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Dual-Band MIMO Antenna with Defected Ground Structure for Sub-6 GHz 5G Applications

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Abstract—In this work, a dual-band compact MIMO antenna for sub-6 GHz 5G applications has been designed, simulated, and implemented. Firstly, a single patch antenna was designed and simulated, and its dimensions were adjusted to exhibit a dual band performance at 3.6 GHz and 5.9 GHz. A two-element MIMO structure was then designed with a defected ground structure, and the S-parameters were recorded. The results showed that the designed MIMO antenna exhibited multiband performance at the sub-6G frequency band with almost omnidirectional radiation pattern and acceptable gain. The achieved results are promising, making the proposed antenna a good candidate for 5G applications. The proposed antennas were fabricated, and their basic parameters such as return loss and radiation pattern were tested experimentally and compared with simulation results. An acceptable agreement was achieved between measurement and simulation results.

1. INTRODUCTION

The last couple of years have witnessed an exponentially increasing demand on high speed networks due to the pandemic of COVID-19. Working from home and online services are the main reason that pushes individuals and organizations to seek more data usage. Thus, a real need for technological development has emerged to meet the demand for the required data growth and to fulfil the data rate requirements for human to human (H2H), device to device (D2D), and human to device (H2D) communication and interaction [1]. Furthermore, the newly emerged high speed Internet of Things (IoT) applications are becoming dependent directly on mobile internet and require high data rate services that must be available in a large coverage area. Such urgent needs concern the mobile manufacturers and researchers worldwide to find a feasible and effective systems that meet all these requirements [2].

Unfortunately, the data rate provided by the existing mobile networks is insufficient to comply with rapidly increasing demand or unable to cope with any peak demand in future pandemics. Therefore, it is necessary to find fast solutions and move several steps forward to the next mobile generation with higher frequency and wider bandwidth.

The recommended fifth generation (5G) system with high frequency has a large bandwidth that is expected to meet the aforementioned requirements of improved data transmission rates. Single antenna element was previously suggested for multiband sub-6 GHz 5G applications [3, 4]. However, the reported bandwidth is still insufficient to fulfil the application requirements. To further increase the data rate, it is recommend to integrate multiband MIMO antenna array into the smartphone handsets which effectively enhance the channel capacity and spectral efficiency as well as mitigating the effect of multipath as single input single output (SISO) systems fail to do so [5, 6]. Several frequency bands at sub-6 GHz were suggested to fulfil the bandwidth demand for future 5G mobile terminal applications.

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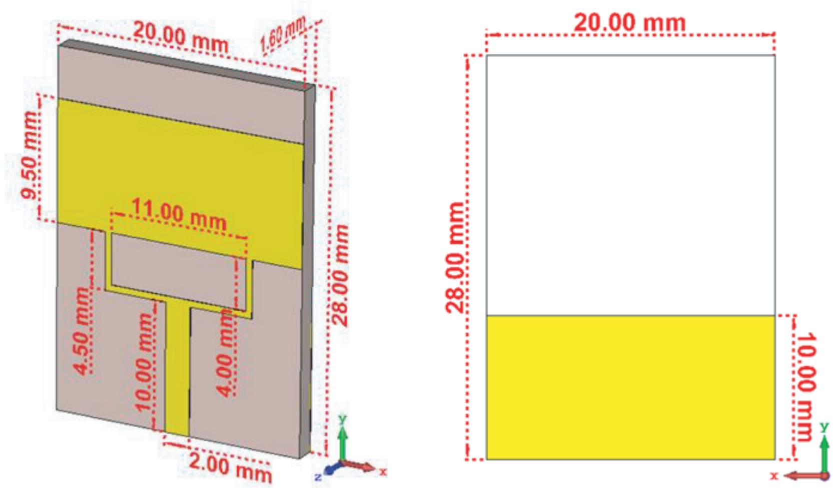
Some of these bands are LTE42/43 bands (3.4–3.8 GHz), LTE46 band (5.15–5.925 GHz), and multiband EU (European Union) 5.9–6.4 GHz [6–8]. Moreover, numerous MIMO antennas operating at mmWave frequencies were suggested to overcome the issues of channel capacity and bandwidth [9, 10].

