Compact ACS-Fed UWB MIMO Antenna with Dual Band Notches

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Abstract **─** In order to improve the channel capacity of communication equipment and reduce the size of antenna, an asymmetric coplanar strip (ACS) fed four-element UWB MIMO antenna with dual band notches is proposed in this paper. The antenna has a simple structure and a compact size of 37×37 mm². The antenna consists of four modifled staircase-shaped radiation elements and four floor on the same side. The antenna elements are placed vertically without additional decoupling structure, and the isolation less than -15 dB in the working bandwidth of 2.9-10.6 GHz can be obtained by using polarization diversity. In addition, the antenna has the notched characteristic of WiMAX and WLAN band. The antenna has good gain and low envelop correlation coefficient (ECC), and the simulation results agree with the measured results, which indicates that the antenna is suitable for UWB system.

Index Terms **─** ACS, band notches, MIMO antenna, polarization diversity, UWB.

I. INTRODUCTION

Ultra wide band (UWB) technology is widely used in many fields of wireless communication due to its inherent advantages such as high transmission rate, strong confidentiality, low cost and low power consumption. However, the power spectral density of UWB system is very low and the problem of signal fading is more prominent under the influence of multipath effect. Multiple Input Multiple Output (MIMO) technology can greatly improve the efficiency of spectrum and realize large capacity and high rate in the limited spectrum resources. The combination of UWB and MIMO technology can perfectly solve the multipath fading problem to improve the communication quality. Meanwhile, the range of UWB includes narrowband systems such as WiMAX (3.3-3.8 GHz) and WLAN (5.15-5.825 GHz). Therefore, it is particularly important to solve the interference between UWB and some narrowband system.

The combination of UWB and MIMO technology has been paid more and more attention by researchers and achieved considerable development. For UWB MIMO system, how to maintain acceptable isolation between antenna elements on the basis of ensuring that the antenna has simple structure and compact size is a challenging task. References [1, 2] introduce the fence-type decoupling structure at the ground to enhance the isolation in operating band. Referencess [3-5] design the T-shaped decoupling structure by extending the branches on the ground, adding parasitic units and slotting on the ground, respectively. The inherent directional radiation of slot antenna and asymmetrical placement are used to obtain high isolation in [6]. The vertical placement of the antenna elements is used in [7-9] to reduce coupling, which is a common way for MIMO antennas to obtain high isolation. The neutralization line is implemented to minimize the mutual coupling between the radiation patches in [10]. Defected Ground Structures (DGS) and structures inspired from Frequency Selective Surfaces (FSS) are used to enhance the isolation in [11]. Polarization diversity among different kinds of antennas can realize lower coupling between antenna elements, and by using a couple of inverted L-shaped stubs and an inverted Z-shaped stub as decoupling structures can obtain a high isolation in [12]. Reference [13] shows that by cutting the antenna element in half, the mutual coupling can be significantly reduced due to the inherent symmetry of the antenna element. By etching two L-shaped slots in the radiators and attaching a rectangular patch on the back, the isolation is enhanced in [14]. In addition, for the realization of notched characteristic, C-shaped [4, 15-17], L-shaped [9] structures are mostly introduced on ground or radiation patch. However, these proposed antennas rarely take into account compact size, simple structure, high isolation and notched characteristic at the same time.

This paper proposes a compact UWB MIMO antenna with dual band notches. The antenna structure is simple, and the different elements are placed vertically. With the use of polarization diversity, less than -15 dB isolation can be achieved in the whole UWB range without additional decoupling structure. The introduction of L-shaped parasitic elements makes the antenna realize notched characteristic in WiMAX band. In addition, the

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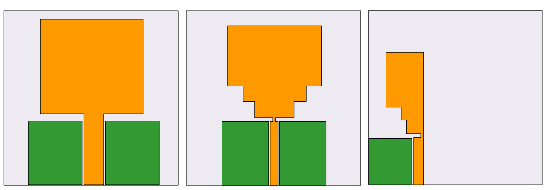
interference of WLAN band is suppressed by the slot on the floor consisting of a C-shaped and two L-shaped structures. (We abbreviate it as LCL-shaped)

