Increasing Gain Evaluation of 2×1 and 2×2 MIMO Microstrip Antennas

Majed Omar Dwairi
Al-Balqa Applied University
Faculty of Engineering Technology
Department of Communication Technology
Jordan, Amman
majeddw@bau.edu.jo

Abstract-In this paper, a semi-circular ultra-wideband antenna has been modified according to the 2×1 and 2×2 MIMO scenarios. The proposed antennas were designed based on the FR-4 substrate material with dimensions of 36×50mm and 60×60mm for 2×1 and 2×2 scenarios respectively. Simulation results show that a gain improvement of the proposed MIMO antennas from 1 to 2.5dB has been achieved in comparison with the single patch antenna. The radiation pattern for the original and the proposed 2×2 MIMO antennas are exhibited. The main advantage of the proposed antennas is that the gain improves without the need to increase the operating power. This makes the proposed MIMO antennas suitable to be used for UWB antenna applications.

Keywords-microstrip antenna; ultra-wideband; multi-input multi-output; released gain

I. INTRODUCTION

The microstrip antenna has received the attention of microwave antenna designers in ultra-wideband (UWB) applications. This can be clearly seen after the adaption of the UWB range of 3.1-10.6GHz from the Federal Communication Community 2002 [1]. Microstrip antennas received much attention due to their advantages, when compared with other microwave antennas, such as low profile, light weight, low cost, capability of many frequency operations, and easy integration with the microwave integrated circuit. Many investigated directions in microstrip antenna design have been proposed. Also, many researchers analyzed and experimented with different microstrip antenna simulation tools [2]. The effect of inserting different slots in order to enhance the operating bandwidth has also been studied [3-8]. In [9-12], different patch and ground slots were inserted to eliminate unwanted narrow frequency bands, known as filters. Muli-Input Multi-Output (MIMO) microstrip antenna technology received more attention in microwave wireless communications, due to its ability to increase operating data throughput and its range without the need for additional transmitted power or bandwidth. MIMO technology received more attention as it does not need any additional spectrum while transmitting and receiving information from its multiple channels at the same time. By a proper design and layout of MIMO antenna, multipath characteristics of the wireless communications can be controlled. In [13], a high gain MIMO antenna was introduced for a mm-wave planar antenna by choosing the proper size of the feeding line and loading shorted vias on the particular location of the microstrip line. The mutual coupling effect is one of the most challenging in designing MIMO antennas. The authors minimized the mutual coupling for the designed MIMO by inserting ground slots orthogonally, receiving a triple band resonance frequency: 2.11GHz-2.23GHz, 3.24GHz-3.32GHz, and 3.92GHz-4.42GHz [13]. In [14-16], the authors produced insulation between the patch and the feeding element using aperture - coupling and DGS for isolating the ground. To achieve high isolation MIMO microstrip for WLAN applications, aperture-coupling was used to isolate the T-shaped and orthogonal microstrip around the squared patch. In [17], four pair conformal microstrip MIMO antennas of 35GHz have been investigated, resulting in increased bandwidth with reduced side lobes at the same time. Authors in [18, 19] experimented with a 2×2 MIMO microstrip antenna, suitable for new wireless communication demands. The investigated antenna was designed for 5G mobile handset. In [20], the authors designed a four-element MIMO patch antenna for the 5G mobile handset that increases the signal-to-noise ratio and reduces Bit Error Rate (BER). In [21], a high gain pentagonal microstrip antenna compatible for 5G applications, with a received gain of 6.17dB was proposed.

In this paper, an UWB antenna [7] has been modified to 2×1 and 2×2 MIMO scenarios. The modified antennas are compared in terms of increased released gain without any additional power. The expected gain increased from 1 to 2.5dB which shows the effectiveness of the proposed antennas.

II. MIMO ANTENNA DESIGN

Figures 1(b) and 2(b) show the front and back views of the investigated antenna respectively. This antenna was modified to the case of 2×1 structure by extending the width of the substrate to the double of its original value and adding P = 2mm to separate the ground of two antennas. The added patch antenna chased the same dimensions with inverting 180 degrees. The modified 2×2 microstrip antenna was designed by extending the dimension of the substrate width and length to the substrate width plus substrate length (Ws + Ls) as shown in

Corresponding author: Majed Omar Dwairi

Figures 1(c) and 2(c). All the investigated antenna materials are built on FR-4 with the substrate with dielectric tangent loss = tan δ= 0.02 and relative permittivity ε_r =4.4. The dimensions of the investigated antennas are listed in Table I. The microstrip patch antenna in [7] was investigated to enhance the bandwidth by adding different slots on the ground. In our work, the chosen slot is the dinking cup-shaped. The bandwidth of the investigated 2×1 and 2×2 antennas was limited to the maximum frequency of 15GHz in order to increase the released gain. In our work, the CST-2019 simulation tool was used.

