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Compact Ultrawideband MIMO Antenna with WLAN/UWB Bands Coverage

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Abstract—A compact multiple-input-multiple-output (MIMO) antenna that covers the WLAN (2.4 GHz) and UWB (3.1–10.6 GHz) bands for wireless device applications is presented. The proposed antenna consists of two open L-shaped slot (LS) antenna elements and a narrow slot on the ground plane. The antenna elements are placed perpendicularly to each other to obtain a high isolation, and the narrow slot is added to reduce the mutual coupling between antenna elements at the WLAN band (2.4 GHz). The presented MIMO antenna has a small size of $40 \times 40\,\mathrm{mm}^2$, and the prototypes of antenna is fabricated and measured. The measured results show that the antenna has an impedance bandwidth of larger than 2.4–10.6 GHz with the mutual coupling less than 20 dB in WLAN band and 18 dB in 3.1–10.6 GHz, making the antenna a good candidate for portable applications.

1. INTRODUCTION

In recent years, multiple-input–multiple-output (MIMO) technology, which involves the use of multiple antennas at both the transmitter and receiver, is used to significantly enhance the data transmission performance and channel capacity without sacrificing additional energy and bandwidth [1]. With these advantages, the MIMO technology has been introduced to portable terminals to realize high-speed data transmission, such as WCDMA, WiMAX, WLAN, LTE and UWB [2–8].

In the design process of the MIMO antennas for the portable terminal systems, two main challenges are faced. One is to get the compact antenna elements for the MIMO antenna systems. Further, in most cases, these antenna elements should have directional gains. This is especially difficult when the frequency is low, such as WLAN (2.4 GHz) band. The second challenge is to enhance the isolation between the antenna elements. At the same time, the methods used to reduce mutual coupling should have little effect on the wideband impedance matching for the UWB application.

In order to overcome these challenges, various approaches have been proposed. The eigen-mode decomposition scheme is used to reduce the coupling between two closed monopoles [9] and loop antennas [10]. The low mutual coupling can also be obtained by using the inserted component scheme [11–13]. This method is useful for achieving high performance MIMO antenna, especially for the single band operation. In addition, the artificial structures, such as the Electromagnetic Band Gap (EBG) structures [14] and Defected Ground Structures (DGS) [15] are also introduced to the MIMO antenna design. However, all the methods mentioned above have narrow bandwidths which make the antennas not suitable for the UWB application. To get a wide-band MIMO antenna, the UWB diversity antennas are usually used [16–18]. The principle of this method is similar to the dual polarized antennas. As the gain patterns of the antenna elements are perpendicular, the coupling between the antennas is low. Besides, in order to enhance the isolation between antenna elements, the decoupling structures are also used in the MIMO antennas for UWB applications [2, 19–22], such as ground branches [19], tree-like structure [20] and parasitic meander lines [2].

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In this paper, a compact MIMO antenna for WLAN/UWB applications is proposed. The antenna has a compact size of $40 \times 40\,\text{mm}^2$, which is only about 70% and 25% of the antennas proposed in [21] and [22], respectively. Two open L-shaped slot antennas [23] are placed perpendicularly to each other, and a $\lambda/4$ open narrow slot is added between the antenna elements to enhance the isolation in the lower band. The prototypes of UWB antenna are constructed and measured. The measured results show that the isolation is better than 20 dB and 18 dB in the WLAN band and the whole UWB band (20 dB in most of the band), respectively. The design process is described in detail in the following sections.

2. ANTENNA DESIGN AND SIMULATED RESULTS

2.1. Antenna Design

The geometry of the proposed WLAN/UWB MIMO antenna, with a small size of $40 \times 40\,\text{mm}^2$ is shown in Figure 1. It is printed on an FR4 substrate with relative permittivity of 4.4 and thickness of 0.8 mm. The UWB open L-shaped slot antenna presented in [23] is used as a reference, and the antenna's dimensions are optimized to get a smaller size. The proposed MIMO antenna consists of two L-shaped slot antenna elements, denoted as LS 1 and LS 2. The two LSs are placed perpendicularly to each other to achieve good isolation between the two antenna elements.

