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# Broadband printed MIMO dipole antenna for 2.4 GHz WLAN applications

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ABSTRACT: Broadband printed dipole antenna with elliptical-arms and integrated balun for multiple-input-multiple-output (MIMO) antennas at 2.4 GHz frequency is designed and presented. The MIMO structure is composed of four symmetrical dipole elements and a circular ground plane. To enhance the isolation between contiguous elements, they are placed in a perpendicular direction. Isolation of parallel dipoles with identical polarization is guaranteed by a suitable distance. Outstanding impedance matching, good isolation, high-gain, and stable directional radiation pattern are advantages of this design. Structural simplicity is achieved by printing dipole arms, balun structure, and the ground plane on FR4 substrates. The proposed MIMO antenna is manufactured and tested in the anechoic chamber. The empirical results have a proper discrepancy with the simulation outcomes.

KEYWORDS: Antennas; Microwave Antennas

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## Contents



# 1 Introduction

A direct path from a receiver antenna to a transmitter antenna creates a Line of Sight (LOS) communication in the wireless systems. Also, there are some reflections between the transmitter and receiver due to the objects in the environment, which are called multipath. Multipath leads to unwanted effects on the received signals. There is a possibility to amplify the received signal by the multipath phenomenon, but often it suffers the received signals called multipath fading. Consequently, the main aim of introducing the MIMO technique is the suppressing of multipath fading predicament [1]. By employing several antennas at both ends of a communication link, the channel capacity is increased and so, the MIMO system with multiple channels is realized. Furthermore, MIMO technology enhances the link's data rate and reliability without further power transmitting or additional bandwidth [2]. During the last decades, numerous MIMO antennas with various designs investigated [3–5]. A CPW-fed MIMO antenna consists of two equal ring-shaped monopoles, which is covering the UWB frequency band, is introduced in [3]. Also, using small size uniplanar Electromagnetic Band Gap (EBG) structure in [4] reduces the mutual coupling between the elements of this antenna. A compact three-port planar MIMO antenna comprising three T-shaped open-ended slots is proposed in [5], which is suitable for the 2.4 GHz WLAN band. The elements are rotationally symmetric and producing directional patterns at 0°, 120°, and 240°, directions. Nevertheless, one of the preferred elements for MIMO designs is dipole antenna because of significant advantages such as symmetric radiation pattern, simple structure, and easiness of fabrication [6]. Several dipole MIMO antennas developed with different designs and applications recently [7–9]. In [7], a circular polarization spiral-dipole antenna is introduced for MIMO systems. This antenna operates at 5.2 GHz with 3.6 dBic gain and has an isolation of more than 30 dB. Additionally, a 4-element printed MIMO dipole using V-shaped ground branches — to improve the impedance matching — based on the integrated balun is investigated by [8]. This antenna covers three WiMAX bands at 2.30, 2.50, and 3.30 GHz, and also WLAN band at 2.40 GHz. In [9], a printed cross dipole fed through balun and a $4 \times 4$ subarray antenna is proposed for 5G applications.

In this letter, by using four printed dipoles and integrated baluns, a 4-element MIMO antenna is designed for 2.4 GHz applications. According to experiment results, the printed dipole antenna covers from 2.12 GHz to 2.88 GHz frequency band and has a peak gain of 8.82 dB.



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Significant impedance matching and directional radiation pattern with low Cross-polarization are achieved by employing the balun to feed the antenna. The MIMO design has a measured peak gain of 8.52 dB and the difference between the Co- and Cross-polarization is more than 15 dB. Furthermore, to approve the simulations, the printed dipole and MIMO antennas are manufactured and tested.

## 2 Dipole antenna design

The proposed printed dipole antenna is composed of three substrates in a way that the dipole arms, balun structure, and ground plane are printed on upper, middle and lower substrates, respectively. The length of elliptical-dipole arms in this design is named as L-dipole.