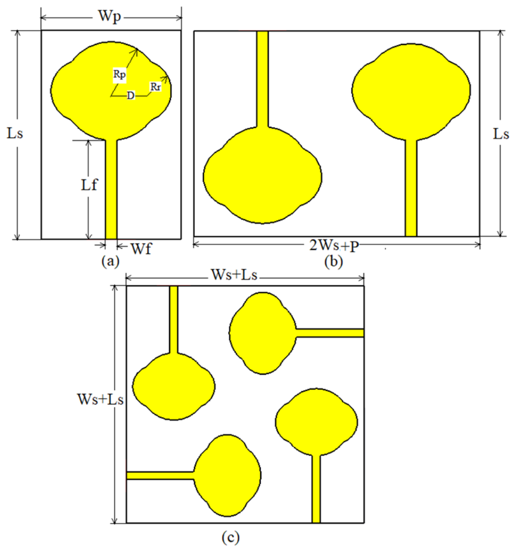


Fig. 1. Front view of (a) the single antenna, (b) the MIMO 2×1 antenna, (c) the MIMO2×2 antenna.

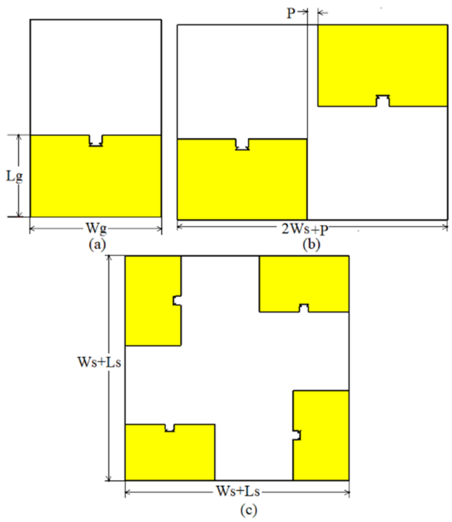


Fig. 2. Back view of (a) the single antenna, (b) the MIMO 2×1 antenna, (c) the MIMO2×2 antenna.

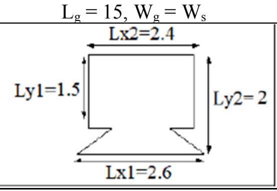
III. Results and Discussion

All simulations were performed with the CST MW studio -2019 simulation tool.

A. Return Loss Results

To investigate the return loss S_{11}, the bandwidth was limited to the frequency band from 2 to 15GHz. The results of S_{11}, S_{22} for the 2×1 antenna are shown in Figure 3 and the results of S_{11}, S_{22}, S_{33}, and S_{44} for the 2×2 antenna are presented in Figure 4. It is evident that all the parameter values are within the investigated UWB. The received return loss for each of the antennas and the coupling of the other antennas are presented in Figures 5-8. In these Figures, it can be seen that the reflection parameters have many resonant frequencies, from -17 to -32dB, while the coupling of the antenna reaches -50dB. The received return loss S_{11} for the original, 2×1, and 2×2 antennas at the operating band of frequencies is shown in Figure 9. Figure 3 shows the return loss versus frequencies for the original, 2×1, and 2×2 antennas. It can be noted that the two investigated antennas are still operating within the UWB range. Moreover, both of them start before the original antenna for return loss $S_{11} < -10$ dB, and the upper frequency ends after the original antenna for return loss $S_{11} < -10$ dB.