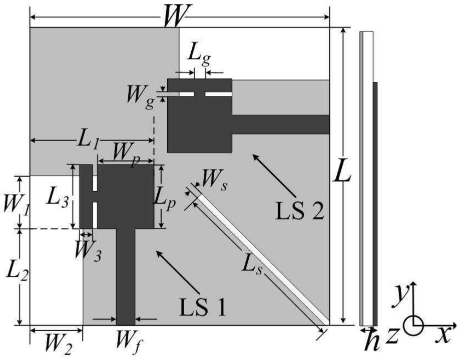


Figure 1. Geometry of the proposed antenna, top view and side view.

The element antenna consists of a L-shaped slot and a rectangular patch fed by a 50-Ω microstrip line. To obtain the bandwidth enhancement for UWB applications, a T-shaped stub is attached to the rectangular patch, which consists of a horizontal stub W_g and a vertical stub L_3. In order to enhance the isolation between the antenna elements at the low band, a narrow rectangular slot with a size of $L_s \times W_s$ is cut on the left bottom of the ground plane. By optimizing the length of the narrow slot, good isolation can be obtained in the interesting bands.

For the required numerical analysis and obtaining the proper geometrical parameters, computer simulation using the EM simulation tool CST Microwave Studio is carried out. The SMA connector was included in the simulated model to improve the simulation precision. The final optimized dimensions of the MIMO antenna are listed in Table 1.

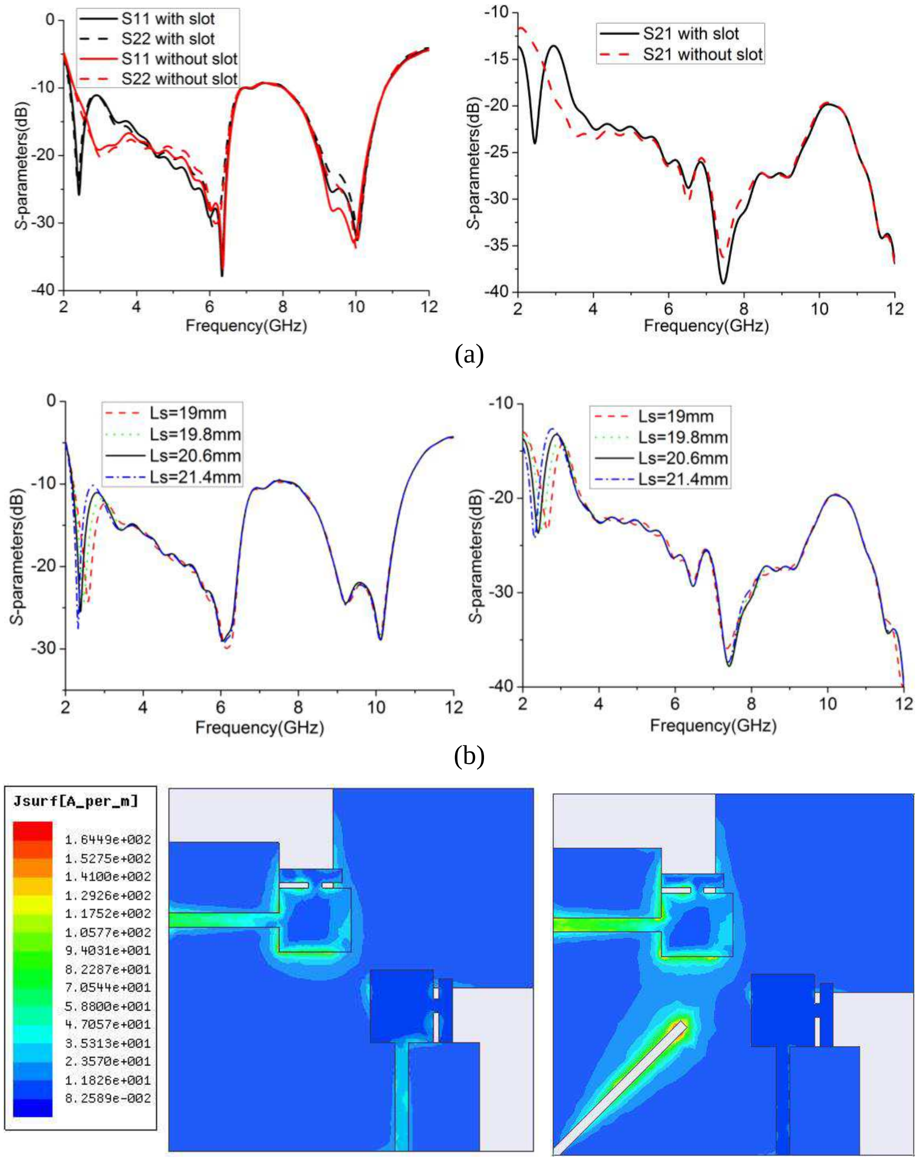
Table 1. Design parameters of the proposed MIMO antenna shown in Figure 1.

