A Differential CPW-fed Ultra-wideband Antenna with Dual Notched Bands

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Abstract ─ In this letter, a differential coplanar waveguide (CPW)-fed ultra-wideband (UWB) antenna with dual notched bands is presented. The proposed antenna is mainly composed of two C-shaped radiating elements and a polygon slot ground plane. To alleviate the electromagnetic signal interference, two pairs of open-ended slots etched on the ground plane are adopted to reject 3.5 GHz WiMAX band while a pair of Y-shaped slots embedded in the C-shaped radiating elements is used to filter 5.5 GHz WLAN band. Measured results demonstrate that a 10-dB impedance bandwidth implemented is 131% (from 2.57 to 12.31 GHz), along with dual notched bands of 3.29-3.95 GHz and 4.73-6.55 GHz. Furthermore, the low cross-polarization is obtained because of differential feeding structure. Finally, the antenna expresses good radiation patterns in the whole operating band.

Index Terms ─ Differential-fed, notched bands, open-ended slot, UWB antenna, Y-shaped slot.

I. INTRODUCTION

Currently, the ultra-wideband (UWB) wireless communication technology operating in the frequency of 3.1-10.6 GHz has gained much attention due to its inherently attractive advantages of wide bandwidth, low power consumption, high data rate and so on. UWB antennas play an important role in the wireless communication systems. In the open literatures, UWB antennas with excellent performances have been presented [1-8]. As is well known, the operating band of UWB communication technology overlaps that of some other existing narrowband services like WiMAX (3.4-3.69 GHz) and WLAN (5.15-5.825 GHz) which may cause electromagnetic signal interference. To alleviate this problem, a band-rejection filter is always adopted to filter the bands of the existing narrowband services. However, the system complexity is increased due to the additional filter. Therefore, the UWB antennas with band-notched characteristics are desirable. In [9], an open loop resonator is introduced to obtain a notch band at 5.15 GHz. The proposed antenna achieves good notched band characteristics by optimizing the position and dimension of the open-loop resonator. In [10], by using an inverted π-shaped parasitic structure in the ground plane, a frequency notch band of 5.11-6.02 GHz is achieved. In the design of [11], a compact UWB slot antenna with band-notched characteristics is proposed. Combining a short-ended split-ring slot and an open-ended slot, a notched band ranging from 5.15-5.9 GHz with sharp selectivity is achieved. However, the mentioned designs [9-11] have a single notched band, and they cannot filter the 3.5 GHz WiMAX band. In [12], a microstrip line-fed planar antenna with dual notched bands is designed by etching a single tri-arm resonator below the patch. It has a wide bandwidth (return loss ≤ -10 dB) ranging from 2.98 to 10.76 GHz with two notched bands operating at 3.56 and 5.5 GHz. In [13], a dual-notched characteristic is presented by utilizing the semi-circular and annular circular slot etched on the circular ring radiator. However, the cross polarization problem in these antennas is needed to be improved. To enhance the purity of polarization, a differential feeding technology has been widely applied in the RF system. Normally, a balun is adopted to transform differential signals into single-ended signals, leading to cause additional losses and shrink the impedance bandwidth. The single-ended antenna is hard to be directly integrated with the differential circuit. Hence, a differential-fed antenna excited by two signals with uniform amplitude but 180° phase difference is needed. In [14], a differential-fed magneto-electric (ME) dipole antenna is designed for UWB communication system. However, the antenna has a bulky volume and cannot reject the operating bands of narrowband communication systems. In [15], a differential-fed UWB antenna with good radiation patterns is presented. It is clear that the radiation patterns are greatly improved by using differential feeding structure. Nevertheless, the antenna does not have the function of filtering undesired band. A differential-fed tapered-slot UWB antenna with band-rejected characteristics is designed [16], but it just has a single notched band of 5.2-6.0 GHz which cannot reject the 3.5 GHz WiMAX operating band. In the design of [17], a planar differential-fed antenna with dual band-notched characteristics is presented for UWB applications.

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Nevertheless, the planar feeding structure is not preferred because it cannot offer easy integration with the existing fabrication facilities.

However, CPW feed lines have several useful characteristics, low radiation losses, less dissipation, and uniplanar configurations. For RF applications, they can be easily mounted and they have good compatibility with other active devices, which is very important for Miniature Hybrid Microwave Integrated Circuits and Monolithic Microwave Integrated Circuits technologies.