II. ANTENNA DESGIN

A. Design of UWB MIMO antenna element

Antenna 1 shown in Fig. 1 (a) is a planar monopole antenna with regular rectangular radiation patch, which is printed on the FR4 substrate with thickness of 1.6 mm and size of 22×22 mm². As shown in Fig. 1 (b), the radiation patch of antenna 1 is improved into a stepped structure to form antenna 2. This progressive form increases the uniform distribution of surface current and improves the stability of input impedance, so it greatly increases the working bandwidth of the antenna element. Impedance matching can be further improved by adjusting the width of the center conductor connecting the radiation patch. Figure 2 shows the simulated S_{11} of antenna 1 and 2. According to the figure, the bandwidth of the antenna 2 can cover the whole UWB range.



(a) Antenna 1 (b) Antenna 2 (c) Antenna 3

Fig. 1. Design of UWB MIMO antenna element.

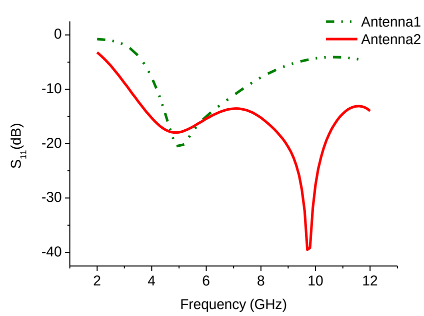


Fig. 2. Simulated S_{11} of antenna 1 and 2.

To further reduce the antenna size, we use the feeding method of an ACS to cut the antenna 2 in half to form antenna 3 and optimize the parameters, as shown in Fig. 1 (c).

B. Design of UWB MIMO antenna

In the previous section, the design of the UWB antenna element was preliminarily completed. In this section, we mainly introduce the integrated design of four-element UWB MIMO antenna. Four elements that are identical to antenna 3 are integrated to form antenna 4 as shown in Fig. 3. In antenna 4, four ports are placed orthogonally to each other to improve the isolation through polarization diversity. Figure 4 shows the simulated S_{11} of antenna 3 and 4. According to the figure, S_{11} does not change much after the antenna is integrated.

Further, we show the isolation between antenna elements. According to the principle of reciprocity, we only demonstrate the isolation between antenna elements in adjacent (S_{12}) and diagonal (S_{13}) positions in Fig. 5. In the integrated antenna, we do not need to use an additional decoupling structure, only using polarization diversity can achieve isolation requirements.

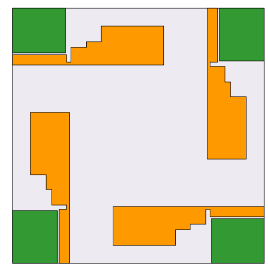


Fig. 3. Antenna 4 integrated by four antenna 3.

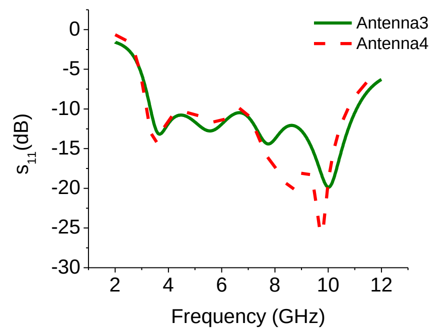


Fig. 4. Simulated S_{11} of antenna 3 and 4.

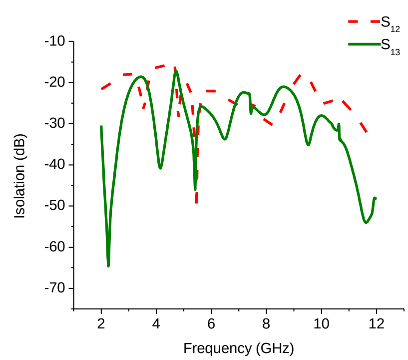


Fig. 5. Simulated isolation of the MIMO antenna.

