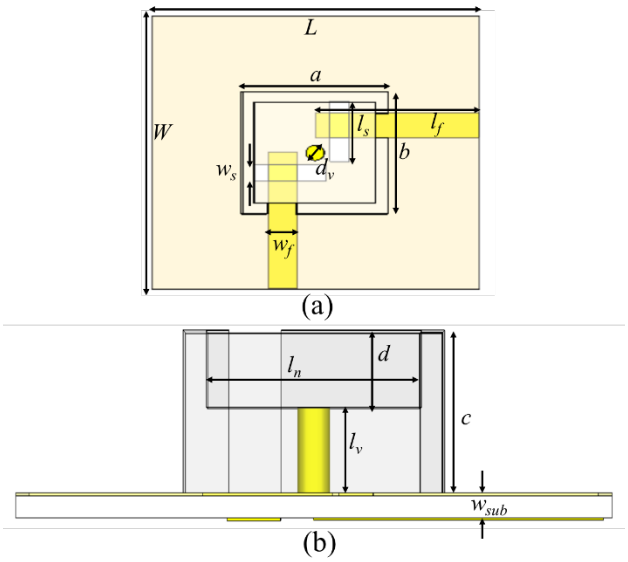

Figure 2. Proposed design (a) top view (b) side view. *[L = 9, W = 9, a = b = 3.6, c = 1.8, d = 0.7, d_v = 0.5, l_f = 4.5, l_s = 2, l_n = 2.9, lv = 1.1, w_f=0.8, w_s = 0.5, w_{sub}= 0.254]mm*

3. ANTENNA DESIGN AND EVOLUTION

The proposed design originates from a basic configuration involving a single-element rectangular dielectric resonator antenna (DRA) positioned on a ground plane, with excitation provided by a microstrip feedline through a slot aperture. For the specified dimensions of the rectangular DRA, the resonant frequency of the fundamental TE mode can be determined using transcendental equations (1) and (2).

$$k_x = \frac{\pi}{a}, k_y = \frac{\pi}{b}, k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \quad (1)$$

$$k_z \tan(k_z \frac{c}{2}) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_z^2} \quad (2)$$

To further enhance the design, an orthogonal feed line is incorporated, thereby transforming the system into a two-port multiple-input multiple-output (MIMO) structure. This additional feed not only facilitates MIMO functionality but also contributes to a reduction in mutual coupling between the ports. Bandwidth improvement is achieved by etching a notch from the center of the DRA, effectively optimizing its performance. Moreover, a metallic via is introduced into the DRA, serving to enhance impedance matching and further improve isolation between the ports. Finally, additional modifications are made by trimming sections from the adjacent sides of the DRA, enabling the antenna to achieve the desired bandwidth within the 28 GHz frequency band, which is crucial for 5G millimeter-wave applications.

4. RESULTS AND DISCUSSION

The proposed antenna design was simulated and optimized using CST Microwave Studio. To enhance bandwidth, a portion of the DRA's center was strategically removed and cutouts from the DRA side walls were introduced, while isolation was improved through a combination of techniques, including the insertion of a metallic via inside the DRA and orthogonal excitation at the two ports. As shown in the simulated S-parameters in Figure 3, the -10 dB impedance bandwidth of the design spans from 27.4 GHz to 29.8 GHz, with isolation exceeding 15.5 dB across the entire operational range.

The simulated realized gain and radiation efficiency are illustrated in Figure 4. The peak gain reaches 5 dBi at 29 GHz while the radiation efficiency exceeds 94.5% throughout the bandwidth with a maximum efficiency greater than 96.5 %. These results highlight the design's efficient performance in terms of radiation properties.