In this letter, a differential CPW-fed UWB antenna with dual notched bands is presented. A wide impedance bandwidth of 131% (from 2.57 to 12.31 GHz) for differential reflection coefficient less than -10 dB is obtained. By introducing the open-ended slots and the Y-shaped slots, two notched bands are implemented to reject the 3.5 GHz WiMAX band and the 5.5 GHz WLAN band, respectively. In addition, the antenna has low cross polarization because of differential feeding mechanism. Based on the design parameters, the antenna is fabricated and tested.

II. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed antenna. The proposed antenna is composed of two parts: two C-shaped radiating elements placed face to face and a polygon slot ground plane. Each C-shaped radiating element has a Y-shaped slot and the ground plane has two pairs of open-ended slots. Both the radiating elements and the ground plane are etched on FR-4 substrate with a thickness of 1 mm, relative dielectric constant of 4.4 and loss tangent of 0.02. The simulation and analysis for the proposed antenna are performed using the electromagnetic simulator ANSYS HFSS. The optimized design parameters of the antenna are shown in Table 1.

Table 1: Optimized parameters of the proposed antenna

Parameters	W	g	Lt	Ws	L1
Values/mm	28	0.4	2	0.2	5.6
Parameters	Wg	R1	Ls	W2	Wf
Values/mm	3.8	6	12.8	1.7	2.2
Parameters	R2	ds	L2	s	Wt
Values/mm	5.5	1.4	2.2	0.3	8
Parameters	W1	ts	L	Lg	dr
Values/mm	1.4	0.2	30	5	3

As is known, the two-port s-parameter matrix [18] is shown in (1):

$$S=\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}. \tag{1}$$

For the convenience in analyzing differential signals, the s-parameter matrix S^{mm} is presented, which is employed to describe the transmission characteristic of differential circuits. Usually, a differential-fed antenna can be regarded as a two-port network. Then, the s-parameter matrix can be simplified as (2):

$$S^{mm}=\begin{bmatrix} S_{dd} & S_{dc} \\ S_{cd} & S_{cc} \end{bmatrix}. \tag{2}$$

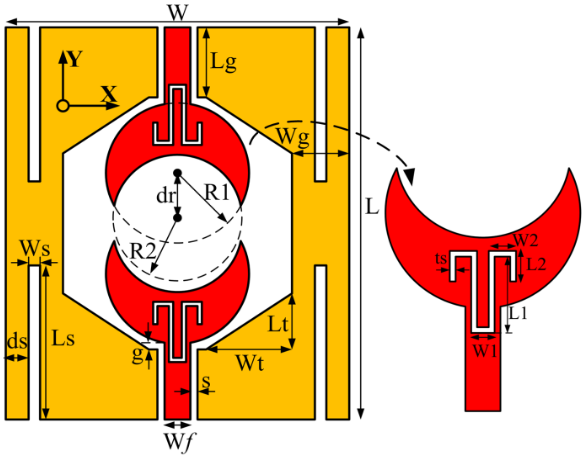


Fig. 1. Geometry of the proposed antenna.

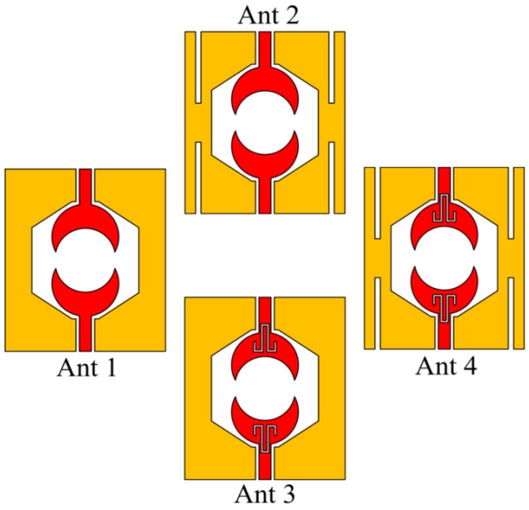


Fig. 2. Evolution of the proposed antenna.

Each of the s-parameters is as follows:

$$S_{dd}=\frac{1}{2}(S_{11}-S_{12}-S_{21}+S_{22}), \tag{3}$$

$$S_{dc}=\frac{1}{2}(S_{11}+S_{12}-S_{21}-S_{22}), \tag{4}$$

$$S_{cd}=\frac{1}{2}(S_{11}-S_{12}+S_{21}-S_{22}), \tag{5}$$

$$S_{cc}=\frac{1}{2}(S_{11}+S_{12}+S_{21}+S_{22}). \tag{6}$$

S_{dd}: Differential-mode of the s-parameters;
S_{dc}: Common-mode to differential-mode;
S_{cd}: Differential-mode to common-mode;

S_{cc}: Common-mode of the s-parameters.