TABLE I. INVESTIGATED ANTENNA PARAMETERS

Antenna elements	Dimensions [mm]
Patch	R_p=8.5, Rr=5.36, t_p=0.009
Feed line	L_f = 16.82, W_f = 2
Substrate [mm]	L_s = 36, W_s= 24 , t_s= 1.6 ,P=2
Partial ground plane [mm]	L_g = 15, W_g = W_s
Drinking cup shape ground slots dimensions [mm]	

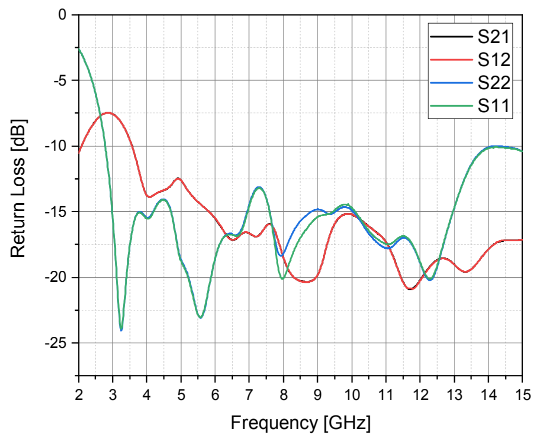


Fig. 3. Reflection and transmssion coefficients for the 2×1 MIMO antenna.

Table II lists the comparison between the original and the two investigated antennas in terms of bandwidth and relative bandwidth. The relative bandwidth for the 2×1 and 2×2 antennas are more than the original antenna by 7.5% and 11.4%, respectively. The relative bandwidth is given by:

$$FBW = 2\frac{f_H - f_L}{f_H + f_L} \quad (1)$$

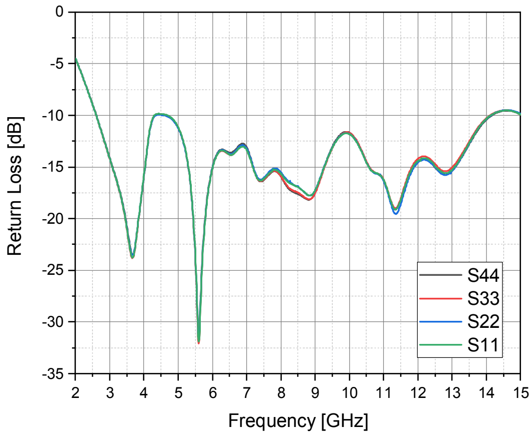


Fig. 4. Return loss for 2×2 MIMO antenna.

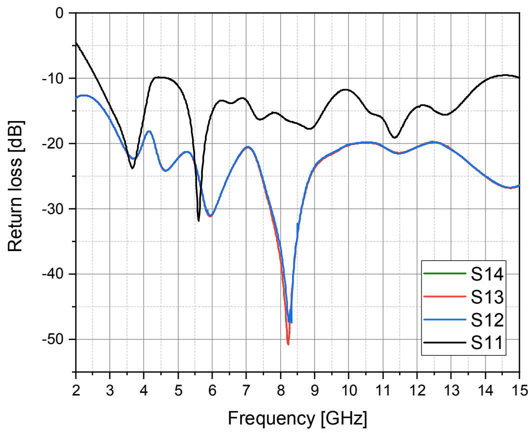


Fig. 5. The return loss for the first antenna and the coupling antenna for 2×2 MIMO.

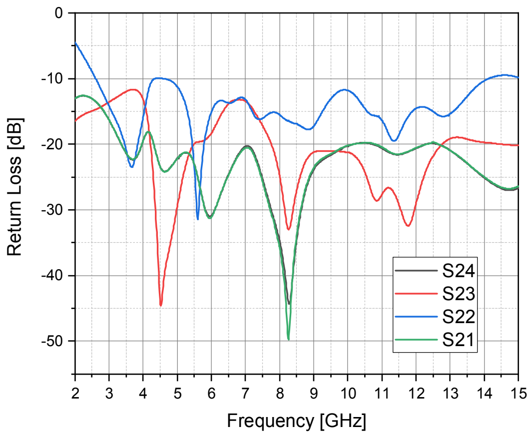


Fig. 6. The return loss for the second antenna and the coupling antenna for 2×2 MIMO.

TABLE II. RELATIVE BANDWIDTH

Antenna	Bandwidth [GHz]	Relative bandwidth %
Original	3.02-13.9	128.6
MIMO 2×1	2.85-15	136.1
MIMO 2×2	2.65-15	140

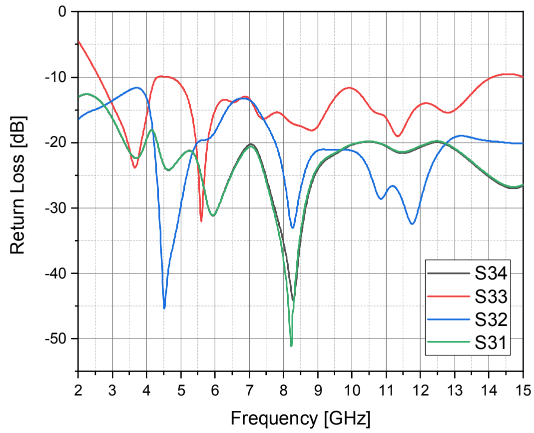


Fig. 7. The return loss for the third antenna and the coupling antenna for 2×2 MIMO.