Several MIMO antenna structures for 5G mobile handsets at the sub-6 GHz frequencies have been proposed in literature recently [11]. Among these reported antennas, some of them operated at a single frequency. For example, a 5G two elements T-shaped meander line MIMO antenna operating within 4900 to 5060 MHz has been reported in [12], and a transparent 2-element 5G MIMO antenna was reported in [13]. In contrast, there were various dual band MIMO antenna designs reported in literature such as the orthogonal pairs of antennas consisting of folded monopoles published in [14] and operating within 3100–3850 MHz and 4800–6000 MHz. Other examples of dual band MIMO antennas are T-slot antenna elements with excitable dual-resonant mode covering LTE 42 and LTE 46 [15], and the MIMO array of coupled-fed T-shaped slot antennas reported in [7] that covers the LTE42/43 and LTE46 bands. Furthermore, MIMO antenna arrays that exhibit triple or multiband performance for sub-6 GHz 5G networks have also been reported in literature [6, 16].

In this article, a dual-band two-element MIMO antenna for sub-6 GHz 5G applications is proposed. In the first stage, the design and simulation of a single-element geometry are presented. In the next stage, the same single antenna is replicated and mirrored along the horizontal axes to form a MIMO structure with an implemented defected ground structure. The proposed antenna structures (single and MIMO) are simulated, fabricated, and tested. The typical results, such as reflection coefficient, radiation patterns, and efficiencies, are presented.

2. STRUCTURE OF SINGLE ANTENNA

The geometry and structural dimensions of the proposed 5G compact patch antenna are shown in Fig. 1. The designed antenna is a dual-feed rectangular patch placed on an FR-4 substrate with dielectric constant of 4.1 and substrate height ($h = 1.6$ mm).



(a) (b)

Figure 1. The proposed dual-feed rectangular patch antenna, (a) front and (b) back.

CST electromagnetic simulation tool is employed to calculate the antenna performance parameters such as S-parameters, efficiency, gain, and radiation pattern. Fig. 2 illustrates the reflection coefficient represented by S_{11} of the single antenna element. It can be seen from the reflection coefficient characteristics that the antenna exhibits wide resonance from 3 GHz to 7 GHz covering the sub-6 GHz 5G spectrum mainly at 3.56 GHz and 5.87 GHz with return loss values below 40 dB.

The surface current distributions of the designed antenna at two different frequencies (i.e., 3.56 GHz and 5.87 GHz) are illustrated in Fig. 3 showing the main antenna parts that contribute in the radiation process at each resonant frequency.

