



Minimally Coupled Two-Element MIMO Antenna with Dual Band (28/38 GHz) for 5G Wireless Communications

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Abstract

This paper presents a dual-band 28/38 GHz two elements multiple-input multiple-output (MIMO) antenna with high isolation for 5G applications. The suggested antenna is a monopole with rectangular and triangle stubs added to the patch and a partial ground plane to achieve the dual band's behavior. Two elements of the suggested antenna are combined and placed orthogonally to achieve the high isolation features of the MIMO configuration at 28/38 GHz. The MIMO configuration has a size of $27.65 \times 12 \times 0.273 \text{ mm}^3$. The suggested MIMO prototype is fabricated and tested. The tested results achieved dual frequency bands with S_{11} lower than -10 dB within two frequency bands (26–30 GHz and 36–41.5 GHz) and S_{21} lower than -20 dB through the two operated bands. The suggested antenna has semi-omnidirectional radiation patterns in both planes. As well, its measured peak gain is 5.2 dBi and 5.3 dBi at the two operated frequency bands, respectively. Also, the MIMO parameters are extracted to validate the simulated results. The simulated and tested results have a good matching within the two operating bands which suggests the proposed structure be utilized in 5G communications.

Keywords Dual-band antenna · MIMO antenna · 28/38 GHz applications · MIMO performance · 5G communications

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1 Introduction

The rapid development of the fifth generation (5G) enhances the performance of the wireless communication systems such as increasing data rate, connectivity, and spectral efficiency and reducing the latency of these systems [1–3]. The data rate of the 5G systems is 10 times more than the 4G systems and has high connectivity between devices which achieves the Internet of Things (IoT) technology with high reliability [4]. The FCC assigned frequency bands from 25 GHz up to 70 GHz to be utilized for the 5G applications [2, 5]. These bands suffer from attenuation because of the path loss and atmospheric absorption which makes the antenna researchers design antenna with high gain and wideband features to tackle these problems [6–10]. Also, an increasing number of antenna elements (MIMO technology) enhances the transmission quality and increases the capacity of the system and reduces the multipath problems [11–13]. So, by introducing a MIMO system with high isolation between antenna elements, the overall performance of the system as high data rate, high capacity, lower multipath effect, and reliability can be improved [14–16]. Recently, a dual-band 28/38 GHz MIMO antenna is developed by researchers [7, 12, 17–27]. In [7], dual bands 27/39 GHz MIMO antenna with two elements, isolation higher than 25 dB, and peak gain around 5 dBi is introduced. A dual-band circular polarized 4 ports antenna operated at 28/38 GHz with isolation around 36 dB and peak gain higher than 7 dBi is discussed in [12]. In [17], a dual-band 28/38 GHz two elements MIMO antenna with 30 dB isolation and simulated peak gain of 7 dBi is achieved. A dual-band 28/38 GHz circular polarized two ports MIMO antenna using an artificial neural network (ANN) is proposed in [18]. In [19], dual bands 28/38 GHz MIMO antenna with two ports, isolation higher than 25 dB, and peak gain around 1.7 dBi is introduced. A four-port MIMO antenna operated at 28/37 GHz is investigated in [20]. A dual-band 28/38 GHz slot MIMO antenna with two elements and isolation higher than 20 dB is introduced [21]. In [22], four ports dual-band 28/38 GHz antenna with more than 20 dB isolation and peak gain more than 7 dBi is accomplished. A dual-band four ports antenna worked at 28/38 GHz with isolation around 25 dB and peak gain higher than 5 dBi is discussed in [23]. In [24], a dual-band 28/38 GHz four elements MIMO antenna with 30 dB isolation and simulated peak gain of 9 dBi is achieved. A dual-band 28/38 GHz 2-port MIMO SIW antenna with peak gain higher than 5 dBi is proposed in [25]. A dual-band 28/38 GHz four elements MIMO/array antenna with a simulated peak gain of 9 dBi is investigated in [26]. In [27], six ports dual-band 28/38 GHz loop antenna with more than 25 dB isolation and simulated peak gain of more than 4.5 dBi is accomplished.

