Research and Development on Information and Communication Technology

A Microstrip MIMO Antenna with Enhanced Isolation for WiMAX Applications

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Abstract: In this paper, a multiple-input multiple-output (MIMO) antenna with high isolation is designed using defected ground structure (DGS). The proposed antenna is constructed by two sets of four elements (2×2), which are designed at the central frequency of 3.5 GHz for Worldwide Interoperability for Microwave Access (WiMAX) applications. The antenna is fabricated on a FR4 substrate with an overall size of $144 \times 99 \times 1.6$ mm. Thanks to DGS, the designed MIMO antenna achieves a high isolation of 30 dB and a high radiation efficiency of over 90%. Besides, this MIMO antenna attains a 7.5 dBi gain. There is a good agreement between the simulated S-parameters and the measurement results.

Keywords: *MIMO antenna, mutual coupling, defected ground structure (DGS), microstrip antenna.*

I. INTRODUCTION

Multiple-output multiple-input (MIMO) is one of the prominent solutions to satisfy the high data rate demand of end users in wireless networks. Employing multiple-element antennas, MIMO can improve both the spectral efficiency and reliability of the transmission without increasing transmitting power or bandwidth [1]. However, when the distance between the antenna elements is not large enough, mutual coupling happens. This is an undesired phenomenon because it not only reduces channel capacity [2], but also introduces extra power loss to the system [3].

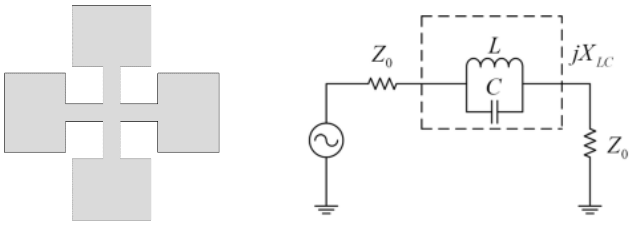
Many solutions have been proposed to reduce mutual coupling between antenna elements using, *e.g.*, shorting pins [4], compact coplanar waveguide (CPW) feeding [5], electromagnetic band gap (EBG) [6], parallel coupled-line resonators [7]. These methods have reached a recognizable improvement in isolation enhancement. The isolation between the antenna elements in [4–6] is around 20 dB. The antenna gains are under 2 dBi in [5] and [7]. In addition, the radiation efficiency of the antenna in [5] is 70%. However, these figures can be further improved. In fact, it is challenging to simultaneously optimize multiple parameters, such as the isolation and radiation efficiency, in designing MIMO antennas.

In this paper, we propose a MIMO antenna with enhanced isolation. The antenna is designed at the central frequency 3.5 GHz. We apply a defected ground structure (DGS) to achieve a high isolation between the antenna elements of over 35 dB although the edge-to-edge distance is only 4.3 mm. Based on a FR4 substrate with a thickness of 1.6 mm, $\varepsilon_r = 4.4$, and $\tan\delta = 0.02$, the antenna has dimension $144 \times 99 \times 1.6$ mm. At the central frequency 3.5 GHz, the MIMO antenna reaches over 7.5 dBi gain. The antenna is designed, simulated, and optimized with the Computer Simulation Technology (CST) Studio software. The simulation results are compared with the measurement ones to verify the performance of the proposed antenna.

