Griffiths, G. J., Alkaraki, S., Aslam, M., Abbasi, Q. H., Evans, A. and Jilani, S. F. (2023) Millimeter-wave Defected Ground Structure-based MIMO Antenna for 6G Wireless Applications. In: 2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Portland, Oregon, USA, 23–28 July 2023, pp. 1399-1400. ISBN 9781665442282.

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Deposited on: 25 April 2023

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Millimeter-wave Defected Ground Structure-based MIMO Antenna for 6G Wireless Applications

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***Abstract*—In this paper, a 2×2 multiple-input-multiple-output (MIMO) assembly of an elliptical-shaped millimeter-wave (mm-wave) antenna with defected-ground structures (DGS) is presented. The antenna is integrated with ring slot-shaped cut-outs as DGS on the bottom ground to generate multiple resonances combined in a wide bandwidth of 25.0-29.7 GHz. The simulated results show an efficiency above 75% and realized gain above 4.5 dBi in the entire range with a peak gain of 7.64 dBi at 27 GHz. The proposed MIMO antenna is well-suited for the 6th Generation (6G) wireless applications.**

I. Introduction

In the modern era of the internet-of-things (IoT) and 5th generation (5G) wireless communication, there is a growing interest in sectors like healthcare, autonomous vehicles, device-to-device communication, etc. Further innovations in these sectors are anticipated from the upcoming 6G networks. For instance, problems including the time and cost efficiency of constant patient monitoring can be tackled with automated wearable devices [1]. An antenna is the core of a wireless device, and patch antennas are notable due to their low cost, small size, and lightweight properties, and they are easy to integrate [2]. Several patch antennas are deployed in the 5G wireless bands. For 6G, millimeter-waves (mm-waves) bands are expected to be real game-changers. However, these bands pose limitations due to atmospheric attenuation and absorptions which can be handled with pico- and femtocell architecture [3].

Bandwidth and efficiency are critical requirements for 6G antennas and have become more crucial for body-centric antennas because the human body acts as a lossy material [4]. One method to design a multiband antenna is defected-ground structures (DGS) [5]. DGS incorporates abnormalities like cuts and slots at the antenna's ground to disturb the uniform current distribution, which creates resonances and sinks [6]. It sustains the antenna compactness and enables it to radiate at multiple frequencies and thus increase the operating bandwidth whilst maintaining good performance [7].

The proposed 2×2 MIMO antenna array has kept the needs of 6G communication at the forefront of the plan. The ground has been made defective with ring-shaped slots to excite multiple frequencies to achieve a wide bandwidth. In addition, a MIMO configuration in the design introduces the adaptability and cognitive behavior desired for 6G wireless applications.

II. Antenna Design and Fabrication

The DGS antenna and 2×2 MIMO assembly were created, optimized, and evaluated using CST Microwave Studio Suite. An elliptical copper patch is designed with a 50Ω-coplanar waveguide feed (CPW) on a Rogers RO 4003 substrate (ε= 3.55, $\tan(\delta)$= 0.0027) of 11.60 × 12.10 × 0.51 mm^3. The bottom part consists of a copper partial ground with DGS. The DGS was designed as 6-ring slot cut-outs. Once the initial design was completed, a 2×2 MIMO assembly was constructed using the same patch layout with a slightly widened substrate to achieve a symmetric orthogonal placement. The designed dimensions are depicted in Figure 1 (a)-(d).

III. Results and Discussion

This section presents the quantitative analysis of the proposed antenna performance in simulation.

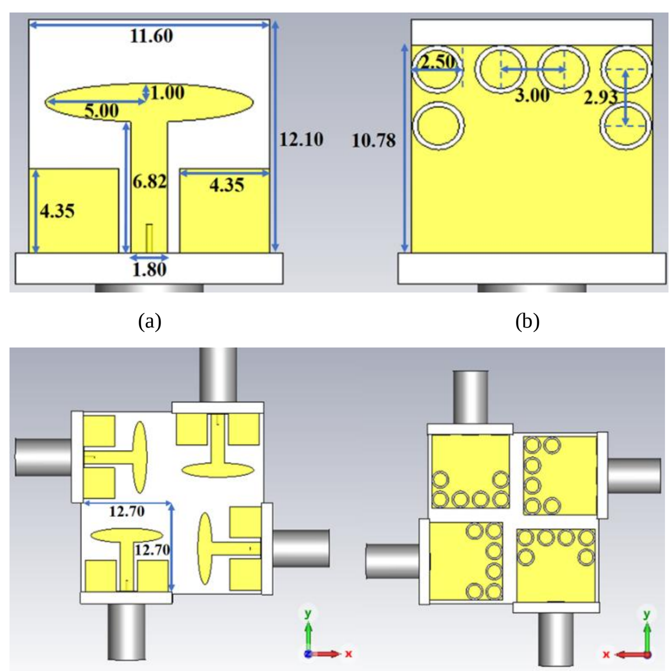


Figure 1. Proposed DGS-based antenna and MIMO assembly; (a) top-view of a single antenna, (b) bottom view of a single antenna, (c) top-view of 2×2 MIMO, (d) bottom view of 2×2 MIMO antenna array.

