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W-Shaped Eight-Port Wideband MIMO Antenna

Hussein M. Naser*, **Oras A. Al-Ani, and Mahmood F. Mosleh**

Abstract—The main challenges of designing an antenna for modern wireless communication are size reduction and mutual coupling. An ultra-wideband (UWB) multiple input multiple outputs (MIMO) antennae with four elements is suggested by this paper. Each element has two ports with dual-polarized patches to reduce the result of reciprocal coupling, increase the capacity, and keep a proper size. A circular geometric shape is in front of the patch of the proposed antenna to reduce the impact of mutual coupling. The CST STUDIO 2019 program simulates the single antenna element and MIMO antenna using four integrated elements, eight integrated ports, and an Fr-4 insulating layer in an area of $(70 \times 70)\,\text{mm}^2$. The MIMO antenna's operating frequency, which has a band of 2.85 (3.15–6) GHz at -10 dB, is 3.67 GHz while the operating frequency of a single antenna element, which has a band of 2.8 (3.1–5.9) GHz at -10 dB and a resonance return loss of 36 dB, is 3.64 GHz. The MIMO antennas obtained a diversity gain (DG) of about 10 with a good gain of about 8 dB while the envelope correlation coefficient (ECC) was equal to or less than 0.0001.

1. INTRODUCTION

In 2002, the Federal Communication Commission (FCC) approved Ultra-Wideband (UWB) systems' usage of the frequency range (3.1–10.6) GHz [1]. Although UWB has been around for more than 40 years, it has recently gained popularity for radar applications, localization, and data communications as a promising technology. Unfortunately, because of the transmission link's weak and low-powered pulses, UWB can be considerably distorted [2]. Accordingly, multiple-input multiple-output (MIMO) technology has been developed to provide diversity, such as boosting the channel capacity without the need for more spectrum, to produce efficient solutions for the congested UWB limited power dilemma [3]. However, a MIMO system can be strengthened by using a variety of strategies, such as space-time block code [4], to increase the attenuation of the UWB signal. To integrate a variety of MIMO systems, including an alternative tiny-size printed circuit board (PCB), a successful polarization technique is employed to deal with a high number of antenna arrays in a small space. Slot antenna kind is one of the multi-antenna variants used for UWB applications [5, 6]. The current study work is an attempt to employ this strategy since slot antenna has several benefits, including being reasonably priced and covering a wide frequency range that satisfies the UWB requirement. In order to build an antenna that somewhat approximates the wide frequencies of UWB, the band can also be expanded using either a tapered [7] or forklike stub [8], which will be used in this research.

To approach an acceptable model, the stub model needs precise dimension value selection. On the other hand, altering the antenna design to enable the rejection band capability is challenging, which is a characteristic that benefits UWB systems. A similar approach has been employed in other studies, including [9], a small orthogonal port with superior MIMO antenna system isolation created by the researcher, and the researchers in [10] propose a dual-polarized wideband aperture operating

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* Corresponding author: Hussein Mohammed Naser (hussainmoh1983@gmail.com).
The authors are with the Department of Computer Engineering Techniques, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq.

on 5G millimeter waves. In this research, a prototype MIMO antenna will cover a significant amount of the UWB range frequency. The polarization has been utilized to boost the data rate, and utilizing a duplicate of parasitic opening ring circles will result in good isolation. In hopes of achieving UWB qualities, a coplanar waveguide (CPW) with a W-shape will be used in this study to make use of the technique's benefits.

Some of the relevant studies in this field are MIMO system, for cognitive radio applications, and a brand new eight-element small MIMO slot antenna design is given. It features a broad frequency reconfigurable band ranging from 1.6 to 2.48 GHz, as well as long-term evolution (LTE), worldwide interoperability for microwave access (WiMAX), and a global system for mobile communications (GSM) [11]. An eight-port dual-polarized high-efficiency shared-radiator antenna operating in the 3.5 GHz (3.4–3.6 GHz) band for 5G mobile devices is conceived and developed. The MIMO antenna system has a total size of $(150 \times 80 \times 1.6)\,\text{mm}^3$ and four radiators. The final simulated outcomes are as follows: The gain is 6.5 dB; the envelope correlation coefficient (ECC) is less than 0.065, the isolation is 14 dB; and the total efficiency (TE) is (75–85%) [12]. A UWB 8-port MIMO antenna array on a smartphone with an open-slot aluminum frame is proposed for fifth-generation (5G) communications. Each slot element on the ground only occupies a $15 \times 3\,\text{mm}^2$ area. The antenna array has an ultra-wide operating range of 3.3–6 GHz (S_{11}–6 dB) [13]. A dual-polarized MIMO antenna design operating in the sub-6 band with a band of 2.93 GHz (7.42–10.36) GHz at -10 dB with a return loss of -44 dB at resonance is required for applications requiring 5G phones [14].