II. MIMO ANTENNA DESIGN

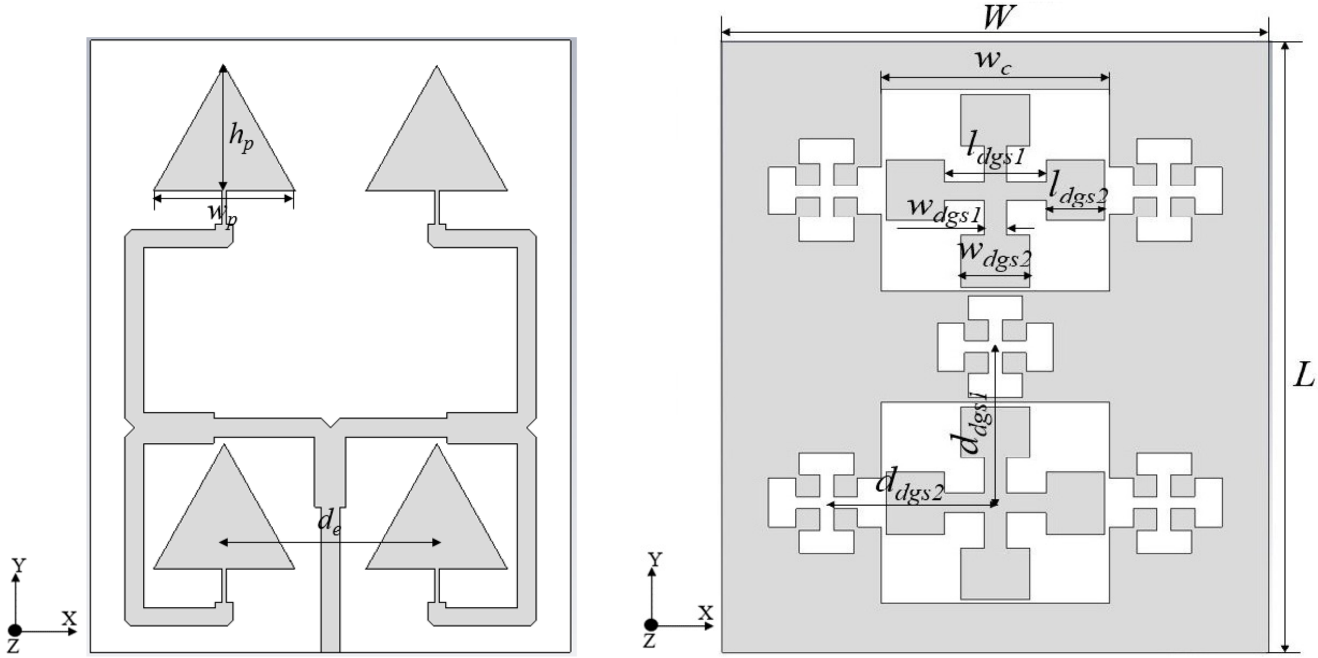
1. Design of the Antenna Array

Our antenna array design is based on the DGS. Figure 1 shows the model of DGS and its equivalent circuit. The DGS is created by connecting two rectangular areas and a microstrip line. The equivalent circuit is made based on the following principle: two rectangles can be considered as an inductance while a microstrip line corresponds to



(a) Model (b) Equivalent circuit

Figure 1. Defected ground structure (DGS) [9].



(a) Top view

(b) Bottom view

Figure 2. Configuration of proposed DGS-based antenna array.

a capacitance. Therefore, the capacitance and inductance values are given by [8, 9]

$$C = \frac{\omega_c}{2z_0\left(\omega_0^2 - \omega_c^2\right)}, \tag{1}$$

$$L = \frac{1}{4\pi^2 f_0^2 C}, \tag{2}$$

where Z_0 is the input and output port impedance; ω_0 is the angular frequency of the parallel LC resonator, f_0 is the resonant frequency, and ω_c is the cutoff angular frequency.