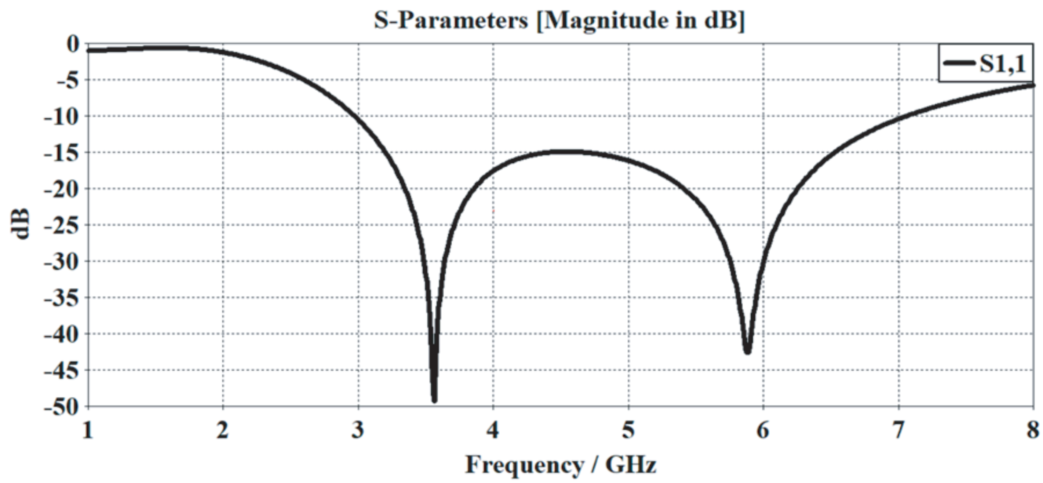
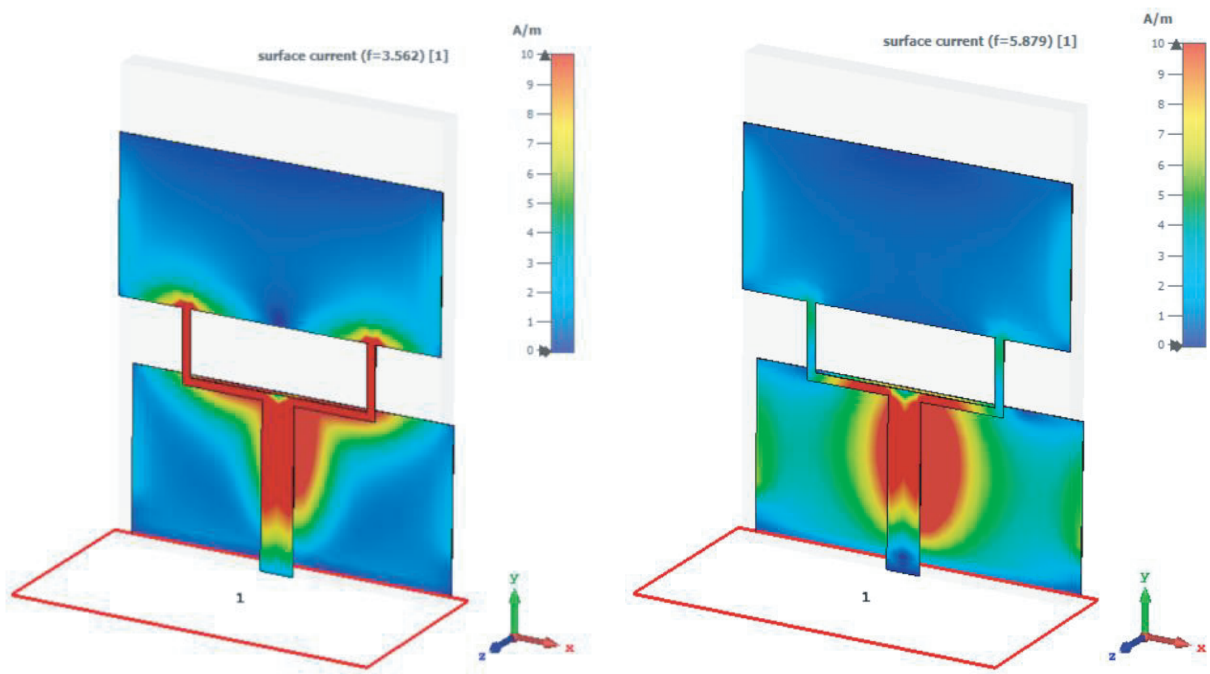


Figure 2. Simulated return loss of the single element 5G antenna.



(a) (b)

Figure 3. Simulation of the surface current distribution at 3.56 GHz and 5.87 GHz. (a) 3.56 GHz. (b) 5.87 GHz.

The 2D and 3D radiation patterns for the proposed 5G antenna at 3.56 GHz and 5.87 GHz are shown in Fig. 4. It can be seen from the 3D radiation pattern that the proposed antenna exhibits an almost omnidirectional radiation pattern. It is also observed that the antenna exhibits almost similar radiation characteristics at both frequencies of interest, but it is slightly squeezed in the middle at 5.87 GHz. This similarity in radiation pattern at different frequencies makes the antenna have a constant performance at wide range of 5G spectrum.