A team of researchers have developed eight-port antenna models similar to those in design, for anti-collision radar sensing, an eight-port mm-wave MIMO antenna with hybrid approaches is proposed. The design is printed with a 0.8 mm height on Roger RT/5880. Between 23.3 GHz and 27.6 GHz, the reflection coefficient is less than 10 dB, while the mutual coupling is less than 26 dB. Peak gain is 8.6 dBi; multiplexing efficiency is 0.5 dB; diversity gain is > 9.99 dB; and the envelope correlation coefficient is 0.0004 [15]. Another group works on designing models with two ports, a small MIMO system with a mountain-shaped ground plane and flag-shaped radiators is given with two ports. The suggested antenna measures $15 \times 25 \times 1.6\,\text{mm}^3$ in total. Between 3 and 10.9 GHz, the reflection coefficients are less than -10 dB. Both the diversity gains and envelope correlation coefficient (ECC) are larger than 9.9 dB [16]. An antenna has two notch bands for MIMO-UWB with two ports. Extending from the ground plane, a novel elliptical T-shape stub is used to create high isolation between radiating elements, and a novel G-shape stub is used to notch dual bands. The antenna measures $18 \times 36 \times 1.6\,\text{mm}^3$ [17]. The proposed antenna design is an isolation stub-equipped coplanar waveguide-fed ultra-wideband multiple input multiple outputs (UWB-MIMO) antenna with two ports. The suggested antenna has the following measurements: $18 \times 22 \times 1.6\,\text{mm}^3$. With an impedance bandwidth of 10.2 GHz, the given MIMO antenna's $|S_{11}|$ is less than 10 dB between 2.8 and 13 GHz. The DG is larger than 9.97 dB, while the ECC is less than 0.007 [18].

This paper is done to develop a small, wideband MIMO antenna, an inventive MIMO antenna with wide and numerous bands. It consists of four single antennas that are combined from the middle to form a model containing eight ports more like a fan with four arms. The antenna's efficiency and the proposed model will be evaluated by using the CST studio 2019 program and the Proto Mat S100 Laser and Electronics machine in the Industrial Research and Development Division of the Science and Technology Ministry of Iraq.

The organization of this essay is described in the sections as follows. The design and construction of the antenna are covered in Section 2. Section 3 displays the simulation results for the proposed design. Section 4 concludes the proposed concept.

2. SUGGESTED ANTENNA ARRANGEMENT

Using a single antenna element with two ports as well as a MIMO antenna with four elements and eight ports is suggested. This proposed design consists of a single-layer patch antenna. The top layer is a W shape patch that contains a microstrip feed line with a resistance of $50\,\Omega$. This geometric form can be modified by varying the substrate's size and thickness of the substrate layer and made from Fr-4 material which has good insulating properties, enhancing the antenna's effectiveness. The microstrip antenna (MSA), with a thickness of $0.035\,\text{mm}^2$, depends on the ground layer to regulate its bandwidth.

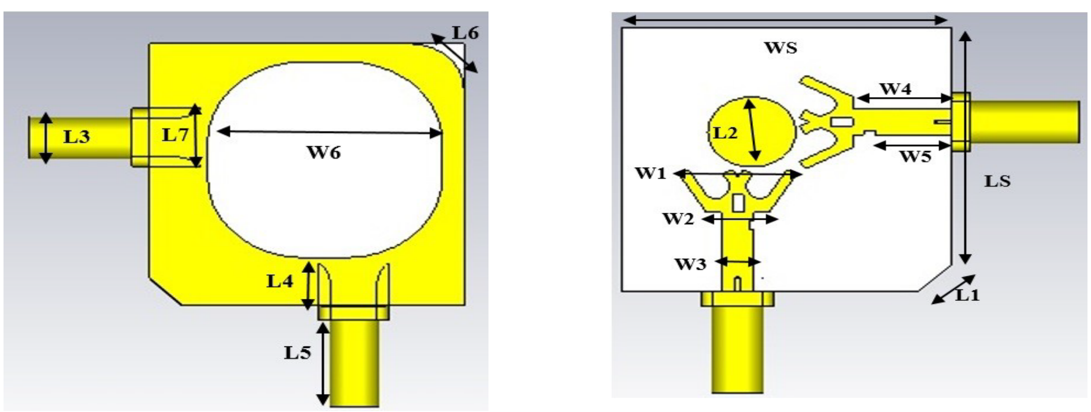
Before obtaining the final dimensions of the proposed model, several modifications have been made by adjusting the length of the feed patch between 7 and 9 mm in addition to changing the distance between the ports, and several results are obtained as indicated in Table 1.

Table 1. Results of parametric studies for the proposed antenna.

	Single Element Antenna			*MIMO Antenna*		
length feed patch *(mm)*	Return loss	Operating frequency (GHz)	Bandwidth (GHz)	Return loss	Operating frequency (GHz)	Bandwidth (GHz)
9	-36	3.64	2.8 (3.1-5.9)	-29	3.67	2.85 (3.15-6)
7.8	-38	3.66	2.81 (3.13-5.94)	-28.8	3.7	2.85 (3.17-6.02)
7	-28	3.65	2.78 (3.1-5.88)	-25	3.67	2.88 (3.14-6.02)

2.1. Single-Antenna Configuration

The basic dimensions for a single antenna structure with two ports are shown in Figs. 1(a), (b) with a size of $(30 \times 30\,\text{mm}^2$. To improve port isolation, the patch has a character form W made of copper alloy. The separating layer is made of Fr-4 material of $1.6\,\text{mm}^2$ thick. Copper again makes up the ground layer, which is $0.035\,\text{mm}^2$ thick.