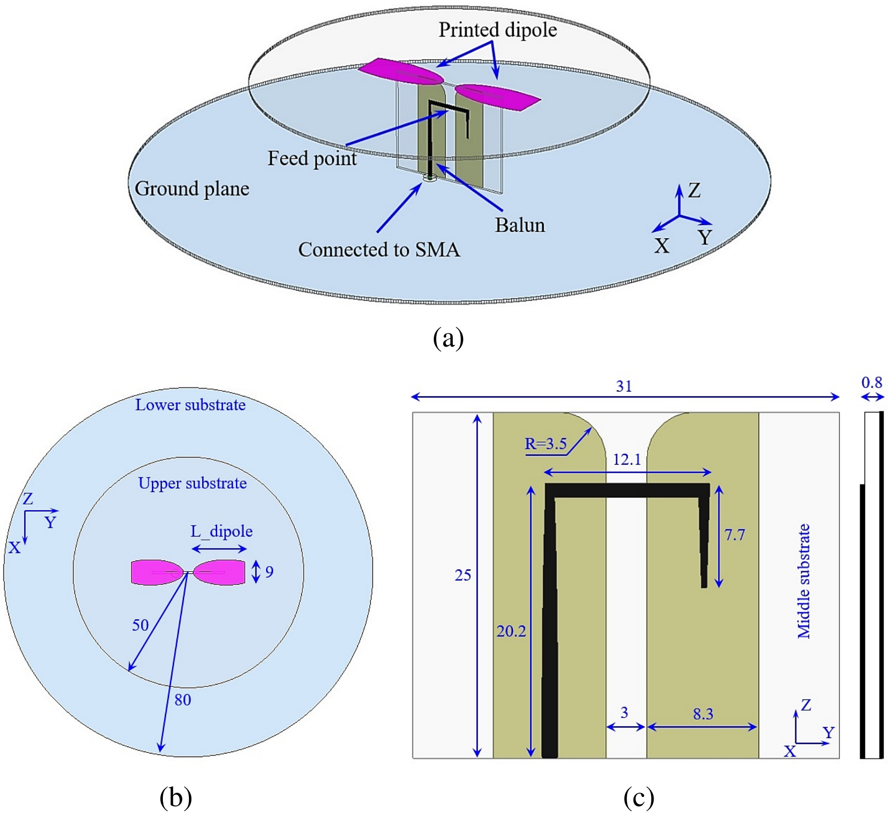



**Figure 1**. The printed dipole antenna configuration (a) 3D view, (b) top view and (c) balun structure. (Dimensions in mm).

Figure 1 exhibits the geometry of the printed dipole antenna in this letter. The 3D and top view of this antenna structure is displayed in figure 1(a) and (b). It shows the antenna is arranged symmetrically. According to figure 1(c), the balun structure is printed on two sides of the FR4 substrate and then placed vertically on the middle of the ground plane. Therefore, the lower substrate has two roles, it contains the ground plane and also supports the balun and dipole arms substrates mechanically. All substrates used in this work have a thickness of 0.8 mm with a relative permittivity of 4.4.

The dipole antenna is fed with a coaxial cable by an SMA connector which is located under the lower substrate. The inner conductor of SMA connector is soldered to the $\lambda/4$ microstrip line ($\lambda$ is referred to the wavelength of the operating frequency of dipole) of the balun structure, and the external conductor, to the ground plane. Some properties of the dipole antenna such as impedance matching and level of Cross-polarization are controlled by the balun.

