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A Tri-Band MIMO Antenna for WLAN/WiMAX Application

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Abstract—A tri-band multiple-input-multiple-output (MIMO) antenna that covers all frequency bands required for WLAN and WiMAX applications is presented. Three resonant bands are achieved by a folded monopole with a compact size of $11.5 \times 15.6\,\text{mm}^2$. The MIMO system consists of two symmetrically placed monopoles. A stepped slot ended with an ellipse on the ground plane is etched to reduce the mutual coupling between the two monopoles. The overall dimension of this MIMO system is $50 \times 50\,\text{mm}^2$. The prototype of the antenna is fabricated and measured. Measured results show that the antenna's impedance bandwidth is 450 (18%), 350 (10%), 1200 (21.8%) MHz at the three resonant frequency points (2.5 GHz, 3.5 GHz, 5.5 GHz) with mutual coupling between the antenna elements less than −18 dB in whole frequency band, making this antenna a good candidate for portable application.

1. INTRODUCTION

The MIMO technology, characterized by using multiple antennas as transmitter and receiver, exploits the multipath property to improve the communication quality, increase the system capacity and achieve high data rates [1]. With these advantages, MIMO technology has been introduced to portable terminals such as laptops, mobile phones, USB dongles and others to realize high-speed data transmission [2–6]. In the design process of the MIMO antennas for WLAN/WiMAX, the main challenge is to ensure sufficiently wide bandwidth to support WLAN/WiMAX application while maintaining high isolation between the antenna elements within a compact size. Three operating bands are achieved by inserting a pair of T-shaped strips into a wide rectangular slot in [7]. In [8], a modified F-shaped slot antenna for WLAN/WiMAX is presented. But the bandwidth of these antennas is not enough to cover the whole band for WLAN/WiMAX. The mutual coupling less than −15 dB was achieved through the two grounded branches [9]. A T-shaped parasitic element was added on the ground plane in [10] to reduce the mutual coupling. In [11], the elements of the system are placed vertically to obtain high isolation. However, the isolation in most of these letters is not high enough.

In this letter, a compact MIMO antenna for WLAN/WiMAX application is presented. Two modified C-shaped monopoles are symmetrically placed upon a same ground to form a MIMO system. The three resonant bands achieved by the folded monopoles are 2.3–2.75 GHz, 3.4–3.75 GHz, 4.8–6 GHz, utilizing a limited space of $11.5\times15.6\,\text{mm}^2$. A stepped slot ended with an ellipse is etched on the ground to mitigate the mutual coupling. 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 antenna is shown in Fig. 1. It is printed on a FR4 substrate with relative permittivity of 4.4 and a thickness of 0.8 mm. The overall dimension is $50\times50\,\text{mm}^2$. The three resonant

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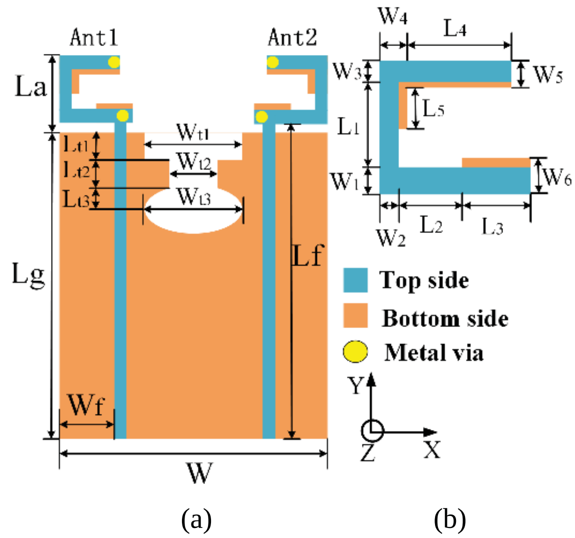

Figure 1. Geometry of the proposed antenna.

frequency points are achieved by the C-shape and the branches on the bottom side connected with the main antenna. A stepped slot ended with an ellipse is etched on the ground to reduce the mutual coupling between the two monopoles.