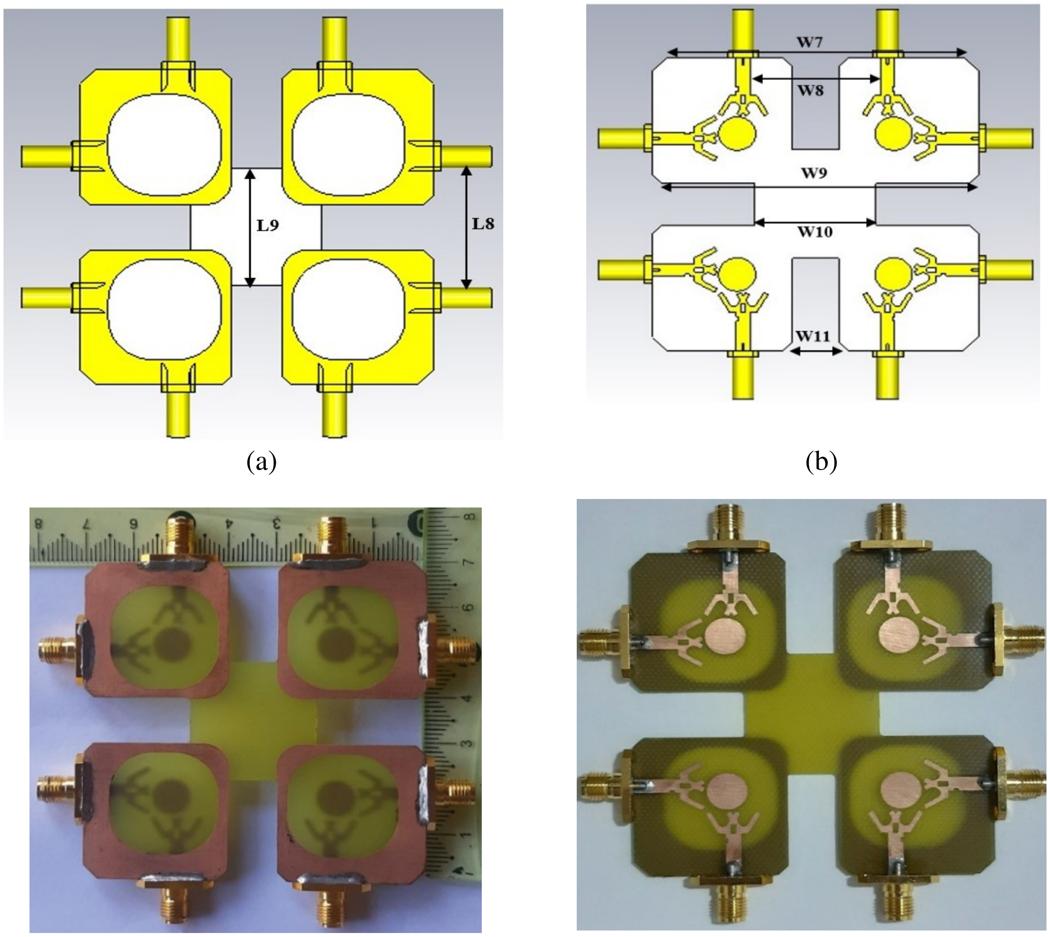


(a) (b)

Figure 1. Details of basic dimensions for a single antenna with a circular patch to reduce the mutual coupling.

2.2. A MIMO Antenna that Contains Eight Ports

On a dielectric material with the size of $(70 \times 70)\,\text{mm}^2$, 4 elements of the one antenna element having two ports are combined to create a MIMO antenna. Additionally, the MIMO antenna system was created using the Proto Mat S100 Laser and Electronics machine in the Industrial Research and Development Division of the Iraqi Ministry of Technology and Science. Figs. 2(a), (b), (c), and (d) display the suggested design's dimensions and measurements.



(a) (b)

(c) (d)

Figure 2. Details and dimensions of the suggested design for the MIMO antenna with eight ports.

Table 2 provides comprehensive information about the single antenna in Fig. 1 as well as the MIMO antenna in Fig. 2.

Table 2. The antenna design dimensions.