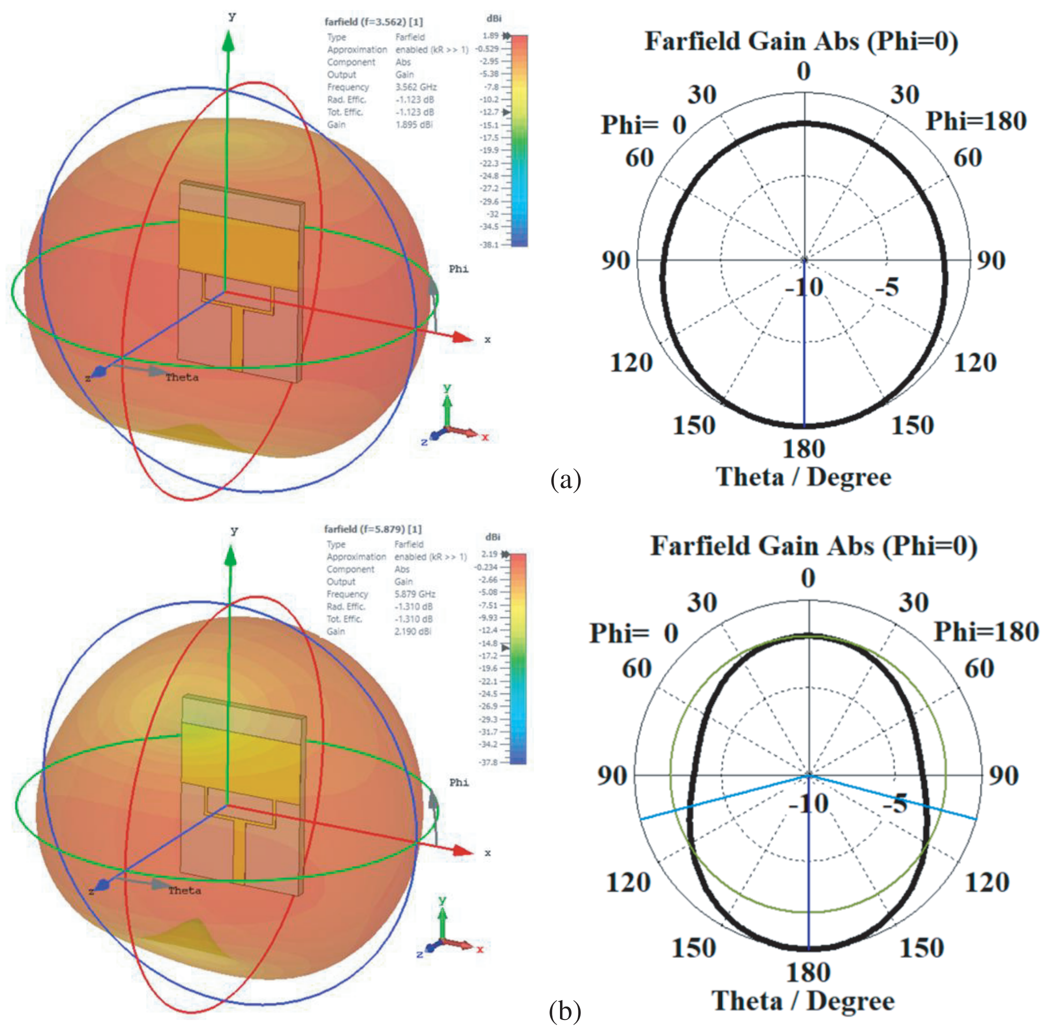


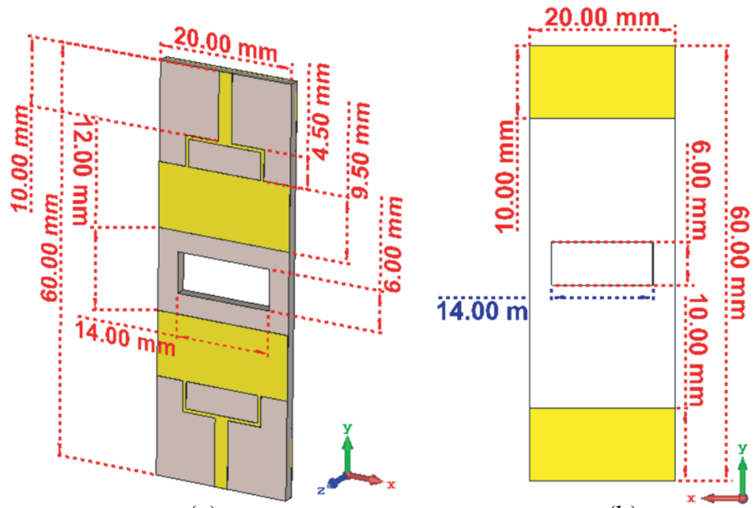
Figure 4. Simulated 3D and 2D radiation pattern, (a) 3.56 GHz and (b) 5.87 GHz.

3. MIMO CONFIGURATION BASED ON TWO ANTENNA ELEMENTS

The proposed antenna is replicated vertically to form a MIMO configuration as shown in Fig. 5. A rectangular defect (6×14 mm) is introduced in the substrate with keeping only partial ground plane to perturb the radiating or receiving fields, and hence improve the isolation and bandwidth. The overall dimensions of the proposed 2-element MIMO 5G antenna are (60×20 mm). An interelement distance of 12 mm is kept between the adjacent elements to provide the required spatial diversity. The MIMO antenna structure is kept as simple as possible without any isolation techniques to avoid any structural complexities that make the fabrication process difficult. The distance between the partial grounds is 40 mm, which is sufficient to achieve acceptable isolation with the help of the introduced defect.