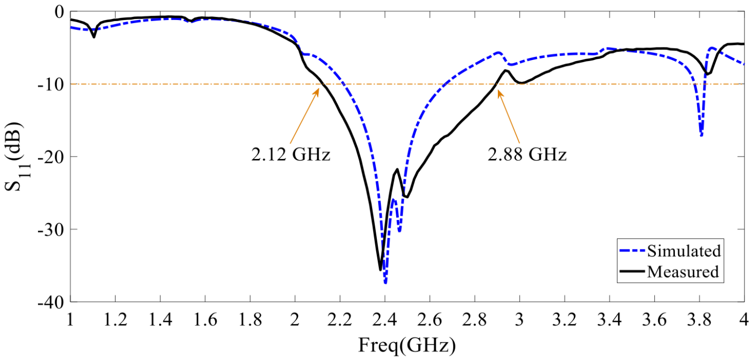



**Figure 2**. Simulated and measured return loss curves of the proposed printed dipole antenna.

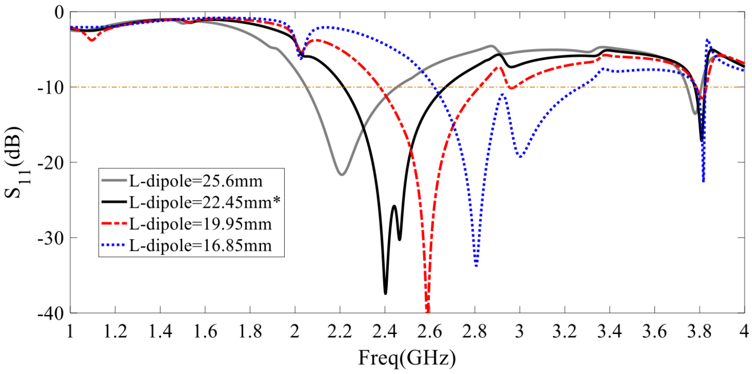



**Figure 3**. S11 response as a function of L-dipole.

Moreover, dipole length adjusts the operating frequency band of the antenna. Figure 2 shows the simulated and measured return loss responses of the proposed printed dipole antenna. According to the measurement, the dipole antenna has a wide impedance bandwidth (IBW) of 700 MHz from 2.12 GHz to 2.88 GHz, which covers 2.4 GHz WLAN frequency band. It has been found that the operating frequency band is governed mainly by the length of the dipole arms. Figure 3 shows the simulated IBW of the antenna as a function of L-dipole. When L-dipole decreases from 25.60 mm to 16.85 mm, the center frequency band shifts from 2.2 GHz to 2.8 GHz. The simulated and measured gain curves of the proposed antenna at $\theta = 0$ and $\Phi = 0$ direction are plotted in figure 4. It is worth noting that to have an accurate measuring, the steps of measurement setup is chosen 50 MHz. Regarding to the results, 8.82 dBi measured peak gain at 2.5 GHz is achieved for the proposed antenna. The measured and simulated gain values have negligible differences. This discrepancy can be owing to the extra loss inducted by the SMA connector and the alignment inaccuracy of the measurement setup.

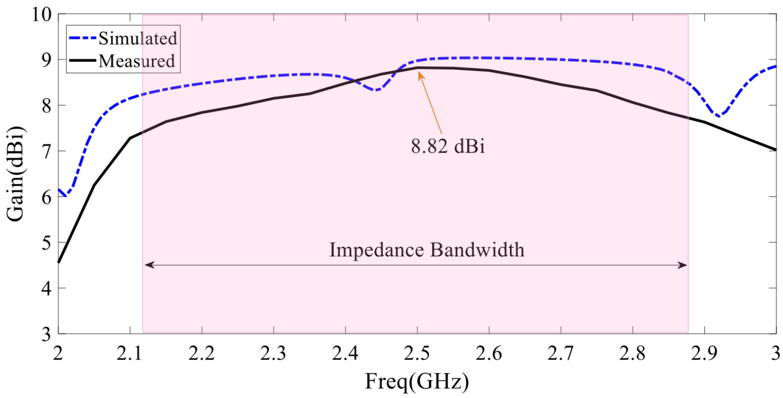
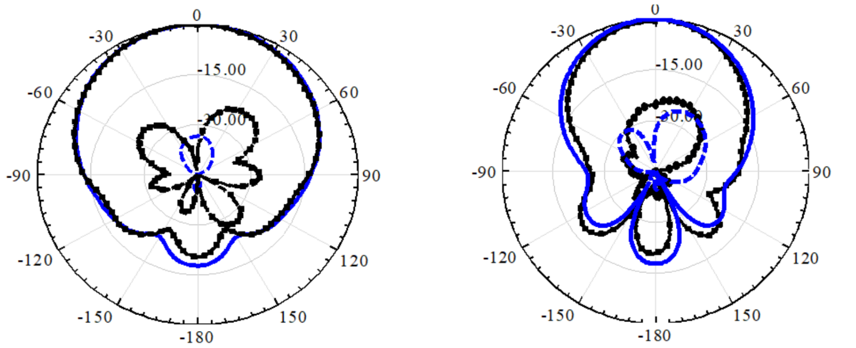



**Figure 4**. Simulated and measured gain of the proposed printed dipole antenna.




(a) (b)

**Figure 5**. Simulated (blue lines) and measured (black lines) radiation patterns of the proposed printed dipole antenna (a) H-plane, and (b) E-plane. (Solid lines are Co-polarization and dash lines are Cross-polarization).

The simulated and measured radiation patterns in the XZ-plane (E-plane) and YZ-plane (H-plane) at 2.4 GHz are depicted in figure 5. As seen, directional radiations along the Z-axis are accomplished, and the simulated and measured results are in a good agreement as well. Also, using the integrated balun to feed the dipole leads to Co-polarization at least 17 dB more than the Cross-polarization.

## 3 MIMO antenna design and discussion

The proposed printed MIMO antenna structure, shown in figure 6, is fed by four coaxial cables that are named as Port-1 to -4. The MIMO antenna substrates are similar to the printed dipole antenna. In this design, two circular substrates with diameters of 80 mm and 50 mm are used for the ground plane and four pairs of dipoles, respectively. Also, four identical integrated balun structures are utilized to feed the dipoles. The numerical and experimental S-parameters for the proposed printed MIMO dipole antenna at four ports is depicted in figure 7 seprately. Simulated results show that the MIMO antenna has a wide impedance bandwidth of 520 MHz from 2.20 GHz to 2.72 GHz, which is suitable for 2.4 GHz WLAN applications.

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According to the measured results, the experimental IBW is a little bit more than simulation results for all ports.

