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# MIMO Slot Antenna with Four Ports for Future 5G Networks

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**Abstract** In this study, a 4-port MIMO antenna structure with multiple inputs multiple outputs is presented. The proposed structure is intended to run at 28 GHz. This is an indication of the 5G communication systems. A microstrip feed line is positioned on the top side of a Rogers RO 4003C substrate with a permittivity of 3.38, tan $\delta = 0.002$, and a height of 0.213 mm. A full ground plan with a rectangular slot is located on the substrate's backside. The 24 ×24 $mm^2$ proposed antenna has a bandwidth of 5 GHz (17.54%) and operates from 26 GHz to 31 GHz frequency range. The four elements of the MIMO antenna are positioned perpendicularly to improve diversity and isolation among the radiators. It achieves a peak gain of around 5 dB, which occurs at a frequency of 28 GHz. This antenna is fabricated and measured. The proposed design is employed in 5G applications, according to the results of the simulation and measurement, which demonstrate a satisfactory match with the target band.

**Keywords:** MIMO antenna, Slot antenna, 5G applications, Wideband antenna

## 1 Introduction

In recent decades, there have been major advancements in mobile wireless communication networks. The first era of mobile wireless communication was titled 1G, and the next generations were 2G, 3G, 4G, and 5G. Mobile wireless generation often refers to a change in the nature, speed, technology, frequency, data capacity, latency, and other features of the system [1-2]. Several antenna designs are introduced by the researchers [3-13]. In [3], a small, slot-based MIMO antenna tuned to 28 GHz that is idea for 5G communication systems is presented. The antenna achieved a 5.78 dBi gain. The design focused on optimizing element placement to enhance performance and achieve high gain isolation, with mutual coupling observed to be below -20 dB throughout the entire 28 GHz frequency range. In [4], a four-element MIMO antenna with a large bandwidth intended for 5G applications, with operation across the 28/37 and 39 GHz frequency bands is presented. The antenna achieved a gain ranging from 5.28 dBi at 28 GHz. The design included an inverted F-shaped slot and specific decoupling techniques to enhance isolation and bandwidth. Investigations are conducted into a four-element MIMO microstrip patch antenna, designed for use in 5G networks and adjusted to run at 28 GHz [5]. The antenna achieved a 6.34 dBi gain. The design focused on optimizing element placement to enhance performance and ensure high isolation, with mutual coupling observed to be below -20 dB at 28 GHz [7]. In [8], a 28 GHz broadband helical and end-fire antenna with a MIMO configuration is presented. It is intended for 5G pattern diversity. At 28 GHz, the antenna produced a 5.83 dBi gain. Throughout the entire frequency range, mutual coupling was measured to be below -31 dB, showing the design's focus on optimizing element place for maximum isolation and enhanced performance. In [9], for future wireless networks, a compact mm Wave MIMO antenna is designed. The antenna achieved gains ranging from 4.98 to 5.66 dBi at 28 GHz. The design focused on optimizing element placement

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to enhance performance and ensure high isolation, with mutual coupling kept above 25 dB across the frequency range. A high-gain MIMO antenna array system intended at 28 GHz for human body communication is examined in [10]. A gain of 4.168 dBi was obtained by the antenna. In [11], the MIMO antenna array configured as an infinite shell, intended for millimetre-wave 5G applications at 28 GHz, is discussed. The antenna is designed as a compact wideband patch featuring a MIMO configuration. Demonstrated a gain of 5.5 dBi, and is tailored for 5G communication systems at 28 GHz. The antenna performs efficiently within the 28 GHz frequency band. The single-element antenna performance at the target frequency is enhanced by the modified antenna with a defective ground structure (DGS), which offers an average gain of 4.5 dBi and a peak gain of 5.6 dBi at the same frequency. The single-element antenna peak gain is 5.42 dBi at 27.8 GHz [12]. The antenna gain was 3.59 dBi. A novel hook-shaped antenna at 28 GHz is demonstrated in [13]. Intended for upcoming 5G millimetre-wave applications, this paper presents a 4-port Multiple Input Multiple Output (MIMO) antenna structure comprising four identical slot antennas arranged perpendicularly to each other. This antenna is fabricated using Rogers RO 4003 and features an overall size of 24 ×24 mm$^2$. The design and simulation were carried out Utilizing an EM simulator. The manufactured antenna has been tested, measured, and intended to be used in 28 GHz 5G applications. The result shows suitable matching between the simulated and fabrication of the proposed antenna. As well, MIMO parameters are calculated and investigated.