The simulated S_{11} and S_{21} of the designed two-element MIMO antenna are depicted in Fig. 6. The proposed MIMO antenna has preserved similar resonance characteristics to a single element antenna by maintaining the resonance within 3–7 GHz with two obvious bands at 3.56 GHz and 5.87 GHz. In contrast, the proposed MIMO antenna exhibits an acceptable isolation between the two elements with S_{21} of -16 dB at 3.56 GHz, and S_{21} equals -24 dB at 5.87 GHz.

The radiation patterns (2D & 3D) of the proposed two-element MIMO antenna are simulated at 3.56 GHz and 5.87 GHz frequency bands and plotted as shown in Fig. 7. It is clearly seen that there is not much difference in the radiation pattern compared with the case of single antenna at 3.56 GHz.



(a) (b)

Figure 5. The proposed 2-element MIMO antenna geometry, (a) front and (b) back.

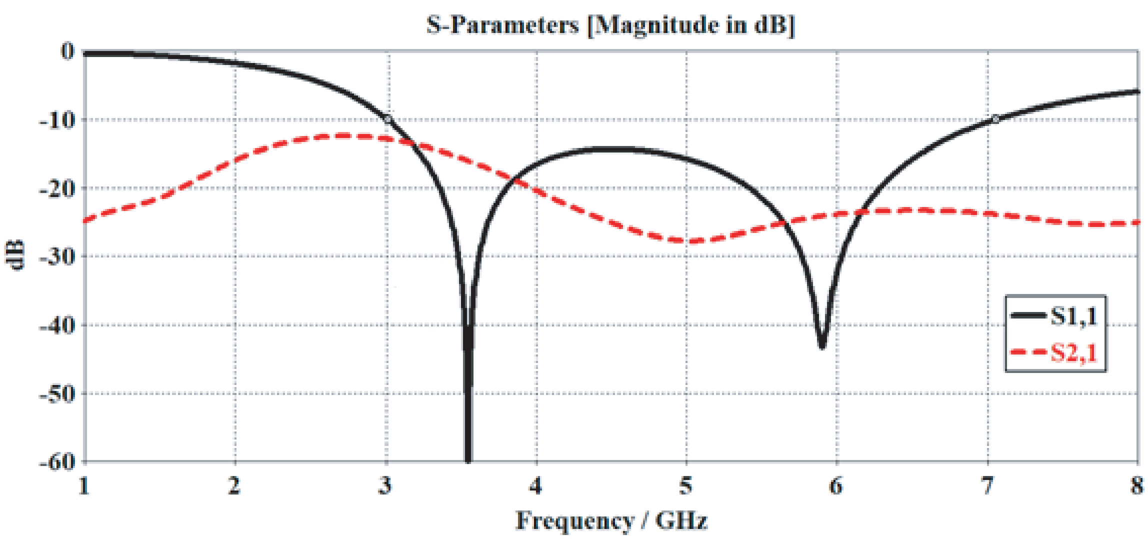


Figure 6. Simulated S-parameters for the 2-element 5G MIMO antenna.

4. EXPERIMENTAL RESULTS

The designed single and 2-element MIMO antennas were fabricated and printed on an FR-4 substrate as shown in Fig. 8. The experimental setup used to measure the S-parameters and the radiation pattern is depicted in Fig. 9. The reflection coefficient (S_{11}) of the fabricated structures was tested over the frequency range (1–8 GHz) as illustrated in Fig. 10. Two identical prototypes of each antenna were fabricated in order to measure the radiation characteristics and to avoid using a standard antenna that is not available in the testing lab.

A closer look to Fig. 10 reveals that the fabricated MIMO antennas exhibit excellent isolation between elements and have shown S_{21} characteristics that are similar to simulations in terms of the shape but with better isolation behavior. On the other hand, it can be seen from the S_{11} results that there is a slight difference between the simulated and measured reflection coefficients due to the imperfect testing environments where the anechoic chamber is incomplete. It is observed from measurements that