Parameters	W	L	L_1	L_2	L_3	W_1	W_2	W_3
Unit (mm)	40	40	18	12	7	6	6	1.5
Parameters	L_g	W_g	L_p	W_p	L_s	W_s	h	W_f
Unit (mm)	1.5	0.6	8	7	20.2	1	0.8	1.53

2.2. Effects of Narrow Ground Slot

The narrow rectangular slot is introduced on the ground to reduce the mutual coupling between two antenna elements in the WLAN (2.4 GHz) band. The slot, which resonates at the length of about $\lambda_g/4$, makes the current mainly distribute near it at the resonant frequency and leads to improved isolation, shown in Figure 2. Figure 2(a) shows the simulated S-parameters with and without the narrow slot. As can be seen, before adding the slot, S_{21} is as high as -10 dB from 2 to 2.5 GHz. Affected by the low isolation, the S_{11} of the antenna at 2.4 GHz band is not so good, which only reaches about -14 dB. When the slot is present, the value of S_{21} is significantly reduced to less than -20 dB at 2.4 GHz band and less than -18 dB at the UWB band. At the same time, the antenna has a good impedance matching over the interesting bands, meeting the requirement of typical MIMO/diversity antennas.

Figure 2(b) gives the simulated S-parameters of the proposed antenna with different lengths of the



(a)

(b)

(c)

Figure 2. (a) Simulated S-parameters with and without slot. (b) Simulated S-parameters with different length of slot. (c) The current distribution at 2.4 GHz.