## 2 Single element configurations

The slot antenna element is designed in a rectangular shape with a dimension. $L_{slot} = 2.6\ mm$ and $W_{slot} = 3\ mm.$ This geometry of the proposed antenna is designed on a Rogers RO-4003C substrate (εr = 3.38, and tan δ = 0.0027) and a height of 0.203 mm. The over ball size of the single-element antenna structure is 12 mm × 12 mm which is a compact dimension and suitable for 5G applications. Figure 1 shows all of the proposed structure's dimensions.

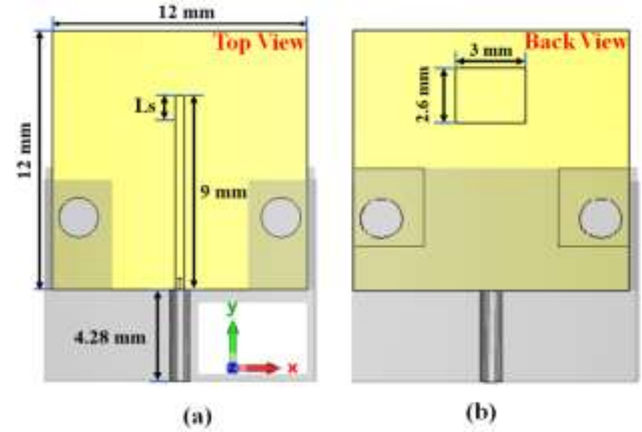


**Fig.1** The slotted antenna configuration with launcher (a) Top view (b) back view

Figure 2 shows the simulated return loss of the presented antenna. The bandwidth of the antenna design starts from 25 GHz up to 30 GHz with a total bandwidth equal to 5 GHz (17.85 % bandwidth fraction).

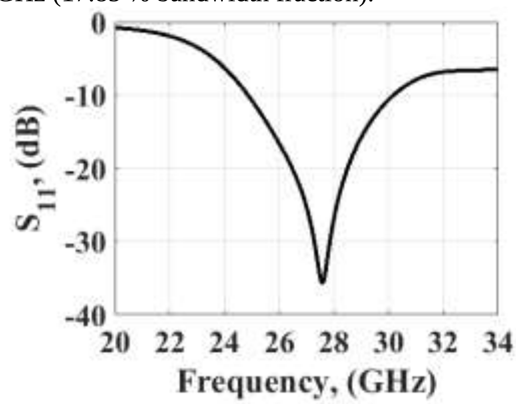


**Fig.2** The simulated return loss of the single-element antenna structure.

A parametric study is obtained individually for each dimension to achieve the best matching result. Figure 3 shows the parametric study of the length $L_s$. Where a value of 1.3 mm is selected. In Fig.4, the current distribution of the proposed slot antenna is shown. The current is concentrated around the slot edges, ensuring effective radiation of the slot antenna.

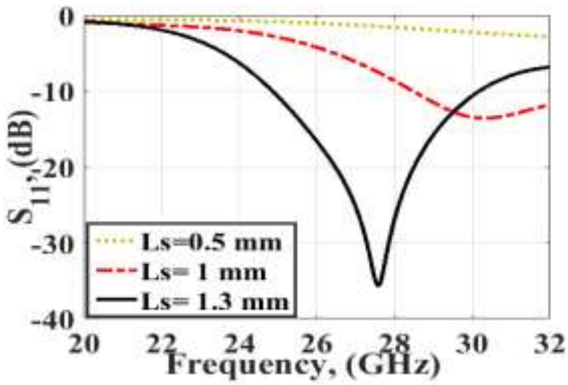


**Fig.3** The parametric study of the length LS

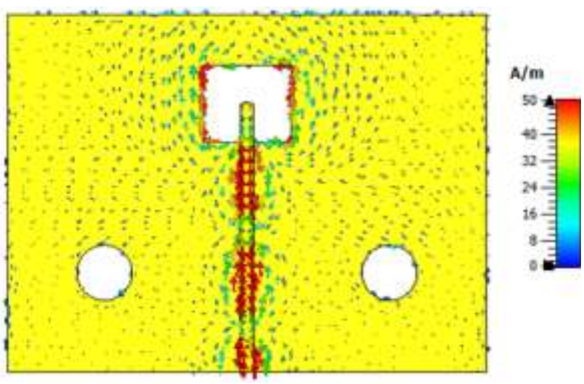


**Fig.4** Current distribution of the slot antenna at 28 GHz

## 3 Initial design of 4 elements MIMO antenna

As previously indicated, four symmetric elements are printed on the same substrate in the proposed MIMO antenna configuration, as shown in Fig.5. It is 24 × 24 $mm^2$ in compact size. The antenna elements have been arranged to be orthogonal to one another to maximize the isolation between them without increasing the antenna's size.