Due to the antenna structure, each dipole is positioned in a perpendicular direction to the next one, which enhances the isolation between them. The center to center distances between the elements are 84.7 mm ($4.25\lambda$) and 60 mm ($3\lambda$) for parallel and orthogonal elements, respectively. Adjacent orthogonal dipoles have different polarization, vertical and horizontal polarizations, to attain appropriate isolation.

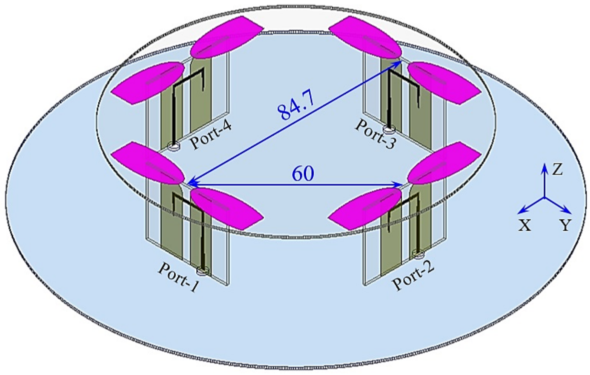


**Figure 6**. The printed MIMO dipole antenna configuration.

Isolation of parallel dipoles with identical polarization is guaranteed by using a suitable distance. So, the distance between them is a little more than perpendicular dipoles. It is well-known that strong mutual coupling between the MIMO elements and high correlation in the channel reduces the performance quality of a MIMO antenna. S-parameters are a way to show a MIMO antenna elements isolation. Figure 8 displays the simulated and measured isolations of the printed MIMO dipole antenna between diffrent ports in this study. According to the results, the isolation between the elements in this design is more than 15 dB.

Diversity of the MIMO system is considered by calculating the envelope correlation coefficient (ECC). A low value of the ECC guarantees the higher data throughput of the MIMO system. Generally, the ECC is calculated between the elements of the MIMO system based on their S-parameters. Due to figures 9 and 10, the measured ECC values of orthogonal and parallel elements are below 0.01 across the operating frequency band (the oprating frequency band is determined in this figure).

Moreover, the simulated gain curves for all ports are ploted in figure 11. Likewise, the simulated and measured gain curves of the proposed printed MIMO dipole antenna at $\theta = 0$ and $\Phi = 0$ direction for Port-1 are displayed by figure 12. Regarding to the results, the measured peak gain of the MIMO antenna for Port-1 is 8.37 dBi at 2.55 GHz.

Furthermore, the simulated and measured radiation patterns in the XZ-plane (E-plane) and YZ-plane (H-plane) at 2.4 GHz for Port-1 are illustrated in figure 13. Similarly to the printed dipole antenna, directional radiation along the Z-axis is achieved for the MIMO antenna. Moreover, the Co-polarization of the pattern is 15 dB more than the Cross-polarization.



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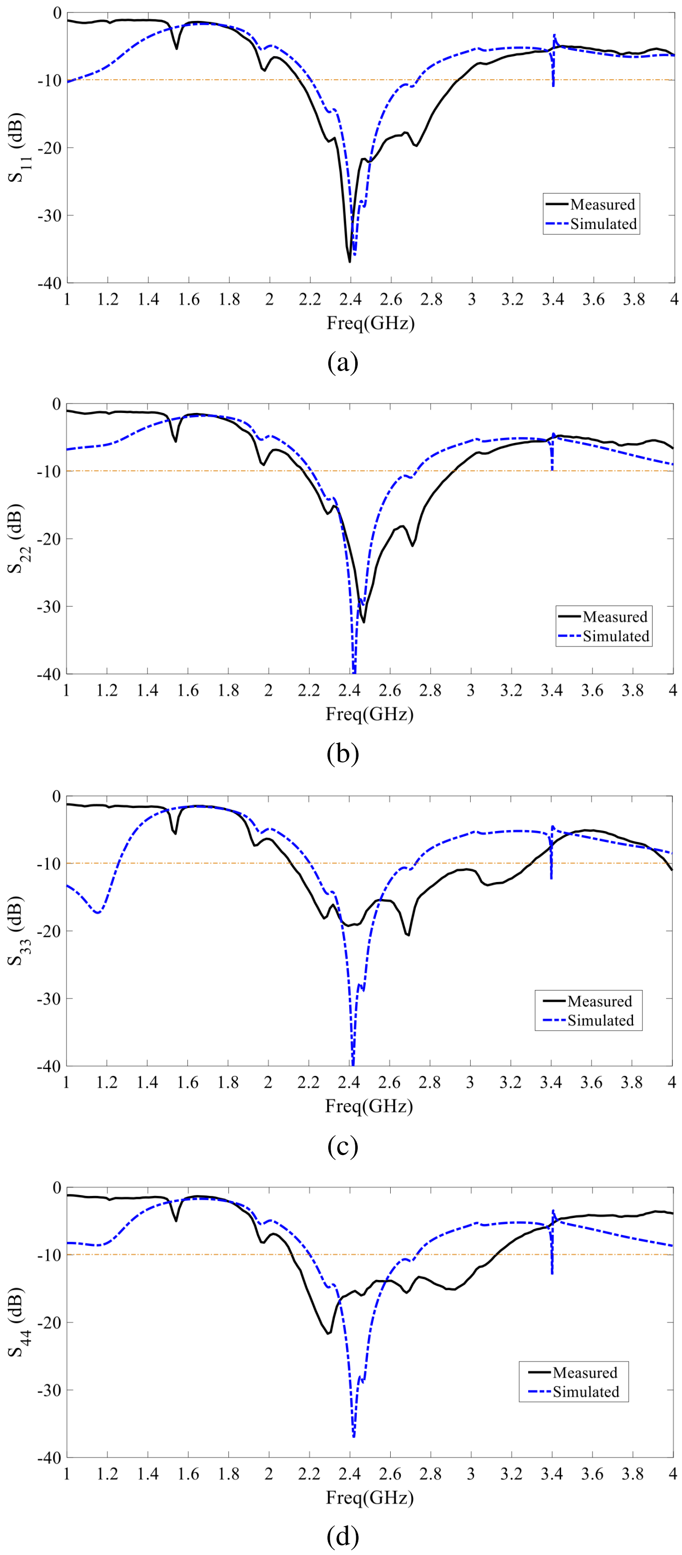