A. Reflection Coefficient

The reflection coefficient (S_{11}) plot in Fig. 2(a) shows a single antenna's simulation bandwidth of 25.0-29.7 GHz. The effect of the designed DGS is distinct, with a remarkable bandwidth increase due to two additional resonances. The transmission coefficients of the 2×2 array are below -20 dB across the bandwidth in Fig. 2(b), displaying low mutual coupling and good isolation required for the MIMO operation.

B. Radiation Patterns

Fig. 3 shows the simulated radiation patterns (E-plane cut: φ = 90° and H-plane cut: φ = 0°) of the proposed DGS antenna element at distinct frequencies of 25 GHz, 27 GHz, and 29 GHz. The plots show fairly omnidirectional radiation.

C. Realised Gain and Efficiency

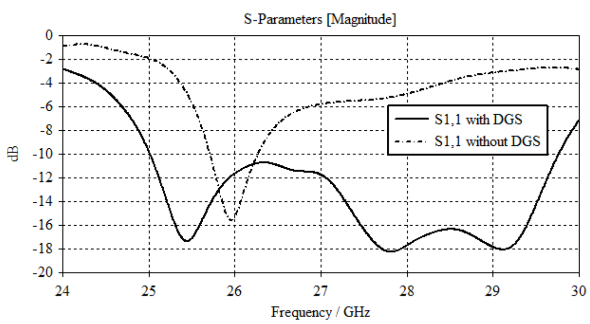
Within the operating bandwidth, the simulated efficiency of the proposed DGS antenna remains above 75% with a realized gain above 4.5 dBi, as shown in Table I. The maximum gain of 7.64 dBi is observed at 27 GHz. The MIMO antennas work independently, so the gain and efficiency performances can be presumed identical for each element of the MIMO array.

D. Current density

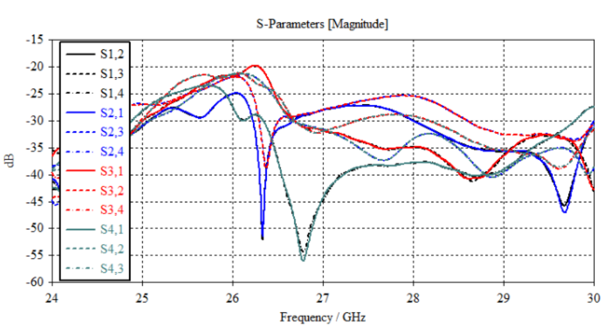
Fig. 4 shows simulated current densities for the DGS-based antenna. A high gradient of current distribution at multiple points generates multiple frequencies.

TABLE I. REALISED GAIN OF THE PROPOSED ANTENNA.

Frequencies	**25 GHz**	**26 GHz**	**27 GHz**	**28 GHz**	**29 GHz**
Gain (dBi)	5.16	6.62	7.64	5.83	4.68

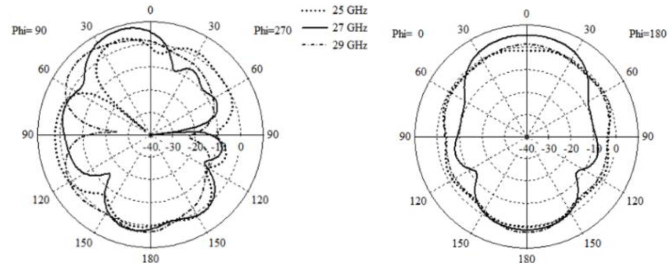


(a)



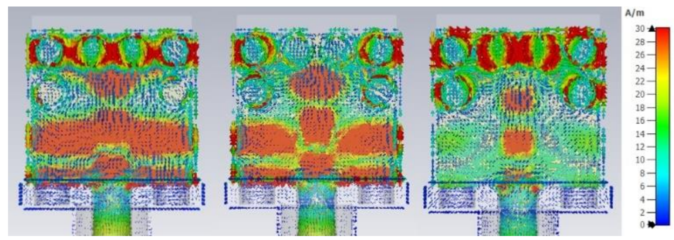
(b)

Figure 2. S-parameters of the DGS-based MIMO antenna; (a) S11 of the antenna with/without DGS, (b) Transmission coefficients of the 2×2 MIMO.



(a) (b)

Figure 3. Simulated radiation patterns of the DGS-based antenna at frequencies of 25 GHz, 27 GHz, and 29 GHz; (a) E-plane: φ = 90°, (b) H-plane: φ = 0°.



(a) (b) (c)

Figure 4. Simulated current density plots of the DGS-based antenna at distinct frequencies, (a) 25 GHz, (b) 27 GHz, and (c) 29 GHz.

IV. CONCLUSION

This paper has presented a mm-wave antenna design using ring-slot DGS on a partial ground to achieve a wide bandwidth of 25.0-29.7 GHz, an efficiency above 75%, and a maximum gain of 7.64 dBi. In addition, the 2×2 MIMO array of the proposed design showed high isolation, adaptability, and cognitive response. The performance attributes signify that the design is suitable for 6G wireless applications.

ACKNOWLEDGMENT

Special thanks to TRL Technologies for the kind support.

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