No.	term	Value (mm)	No.	term	Value (mm)
1	WS	30	13	W11	10.13
2	WG	24.79	14	LS	30
3	W1	9	15	LG	24.79
4	W2	5.73	16	L1	4.24
5	W3	3	17	L2	8
6	W4	9	18	L3	4.76
7	W5	7	19	L4	4.90
8	W6	22.40	20	L5	9.92
9	W7	63.76	21	L6	7.37
10	W8	28.06	22	L7	6.62
11	W9	66	23	L8	26.69
12	W10	26	24	L9	26

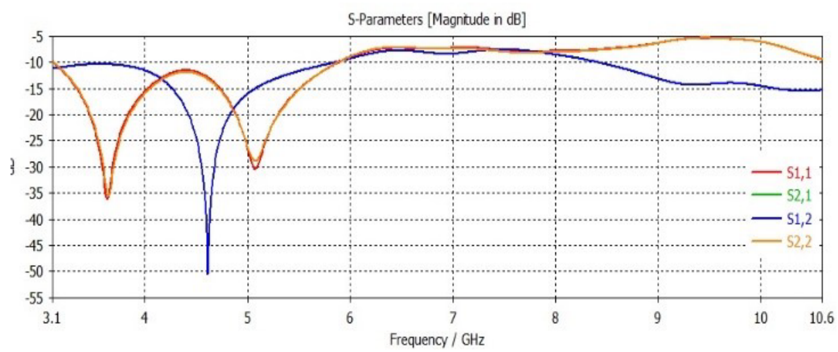
3. THE RESULTS OF THE SIMULATION AND DISCUSSION

The proposed prototype for the design was examined and simulated in addition to reviewing and discussing the results using the CST studio 2019 application.

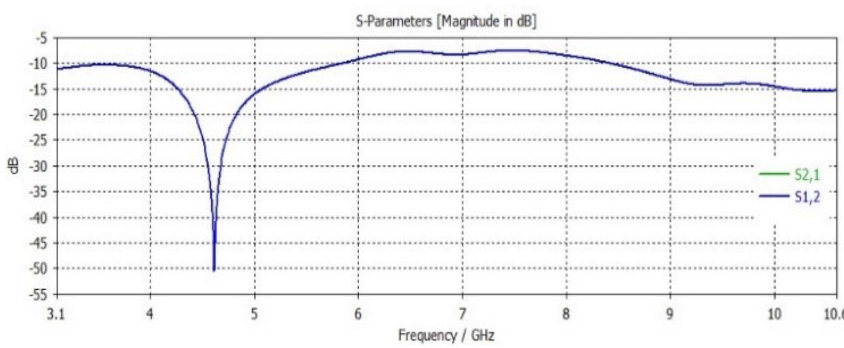
3.1. Simulation of the Single Antenna

Figures 3(a), (b) show the S-parameter for just a one-element antenna with two ports, where this simulation results in a nearly 2.79 GHz band at -10 dB, resonance isolation near 36 dB at a 3.64 GHz resonance frequency, and curves for the two-port antenna indicated by S_{12} and S_{21}, where S_{12} and S_{21} are noted as being 50 dB at 4.615 GHz. Because the two ports are independent of one another, the value of mutual coupling between the two antennas is therefore relatively low while Figs. 3(c), (d), and (e) show the measurement results in the Industrial Research and Development Division of the Iraqi Ministry of Science and Technology.

The voltage stands wave ratio (VSWR), a vital indicator of efficiency, is closer to 1 because it is less than 2, as defined by [19], as well as having reached 1.032. The VSWR of the recommended antenna and a lab examination are displayed in Figs. 4(a), (b).



(a)



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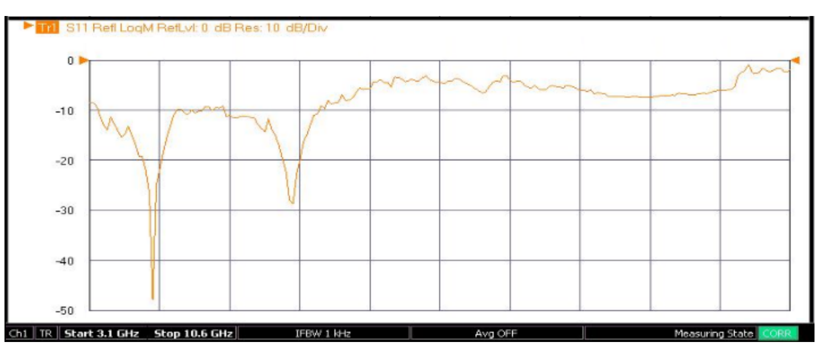

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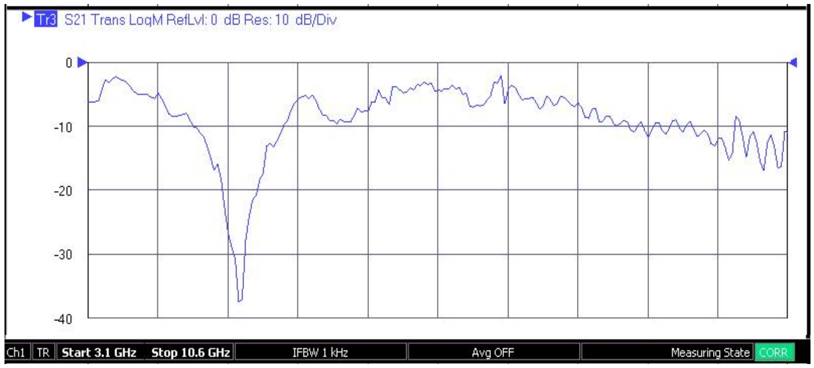