In this paper, a dual-band 28/38 GHz two elements MIMO antenna with high isolation for 5G applications is suggested. The triangle and rectangular stubs are merged with the patch to achieve the proposed 5G frequency bands. The two elements of the suggested antenna with a size of $27.65 \times 12 \times 0.203 \text{ mm}^3$ are combined and placed orthogonally to achieve the high isolation features of the MIMO configuration. The HFSS commercial software is used in the antenna design. This

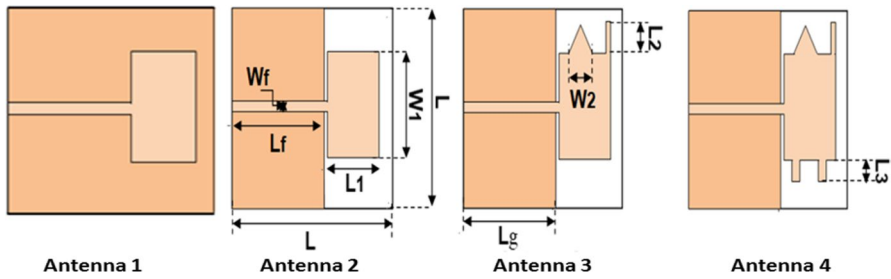
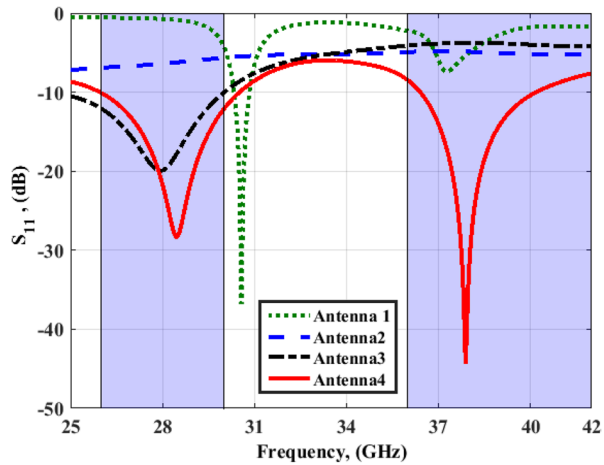


Fig. 1 The development of the suggested single element dual-band antenna

Fig. 2 The simulated S_{11} results of the different antennas



paper has arranged with the following sections: first, Section II, the design of the single element antenna to achieve the desired 28/38 GHz frequency bands is discussed. Second, in Section III, the MIMO antenna design procedures are presented. Third, in Section IV, the MIMO tested results (impedance and radiation characteristics), and its diversity parameters such as envelop correlation coefficient (ECC), the diversity gain (DG), and channel capacity loss (CCL) are extracted and presented. Finally, the conclusion of the paper is introduced to summarize the antenna performance and presented in Section V.

2 Design Procedures for Single Antenna

The development of the suggested antenna is illustrated in Fig. 1. The antenna is designed using Rogers RO4003 substrate with thickness and dielectric constant of 0.203 mm and 3.55, respectively. As the initial start, the conventional patch antenna with a rectangular patch of $W_1=5$ mm and $L_1=4$ mm (antenna 1) with the full ground plane of 12 mm length, and microstrip line with $W_f=0.4$ mm and $L_f=7$ mm

as shown in Fig. 1a, is designed to operate at fundamental mode around 30.5 GHz as shown in Fig. 2 (green dotted line). Second, a partial ground plane (L_g) with a length of 6 mm is utilized instead of the full ground plane (antenna 2) to enhance the antenna bandwidth. By adding rectangular stub (L_2) of 2.1 mm and triangular stub (W_2) of 2.05 mm on the same side of the rectangular patch, a resonance response extended with S_{11} lower than -10 dB from 25.9 and 30.4 GHz as illustrated in Fig. 2 (antenna 3). Finally, to achieve the second resonance, another two rectangular stubs (L_3) of 1 mm are added to achieve a response from 36.4 to 40.2 GHz as shown in Fig. 2 (antenna 4). The HFSS simulator is used to achieve the results of the suggested antenna.