The differential reflection coefficient of the antenna can be calculated by Equation (7):

$$\Gamma_{odd} = S_{dd} = \frac{(S_{11} - S_{12} - S_{21} + S_{22})}{2}. \qquad (7)$$

Thus, the results of two port simulations and measurements can be used to calculate the reflection coefficients that the will be seen by the source in an odd mode excitation. An Agilent N5230A vector network analyzer is used to measure the S-parameter, S_{11}, S_{22}, S_{12} and S_{21}, for the proposed antenna. The odd mode return loss in dB is defined as $20\log_{10}\left|\Gamma_{odd}\right|$.

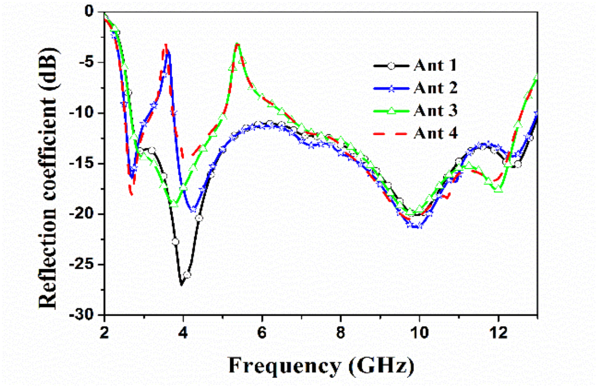


Fig. 3. Simulated reflection coefficients of various antennas mentioned.

Figure 2 shows the evolution of the proposed antenna, and the corresponding simulated differential reflection coefficient for each antenna is exhibited in Fig. 3. As shown in Fig. 2, the original antenna named as Ant 1 consists of two C-shaped radiating elements and a polygon slot ground plane. Meanwhile, a wide impedance bandwidth is obtained from 2.67 to 13 GHz when C-shaped radiating elements excite the polygon slot using differential feeding mechanism in Fig. 3. Nevertheless, the operating band of the UWB communication technology overlaps that of some other existing narrowband services like WiMAX (3.4-3.69 GHz) and WLAN (5.15-5.825 GHz) which may cause electromagnetic signal interference. To eliminate the adverse effects, two different methods are adopted to filter the operating bands of WiMAX and WLAN communication systems.

First, two pairs of open-ended slots etched on the ground plane are introduced into Ant 1, and the new antenna named Ant 2 is formed. Therefore, it can be seen that a rejected band is obtained covering the band of 3.5 GHz WiMAX, as shown in Fig. 3. The bandwidth and resonant frequency of the rejected band can be easily controlled by adjusting the dimension and position of the open-ended slots. Additionally, each open-ended slot is approximately equal to a quarter guided wavelength λg at 3.6 GHz. The guided wavelength λg can be calculated by Equation (8) as follows:

$$\lambda_g = \frac{c}{\sqrt{\varepsilon_{\text{eff}} f}}, \qquad (8)$$

where c is the velocity of light in free space, f is the resonant frequency of notched band, and ε_{eff} is the effective relative permittivity.

Second, two identical Y-shaped slots are embedded in Ant 1, and Ant 3 with a notched band to filter 5.5 GHz WLAN band is implemented. The corresponding reflection coefficient depicted in Fig. 3 demonstrates the good operation of Y-shaped slots, and the resonant frequency of the notched band is 5.4 GHz. Meanwhile, the length of Y-shaped slot is about half of one guided wavelength at 5.4 GHz. Finally, the proposed UWB antenna with dual notched bands (Ant 4) is obtained by a subtle combination of open-ended slots and Y-shaped slots, and the relevant reflection coefficient is illustrated in Fig. 3.

To further demonstrate the operation mechanism of open-ended slots and Y-shaped slots, the simulated surface current distributions on the proposed antenna at the rejected bands are shown in Fig. 4. It is clear that the simulated current has various distributions on the proposed antenna. The surface current distributions focus mainly on the edge of the open-ended slots at the frequency of 3.6 GHZ. In addition, the surface current distributions mainly concentrate along the edge of the Y-shaped slots at the frequency of 5.4GHz. Because the open-ended slots and the Y-shaped slots work as resonators in the notched bands and the impedance mismatching of the proposed antenna is serious, the antenna cannot radiate outside in the notched bands.