C. Design of dual-notched UWB MIMO antenna

In order to suppress the interference of WiMAX band, an inverted L-shaped parasitic unit is added on the top of the four radiation patches respectively. The initial length L of the parasitic unit can be obtained by Eq. (1) [9]. Here f_{notch} is center frequency of the notch-band, c is the speed of light in free space, and ε_r is the relative dielectric constant:

$$L = \frac{c}{2 f_{notch}\sqrt{\varepsilon_r}}. \tag{1}$$

The UWB MIMO antenna with WiMAX band-rejection and its simulated S_{11} are shown in Fig. 6. From Fig. 6, we can see that the simulated S_{11} is less than -10 dB from 2.9 to 10.6 GHz except for the rejected band of WiMAX.

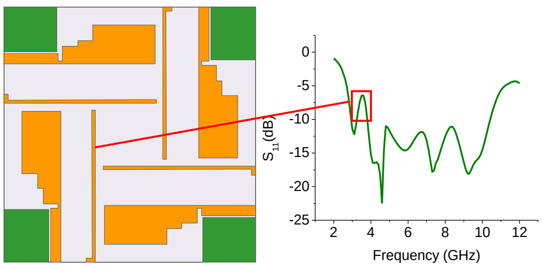
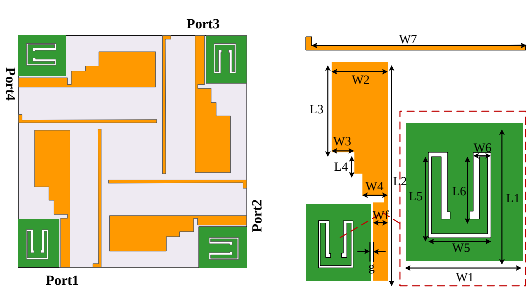


Fig. 6. UWB MIMO antenna with WiMAX band-rejection and its simulated S_{11}.

To further suppress the interference of WLAN band, we designed a LCL-shaped slot on the ground, which is a combination of one C-shaped and two L-shaped structure. The length of the LCL-shaped slot is optimized according to Eq. (1).

The final four-element UWB MIMO antenna with dual-notched is shown in Fig. 7 (a), and the relevant dimensions are shown in Fig. 7 (b). The simulated S_{11} of the proposed antenna is shown in Fig. 8. As can be seen from Fig. 8, the proposed UWB MIMO antenna can achieve a working bandwidth of 2.9-10.6 GHz under the return loss of -10 dB except for the rejected bands of WiMAX and WLAN. The notch frequency band realized by the L-shaped parasitic unit and the LCL-shaped slot is 3.32-3.79 GHz and 5.17-5.77 GHz, respectively.



(a) Proposed MIMO antenna (b) Size

Fig. 7. Four-element UWB MIMO antenna with dual-notched.

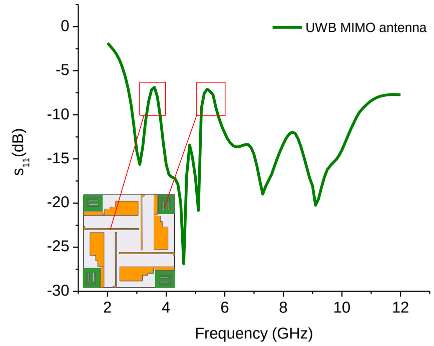


Fig. 8. Simulated S_{11} of proposed MIMO antenna.

The total size of proposed UWB MIMO antenna with dual band notches is 37×37 mm², and the detailed dimensions are shown in Table 1.