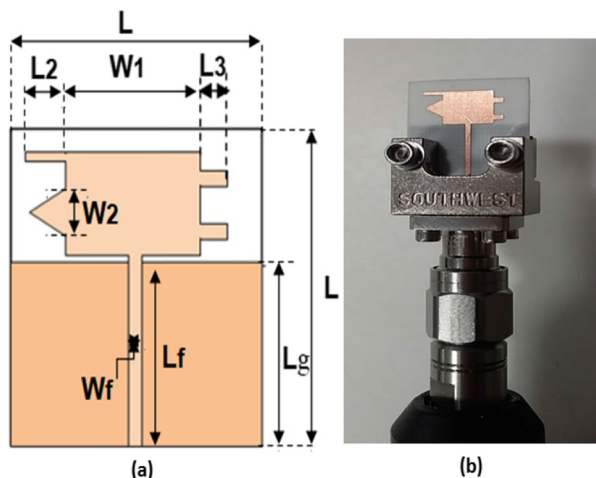
Based on the previous design procedures, antenna 4 is considered the suggested antenna to produce the proposed 28/38 GHz frequency bands. So, the suggested antenna layout as shown in Fig. 3a is fabricated, and its prototype photograph with a launcher connector is illustrated in Fig. 3b.

The simulated as well as the tested S_{11} results with a frequency of the suggested single element dual-band antenna are displayed in Fig. 4. The simulated results are tested using the vector network analyzer (VNA) (Rohde & Schwarz ZVA 67), and achieved frequency bands are from 26 to 30 GHz in the first band, while the second frequency band is from 36.5 up to 40 GHz. However, the tested results are achieved frequency ranges from 28 to 29 GHz for the first band and from 37.5 up to 39 GHz for the second band. There is a small discrepancy between the two results due to the fabrication and measurements tolerance which cannot be tackled.

3 The Suggested MIMO Antenna and Parametric Analysis

The design of the two elements MIMO antenna and the technique used to eliminate the mutual coupling to enhance the antenna operation are investigated in this section. There are two configurations which are studied as shown in Fig. 5. The first one

Fig. 3 The configuration of the suggested single element dual-band antenna. **a** Simulated 2-D layout. **b** Fabricated prototype with connector



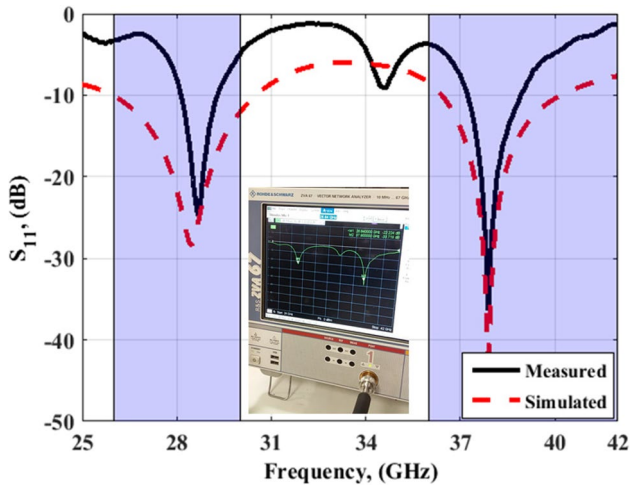
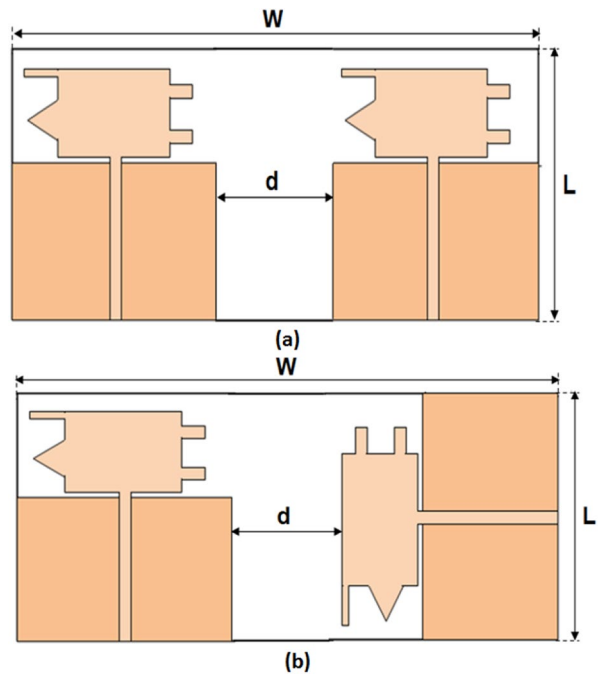