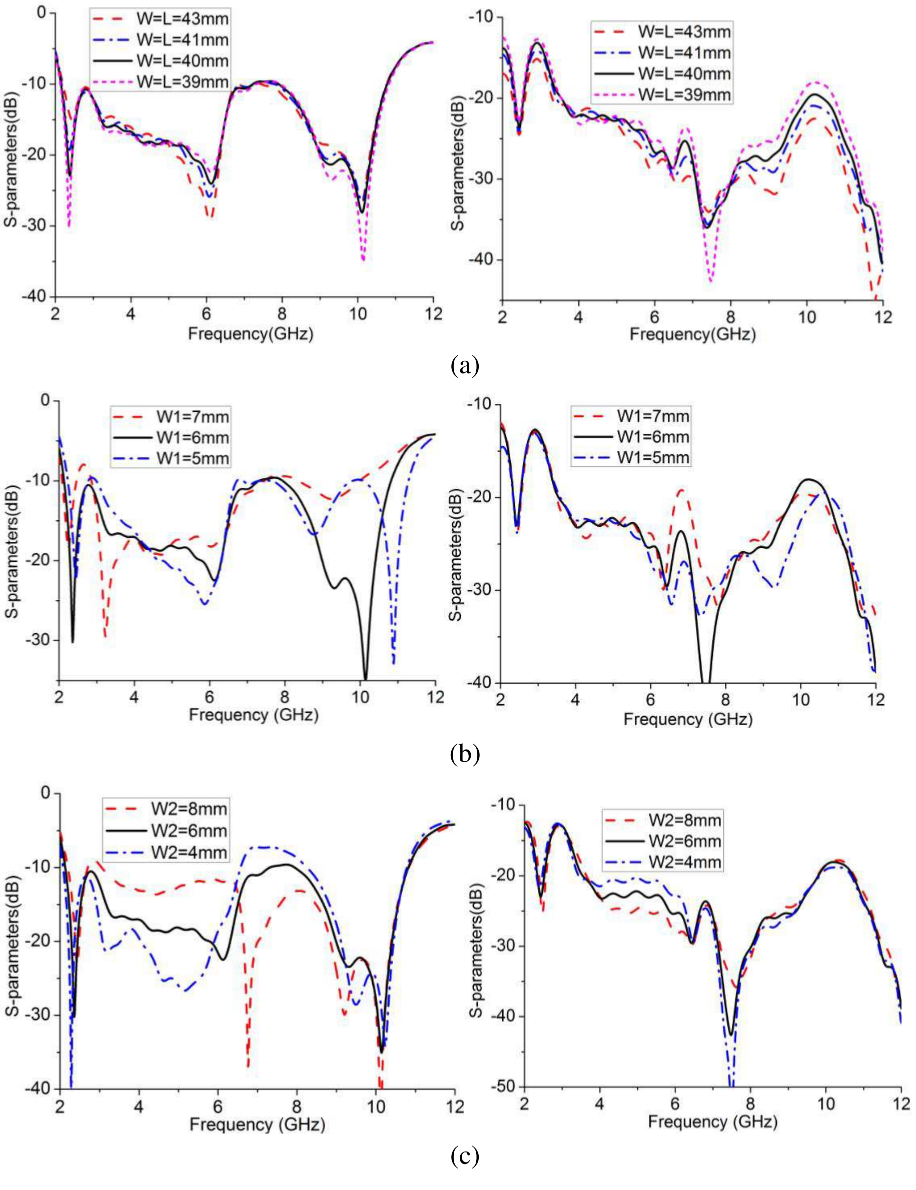
slot. The simulated results reveal that with the increase of the length, the high isolation band moves to lower frequency. The optimized value of L_s is 20.2 mm.

To further express the influence of the rectangle slot, Figure 2(c) compares the surface current distributions with and without the slot at the resonant frequency 2.4 GHz. As seen, the current flowing from port 1 to port 2 is blocked by the slot, and when port 1 is excited, the coupling current on antenna 2 is reduced significantly. The effect is the same from port 2 to port 1.

2.3. Parameter Study

In order to understand the effects of various parameters and to optimize the performance of the final design, a parameter study is carried out in this section.

For the proposed antenna, the size of the ground plane has an effect on the performance of the antenna. Figure 3(a) shows the simulated S-parameters for the proposed antenna with different W and



(a)

(b)

(c)

Figure 3. (a) Simulated S_{11} and S_{21} against frequency for the proposed antenna with various W and L. (b) Simulated S_{11} and S_{21} with various W_1. (c) Simulated S_{11} and S_{21} with various W_2.