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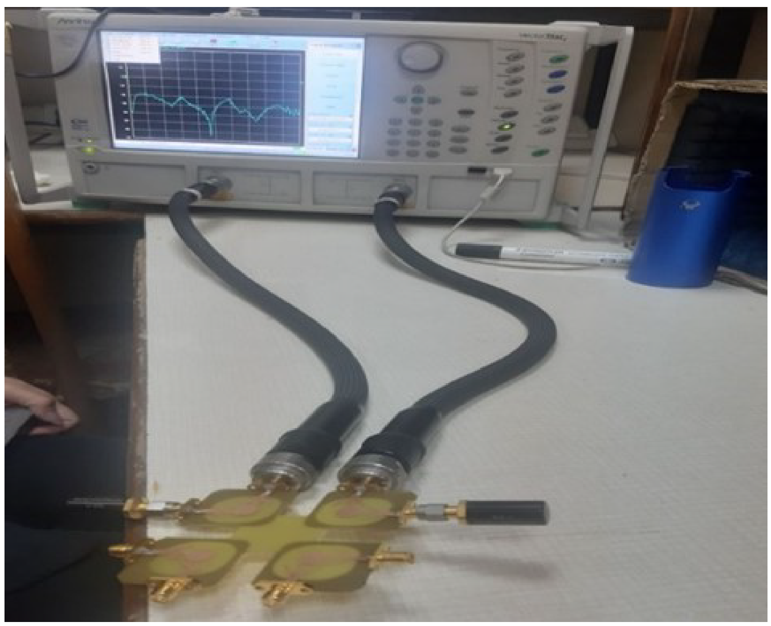
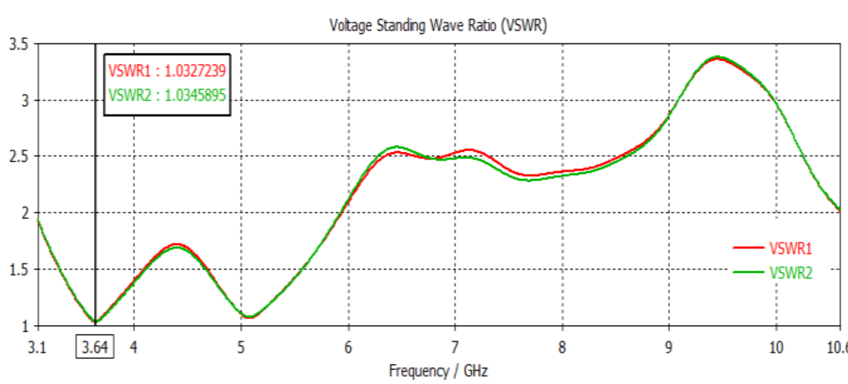


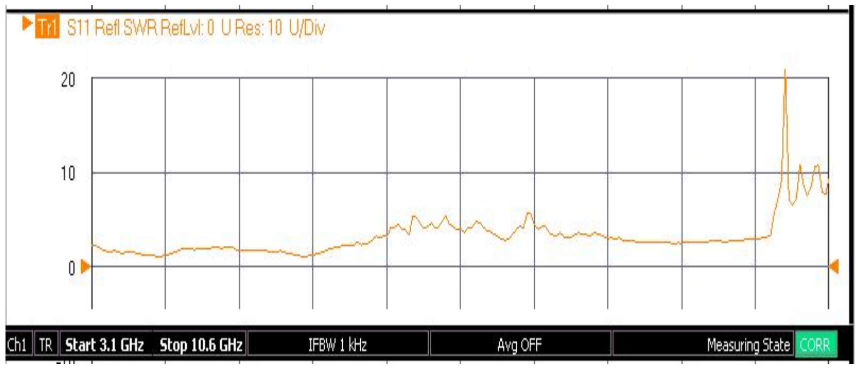
(e)

Figure 3. The measure and simulation results of parameter S of the single antenna.

The radiation pattern shown in Fig. 5 covers both the high and low portions of the suggested antenna and has a maximum radiation of $-30.98\,\mathrm{dB}$ at the resonant frequency.



(a)



(b)

Figure 4. Details of VSWR in simulation and a lab examination.

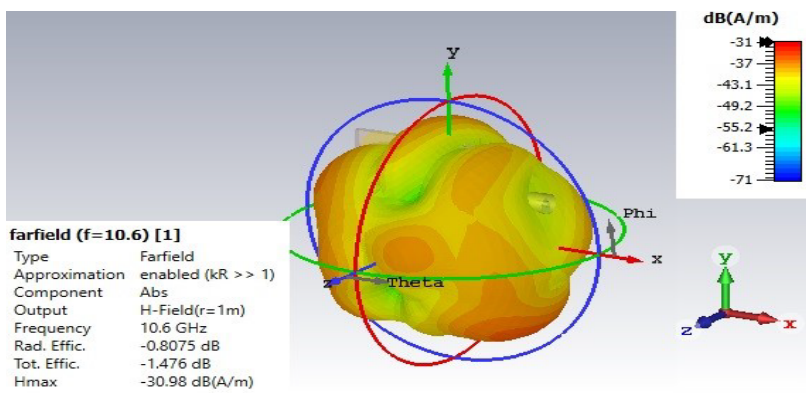


Figure 5. Details of the radiation pattern for the single antenna.