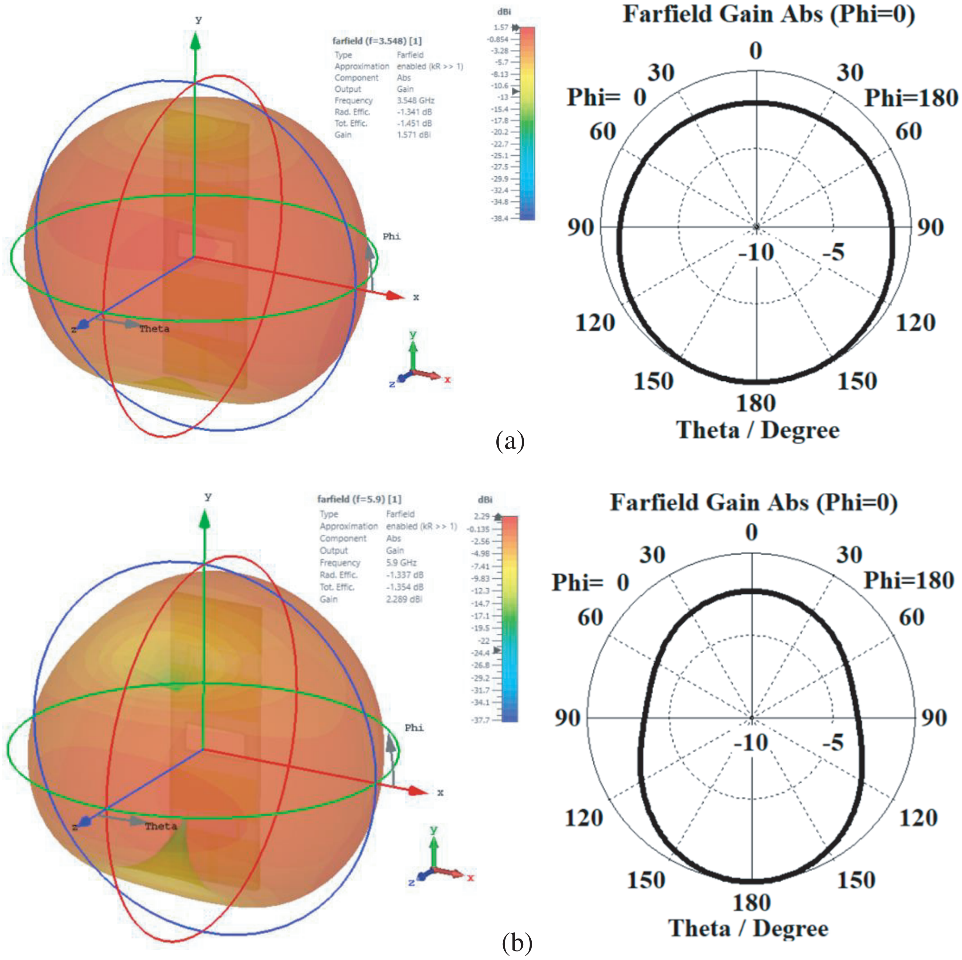


Figure 7. Simulated 3D and 2D radiation pattern of the proposed 2-element MIMO antenna. (a) @ 3.56 GHz. (b) @ 5.9 GHz.

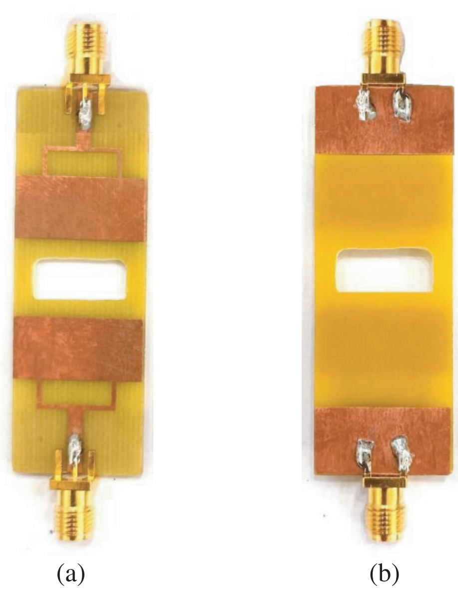


Figure 8. Fabricated MIMO antenna: (a) front, (b) back.