Then, the resonant frequency can be calculated as

$$f_r = \frac{1}{2\pi\sqrt{LC}}. \tag{3}$$

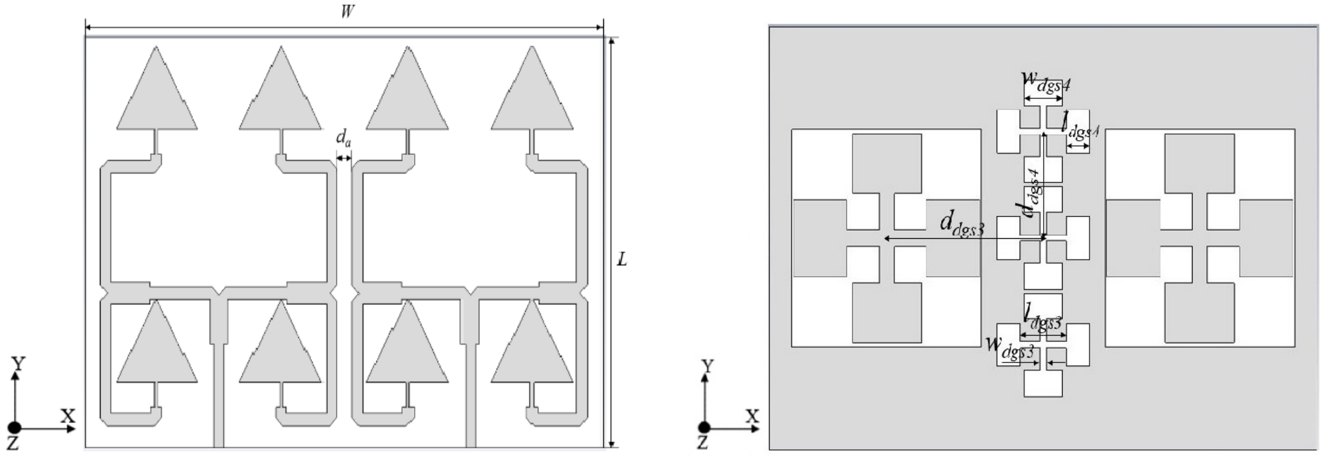
Next, Figure 2 shows the model of our proposed DGS-based antenna array. The antenna is designed to operate at 3.5 GHz and it is printed on a single layer FR4 substrate with a dielectric constant of 4.4, a thickness of 1.6 mm, and a loss tangent of 0.02. The antenna array includes four radiation elements (2 × 2) and three power dividers on top of the substrate. The ground plane with DGS is placed on the bottom. Using the formula in [10], we can calculate the size of each radiation element. Furthermore, we select equal dividers whose principle can be found in [11]. We use the CST Studio software to optimize and obtain that the dimension of each element is 23.6 × 20.8 mm and the distance between elements is approximately 0.4λ where λ is the wavelength in free space. The overall size of the antenna array is 80 × 102 mm. Table I lists the values of some dimension parameters of the designed antenna array. These parameters are defined in Figure 2.

TABLE I
DIMENSION PARAMETERS (DEFINED IN FIGURE 2) OF PROPOSED ANTENNA ARRAY

Parameter	**Value** (mm)	**Parameter**	**Value** (mm)
W	80	L	102
w_p	23.6	l_p	20.8
l_{dgs1}	15	w_{dgs1}	3.2
l_{dgs2}	8.5	w_{dgs2}	10.2
d_e	35.4	d_{dgs1}	26
w_c	33.5	d_{dgs2}	24.7

2. Design of the MIMO Antenna

The MIMO antenna consists of two symmetric antenna arrays placed side by side with a separation of 4.3 mm from edge to edge as illustrated in Figure 3. There are many feeding techniques for antenna such as coaxial feed, coupled, and $\lambda/4$ impedance transformer [10, 12]. We choose the $\lambda/4$ impedance transformer in this paper due to its simplicity in impedance matching. Based on a FR4 substrate with a thickness of 1.6 mm, the MIMO antenna has overall size of 144 × 99 × 1.6 mm while the size of one patch is 23 × 20.125 mm.



(a) Top view (b) Bottom view

Figure 3. Configuration of proposed MIMO antenna.

TABLE II
DIMENSION PARAMETERS (DEFINED IN FIGURE 3) OF PROPOSED MIMO ANTENNA

Parameter	**Value** (mm)	**Parameter**	**Value** (mm)
W	144	L	99
d_a	4.3	d_{dgs3}	41.14
d_{dgs4}	25	w_{dgs4}	10
l_{dgs4}	6	w_{dgs3}	1.5
l_{dgs3}	12		

Table II lists the value of some parameters of the proposed MIMO antenna. These parameters are defined in Figure 3. To reduce the mutual coupling between the elements of the MIMO antenna, we integrate a DGS on the ground plane. The DGS consists of five cells (two large cells and three small cells). To make the capacitance (C) and inductance (L) variable, we use a compensation structure as shown in Figures 1 and 2. This makes a flexibility in optimization.

III. RESULTS AND DISCUSSIONS

1. Simulation Results

a) Antenna Array

Figure 4 presents the reflection coefficients of the proposed antenna array over the frequency band from 2.5 GHz to 4.5 GHz. As can be seen, the bandwidth of the antenna is 330 MHz, corresponding to 9.4% of the resonant frequency 3.5 GHz. In addition, the antenna has a low return loss of −30 dB at the resonant frequency.