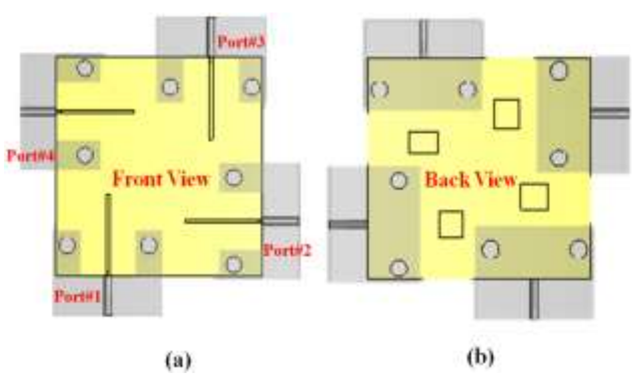


**Fig.5** Configuration of the slotted MIMO antenna (a) front view (b) back view

## 4 Results and discussions

Figure 6 illustrates the proposed MIMO slot antenna. The S-Parameters of the proposed antenna are measured using a vector network analyzer (VNA).

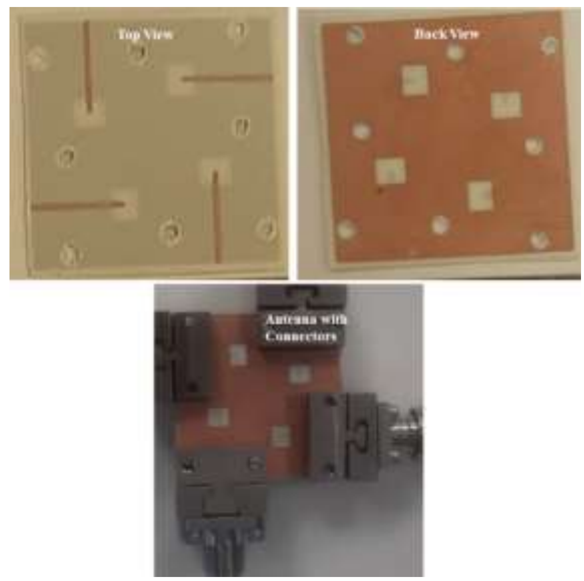


**Fig.6** MIMO Slot antenna prototype

When only (port 1) is excited, the measurement and modeling results of the suggested antenna's return loss are shown in Fig.7. A matching load of 50 ohms terminates the remaining ports. From 26.2 GHz to 31 GHz, a wide frequency range is covered by the designed antenna bandwidth. While from 26.9GHz to 30.4 GHz is achieved from the measured outcome.

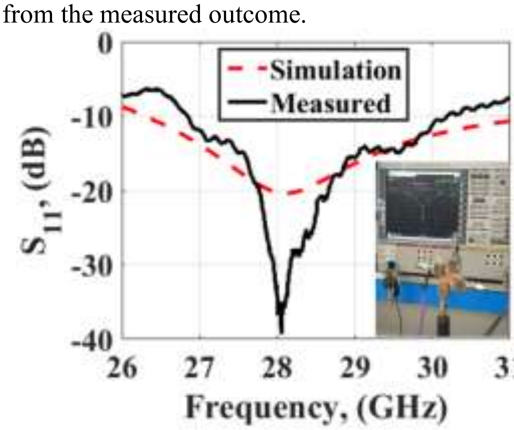


**Fig.7** Configuration of the slotted MIMO antenna, (a) front view (b) back view

Figure 8 shows the transmission coefficients of the proposed antenna. All the simulated and measured transmission coefficients are below -20 dB which indicates the isolation between the elements is very good and accepted. Figure 9 presents the normalized simulated and measured radiation pattern of the proposed MIMO antenna at a frequency of 28 GHz. In both the E and H planes, the antenna design radiation pattern is omnidirectional. Figure 10 shows the simulated and measured maximum gain versus the frequency at port 1. The max gain occurs at a frequency of 28 GHz equals 5 dBi.