3.2. Simulation of MIMO Antenna with 8-Ports

Modeling findings show that the proposed MIMO antenna's resonance frequency and return loss are 6.505 GHz and 57 dB, respectively in addition to the S-parameter details, as shown in Figs. 6(a), (b) where the proposed MIMO antenna prototype is tested utilizing an Agilent N5247A vector network in the Lab of Industrial Research and Development Department of the Iraqi Ministry of Science and Technology.

The VSWR for the proposed MIMO antenna which contains eight ports is displayed in Fig. 7, and it is noted that the value of VSWR is equal to almost 1.07 which is very close to 1.

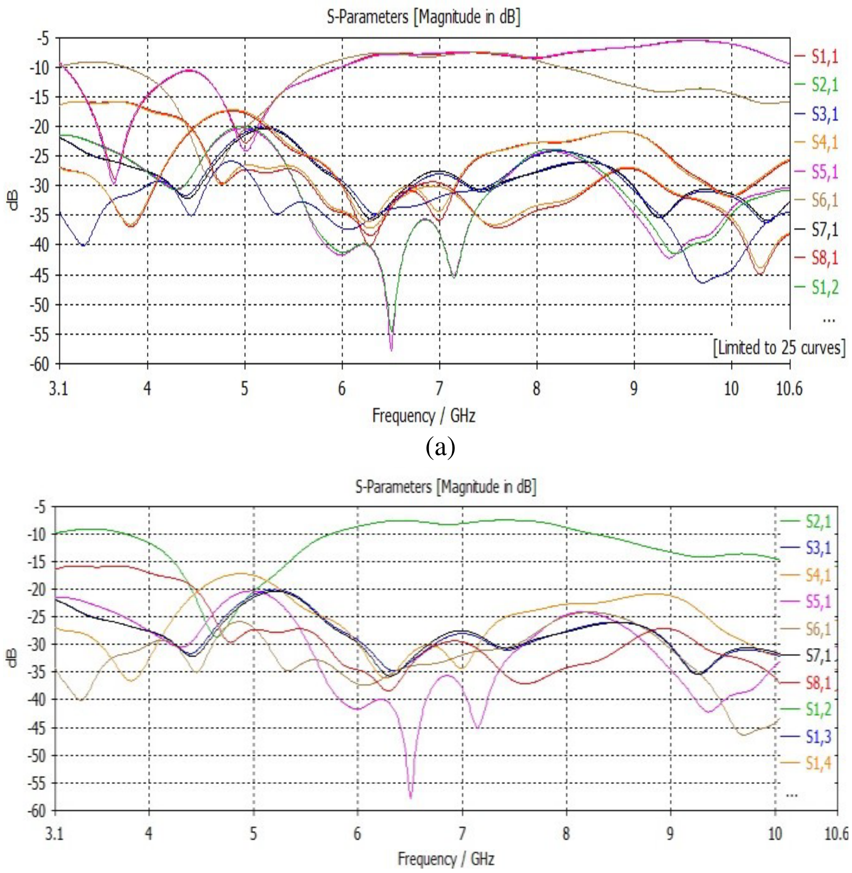
The 2D polar radiation pattern of the omnidirectional PCB-shaped MIMO system is visible, with a main lobe angular width of 71.5 degrees, a side lobe magnitude of -1.1 dB, and a 3D perspective with an H-max of -30.03 dB and gain of 7.649 dBi as shown in Figs. 8(a), (b) and (c).

Equation (1) [20] can be used to calculate ECC which represents a metric for antenna performance.

$$\rho_e = \frac{|S_{11} \times S_{12} + S_{21} \times S_{22}|}{\left(1 - |S_{11}|^2 - |S_{21}|^2\right)\left(1 - |S_{22}|^2 - |S_{12}|^2\right)} \tag{1}$$

where the suggested MIMO antenna's ECC is represented by the S-parameters S_{11}, S_{12}, S_{21}, and S_{22}. The ECC curve frequency in Fig. 9 demonstrates how well the MIMO antenna works at frequencies between 3.1 and 10.6 GHz. Given that the antenna must have an ECC value of less than 0.05 in order to be considered realistic, the curve frequency appears to be less than 0.0001, which is extremely low and excellent.

As a result, it can be concluded that the performance of the suggested antenna is stable within the UWB frequency range.



(a)

(b)

Figure 6. Specifics of the proposed MIMO antenna's S-parameter.