Figure 5 shows the 3D and polar patterns of the proposed antenna array. It can be observed that the the antenna has quite high directivity: it has an angular width (3 dB) of 40.7 degrees. Moreover, the antenna remains a high radiation efficiency of over 90%.

b) MIMO Array

As mentioned in Section II.2, the MIMO antenna is integrated with DGS to reduce the effect of mutual coupling. To better understand the effect of DGS on mutual coupling reduction, we compare the S-parameters of the proposed MIMO antenna with and without DGS. The results are displayed in Figure 6. It can be observed that the isolation between antenna elements is significantly improved in the case of DGS. The mutual coupling is −15 dB without DGS while with DGS, this figure is less than −40 dB. This can be explained as follows. Normally, the current distribution in microstrip antenna is uniform without DGS. When there is DGS, the current is redistributed according to the size and position of DGS. By adjusting the size and position of DGS, we can distribute the current at a desired place while limiting the current at other places. This helps us to achieve a high isolation of 40 dB for the proposed antenna. On top of that, using DGS also improves the bandwidth. We can see that the antenna bandwidth with DGS includes two resonant modes while this value is only one without DGS. As a result, the bandwidth with DGS is larger than without DGS.

Figure 7 shows the pattern of the proposed MIMO antenna. It can be seen that the main lobe direction of the antenna is 190 degrees while the angular width at 3 dB is 40.7 degrees. Normally, the main lobe direction of a microstrip antenna is 0 degree (uniform current distribution). In our case, utilizing DGS causes a distortion in the current distribution, thus the main lobe direction can be changed. This is a common tradeoff when using DGS. However, given the gain in antenna isolation, this main

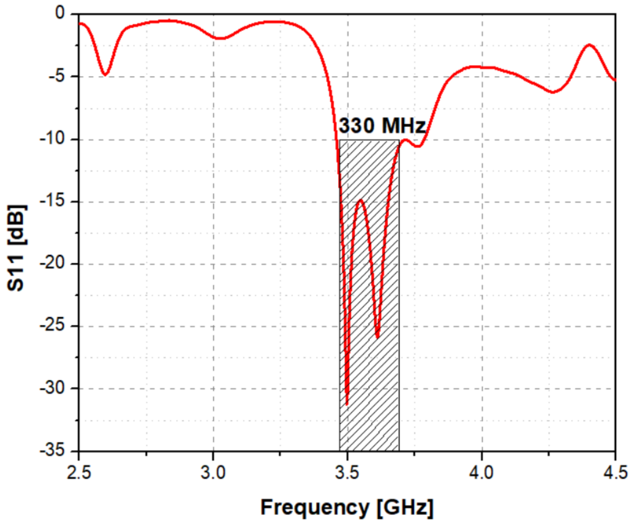


Figure 4. Reflection coefficients of proposed antenna array.

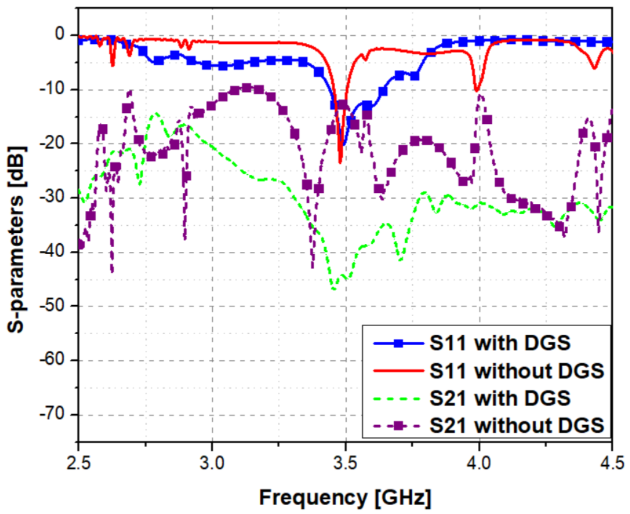
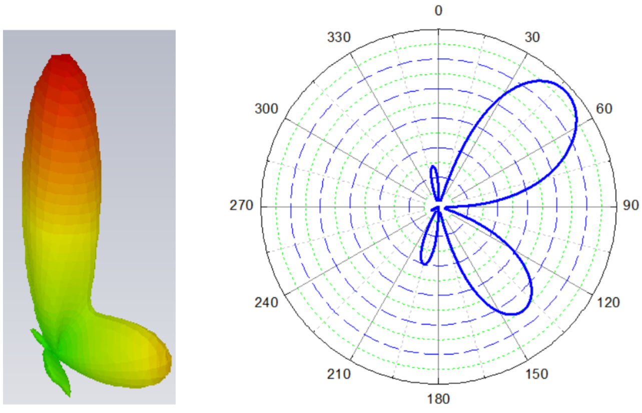