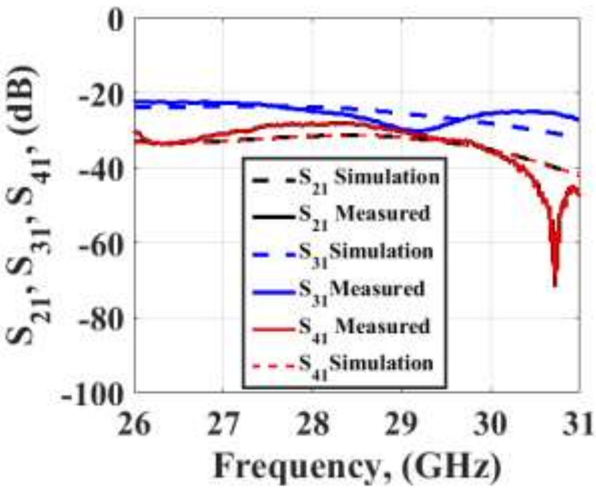


**Fig.8** Simulated and measured S-Parameters of the proposed MIMO Antenna.

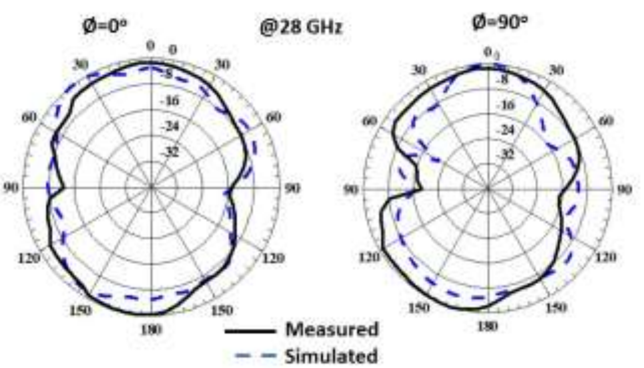


**Fig.9** Radiation patterns (normalized) of the slot antenna at 28 GHz

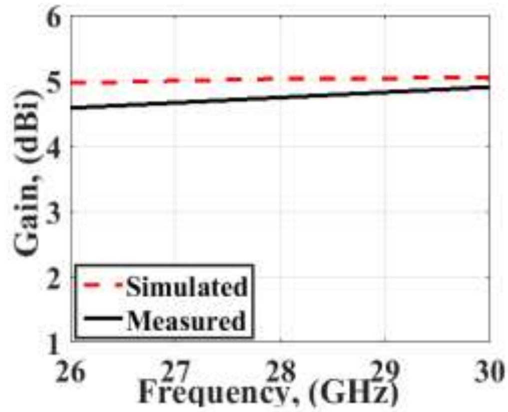


**Fig.10** Slot antenna realized gain

## 5 MIMO parameters of the proposed design

The envelope correlation coefficient (ECC), diversity gain (DG), and channel capacity loss (CCL) are three MIMO antenna system characteristics that characterize the design's performance. The correlation between antenna radiating elements is displayed by the ECC, and a small number is preferable. It can be calculated as in Eq. (1) [14-16]. As shown in Fig .11, ECC [ $\rho_e(i, j, N)$ ] is below 0.05 through the entire bandwidth which proves that the antenna proposed is suitable for use in diversity systems.

$$ECC = \rho_e(i, j, N) = \frac{\left| \sum_{n=1}^{N} S_{i,n}^{*} S_{n,j} \right|^2}{\prod_{k=i,j} \left[ 1 - \sum_{n=1}^{N} S_{k,n}^{*} S_{n,k} \right]} \tag{1}$$

Equation (2) [14-16] can be utilized to compute DG, which is coupled with ECC. Moreover, Fig.12 shows the DG of the proposed antenna, and its value falls inside the working frequency range by around 10.

$$\mathrm{DG} = 10 \times \sqrt{1 - |\mathrm{ECC}|^2} \quad (2)$$

Equations 3,4 [14-16] can be utilized to compute CCL. Fig. 13 shows the CCL of the proposed antenna. As indicated, the CCL value is below the recommended 0.4 Bits/Hz/S value. Table 1 compares the proposed antennas with other previous work by researchers.