Table 1: Dimensions of the proposed antenna

Parameters	L1	L2	L3	L4	L5
Value/mm	6.9	21.8	9.2	2.3	3.7
Parameters	L6	W1	W2	W3	W4
Value/mm	3.1	6.4	5.5	2	2.5
Parameters	W5	W6	W7	Wf	g
Value/mm	3.2	0.8	21.7	1.5	0.2

III. RESULTS AND DISCUSSION

The UWB MIMO antenna proposed in this paper is simulated and optimized by HFSS 15. In order to further verify the practical value and the reliability of the method, the proposed antenna is fabricated based on the size given in Table 1. Figure 9 shows the picture of the fabricated MIMO antenna. By using the vector network analyzer, we measured the S-parameters of the antenna. The radiation pattern and gain of the antenna are also tested in a microwave anechoic chamber.

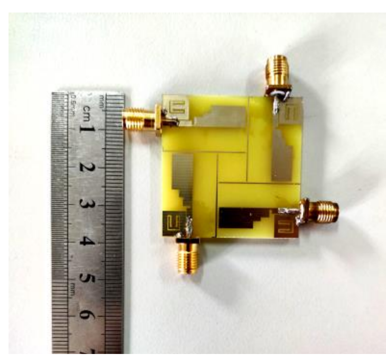


Fig. 9. Photograph of the fabricated MIMO antenna.

A. S parameter

Figure 10 shows the simulated and measured S_{11} of the proposed antenna, it can be seen from the figure that the working bandwidth of the measured antenna is 2.9-10.6 GHz except for WiMAX and WLAN notched bands, which is basically consistent with the simulation results.

The simulated and measured isolations are shown in Fig. 11. From the figure we can see that the measured isolation between antenna elements is less than -15 dB. The deviation between the test and simulation results is acceptable.

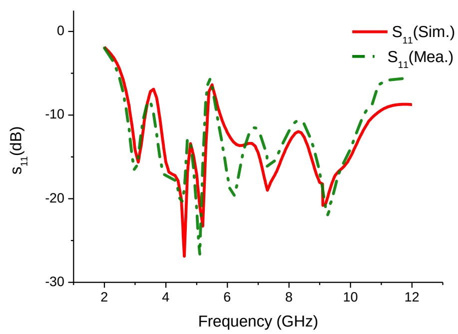


Fig. 10. Simulated and measured S_{11}.

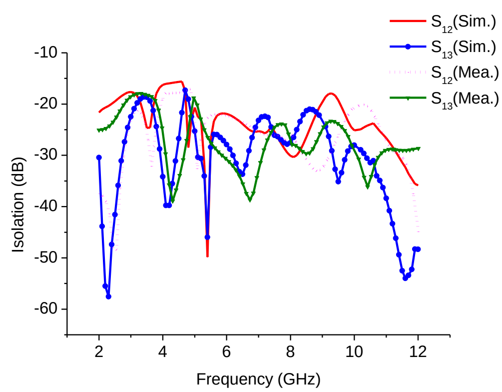
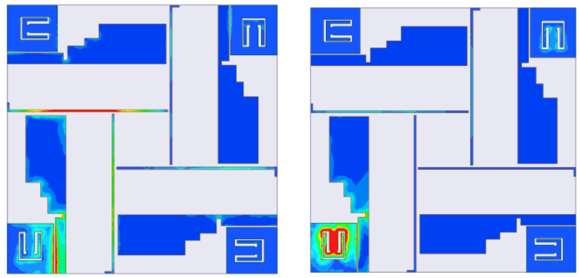


Fig. 11. Simulated and measured isolation.

B. Notch characteristics

To verify the notch characteristics of the UWB MIMO antenna, we analyzed the surface current distributions of the MIMO antenna at 3.5 GHz and 5.5 GHz, as shown in Fig. 12. When the MIMO antenna is working at 3.5 GHz, most of the surface current is concentrated on the L-shaped structure, and the notch band realized at 3.32-3.79 GHz can effectively suppresses interference in the WiMAX band. When the MIMO antenna is working at 5.5 GHz, most of the surface current is concentrated on the LCL-shaped slot, and the notch band realized at 5.17-5.77 GHz can effectively suppresses interference in the WLAN band.