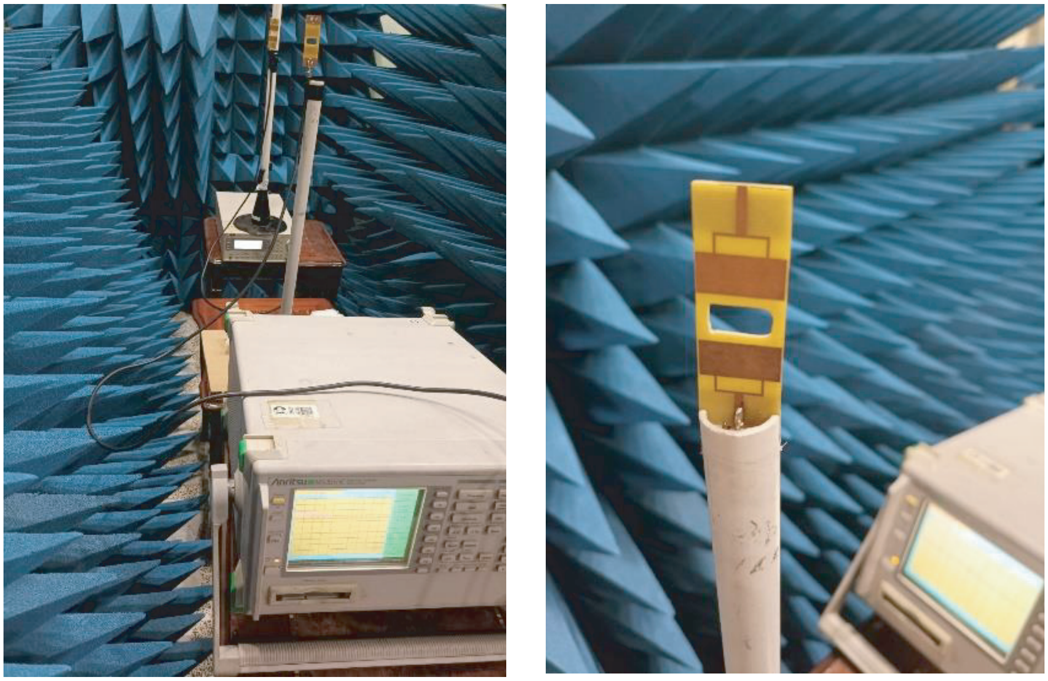


Figure 9. Experimental set up showing the transmitting and receiving ends with the installed absorbers used in measuring the antenna parameters.

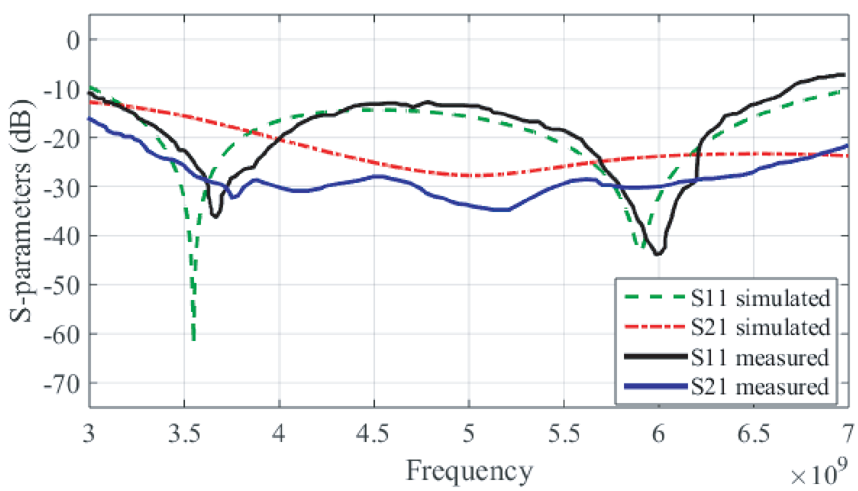
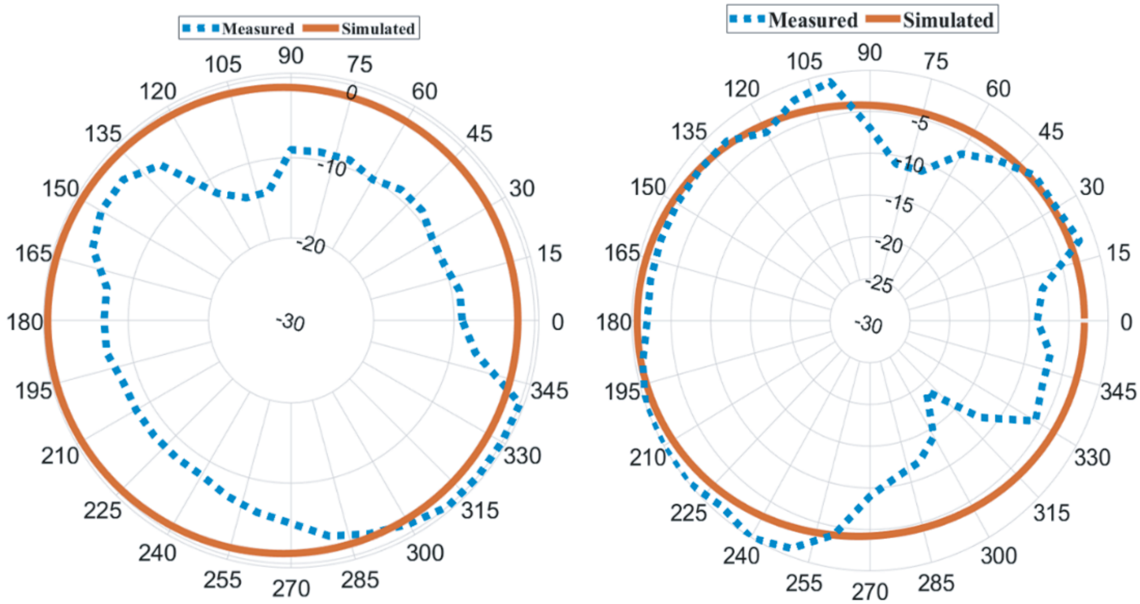


