Design of Quad-Element MIMO Antenna for mmWave Applications

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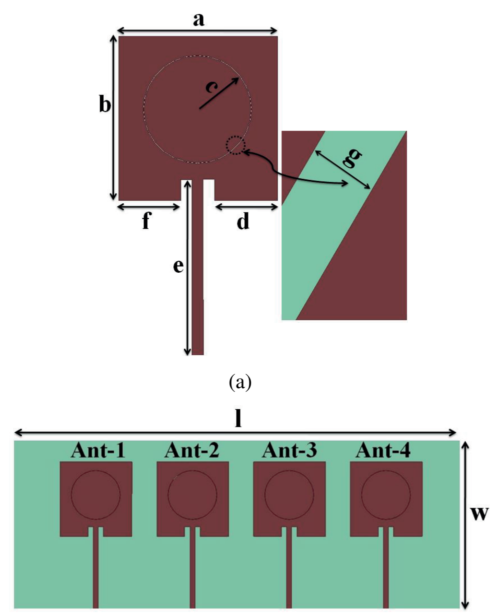
***Abstract*—This paper provides a printed patch with the benefits of low size and easy geometrical arrangement for fifth-generation (5G) 28 GHz communication networks. The patch antenna's radiator is defective with a circular slit for improved performance. The antenna has a wide working bandwidth while maintaining a good gain. Later, A four-element multiple-input multiple-output (MIMO) array is designed using this single antenna. It achieves The MIMO antenna also has an excellent envelope correlation coefficient (ECC) and high diversity gain, indicating that it can be applied in a compact 5G smart device.**

***Index Terms*—5G, MIMO antenna, ECC, DG.**

I. Introduction

The high demand for high data rates in mobile communication has prompted extensive research towards the fifth generation (5G) mobile communication system, which is significantly faster than current technology. The Federal Communications Commission (FCC) has suggested licensed frequency spectrums for 5G connectivity at 28 GHz, 37 GHz, and 39 GHz, along with unlicensed frequency spectrum [1]. A high gain antenna with an appropriate array construction and dynamic beam forming capability is necessary due to high frequency path loss. To obtain a high data rate, a wide bandwidth is also required [2]. Multi-input and multi-output (MIMO) is a promising technology that has been intensively explored to improve the data transmission speed and the anti-multipath fading. The transmitter or receiver in a MIMO system must have two or more antenna elements [3]. Multiple antennas, on the other hand, have the disadvantage of increasing the system size and deteriorating the isolation between them, resulting in a distorted radiation pattern and reduced channel capacity [4]. All relevant parameters must be considered and maintained when designing a MIMO antenna.

A new strategy that does not require any additional isolation elements or decoupling mechanisms is proposed in this paper. Even when the antenna components are put substantially closer to each other, a desired reflection coefficient, strong port isolation, and low correlation can be accomplished by defecting the antenna elements at the top of the substrate. The suggested design is a small, low-complex broadband mmWave MIMO antenna.



(b)

Fig. 1. Geometry of the proposed (a) single antenna and (b) MIMO antenna.

II. Antenna design

The design technique and geometry of the proposed single-element and MIMO antennas are illustrated in Fig. 1(a) and Fig. 1(b), respectively. The antenna elements are arranged in a line on top of a Rogers RT/duroid 5880 substrate with a dielectric constant (r) of 2.2 and a loss tangent (tan) of 0.0009. The proposed MIMO antenna has dimensions of 18 mm in length, 6.8 mm in width, and a height (h) of 0.508 mm.

The design process begins with the creation of a simple rectangular patch antenna, followed by the construction of a circular ring in step-2. Two circular slots of radii 1.04 mm and 1.03 mm are used to create a circular portion of 0.01 mm, which is then subtracted from the patch. The resulting design is a circularly slotted patch antenna, which is optimized for performance in the mmWave frequency range.

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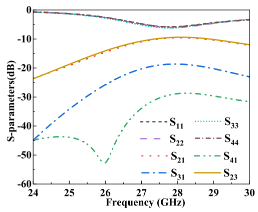

(a)

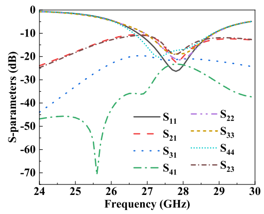

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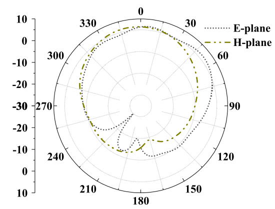
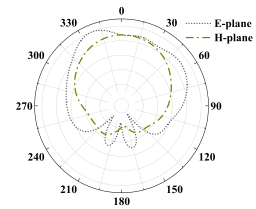
Fig. 2. S-parameters of the MIMO antenna (a) without circular slot and (b) with circular slot.