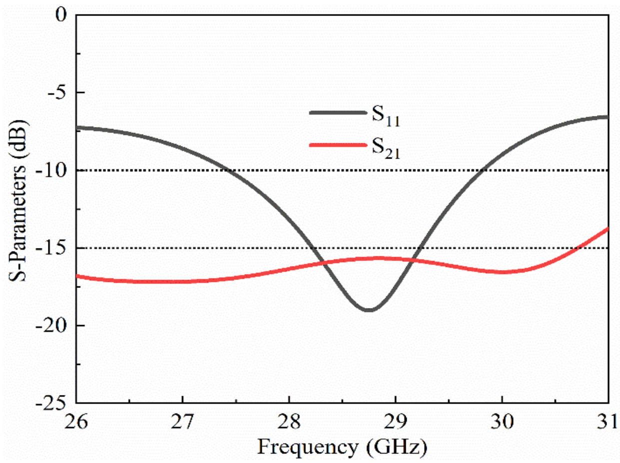

Figure 3. S-parameters of the proposed design

Figure 5 presents key MIMO performance parameters, specifically the Envelope Correlation Coefficient (ECC) and Diversity Gain (DG). The ECC remains below 0.01 across the entire operating band, indicating minimal correlation between antenna elements, while the DG remains above 9.95 dB, ensuring strong diversity performance. Both values are well within acceptable limits, supporting reliable MIMO communication in the 5G mm-wave spectrum.

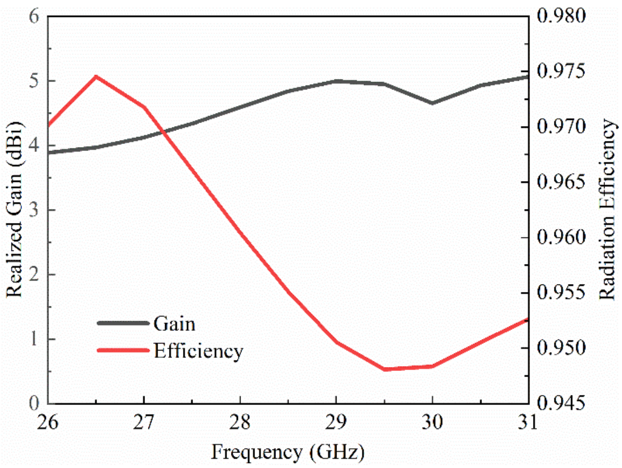

Figure 4. Realized gain and radiation efficiency

Figure 6 illustrates the radiation patterns obtained at port 1 in the E and H-plane of the proposed design in the broadside direction where the DRA is excited in the fundamental mode. Because of the design symmetry, similar patterns are generated at port 2.

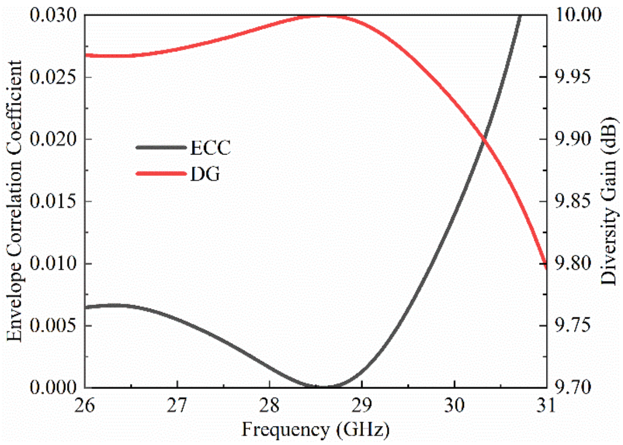

Figure 5. MIMO performance parameters

Figure 7 shows a comparison of the S-parameters for different stages of the evolution of the proposed design. The bandwidth and isolation enhancements of the proposed design is evident as compared to the initial stages of the design. In stage-1, a rectangular DRA alone is employed without the inclusion of notch or metallic vias. It can be observed that impedance matching in the desired band is not significant although two bands are formed. Also, the isolation achieved is less than 15 dB for this case. In stage-2, notches and trimmed portions are incorporated in the design. It can be observed that a significant -10 dB impedance matching is generated although the bandwidth is low. The isolation, however, for this case is high and remains above 17 dB throughout the operating band. In stage-3, the proposed MIMO design is obtained by inserting metallic via inside the DRA. It can be observed that the bandwidth in the required band of interest is maximum for this case as compared to the previous stages and the isolation is also stable above 15 dB.