$$C(Loss) = -\log_2 \det(\psi^R) \quad (3),$$

$$\psi^R = \begin{bmatrix} \rho_{11} & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{21} & \rho_{22} & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & \rho_{33} & \rho_{34} \\ \rho_{41} & \rho_{42} & \rho_{43} & \rho_{44} \end{bmatrix}, \rho_{ii} = 1 - \sum_{n=1}^{4} |S_{in}|^2$$

$$and \quad (4)$$

$$\rho_{ij} = -\left|\sum_{n=1}^{4} S_{in}^{*} S_{nj}\right|, \; for \quad i, j = 1,2,3 or 4$$

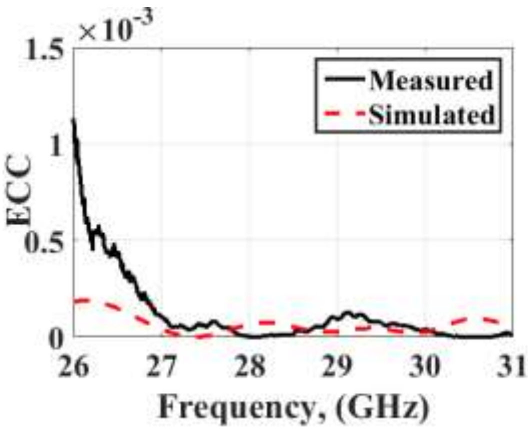


**Fig.11** Simulated and measured ECC for MIMO antenna elements

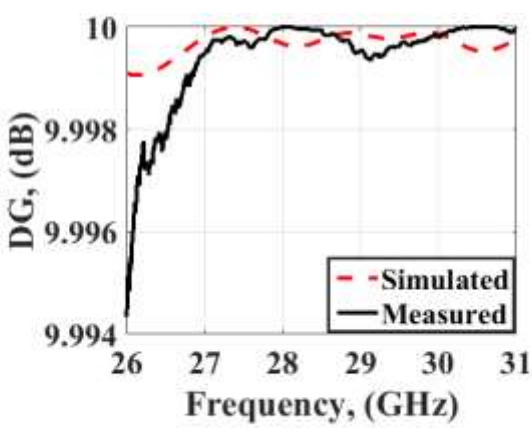


**Fig.12** Simulated and measured DG for MIMO antenna

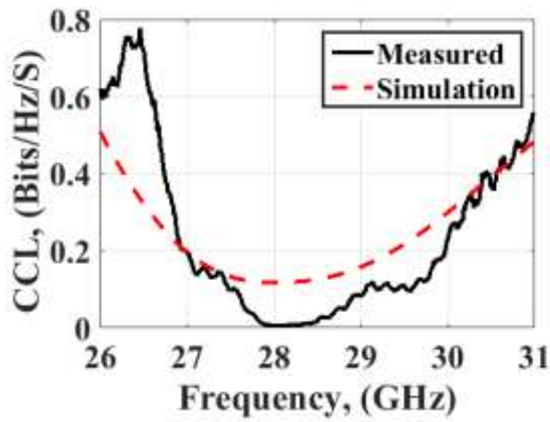


**Fig.13** Simulated and measured CCL for MIMO antenna.

**Table 1** A comparison of the proposed design with previous research

| Ref | Antenna size | Freq. [GHz] | Single or MIMO | Isolation | Gain [dBi] |
|---|---|---|---|---|---|
| [4] | 25×30 | 28/37/ 39 | MIMO 4 unit | <-20 | 5.28 |
| [7] | 13.5× 13.5 | 27.5- 28.5 | MIMO 4 unit | >18 | 5.6 |
| [9] | 24 × 24 | 22.43 to 31.66 GHz | MIMO 4 unit | >25 | 5.2 |
| [10] | 26×25.6 | 28 | MIMO 2 unit | >25 | 4.168 |
| **This work** | **24×24** | **28** | **MIMO 4 Units** | **<-22** | **5** |

## 6 Conclusion

In conclusion, this paper introduces a MIMO slot antenna with a rectangular cut on the ground. The proposed MIMO is placed on an RO 4003C substrate with a compact size of 24×24 $mm^2$. Operating in 5G applications within 26 GHz up to 31 GHz, and consist of four elements. Its return loss, peak gain, and radiation pattern characteristics, have been discussed. In Addition, this proposed MIMO slot antenna is fabricated and measured. Good agreements are reached in the measurement and simulation results.

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