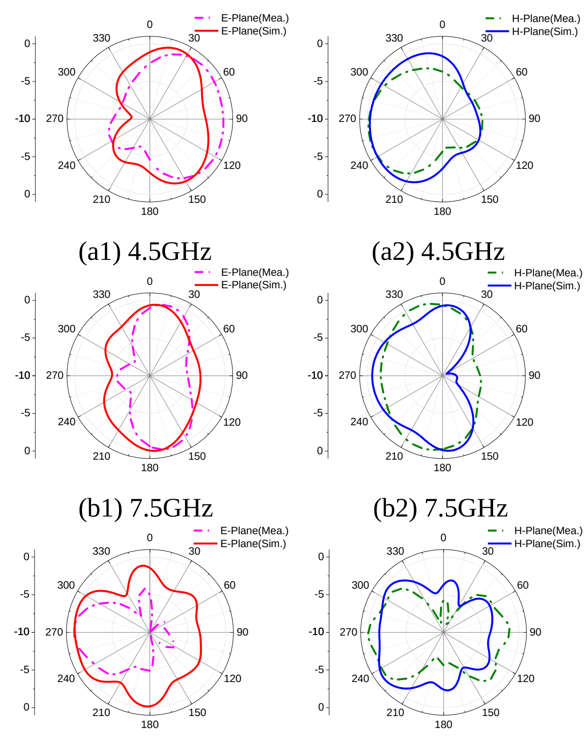


(a) 3.5 GHz (b) 5.5 GHz

Fig. 12. Surface current distributions at (a) 3.5 GHz and (b) 5.5 GHz.

C. Radiation pattern and gain

Figure 13 shows the measured and simulated 2D radiation patterns of proposed MIMO antenna at 4.5, 7.5 and 9.5 GHz. The radiation patterns are measured when the target antenna element is excited and other three antenna elements are terminated with the 50 Ω load. It can be noted from the figure that the simulated and measured results are well matched, and the overall radiation pattern is relatively stable over the entire UWB bandwidth.



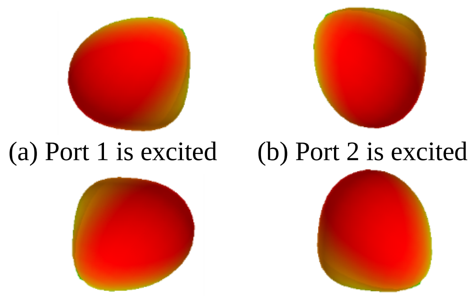
(a1) 4.5GHz (a2) 4.5GHz

(b1) 7.5GHz (b2) 7.5GHz

(c1) 9.5GHz (c2) 9.5GHz

Fig. 13. Simulated and measured radiation patterns at 4.5 GHz, 7.5 GHz and 9.5 GHz.

The isolation mechanism can be better understood by the diversity of radiation pattern when different ports are excited. Figure 14 shows the simulated three-dimensional radiation patterns of the proposed UWB MIMO antenna when port 1 to 4 are separately excited and other ports are terminated with matched loads. The four ports are placed vertically and rotated 90° counterclockwise, so that the radiated field appears rotated 90° in the xy plane, and the pattern diversity is obtained.



(a) Port 1 is excited (b) Port 2 is excited

(c) Port 3 is excited (d) Port 4 is excited

Fig. 14. Simulated 3D radiation patterns of the proposed antenna.

The simulated and measured gains of the proposed UWB MIMO antenna are shown in Fig. 15. From the figure we can see that the gain of proposed antenna is relatively stable and its measured value varies from 0 to 6 dBi within the UWB band except two notched-bands, which indicates that this antenna has good gain characteristic.