For required numerical analysis and obtaining the proper geometrical parameters, computer simulation using the EM simulation tool HFSS 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 antenna shown in Fig. 1.

Parameters	W	L_g	W_f	L_f	L_a	W_{t1}	W_{t2}	W_{t3}	L_{t1}	L_{t2}	L_{t3}
Unit (mm)	50	36.3	11.5	38.5	13.7	11.8	6.5	10.9	2.5	3	2.8
Parameters	W_1	W_2	W_3	W_4	W_5	W_6	L_1	L_2	L_3	L_4	L_5
Unit(mm)	2.4	1.8	2.4	2.4	2.4	2.4	6.7	6.6	6.6	7.6	4.2

2.2. Evolution of the Antenna

Figure 2 shows the evolution of the proposed antenna. To obtain a compact size, the branch of the antenna for the lower frequency resonating is meandered on the bottom side. The tri-band element antenna (referred as antenna 1) is the prototype of the proposed antenna. As shown in Fig. 3(a), S_{11} of antenna 2 has three resonance frequencies centered at 2.4 GHz, 3.5 GHz and 5.4 GHz respectively. For the purpose of meeting the increasing demand for high quality and high data rate communication, naturally two elements can be symmetrically placed to work as a MIMO system. The antenna 2 of Fig. 2 shows the appearance of the initial MIMO antenna. As the two antenna elements are placed closely, the mutual coupling between the antenna elements is intense. The S_{21} of antenna 2, shown in Fig. 3(a), is as high as -12 dB at the middle frequency band and -8 dB at upper frequency band. So the decoupling structure is necessary to ensure the two antennas system operating as MIMO system normally. As shown in Fig. 2(c), a stepped slot ended with an ellipse is introduced onto the ground. Fig. 3(a) shows that the S_{21} of the MIMO system with decoupling structure is less than -18 dB at the middle frequency band and less than -20 dB at the lower and upper frequency bands. This indicates that this antenna system is suitable for WLAN/WiMAX applications worked as a MIMO system.

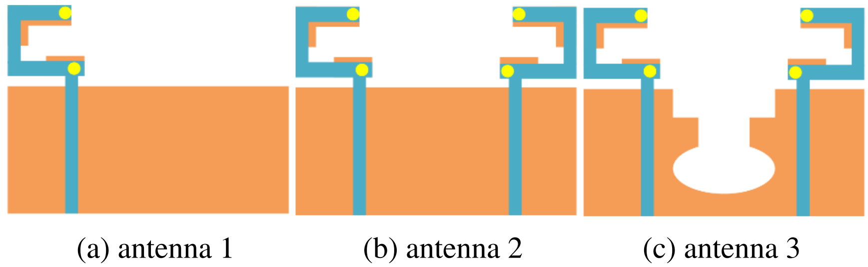

Figure 2. Evolution of the antenna.