Figure 10. Measured S-parameters for the 2-element 5G MIMO antenna compared with the simulated ones.

the fabricated antenna exhibits two obvious resonances at 3.68 GHz with a return loss of 36 dB and the other resonance at 5.98 GHz with a return loss of 43.5 dB. Although the testing environment still needs some improvement, the fabricated antenna shows a good resonance (below −10 dB) for the frequency spectrum from 3 GHz to 7 GHz making the proposed MIMO antenna a good candidate for the sub-6 GHz 5G applications.

The measured radiation pattern of the fabricated MIMO antennas is shown in Fig. 11. The radiation pattern is measured at 3.6 GHz and 5.9 GHz, and the results show that the fabricated antenna exhibits almost omnidirectional radiation pattern which somewhat resembles the simulated radiation pattern.



(a) (b)

Figure 11. Measured radiation pattern for the 2-element 5G MIMO antenna compared with the simulated one. (a) @ 3. 6 GHz. (b) @ 5.9 GHz.

5. COMPARISON WITH PREVIOUS WORKS

A structural and performance comparison between the designed MIMO 5G antenna proposed in this paper and previous works published in the recent literature is listed in Table 1. The focus in this comparison is on the important structural and performance parameters that strongly influence the overall system performance such as antenna size, operation frequency, isolation between elements, diversity gain, and ECC. It is observed from Table 1 that the MIMO antenna proposed in this work has shown excellent performance compared to other antenna designs reported in literature.

Table 1. Performance comparison between the proposed MIMO antennas of this work with other works reported in literature.

References	Year of Publication	No. of Ports	Antenna size ($W \times L\,\text{mm}^2$)	Operating Frequency (GHz)	Isolation Performance (dB)	Diversity Gain (dB)	ECC
[11]	2022	1 & 2	22×24 & 22×56	3.3 to 10	< -21	10	< 0.00
[17]	2017	2	50×82	7 to 13	< -15	6.20	< 0.04
[18]	2017	2	50×30	3 to 13	< -20	7.4	< 0.04
[19]	2019	2	40×80	4.5 to 8	< -20	10	< 0.002
[20]	2020	2	58×58	3 to 16	< -18	6.5 to 8.5	< 0.07
This work	2022	1 & 2	20×28 & 20×60	3 to 7	< -22	10	< 0.001

6. CONCLUSION

In this paper, dual-band single- and two-element dual-feed MIMO patch antennas for 5G sub-6 GHz mobile applications are proposed. The operating frequency bands are 3.6 GHz and 5.9 GHz. The antenna structure consists of a dual-feed rectangular patch with a partial ground plane and defected substrate to improve the isolation and bandwidth. The designed antennas were validated numerically by using CST tool. The simulated S-parameters and radiation pattern of the proposed patch antennas were presented with discussion. The proposed single and MIMO antennas were manufactured, and their reflection and radiation characteristics were tested experimentally. The results showed an acceptable agreement between the simulation and measurements. The fabricated MIMO antennas have shown return loss values below −20 dB at the frequency band of interest and an isolation of more than 20 dB. These tested parameters along with the compact size as well as the geometrical simplicity make the proposed MIMO a good candidate for sub-6 GHz 5G applications.

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