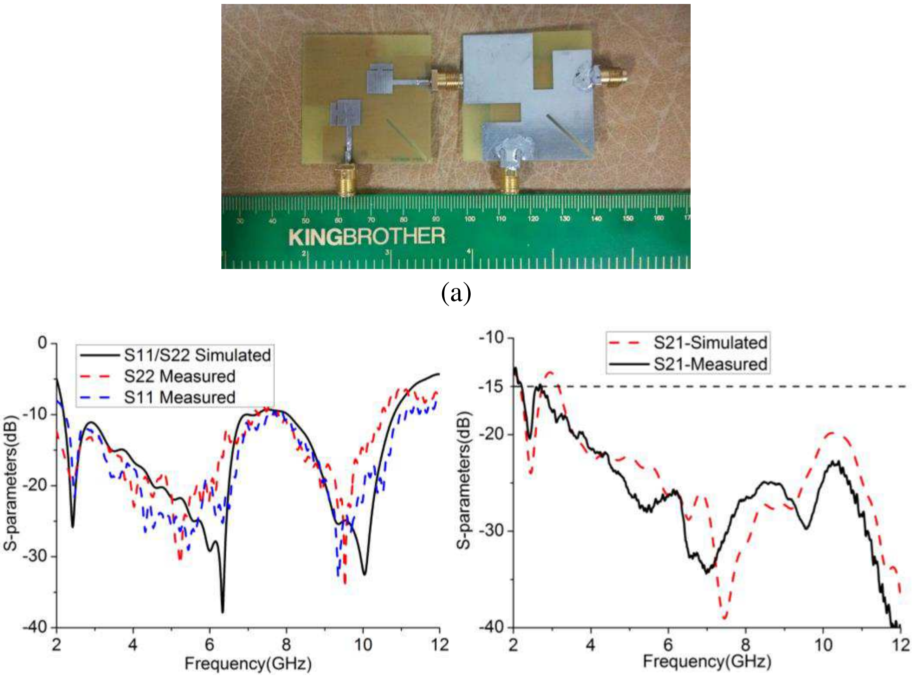
L. It is seen that with the increase of size of the ground plane, the return loss of the antenna varies little, but isolation between the antenna elements decreases, which is caused by the increase of the distance of the antenna elements. This is especially significant at the high band (6–12 GHz). In order to get a compact size and high isolation, W and L are chosen as 40 mm.

Besides the size of the ground plane, the dimensions of the L-shaped slot also have significant effect on the performance of the antenna. Figures 3(b) and (c) give the simulated S-parameters with different W_1 and W_2. It can be seen that with W_1 or W_2 increasing, the resonating frequency of the antenna shifts to low frequency, and the isolation between the antenna elements almost has no change. By optimizing the values of W_1 and W_2, good impedance matching can be obtained in the interesting band.

3. RESULTS AND DISCUSSIONS

3.1. Return Loss and Isolation between Ports

A prototype of the L-shaped slot MIMO antenna described in Section 2 is fabricated, and the picture is shown in Figure 4(a). The bandwidth performance of this proposed antenna is measured by the Anritsu 37269A vector network analyzer. Figures 4(b) and (c) give the simulated and measured S-parameters of proposed antenna. As indicated in Figure 4(b), port 1 has a bandwidth from 2.2 to 10.9 GHz for $S_{11} < -10$ dB, and port 2 has a bandwidth from 2 to about 11.1 GHz for $S_{22} < -10$ dB. The antenna satisfies the impedance matching requirement for the WLAN (2.4 GHz) band and the entire UWB specified by the FCC. The simulated and measured mutual couplings between the two ports are shown in Figure 4(b). It can be seen that the isolation between the antenna elements has a dual-band characteristic. In the WLAN (2.4 GHz) band, the value of the measured S_{21} is lower than -20 dB. And throughout the whole UWB band, the measured isolation is below 18 dB (more than 20 dB during 3.6–12 GHz). As the mutual coupling less than 15 dB is enough for the UWB applications [13], the antenna is suitable for MIMO operation across the entire UWB band.