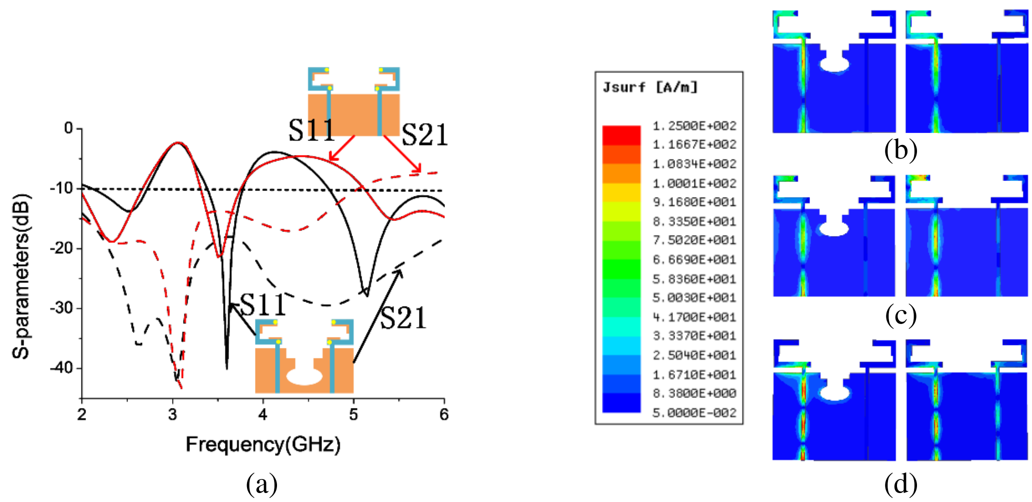

Figure 3. (a) Simulated S-parameters of antenna 2 and antenna 3. (b) The current distribution at 2.5 GHz. (c) The current distribution at 3.5 GHz. (d) The current distribution at 5.5 GHz.

Figures 3(b), (c) and (d) show the surface current distributions with and without the decoupling structure on the ground at the resonate frequency 2.5 GHz, 3.5 GHz, 5.5 GHz respectively. As it is seen, when the port 1 is excited, the coupling current on the antenna 2 is reduced significantly. The effect is the same from port 2 to port 1.

2.3. Effects of the Shape of the Decoupling Structure

In order to understand the physical principles behind the decoupling structure, the effects of the shape of the slot on the ground are studied in this section. As shown in Fig. 4(b), the shape of the decoupling structure has little effect on S_{11} of the three antennas. But the isolation between the antenna elements is enhanced obviously at the middle frequency band when the antenna evolves from antenna a to antenna c.

3. RESULTS AND DISCUSSIONS

3.1. Return Loss and Isolation Between Ports

A prototype of the modified C-shaped MIMO antenna is fabricated, and the picture is shown in Fig. 5(a). The bandwidth performance of this proposed antenna is measured by the Anritsu 37269 A vector network analyzer. As indicated in Fig. 5(b), the bandwidth for $S_{11} < -10$ dB is 2.3–2.75 GHz, 3.4–3.75 GHz, 4.8–6.0 GHz. Which is wide enough to satisfy WLAN and WiMAX applications. It can be seen from Fig. 5(b) that the measured mutual coupling between the two ports is less than -18 dB in the whole measured band, making antenna suitable for MIMO operation across the whole WLAN/WiMAX bands.