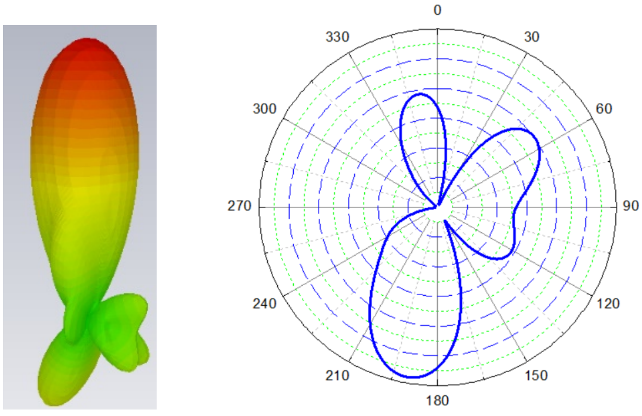
Figure 6. S-parameters of proposed MIMO antenna.



(a) 3D

(b) Polar

Figure 5. Pattern of proposed antenna array.



(a) 3D

(b) Polar

Figure 7. Pattern of proposed MIMO antenna.

lobe direction change is acceptable. Besides, the gain and radiation of the MIMO antenna reach more than 7.5 dBi and 90%, respectively.

Moreover, in MIMO systems, the independence between radiation patterns of the antennas can be evaluated by the enveloped correlation coefficient (ECC), denoted by ρ_e. ECC can be calculated from the S-parameters as [13]

$$\rho_e = \frac{S_{11}S_{12}^* + S_{21}S_{22}^*}{\sqrt{\left(1-|S_{11}|^2-|S_{21}|^2\right)\left(1-|S_{22}|^2-|S_{12}|^2\right)\eta_1\eta_2}}. \qquad (4)$$

It can also be calculated from the radiation patterns as [14]

$$\rho_e = \frac{\iint_{4\pi} E_1(\theta,\phi)E_2^*(\theta,\phi)d\Omega}{\iint_{4\pi} E_1(\theta,\phi)E_1^*(\theta,\phi)d\Omega \iint_{4\pi} E_2(\theta,\phi)E_2^*(\theta,\phi)d\Omega}, \qquad (5)$$

where E_1 and E_2 are the far-field radiation patterns, generated from ports 1 and 2 of the antenna while θ and ϕ represents the spherical angles, namely, the elevation and azimuth, respectively. Figure 8 presents the ECC of the proposed MIMO antenna. It is clear that the ECC is smaller than 0.01 from 3.08 GHz to 3.84 GHz, corresponding to a band of 760 MHz. This is suitable for devices with $\rho_e \leq 0.3$ [15].

2. Measurement Results

In order to confirm the simulation results by experimental measurements, the prototype of the proposed antenna as shown in Figure 9 is implemented based on a FR4 sheet (h = 1.6 mm, ε_r = 4.4 and $\tan\delta$ = 0.02) with a size of 80×102×1.6 mm for a single array and 144×99×1.6 mm for the MIMO antenna.

In Figure 10, we compare the simulated results based on the CST Microwave software and the measurement ones. As can be seen, the measured impedance bandwidths at −10 dB of a single array and the MIMO antenna

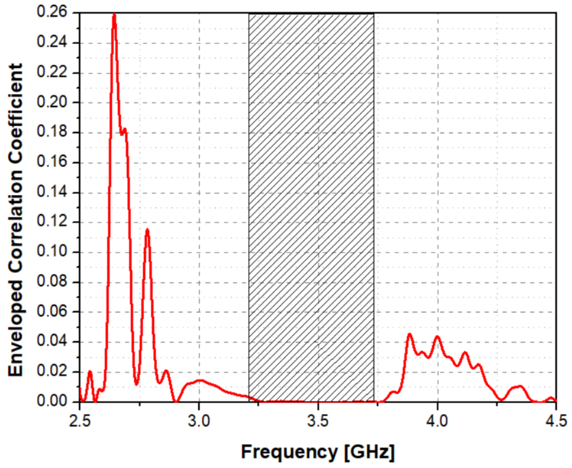


Figure 8. Enveloped correlation coefficient of proposed MIMO antenna.