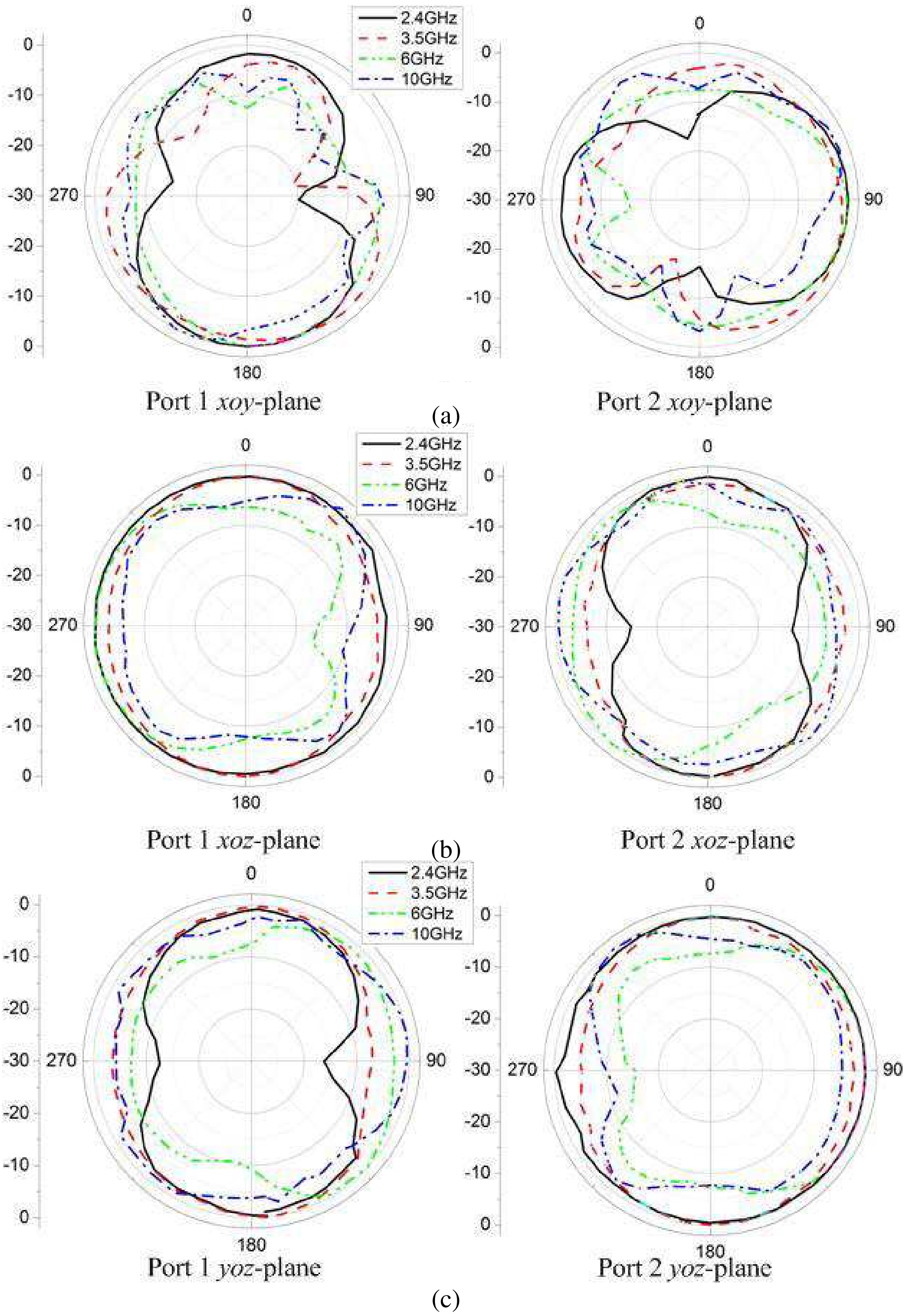


(b) (c)

Figure 4. (a) Fabricated prototype antenna. (b) Simulated and measured S_{11} and S_{22}. (c) Simulated and measured S_{21}.