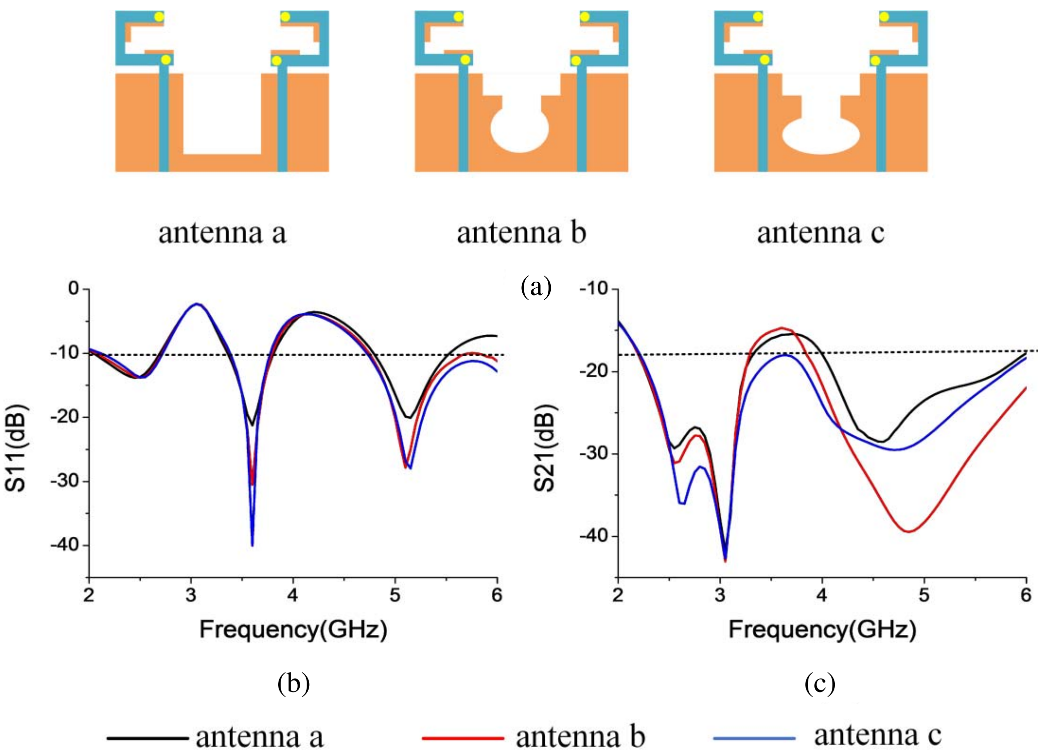

Figure 4. (a) Evolution of the decoupling structure. (b) Simulated S_{11} of the three antennas. (c) Simulated S_{21} of the three antennas.

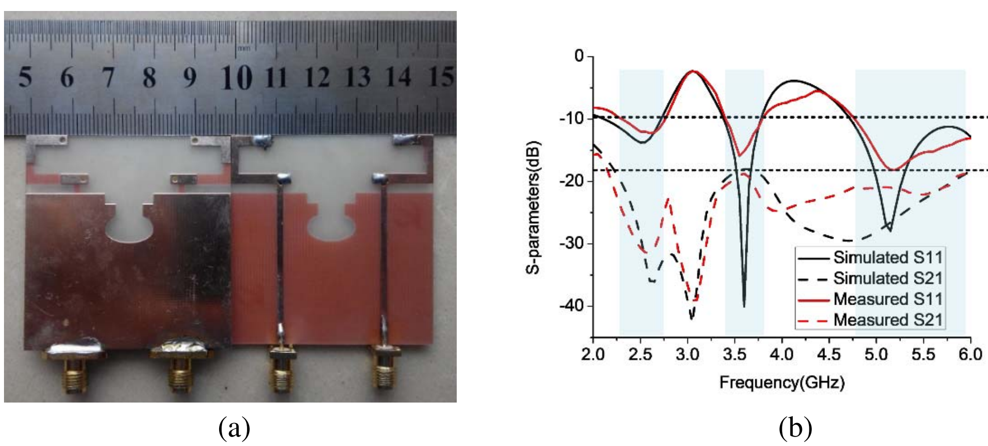

Figure 5. (a) Fabricated prototype antenna. (b) Simulated and measured S-parameters.

3.2. Radiation Patterns

Figure 6 illustrates the measured 2-D radiation patterns (xoz and yoz planes) of the proposed antenna at 2.4 GHz, 3.5 GHz and 5.5 GHz. The antenna has monopole-like patterns at 3.5 GHz. Affected by the imperfection of the ground plane, the radiation pattern in the E-plane are dumb-bell shaped at 2.4 GHz and 5.5 GHz. As seen in Fig. 7, the peak gains of 3.04, 3.06 and 3.89 dBi occur at frequencies of 2.5, 3.5 and 5.5 GHz, respectively. A gain decrease can be found at the middle frequency band, and this is mainly because of the dielectric loss of commercial available substrate which we used.