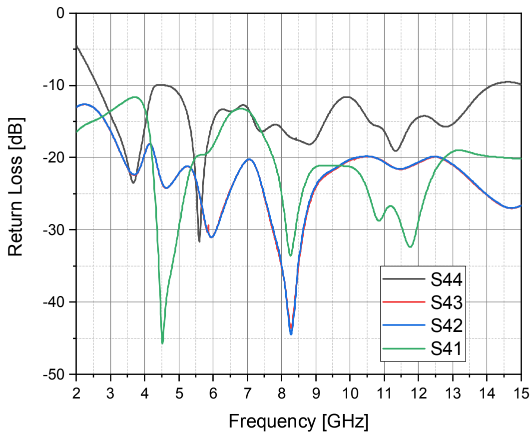


Fig. 8. The return loss for the fourth antenna and the coupling antenna for 2×2 MIMO.

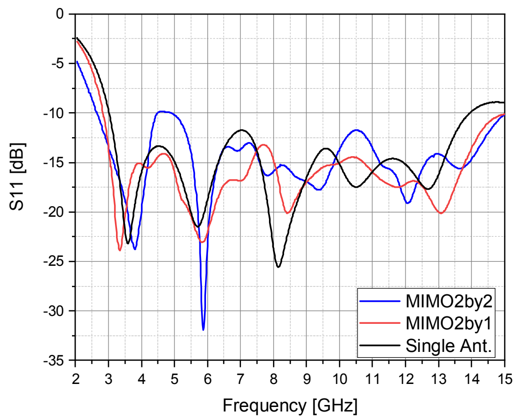


Fig. 9. Return loss versus frequencies for the original, 2×1, and 2×2 antennas.

B. Voltage Standing Wave Ratio (VSWR) Results

Figure 10 shows the results of the investigated antennas in terms of VSWR versus the operating UWB frequencies. As shown, the whole operating bandwidth lies below VSWR equal to 2, which is expected based on the return loss results.

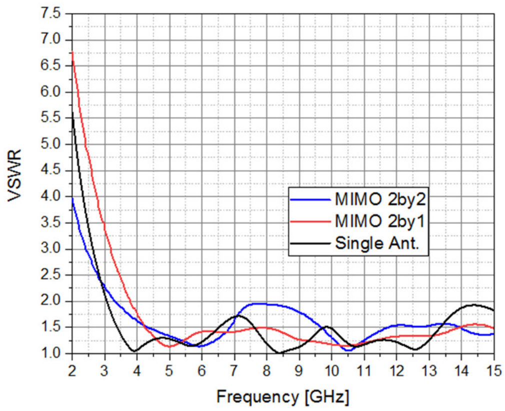


Fig. 10. VSWR versus operating frequencies for the original, 2×1, and 2×2 antennas.

C. Released Gain Investigation

The main purpose of this work was to evaluate the released gain for the original and the proposed 2×1 and 2×2 UWB microstrip antennas. Figure 11 represents the released gain for the original antenna and the proposed MIMO antennas. It can be seen from the Figure that the maximum gain for a single antenna was 5.2dB at 8.4GHz. For the 2×1 antenna, the maximum gain was 5.76dB at 9GHz and for the 2×2 antenna it was 6.03dB at 8.4GHz. Table III lists the gain for the three antennas at different frequencies.

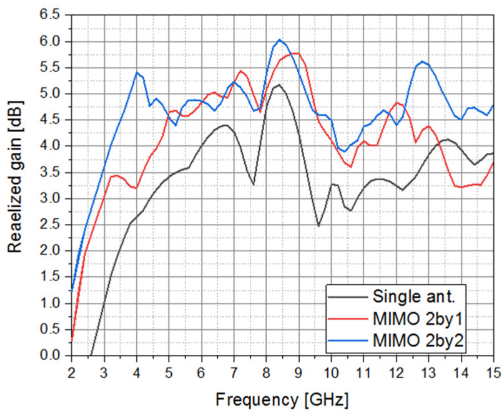


Fig. 11. The released gain for the original, 2×1, and 2×2 antennas.