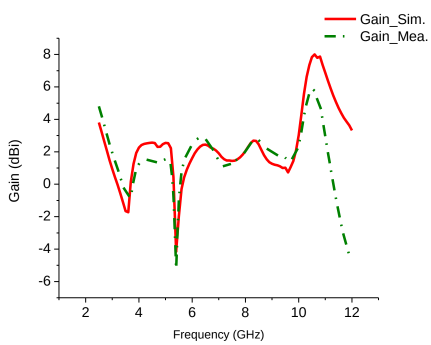


Fig. 15. Simulated and measured gains.

D. Diversity analysis

The diversity characteristic of the proposed antenna can be evaluated by ECC, which represents the correlation of received signals between antenna elements. Generally, low ECC always leads to high diversity gain. For N-element MIMO antenna, the ECC of antenna element *i* and antenna element *j* can be calculated by Eq. (2) [15]:

$$\mathrm{ECC} = \frac{\left|\sum_{n=1}^{N} S_{i,n}{}^{*} S_{n,j}\right|^{2}}{\prod_{k=(i,j)}\left[1-\sum_{n=1}^{N} S_{i,n}{}^{*} S_{n,k}\right]}. \quad (2)$$

The results of ECC are shown in Fig. 16. It can be seen from the figure that the ECC of the proposed antenna is less than 0.02 expect the notch-bands, which indicates the MIMO antenna has a good diversity characteristic.

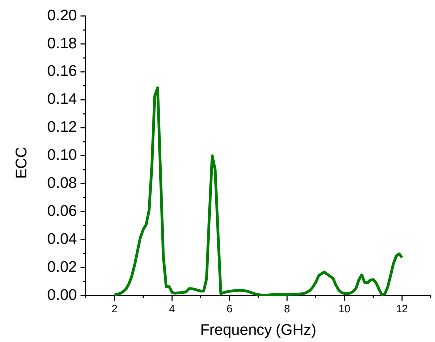


Fig. 16. ECC of the proposed MIMO antenna.

Finally, the comparisons of the recently published four-element UWB MIMO antennas in [8, 9, 11-15, 17, 18] and the proposed antenna in this paper are listed in Table 2. By comparison, it can be concluded that the UWB MIMO antenna proposed in this paper has a simpler structure and a more compact size in addition to satisfying the requirement of UWB. On the premise of compact size, the antenna can satisfy the isolation of -15 dB without decoupling structure. In addition, the antenna also realizes the characteristic of dual-notched.

IV. CONCLUSION

In this paper, a compact UWB MIMO antenna fed by ACS is proposed. The four ports of the antenna are placed vertically, and the isolation less than -15 dB is obtained by using the polarization diversity in the whole UWB range. The L-shaped parasitic unit realizes the notched characteristic in WiMAX band. In addition, the LCL-shaped slot on the ground realizes the suppression of WLAN band. The simulation results show that the antenna has good characteristic, and the measured results agree well with the simulated results, which indicates that the proposed antenna is suitable for UWB applications.

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Table 2: Comparisons of published four-element UWB MIMO antennas and the proposed antenna

Designs	Size (mm^2)	Band (GHz)	Isolation (dB)	Notched Band	Gain (dBi)	ECC (Except Notches)	Decoupling Structure
[8]	50×39	2.7-12	-17	1	2.5-6	/	/
[9]	81×81	3.03-10.74	-20	2	0-9	0.025	/
[11]	58×79	3-11	-15	0	/	/	yes
[12]	70×41	3.1-12	-17	0	1-4	0.012	yes
[13]	70×70	2-14	-15	0	2-6	0.007	/
[14]	36×36	3.1-10.6	-15	0	1.5-3.7	0.02	yes
[15]	73×73	3-18	-20	2	/	0.0015	/
[17]	45×45	2-10.6	-17	1	2-5	0.01	yes
[18]	40×40	2.94-14	-17	0	1-5	0.03	/
Proposed	37×37	2.9-10.6	-15	2	0-6	0.02	/

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