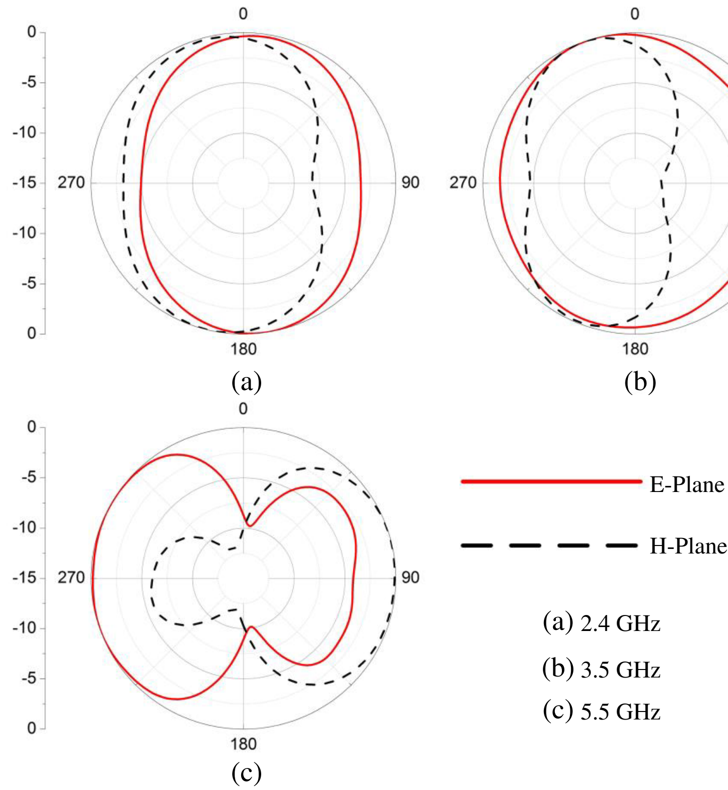

Figure 6. Measured radiation patterns of the proposed antenna system when port 1 is excited.

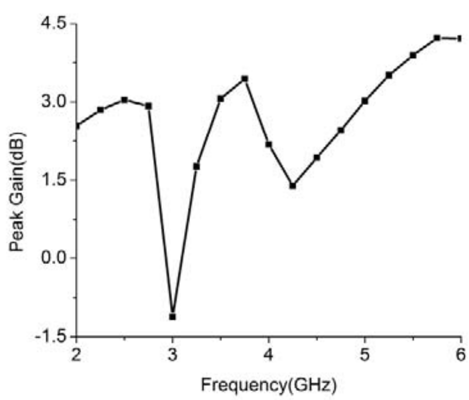

Figure 7. The measured gain of the proposed antenna.

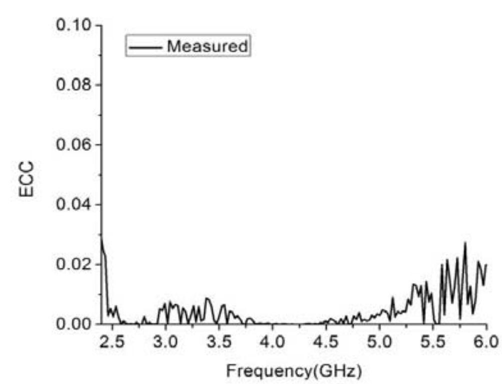

Figure 8. Measured envelope correlation coefficient (ECC).

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 [12].

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

The measured ECC curve is plotted in Fig. 8. The results show that the measured ECCs are below 0.03 during the whole frequency band and low enough to make the presented MIMO antenna have a good diversity performance.

4. CONCLUSION

A compact tri-band MIMO antenna that consists of two folded monopoles is presented for WLAN/WiMAX applications. In order to reduce the mutual coupling between the antenna elements at the operated bands, a stepped slot ended with an ellipse is etched on the ground plane. The prototypes of the antenna are fabricated and measured. The measured results show that the proposed antenna's impedance bandwidth can fully meet the requirement of WLAN and WiMAX applications. Low mutual coupling less than −18 dB in the whole band and excellent ECC values make the antenna a good candidate for modern communication devices in WLAN and WiMAX applications.

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