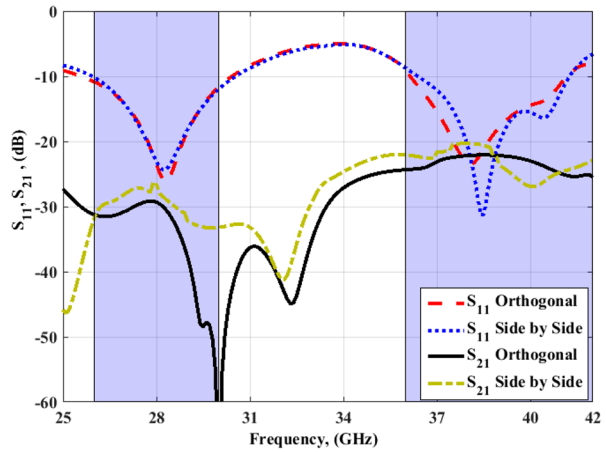
Fig. 4 The simulated and tested S_{11} results with a frequency of the suggested single element dual-band antenna

Fig. 5 The 2-D configuration of the suggested 2 elements MIMO antenna. **a** Side-by-side orientation. **b** Orthogonal orientation



is the side-by-side orientation as shown in Fig. 5a, and the other is the orthogonal orientation as shown in Fig. 5b. The separation (d) between the 2 elements is the same in the two configurations. The simulation results of the two configurations are shown in Fig. 6 to show the effect of the antenna orientation on the matching and the

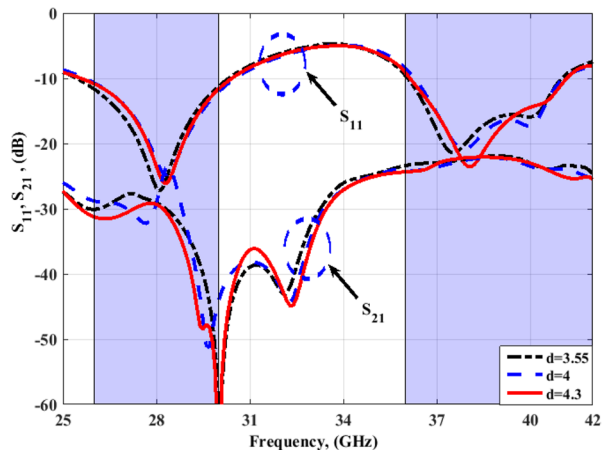
Fig. 6 The simulated S_{11}/S_{21} results with a frequency for the two orientations



isolation between the antenna elements. As shown in Fig. 6, the reflection coefficient of the two configurations is almost the same, while the isolation between antenna elements is enhanced in the case of the orthogonal orientation than the side-by-side orientation, especially at the lower frequency bands. So, orthogonal orientation is suggested in the MIMO antenna design.

The effect of the separation (d) between antenna elements on the antenna performance is illustrated in Fig. 7. When the separation (d) is changed from 3.55 to 4.3 mm, the isolation between elements is enhanced. So, the optimized distance (d) equals 4.3 mm to achieve the desired performance. The simulated surface current distributions for the suggested MIMO antenna at $f=28$ GHz and $f=38$ GHz are shown in Fig. 8. The results are extracted when port 1 is radiated and port 2 is matched to 50Ω and verse versa. It is seen that, first, the current is collected around the rectangular stub and triangular stub at 28 GHz which means the two stubs are responsible for radiation at this frequency band, while the current is collected

Fig. 7 The simulated S_{11}/S_{21} results with a frequency for the suggested orthogonal orientation at different values of the space between elements (d)