TABLE III
PERFORMANCE COMPARISON OF PROPOSED ANTENNA AND RECENT ANTENNAS

References	[17]	[18]	[19]	**This paper**
Frequency [GHz]	2.4	3.5	2.6	**3.5**
Bandwidth [%]	3.3	6.2	14.6	**4.15**
Isolation [dB]	15	22	15	**29**
Efficiency [%]	85	87	x	**90**
Gain [dBi]	x	3.1	4.48	**7.5**

are 120 MHz (3.43%) and 145 MHz (4.15%), respectively, while the corresponding figures from simulation are 330 MHz and 200 MHz, respectively. Moreover, the measured isolation between elements in the MIMO antenna is approximately 30 dB. There is a tolerance between the simulation and measurement results. This can be caused by the instability of parameters in the FR4 substrate [16] and the tolerance in fabrication. However, this tolerance does not affect the operation of antenna and is thus acceptable. To verify the advantage of our proposed antenna, we compare its performance with some previously proposed antenna in the literature in Table III. We can see that the isolation of the antenna in [17] is only 15 dB and the percentage of the impedance bandwidth is not large (3.3%). In [18], although there is a high isolation (22 dB) between array elements, the gain of the antenna is quite low (3.1 dBi). The MIMO antenna in [19] has a large percentage of the impedance bandwidth, but achieves a low gain (4.48 dBi) while the efficiency is not mentioned. In this paper, by using DGS, the proposed antenna achieves a high isolation of approximately 30 dB, and, at the same time, a high efficiency of over 90%. Therefore, despite of the main lobe shift (190 degrees) and a higher complexity when using DGS, our antenna is a promising solution to operate at 3.5 GHz.

IV. CONCLUSION

This paper presents a MIMO antenna with enhanced isolation for WiMAX applications. The antenna is realized at the central frequency of 3.5 GHz and it is built on a FR4 substrate with parameters: $h = 1.6$ mm, $\varepsilon_r = 4.4$, and $\tan\delta = 0.02$. The proposed MIMO antenna contains two sets of 2×2 elements which incorporates DGS to obtain a high isolation between the elements. From measurements, the antenna achieves approximately 30 dB in isolation and 90% in radiation efficiency. Moreover, the antenna has a gain of 7.5 dBi while the measured bandwidth is 145 MHz at -10 dB. The proposed antenna has a compact size, a planar structure, an easy fabrication, and a low cost, thus can be utilized in practice.

