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A Compact Differential-Fed UWB Antenna with Band-Notched Characteristics

Jingjing Zhang*, Tingting Chen, Lu Hua, and Weijiang Wang

Abstract—A compact differential-fed ultra-wideband (UWB) antenna with single band-notched characteristic is proposed in this paper. The antenna consists of a ground plane etched with an octagonal groove and two symmetrical hexagonal radiating patches. Return loss and isolation of the antenna can be effectively reduced by loading a rectangular stub on the ground plane and etching a semi-circular groove on the radiation patch. In order to achieve a controllable single band-notched characteristic, two pairs of quarter-wavelength stubs are introduced into the grounding plane. The antenna has lower cross polarization and stable gains than conventional single feed antennas. The measured impedance bandwidth with $S_{11} \leq -10\,\mathrm{dB}$ is 114% from 3 GHz to 11 GHz, and the notch characteristic is realized in the 7.2–8.4 GHz band.

1. INTRODUCTION

With the continuous advancement of society, people have put forward higher requirements for communication rate and communication efficiency. Ultra-wideband (UWB) communication technology meets the pursuit of high-quality communication with its advantages of high speed, low power consumption, and high stability. In 2002, the Federal Communications Commission (FCC) officially allowed UWB technology to be used in civil industry and designated $3.1 \sim 10.6$ GHz as UWB operating band [1]. There are also narrowband communication systems such as WLAN ($5.15 \sim 5.825$ GHz) and satellite communication X-band uplink and downlink frequency segments ($7.25 \sim 8.4$ GHz) in this band. In order to avoid the interference of narrowband to UWB and meet the needs of system miniaturization and integration, research on UWB antennas with notch function has become a hot topic in recent years. Due to the widespread use of differential signals in RF systems, traditional single-ended antennas cannot be directly connected to differential circuits, and a balanced-unbalanced converter is required to convert differential signals into single-ended signals between differential and conventional antennas, which may result in additional loss, reduce impedance matching bandwidth, and increase cross polarization. Therefore, a differential feed antenna excited by two signals having different phases but equal amplitudes is more suitable for direct integration with a differential circuit.

In recent years, with the development of notch antennas, the theory has become more mature. At present, the most common methods to achieve band-notched characteristics are grooving [2–4], adding parasitic units [5–8], electromagnetic band gap (EBG) [9, 10], on the radiating element, feed or grounding plane. In [11], a dual band-notched UWB antenna based on EBG structure is proposed. Two spiral EBG structures placed on the front and back sides of the dielectric substrate operate at 5.2 GHz and 5.8 GHz, enabling the band-notched characteristics of the wireless local area network (WLAN). [12] proposes a compact semi-elliptical monopole antenna driven by a differential feed system with triple band-notched characteristics. The notch characteristics of the WiMAX band and 8 GHz

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International Telecommunication Union (ITU) band can be achieved by introducing a rectangular Split Ring Resonator (SRR) and an Ω-shaped groove on the radiation patch. In [13], triple band-notched characteristics are achieved by etching two domed grooves on the radiation patch and adding a U-shaped metal strip to the ground plane. In order to avoid the use of baluns, reduce the loss and volume of the entire circuit, and reduce the cross polarization of the antenna, differential-fed antennas are widely used [14, 15]. The paper presents a differential-fed UWB antenna with single band-notched characteristic which consists of a ground plane etched with an octagonal groove and two symmetrical hexagonal radiating patches. By loading a rectangular patch on the ground plane, S_{11} can be effectively reduced, while by etching the semi-circular groove in the radiation patch, the isolation is greatly improved. To achieve a controllable single band-notched characteristic, two pairs of quarter-wavelength stubs are introduced into the octagonal groove of the antenna. Compared with the traditional single-fed antenna, the proposed antenna has lower cross-polarization and more stable gain. The measurement results show that the antenna achieves a relative bandwidth of 114% (3–11 GHz) and a band-notched characteristic of 7.2–8.4 GHz band.