(a)



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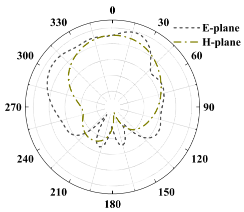
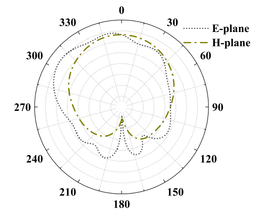
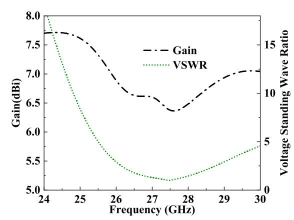


(c)

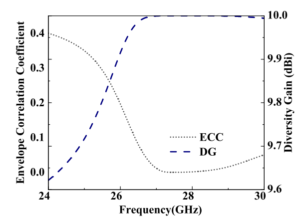


(d)

Fig. 3. E-plane and H-plane radiation patterns of the proposed prototype (a) Ant-1, (b) Ant-2, (c) Ant-3, and Ant-4 at 28 GHz.



(a)



(b)

Fig. 4. depicts (a) Gain and VSWR, (b) ECC and DG of the proposed MIMO antenna.

The MIMO antenna consists of four 1 $\times$ 4 array antennas with four feeding ports on the top layer. The array antennas are separated by a distance of 0.97 mm and are placed on a full ground plane at the bottom layer. The optimized MIMO antenna system is modeled and analyzed using Ansys HFSS. The dimensions of the proposed antenna are given as a = 2.8245 mm, b = 2.925 mm, c = 1.04 mm, d = 1.245 mm, e = 3.25 mm, f = 1.245 mm, g = 0.01 mm.

III. Results and Discussion

Fig. 2(a) depicts the S-parameters of the antenna without the circular cuts in the monopoles. It can be observed that $|S_{11}|$ remains above -10 dB, and the isolation parameter is also above -15 dB across the entire operating band. After introducing the circular slot in the patch, as shown in Fig. 2(b), $|S_{11}|$ drops below -10 dB within the frequency range of 26.4 GHz to 28.6 GHz. The proposed antenna exhibits resonance around the 28 GHz frequency, and the isolation is consistently greater than -15 dB throughout the operational range, with a maximum value of -30 dB.

In Fig. 3, the radiation patterns of all four antennas at 28 GHz are illustrated. Fig. 4(a) shows the gain and VSWR of the proposed MIMO antenna. The design exhibits an average gain of 6.3 dBi, with a peak value of 6.9 dBi at 28.5 GHz. Moreover, the VSWR of the MIMO system remains below 2 across the entire operating band.

Additionally, an analysis of diversity was performed on the proposed MIMO antenna, focusing on its envelope correlation coefficient (ECC) and diversity gain (DG). The ECC was determined to be 0.015, demonstrating excellent diversity performance, as depicted in Fig. 4(b). The DG was found to be 9.999 dBi, indicating a significant level of diversity gain, as evidenced by the data presented in Fig. 4(b).

IV. Conclusion

The proposed low-profile four-element MIMO antenna offers significant performance improvements for 5G mmWave applications. The introduction of a circular slot to the single element antenna not only shifted the resonance frequency to 28 GHz but also enhanced the bandwidth and isolation. Moreover, the integration into a 4-port MIMO design resulted in a wide operating bandwidth, high isolation, low envelope correlation coefficient (ECC), and a very compact and cost-effective design. Overall, this antenna design has the potential to make valuable contributions to the development of mmWave 5G devices and sensors.

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References

[1] Q. Zhu, K. B. Ng, C. H. Chan and K. -M. Luk, "Substrate-Integrated-Waveguide-fed array antenna Covering 57C71 GHz Band for 5G Applications," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 12, pp. 6298-6306, Dec. 2017.

[2] A. Khan, Y. He and Z. N. Chen, "An Eight-Port Circularly Polarized Wideband MIMO Antenna Based on a Metamaterial-Inspired Element for 5G mmWave Applications," *IEEE Antennas and Wireless Propagation Letters,* early access, Mar. 2023.

[3] P. Liu, D. Sun, P. Wang, and P. Gao, "Design of a dual-band MIMO antenna with high isolation for WLAN applications," *Progress In Electromagnetics Research Letters*, vol. 74, pp. 23-30, 2018.

[4] A. Khan, Y. He, Z. He and Z. N. Chen, "A Compact Quadruple-Band Circular Polarized MIMO Antenna With Low Mutual Coupling," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 70, no. 2, pp. 501-505, Feb. 2023.