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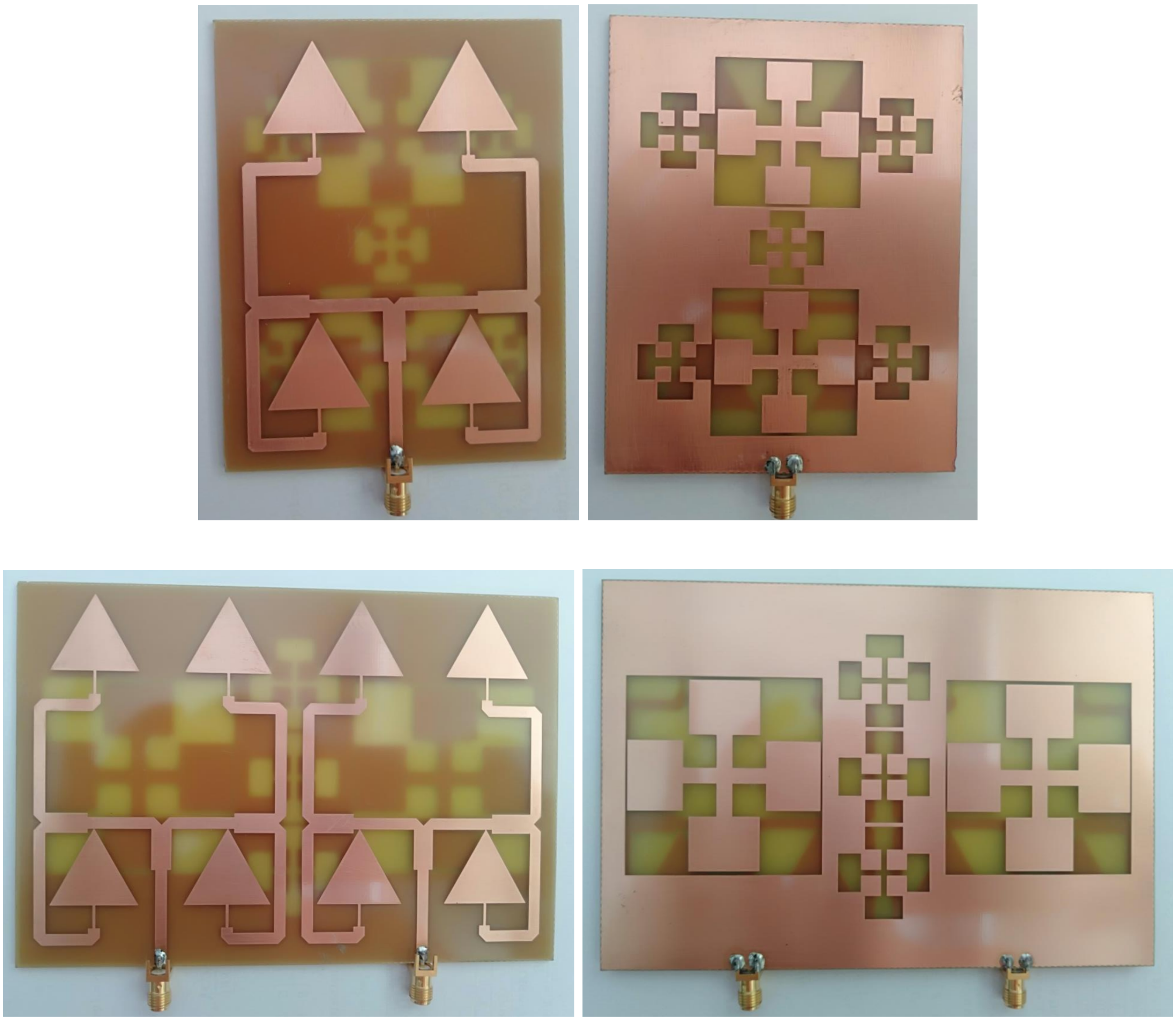
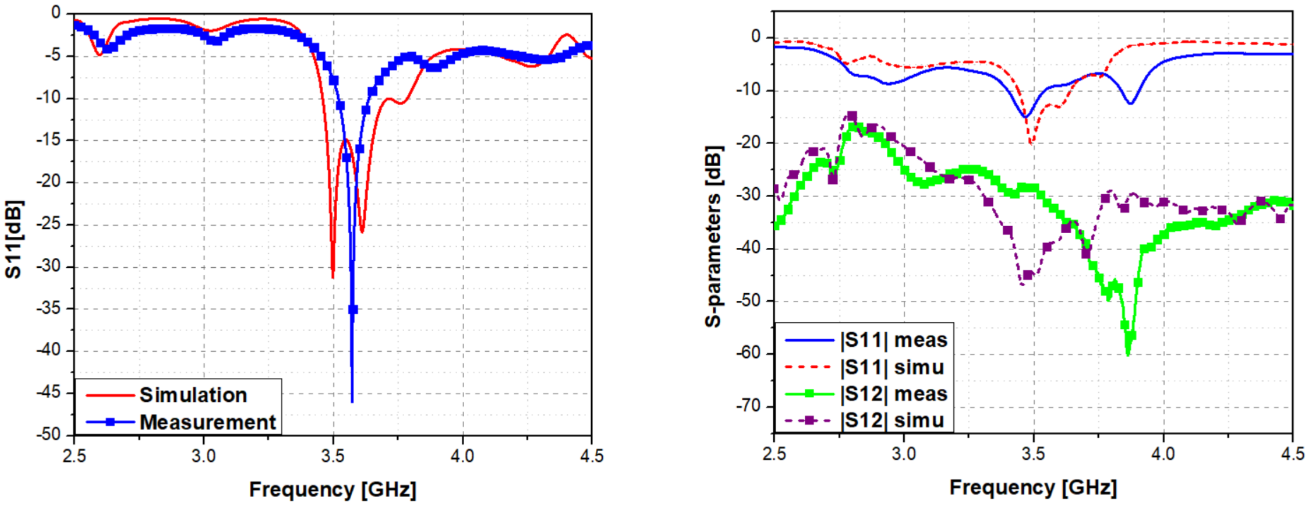


Figure 9. Prototype of fabricated single array (top) and MIMO (bottom) antennas



(a) Single array

(b) MIMO antenna

Figure 10. The measured and simulated S-parameter results of the proposed antenna.

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