**Figure 7**. Simulated and measured S-parameters for the proposed printed MIMO dipole antenna at, (a) port-1, (b) port-2, (c) port-3 and (d) port-4.

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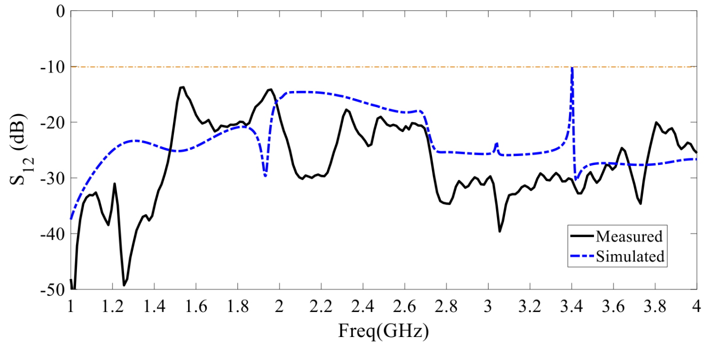
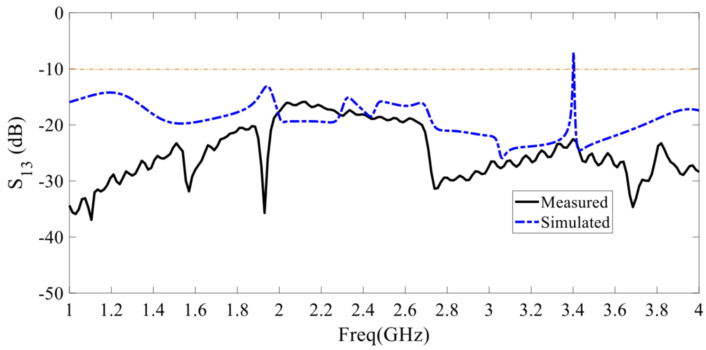
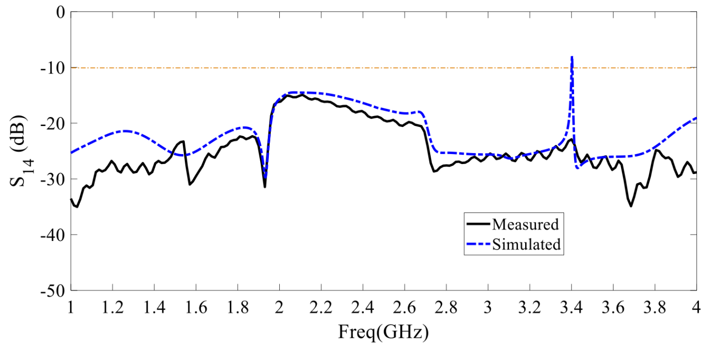