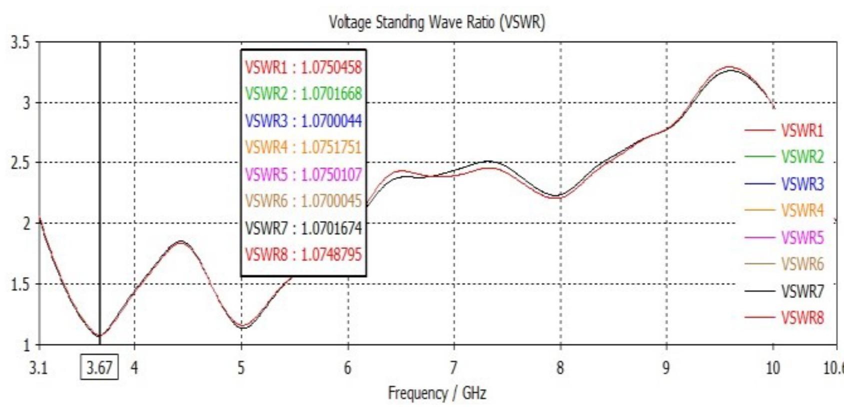
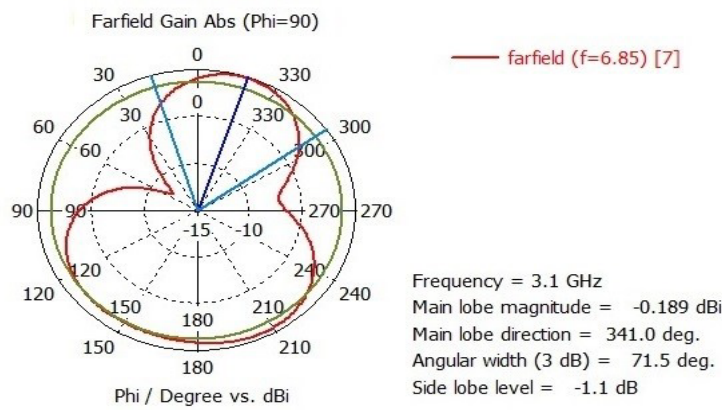


Figure 7. Specifics of VSWR for the proposed MIMO antenna.

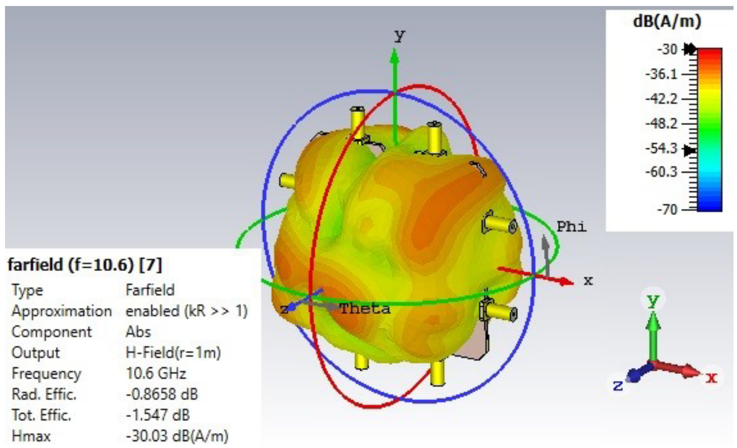
The DG or gain for the MIMO antenna with eight ports is shown in Fig. 10. They are appropriate for applications involving wireless communication networks because they have varied gains across all frequencies. DG must have a value greater than or equal to 9 dB (2) [20].

$$\text{DG} = 10\sqrt{1} - \text{ECC}^2 \tag{2}$$

Figures 11(a), (b) depict the radiation efficiency and total efficiency for the MIMO antenna with eight ports. They are suitable for wireless communication network applications due to their varying gains across all frequencies.



(a)



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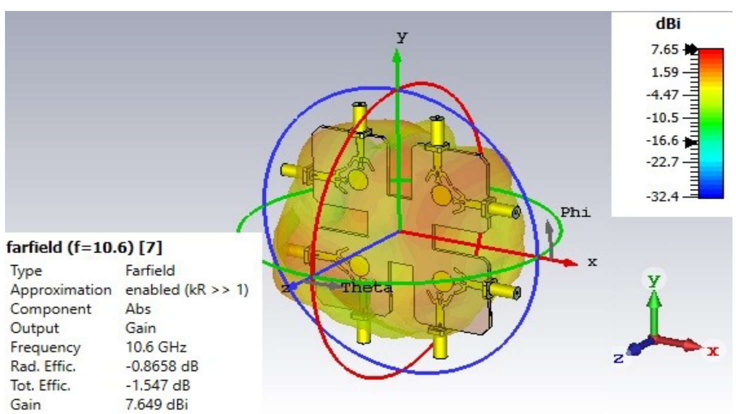

(c)

Figure 8. The 3D and 2D radiation pattern and total gain for the MIMO antenna.

Table 3 compares the data presented in this research for different parameters with some comparable findings reported by other authors.

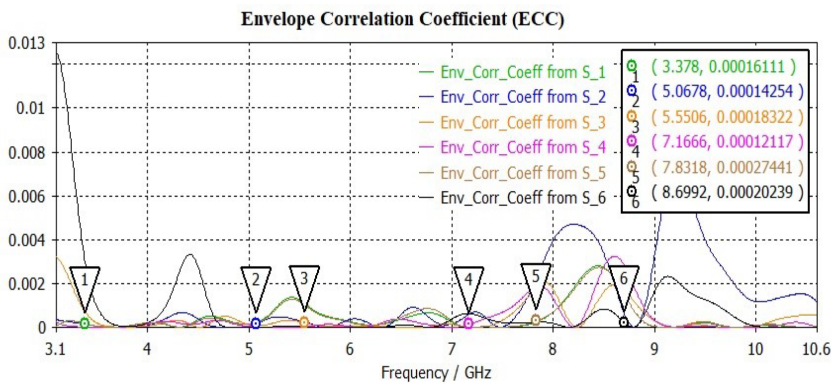

Figure 9. Details of ECC of the proposed MIMO antenna.