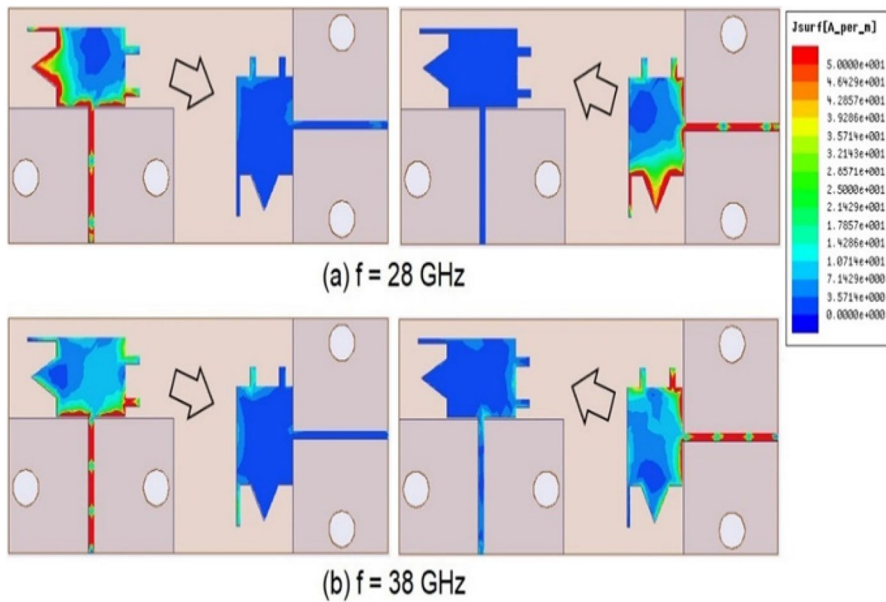


Fig. 8 The simulated surface current distribution of the suggested orthogonal orientation

around the other two stubs (on the right of the patch) at 38 GHz. Second, the current is collected around the operated port with a small amount of current passed to other ports which validate the high isolation between ports.

4 The Tested Results and Investigation

The suggested MIMO antenna is fabricated on the same previous substrate, and the total size of the antenna equals $W=27.65 \text{ mm}$, $L=12 \text{ mm}$, and $d=4.3 \text{ mm}$. The fabricated prototypes with and without connectors are shown in Fig. 9. The two elements are added in orthogonal orientation as discussed in the previous section. Figure 10 illustrates the simulated and tested results of the suggested antenna. The antenna operated (from simulated results) at a frequency band from 25.9 to 30.6 GHz and from 36.1 to 40.3 GHz with isolation lower than 30 dB and 22.2 dB for the first and second bands, respectively. However, the antenna operated (from tested results) at frequency band from 27.5 to 29.4 GHz and from 36.4 to 41.9 GHz with isolation lower than 34 dB and 22.2 dB for the first and second bands, respectively. The differences between the two results are because of the fabrication and measurements tolerance which cannot be overcome.

The simulated and tested radiation pattern results (E-plane and H-plane) at 28 GHz and 38 GHz when antenna is excited at port 1, and terminated with 50Ω load at port 2, are shown in Fig. 11. The antenna has a semi-omnidirectional pattern at the two frequency bands, and there is a consistent trend between the simulated and tested results with small differences between them because of the

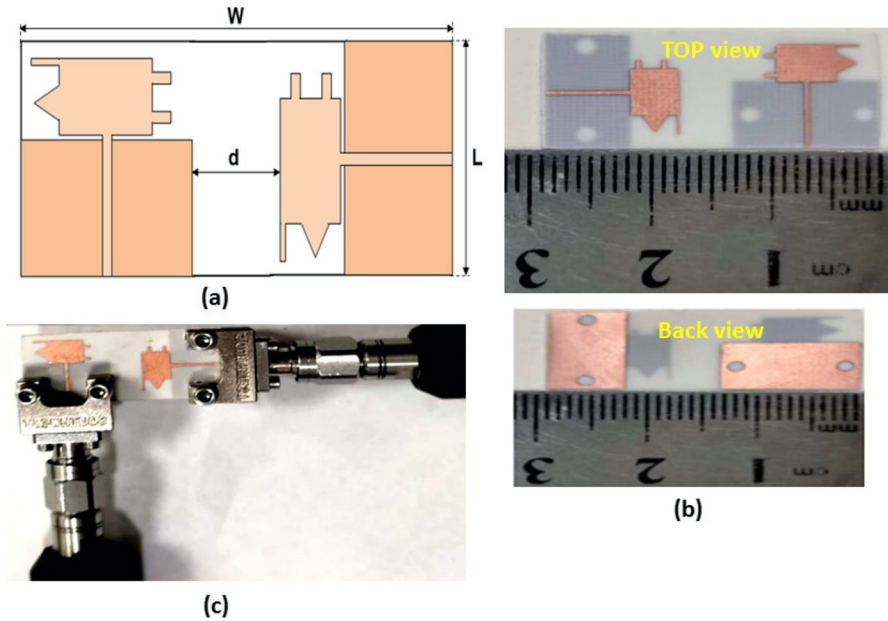
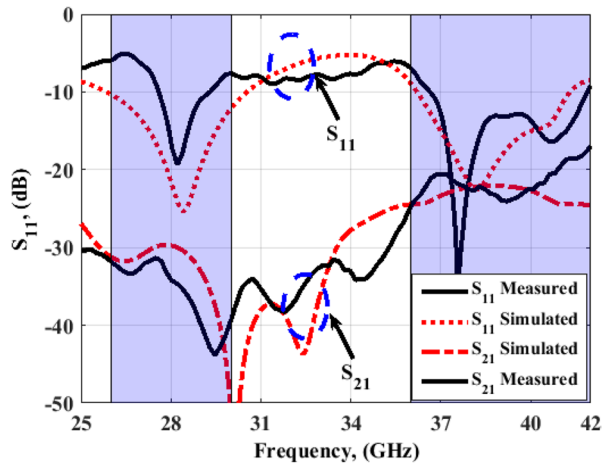