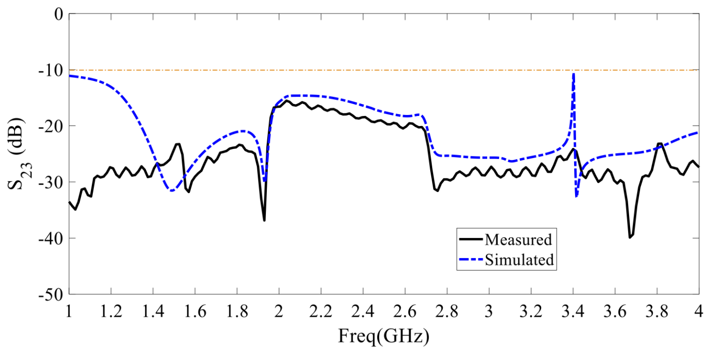

(a)




(b)




(c)




(d)



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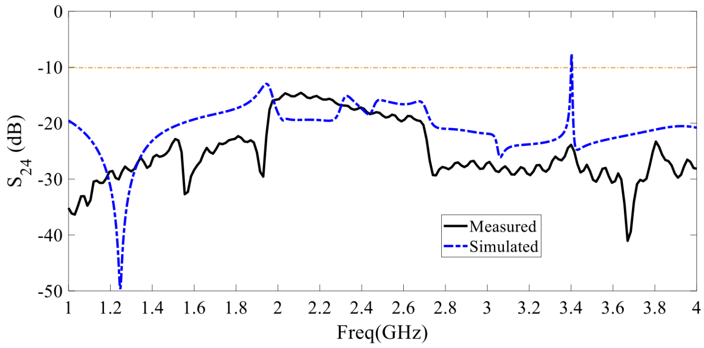
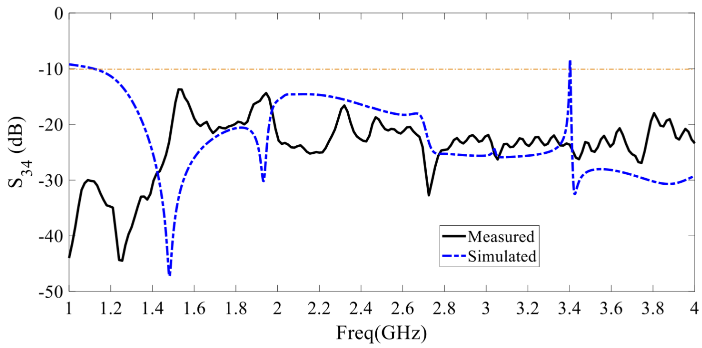



(e)




(f)

**Figure 8**. Simulated and measured isolations for the proposed printed MIMO dipole antenna, (a) S12, (b) S13, (c) S14, (d) S23, (e) S24, (f) S34.

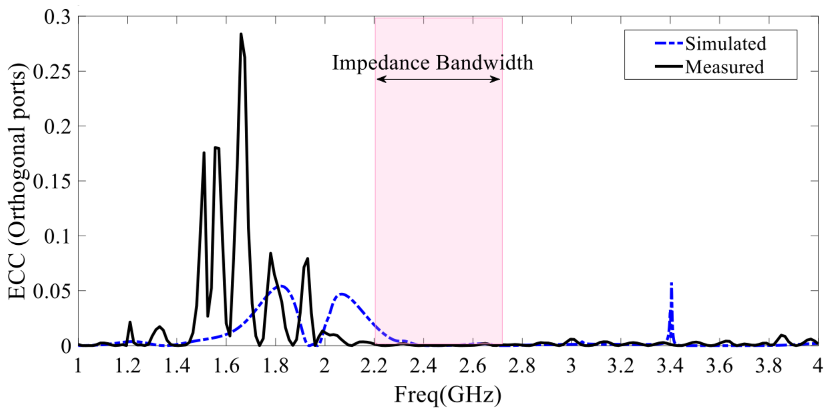



**Figure 9**. Simulated and measured ECC curves of the proposed printed MIMO dipole antenna at orthogonal ports.

In figure 14, the front-to-back ratio (FBR) curves for the single and MIMO antennas across the frequency band are plotted. This figure proves that the FBR parameter for the proposed antennas is more than 15 dB. The proposed antennas in this work are manufactured with optimized dimension. Figure 15 illustrates photographs of the prototype antennas introduced in this letter. Also, in figure 16, two photographs of the proposed antennas inside the anechoic chamber are given.