To better show the performances of the proposed antenna, the figures of merit (including the size, operating bandwidth and notched band) of the previously reported dual-band notched UWB antennas are compared in Table 2. Note that the antenna size in [19], [20] and [21] is not compact and there is incomplete rejection in the bands 3.30-3.80 GHz and 5.15-5.85 GHz. The designed antenna has a compact size of 28×30mm^2. Meanwhile, two frequency bands 3.29-3.95 GHz and 4.73-6.55 GHz for WiMAX and WLAN are sharply notched in the operating band of the proposed antenna.

Table 2: Comparison between the reported antennas with the proposed dual band-notched UWB antennas

Reference	Antenna Size (mm)	Operating Bandwidth (GHz)	Notched Band
[19]	40.4×44	3.1-11.0	5.2-5.3 5.65-5.85
[20]	50×50	2.6-10.8	4.65-4.85 7.4-7.6
[21]	28×18	3.2-11.7	5.1-6.0 7.83-8.47
Proposed antenna	28×30	2.57-12.31	3.29-3.95 4.73-6.55

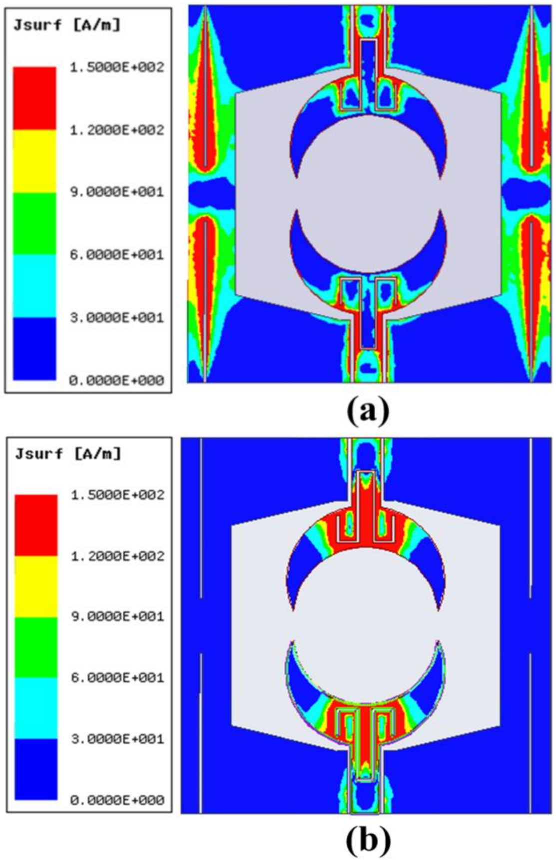
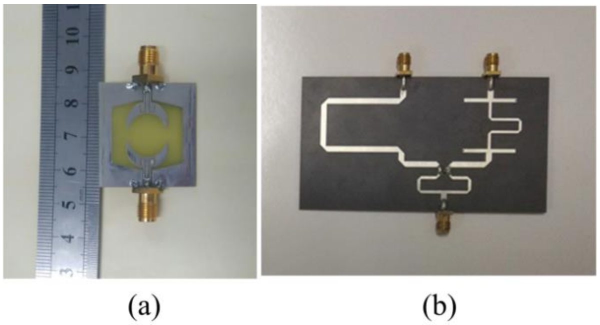


Fig. 4. Simulated current distributions on the proposed antenna at: (a) 3.6 GHz and (b) 5.4 GHz.

III. RESULTS AND DISCUSION

Based on the optimized design parameters mentioned in Table 1, the fabricated antenna and a 180° power-divider which can be used to excite the proposed antenna are shown in Fig. 5. The simulated and measured reflection coefficients of the proposed antenna are illustrated in Fig. 6. It is shown that the proposed UWB antenna achieves a wide bandwidth of 131% (2.57-12.31 GHz), along with dual notched bands of 3.29-3.95 GHz and 4.73-6.55 GHz covering the operating bands of 3.5 GHz WiMAX and 5.5 GHz WLAN. Additionally, the difference between the simulated and measured results may be attributed to the testing circumstance and the error of fabrication.

Figure 7 depicts the simulated and measured radiation patterns at 3.1, 4.5 and 8.5GHz. It can be seen that the quasi-omnidirectional radiation patterns in the *H*-plane and dipole-like radiation patterns in the *E*-plane are obtained. Meanwhile, the polarization purity of the proposed antenna is greatly improved. In Fig. 8, the measured and simulated results agree well with each other. It can be seen that the measured gain is flat in all operating bands, and it declines rapidly in the notched bands.



(a) (b)

Fig. 5. (a) Photograph of the fabricated antenna, and (b) 180° power divider.