Fig. 9 The configuration of the suggested 2 ports dual-band MIMO antenna. **a** Simulated 2-D layout. **b** Fabricated prototype without connector. **c** Fabricated prototype with connector

Fig. 10 The simulated and tested S_{11} results with a frequency of the suggested 2 ports dual-band MIMO antenna at port 1



measurements setup. The technique used to measure the antenna gain is discussed in [24, 26]. Figure 12 shows the simulated and tested peak gain results of the suggested antenna when it is also excited at port 1. The measured peak gain is 5.2 dBi and 5.3 dBi at the operated frequency bands, respectively. Furthermore, the measured gains mimic the simulated one with a small discrepancy due to the tolerance of the measurement setup.

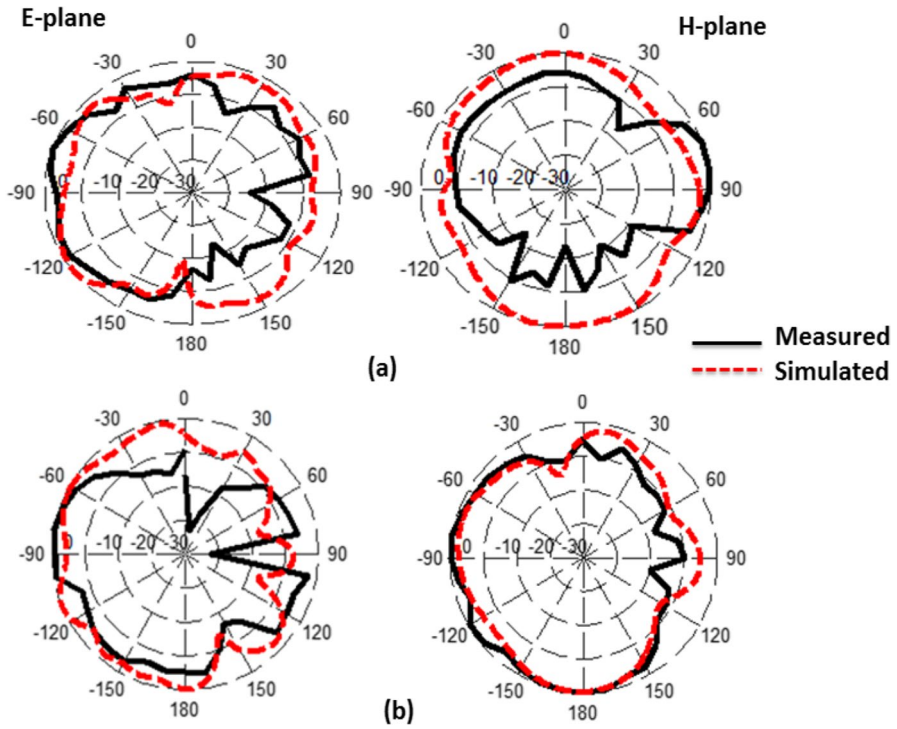


Fig. 11 The simulated and tested radiation patterns of the suggested 2 ports dual-band MIMO antenna at port 1 **a** at 28 GHz and **b** at 38 GHz