TABLE III. COMPARISON OF THE GAIN VS FREQUENCY OF THE ORIGINAL AND THE PROPOSED ANTENNAS

Frequency (Hz)	Antenna gain (dB)		
	Original	**MIMO 2×1**	**MIMO 2×2**
3.2	1.52	3.42	4.01
5	3.42	4.66	4.55
7.6	3.26	4.98	4.68
8.6	5	5.72	5.94
9.6	2.47	4.47	4.6
11	3.2	4.1	4,4
12	3.25	4.93	4.4
14.6	3.73	3.26	4.65

Figure 12 gives a fast view of the comparison between the original and the two proposed MIMO antennas with different gain. The proposed antennas' gain exceed 2.5dB for some frequencies.

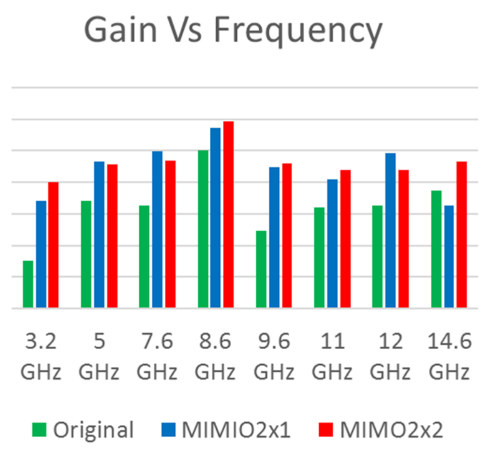


Fig. 12. Comparison between the gain and the frequency for the original, 2×1, and 2×2 antennas.

D. Radiation Pattern

Figure 13 shows the radiation pattern in the far-field for different selected resonance frequencies related to the original antenna and the proposed 2×2 antenna. It is evident that the radiation pattern for both antennas is omnidirectional for the lower resonant frequencies and directional for the higher ones.

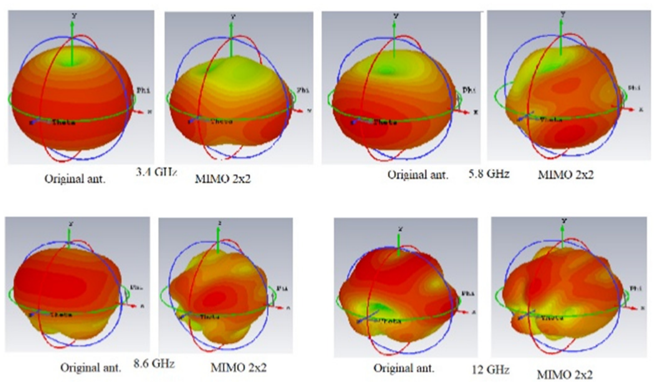


Fig. 13. Radiation pattern (far-field pattern) for the original antenna and the MIMO 2×2 antenna.

E. A Comparison beween the Proposed 2×2 MIMO Antenna and other Reported Works

In order to evaluate the proposed antenna, it is worth to compare it with the results of other reported works. The comparisons were conducted in terms of antenna dimensions, number of antennas in MIMO, operating frequencies, and peak gain. As shown in Table IV, it is clear that some of the reported works have peak gain more than that of the proposed antenna, but, in general, our peak gain is quite satisfying and similar or bigger than that of the other reported gains. The importance of the investigated antenna is that it operates in UWB frequencies which allows it to be implemented in different narrow bands.

TABLE IV. COMPARISON OF THE PROPOSED ANTENNAS AND OTHER REPORTED WORKS

Ref.	Dimensions [mm]	MIMO antenna	Operating Frequency [GHz]	Peak gain for MIMO antenna [dB]
[12]	20×24	2×1	42.0-49.0	>8
[14]	70×70	2×2	2-4.5	1.84-3.49
[18]	20×45	2×2	2.97-19.82	3.3-8.12
[19]	15×10.3	2×2	27-28.95	6.14
[20]	66×66	2×2	2.2-2.7	6.17
Proposed	60×60	2×2	2.65-15	>6

IV. CONCLUSION

Two UWB 2×2 and 2×1 microstrip patch antennas have been introduced in this paper. The released gain improvement, compared to the original one, for the two proposed MIMO antennas varied from 1 to 2.5dB without increasing the radiated power So, it is evident that the proposed MIMO antennas' release gain is bigger than that of the used UWB antenna for the same operating frequencies, which gives more stability. In the future, the simulated antenna will be fabricated for experimental validation.

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