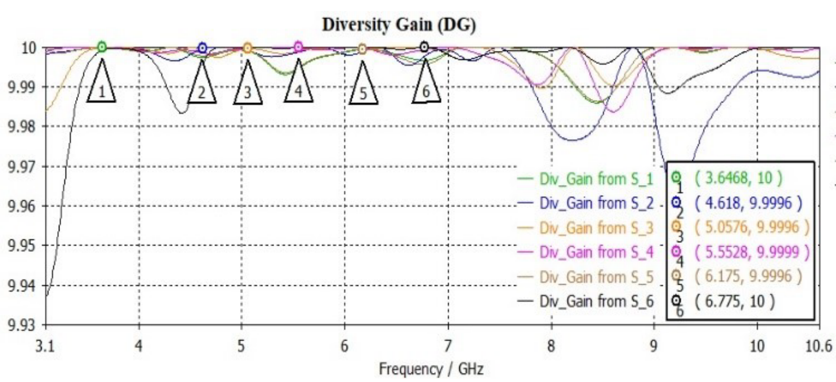

Figure 10. Details of DG of the proposed MIMO antenna.

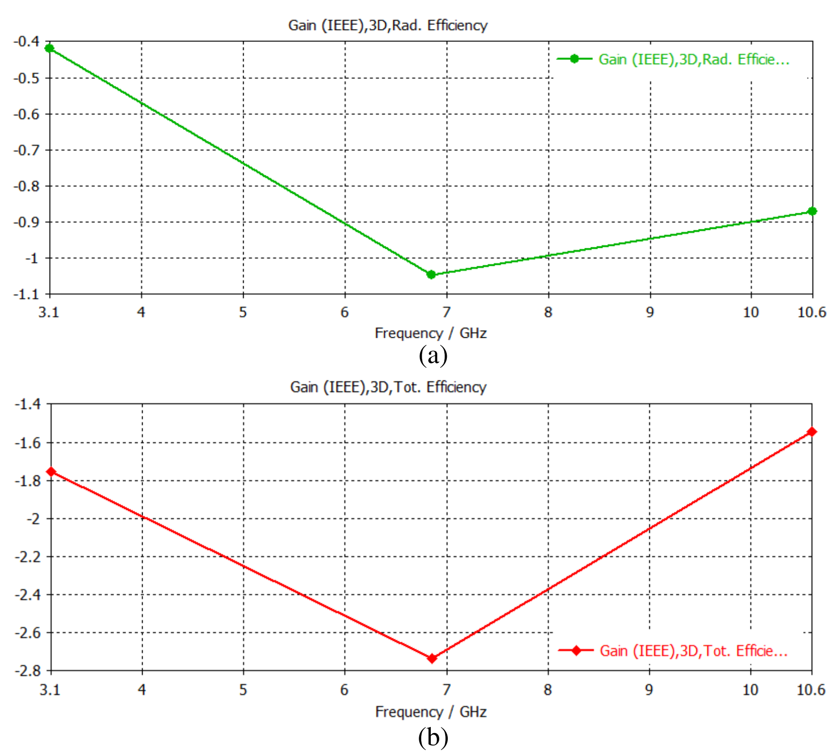

Figure 11. Details the radiation efficiency and total efficiency MIMO antenna.

Table 3. Results comparison for various parameters.

Ref.	*publish date*	*Port no*	*size* (mm)	*B.W* (GHz)	Gain (dB)	*VSWR* dB	*ECC*	*DG*
[21]	2019	8	150 ×75	0.6	5	doesn't approach 2	0.5	-
[22]	2019	8	155 × 85	0.59	-	-	0.01	-
[23]	2020	8	139 × 67	0.85	5.514	doesn't approach 2	0.001	approach 10
[24]	2020	8	150 × 77	1	7.12	Approach 1	-	-
[25]	2021	8	70 × 70	1	7.5	-	0.009	-
My design	2023	8	70 × 70	2.85	7.649	1.07	0.0001	10

4. CONCLUSION

In this study, a four-element MIMO antenna with eight ports is proposed. By drilling holes in the floor layer and modifying the model's corners, several alterations and additions are made to the design model to obtain the desired final shape. The operational frequency of the proposed MIMO antenna is 3.67 GHz, and its effective bandwidth is 2.85 (3.15–6) GHz, while a single antenna element has a bandwidth of 2.8 (3.1–5.9 GHz) at −10 dB and works at 3.63 GHz. Moreover, displaying isolation, the MIMO antennas achieve a resonance level of 36 dB. The high gain and omnidirectional radiation efficiency of the proposed MIMO antennas are also described.

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