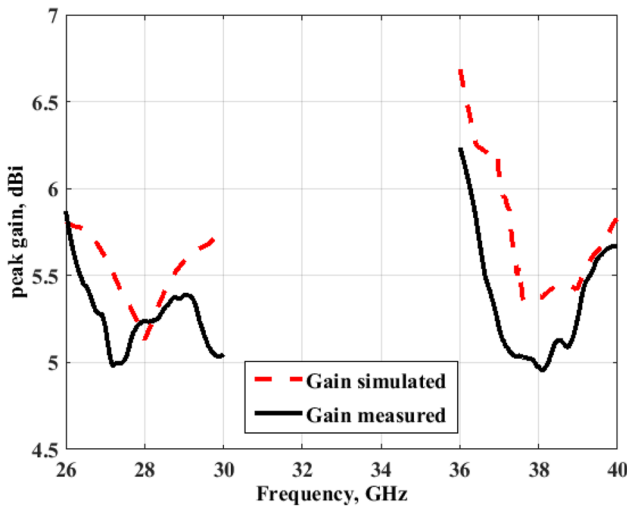


Fig. 12 The simulated and tested peak gain results with a frequency of the suggested 2 ports dual-band MIMO antenna at port 1

The quality of the suggested MIMO antenna is measured by extracting the ECC, DG, and CCL parameters. One of the important parameters is the ECC because it evaluates the correlation between ports. The lower values reflect the higher performance of the MIMO system. By suggesting uniform multipath, the ECC can be extracted and calculated from S-parameters as [28].

$$ECC = \rho_e = |\rho_{ij}| = \frac{|S_{ii}^* S_{ij} + S_{ji}^* S_{jj}|^2}{\left(1 - (|S_{ii}|^2 + |S_{ji}|^2)\right) \left(1 - (|S_{jj}|^2 + |S_{ij}|^2)\right)} \tag{1}$$

Figure 13 shows the simulated and tested ECC results with a frequency of the suggested 2 ports dual-band MIMO antenna. The value of the ECC is lower than 0.0001 in the first band and lower than 0.0002 in the second band (lower than the acceptable level of 0.5 [29]) with the good matching between the simulated and measured results.

The ECC can be connected with DG through Eq. (2) to judge the MIMO performance [30].

$$DG = 10 \times \sqrt{1 - |ECC|} \tag{2}$$

Figure 14 illustrates the simulated and tested DG results with a frequency of the suggested 2 ports dual-band MIMO antenna. The value of the DG equals around 9.99 in both bands with a good tendency between the two results.

The data rate transmitted in the communication channel can be evaluated by CCL (Bit/S/Hz) [29]. The CCL can be calculated using Eqs. (3) and (4) [30]

$$C(Loss) = -\log_2 \det(\psi^R) \tag{3}$$

Fig. 13 The simulated and tested ECC results with a frequency of the suggested 2 ports dual-band MIMO antenna

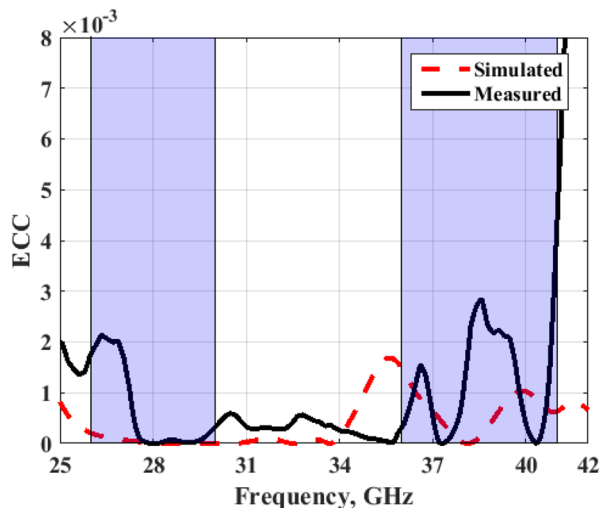
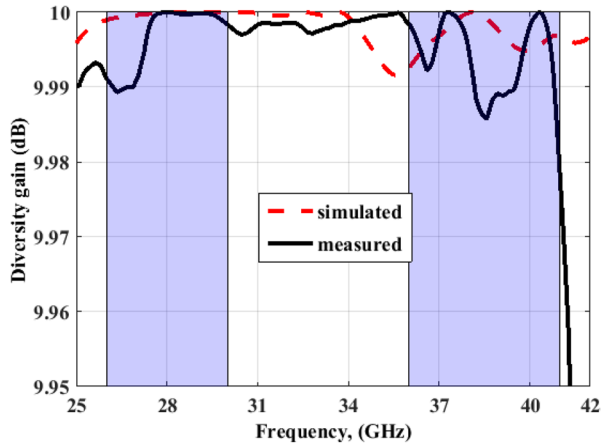