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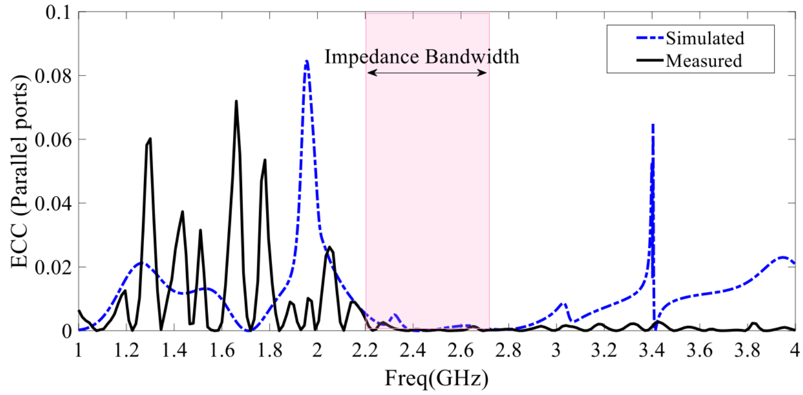


**Figure 10**. Simulated and measured ECC curves of the proposed printed MIMO dipole antenna at parallel ports.

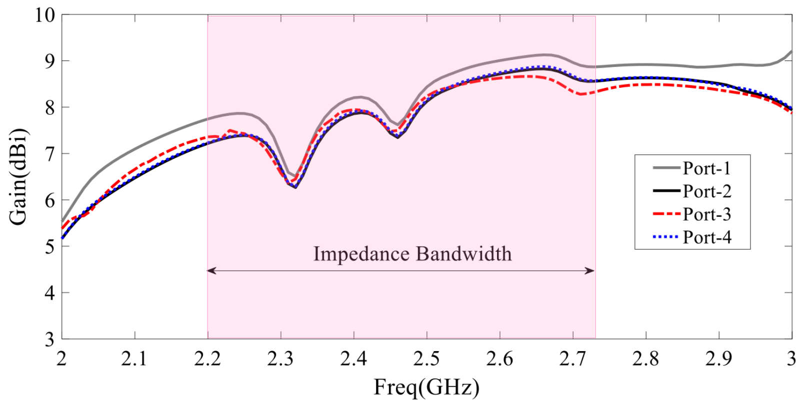


**Figure 11**. Simulated gain curves of the proposed printed MIMO dipole antenna for all ports.

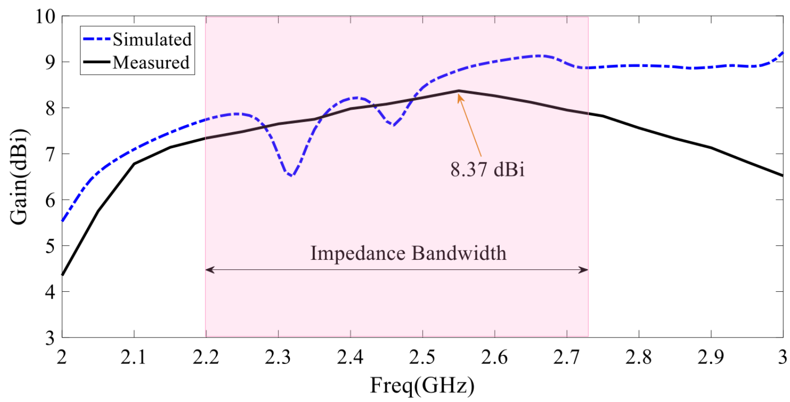


**Figure 12**. Simulated and measured gain curves of the proposed printed MIMO dipole antenna. (Port-1)



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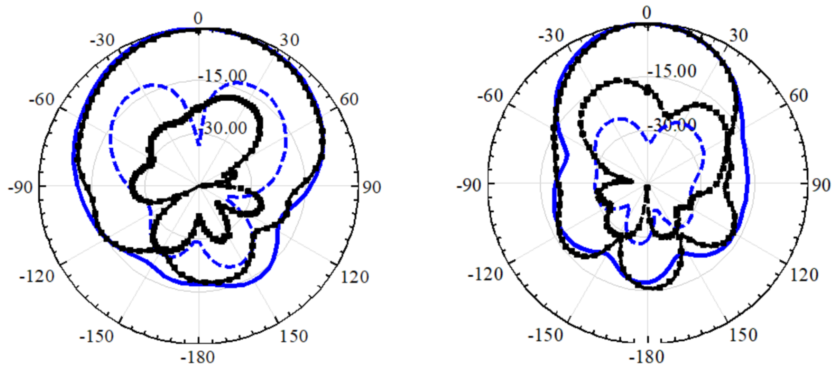



(a) (b)

**Figure 13**. Simulated (blue lines) and measured (black lines) radiation patterns of the proposed printed MIMO dipole antenna (a) H-plane, and (b) E-plane. (Solid lines are Co-polarization and dash lines are Cross-polarization).