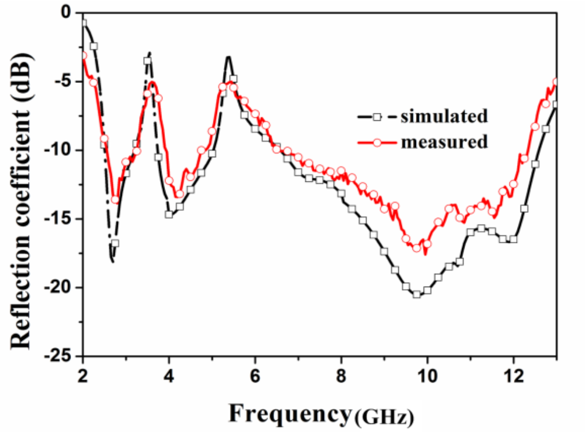
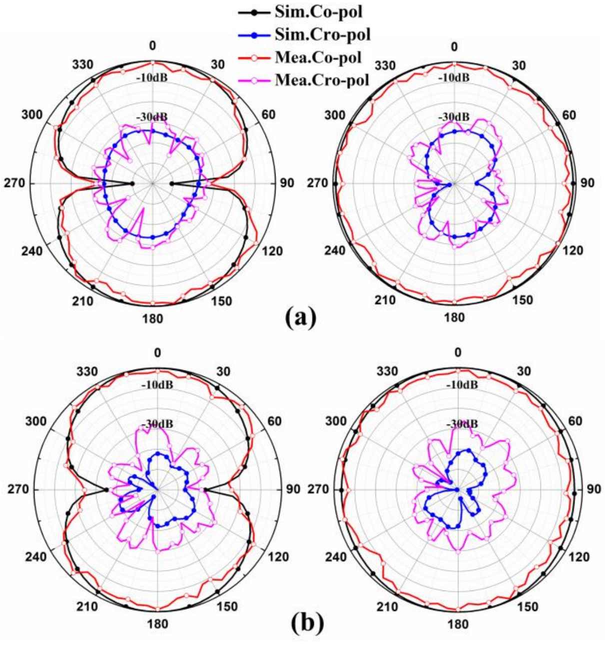


Fig. 6. Simulated and measured reflection coefficients of the proposed antenna.



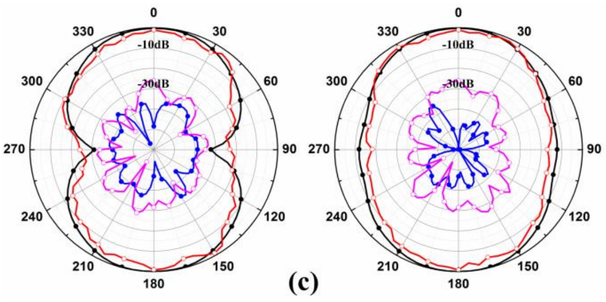


Fig. 7. Simulated and measured E-plane (left) and H-plane (right) radiation patterns of the proposed antenna at: (a) 3.1 GHz, (b) 4.5 GHz, and (c) 8.5 GHz.

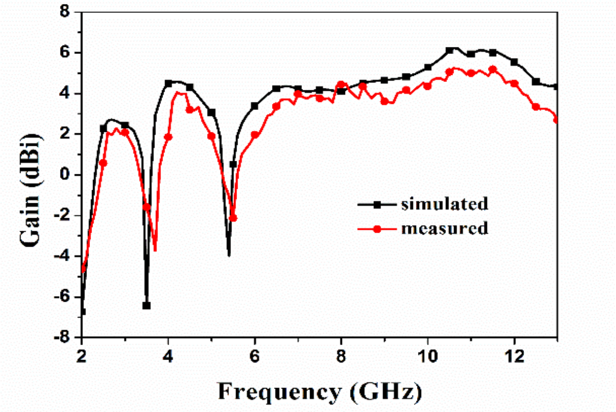


Fig. 8. Simulated and measured gains of the proposed antenna.

IV. CONCLUSION

A differential CPW-fed UWB antenna with dual band-notched characteristics is proposed. To generate filtering behavior, the open-ended slots and the Y-shaped slots are introduced into the antenna design, and two notched bands of 3.29-3.95 GHz and 4.73-6.55 GHz are obtained to filter the 3.5 GHz WiMAX and 5.5 GHz WLAN bands. Then the antenna achieves good radiation patterns and stable gain. In addition, the antenna also has low cross polarization because of differential feeding mechanism. Finally, the measured results demonstrate that the proposed antenna is a good candidate for the UWB applications.

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