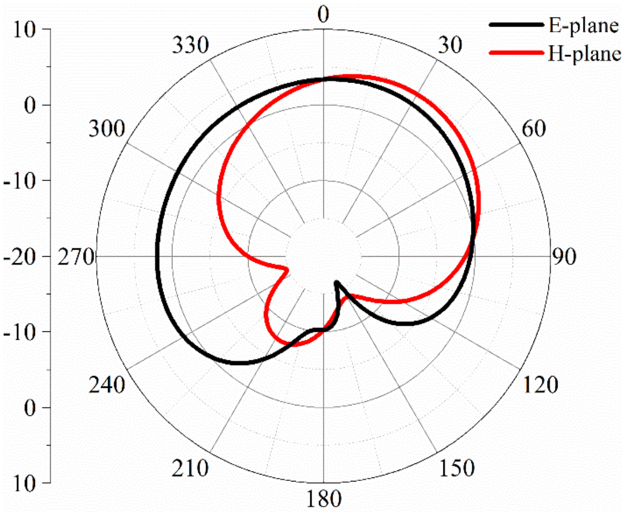

Figure 6. Radiation patterns at 28.75 GHz

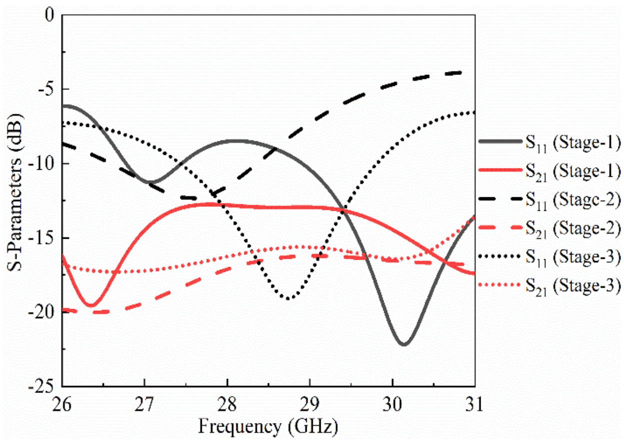

Figure 7. Comparison of S-parameters for different stages of proposed design

Figure 8 compares the realized gain and radiation efficiencies of the proposed design. For stage-1 with a rectangular DRA, the realized gain in the desired band i.e. 27.4-29.5 GHz starts from 4 dBi and reaches up to 5.5 dB. The radiation efficiency is also relatively lower at the start of the band due to poor impedance matching. For stage-2 with notch, the realized gain is stable and stays above 5 dB throughout the band with the radiation efficiency also being higher starting from 96% and staying above 94%. The increase is gain is attributed to lowering of dielectric loss due to the removal of notch from the center. For stage 3, the realized gain of the proposed design is lowered than the previous stages due to the losses incurred by the metallic via. The radiation efficiency, however, is improved in comparison to the previous stage due to better impedance matching.

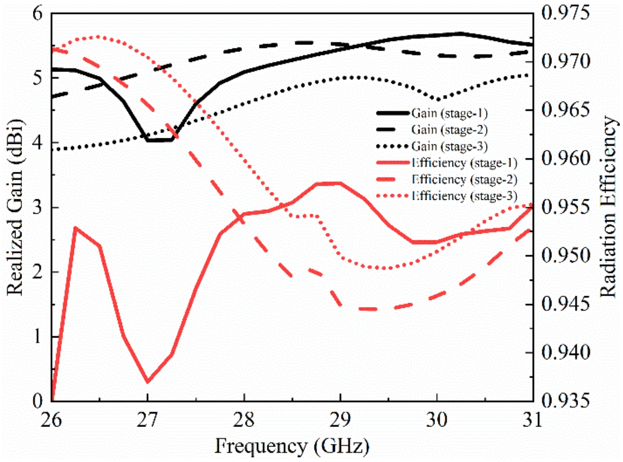

Figure 8. Comparison of realized gain and radiation efficiencies for different stages

The proposed design is superior in performance as compared to the previously reported MIMO DRA for 5G mm-wave applications in terms of compactness while achieving a significant impedance bandwidth with good isolation. Utilizing the single-element design for the proposed MIMO configuration ensures that no extra space on the ground plane is occupied by additional radiators. Also, the decoupling mechanisms employed in the proposed design does not affect the compactness which is a challenging task in the previously reported designs.

5. CONCLUSION

A Multiple-Input Multiple-Output Dielectric Resonator Antenna designed specifically for the 5G n257 band has been developed. The design features a single element modified rectangular DRA with a notched configuration, where a metallic via is strategically inserted within the dielectric material. The antenna operates efficiently within the frequency range of 27.4 to 29.8 GHz, achieving isolation levels greater than 15.5 dB throughout the entire operational bandwidth. Because of the single element design and enhanced bandwidth, the proposed design exhibits superior performance in terms of data rate and compactness. These characteristics make the design an excellent candidate for communication systems operating within the 28 GHz 5G millimeter-wave spectrum, offering a robust and compact solution for next-generation wireless technologies.

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