Fig. 14 The simulated and tested DG results with a frequency of the suggested 2 ports dual-band MIMO antenna



$$\psi^R = \begin{bmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{bmatrix}, \rho_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2 \right) \tag{4}$$

and

$$\rho_{ij} = -(S_{ii}^* S_{ij} + S_{ji}^* S_{ij}), \text{for } i, j = 1 \text{ or } 2$$

Figure 15 shows the simulated and tested CCL results with a frequency of the suggested 2 ports dual-band MIMO antenna. The CCL equals a value lower than 0.4 bit/s/Hz within the operated frequency bands.

Finally, Table 1 shows the comparison between the suggested antennas with other designs to judge the antenna performance. From Table 1, it is obvious that the suggested antenna can be recommended for the dual bands 28/38 5G systems.

Fig. 15 The simulated and tested CCL results with a frequency of the suggested two ports dual-band MIMO antenna

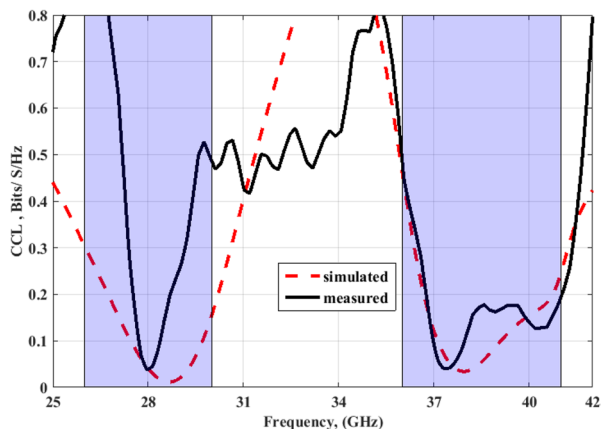


Table 1 Comparison between the suggested antennas with other designs

Ref	Size (mm ²)	No of elements	Frequency [GHz]	Isolation (dB)	ECC	Peak gain (dB)	Material/thickness (mm)
[7]	26×11	2	27/39	> 30/25	> 10 ⁻⁴ /10 ⁻⁴	5/5.7	3.55/0.203
[12]	75×100	4	28/38	-36 -36	> 10 ⁻³ > 10 ⁻³	7.6 8.12	2.2/0.508
[17]	55×110	2	28/38	-29.4	1.36×10 ⁻⁵	7.88	2.2/0.508
[18]	20×15	2	28/38	> 34/30	> 10 ⁻³	6.8/6.8	2.2/0.25 -
[19]	26×14	2	28/38	> 25/20	> 10 ⁻³	1.27/1.8	2.2/0.38
[20]	20×20	4	28/37	> 16/12	NA	7/9	3.48/0.76
[21]	27.5×13.5	2	28/38	> 20/20	> 5×10 ⁻² > 2×10 ⁻³	NA	10.7/0.635
[22]	43.6×43.6	4	28/38	> 20/30	> 2.5×10 ⁻⁴	7.8/13.7	2.2/0.4
[23]	41.5×8	4	28/38	> 25	> 0.004	5.5	2.2/0.787
[24]	150×75	4	28/38	> 35	0.2×10 ⁻³	9	3/0.25
[25]	25×15	2	28/38	NA	NA	9/5	2.2/0.25
[26]	79.4×8	4	28/38	> 35	NA	9	3/0.25
[27]	110×55	6	28/38	> 30	5×10 ⁻⁵	5/4	4.4/1.6
This work	27.65×12	2	28/38	> 30/22	< 10 ⁻⁵	5.2/5.3	3.55/0.203

5 Conclusion

Two elements with dual bands MIMO antenna have been suggested for 5G communications. The suggested antenna has been designed to operate at frequency bands from 26 GHz up to 30 GHz, from 36 GHz up to 41.5 GHz, and S_{21} lower than -20 dB through the two operated bands. MIMO parameters as ECC, DG, and CCL have been extracted from simulated and measured results to validate the antenna design and show the high quality of the suggested two elements MIMO antenna. The simulated and tested results have a good trend within the two operating bands which suggests the proposed structure to be utilized in 5G communications.

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Data Availability There are no supplementary materials, and the data is available upon reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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