3.2. Radiation Patterns

Figure 5 illustrates the measured 2-D radiation patterns (xoy-, xoz- and yoz-planes) of the proposed antenna at 3.5 GHz, 6 GHz and 10 GHz when port 1 is excited. Port 2 is terminated with a 50-Ω load, and vice versa. From the results, it can be seen that at 2.4 GHz, antenna 1 and antenna 2 have monopole-like patterns. The radiation patterns in the H-plane (the xoz-plane of port 1 and the yoz-plane of port 2, respectively) are omnidirectional, and the radiation patterns in the E-plane (yoz-plane of port 1 and xoz-plane of port 2) are dumb-bell shaped. At 3.5 GHz, affected by the ground plane, the antenna's



(a)

(b)

(c)

Figure 5. Measured radiation pattern of the proposed antenna at 2.4, 3.5, 6, and 10 GHz: (a) xoy-plane; (b) xoz-plane; (c) yoz-plane.

pattern in the E-plane is deviate to the opposite side of the narrow slot. At the higher frequency of 6 GHz, LS 1 and LS 2 have quasi-omnidirectional radiation patterns in the H-plane. However, at the higher frequency of 10 GHz, the radiation patterns in the H-plane are less omnidirectional because of higher-order resonant modes.

The measured peak gains and radiation efficiency of the antenna with ports 1 or 2 excited are shown in Figure 6. It can be seen that the measured peak gains range from 2.3 to 5.2 dB across the frequency band from 2.4–10.6 GHz and that the radiation efficiency is above 60%. The gain is lower than that of [14, 15] as the antenna has a smaller size. A gain decrease can be found at the high frequency, and this is mainly because the substrate that we used is commercial available, and the efficiency of the antenna deceases for the dielectric loss.

3.3. Diversity Performance

For the antenna used for MIMO application, the two-port ECC is an important parameter, and for a lossless MIMO antenna, the ECC can be calculated using the method proposed in [24].

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

The simulated and measured ECC curves are plotted in Figure 7. The results show that the measured ECCs are below 0.01 during the WLAN (2.4 GHz) and below 0.005 through the whole UWB band, which is low enough to make the presented MIMO antenna have a good diversity performance.

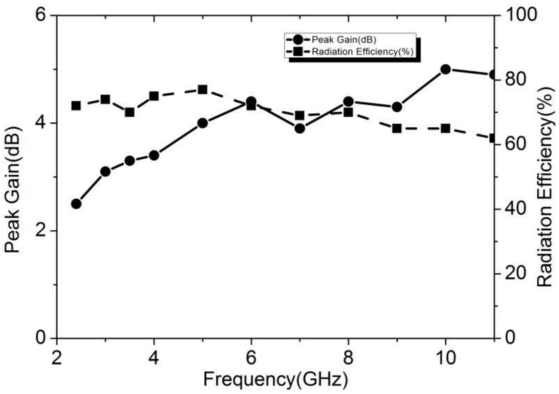


Figure 6. The measured gain and radiation efficiency of the proposed antenna.

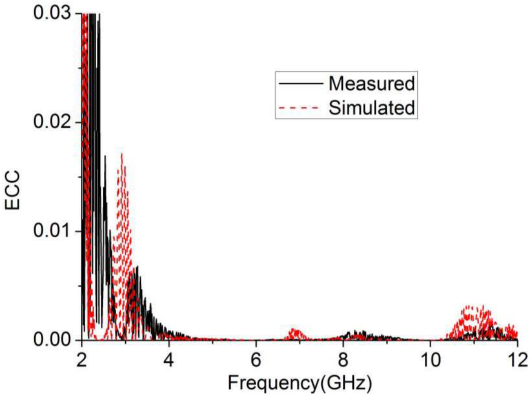


Figure 7. Simulated and measured envelope correlation coefficient (ECC).

4. CONCLUSION

A compact MIMO antenna that consists of two open L-shaped slot antennas is presented for WLAN/UWB applications. In order to reduce the mutual coupling of antenna elements at the low frequency (2.4 GHz), a narrow slot is added to the ground plane. The prototypes of the antenna is fabricated and measured. The measured results show that the proposed antenna has an impedance bandwidth of larger than 2–10.6 GHz, low mutual coupling of less than 20 dB in the WLAN band and 18 dB through the whole UWB band which make the antenna a good candidate for WLAN/UWB applications.

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