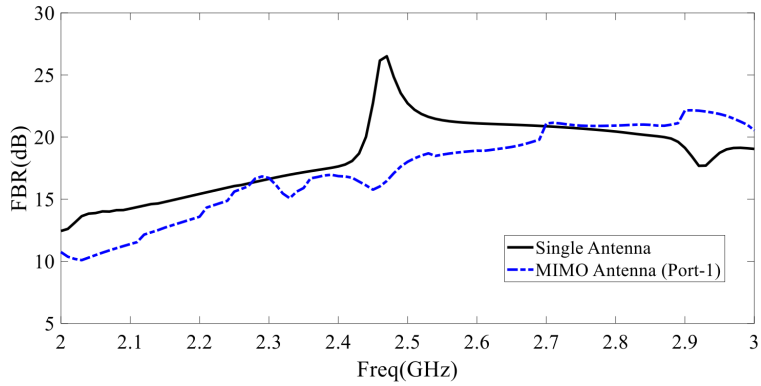


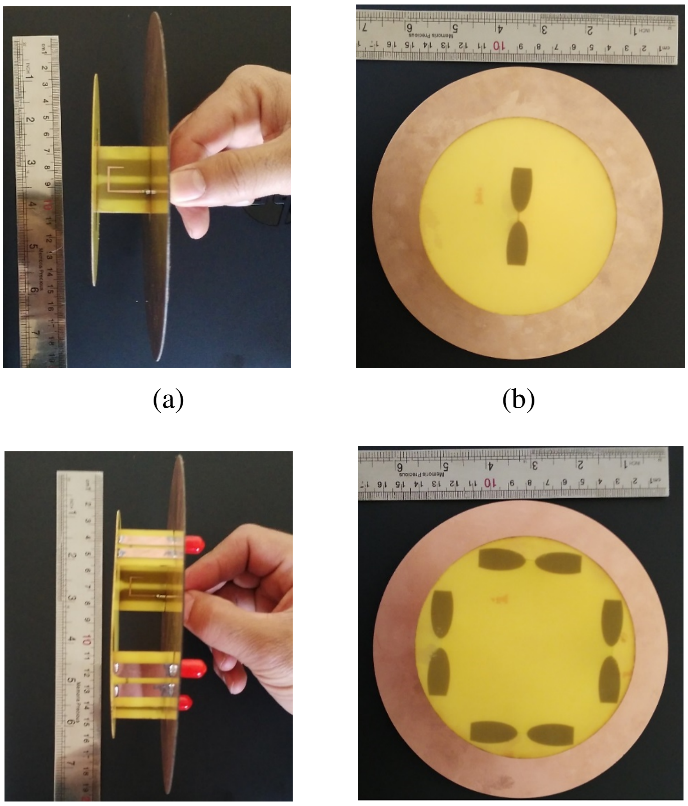

**Figure 14**. FBR curves for the proposed antennas.

## 4 Conclusion

A printed dipole antenna is presented in this letter for MIMO system applications. The proposed MIMO antenna consists of four pairs of printed dipoles placed vertically next to each other and fed by integrated baluns. The advantages of this new design are structural simplicity, proper radiation pattern, and low Cross-polarization. Besides, it is possible to control the antenna operating frequency band by changing the length of dipoles. Additionally, the proposed structure has a wide impedance bandwidth of 520 MHz from 2.20 GHz to 2.72 GHz, which is suitable for 2.4 GHz WLAN applications and it has a maximum gain of is 8.37 dBi at 2.55 GHz frequency.

## Acknowledgments

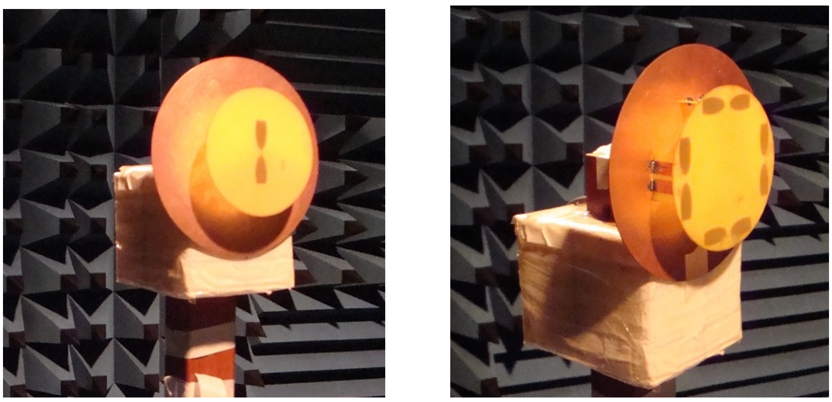
The authors would like to thank the Northwest Antenna and Microwave Research Laboratory (NAMRL) at Urmia University for technical supports.



(a) (b)

(c) (d)

**Figure 15**. Photographs of the manufactured proposed antennas, (a) and (b) printed dipole antenna, (c) and (d) printed MIMO dipole antenna.



(a) (b)

**Figure 16**. Photographs of the proposed antennas at the antenna labratoary, (a) printed dipole antenna, and (b) printed MIMO dipole antenna.

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