2. ANTENNA DESIGN

The antenna originally proposed is antenna 1 shown in Figure 1, which is printed on a Rogers Ultralam 2000 (tm) substrate with a thickness of 0.8 mm, relative dielectric constant of 2.5, and loss tangent of 0.019. In order to reduce S_{11}, a rectangular stub is loaded in the octagonal groove of the ground plane of antenna 1. By optimizing its size, the UWB antenna has a bandwidth of 3–11 GHz and relative bandwidth of 114%. As shown in the proposed antenna, in order to realize the band-notched characteristic in the X-band, two pairs of quarter-wavelength stubs are loaded in the octagonal groove

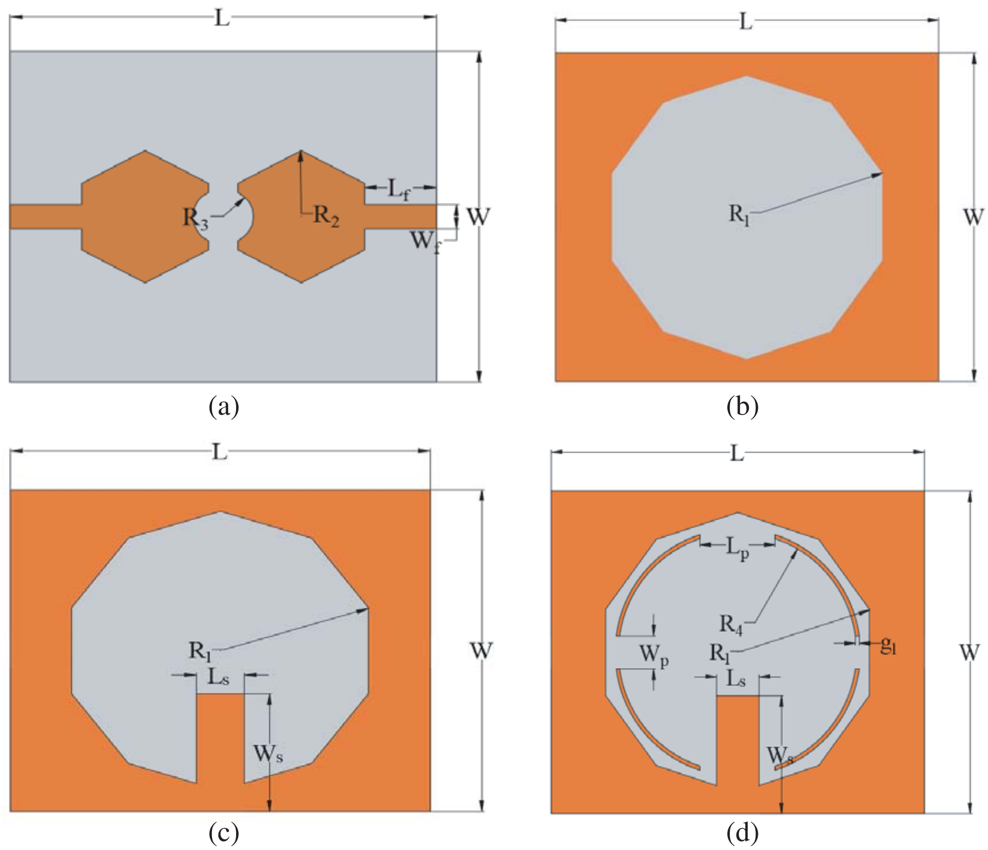


Figure 1. Design evolution and geometry of the proposed antenna. (a) Radiation patch. (b) Grounding plate of antenna 1. (c) Grounding plate of antenna 2. (d) Grounding plate of the proposed antenna.

of the ground plate.

The size of the differential-fed UWB antenna with band-notched characteristic designed in this paper is optimized as shown in Table 1.

Table 1. Parameters of the differential-fed UWB antenna with band-notched characteristic.

Parameter	L	W	L_s	W_s	L_p	W_p	L_f
Value/mm	35	30	4	11	6.2	2.5	8
Parameter	W_f	R_1	R_2	R_3	R_4	g_1	H
Value/mm	2.2	13	6	2.5	11.1	0.4	0.8

According to [16], the length of the stub is usually quarter of the wavelength corresponding to the center frequency of the notch band, and the empirical formulas (1), (2), and (3) are given as follows.

$$L_{slot} = \frac{c}{2f_{notch}\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$L_{stub} = \frac{c}{4f_{notch}\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{3}$$

L_{slot} is the length of the slot, L_{stub} the length of the stubs, ε_r the relative dielectric constant of the medium, and C the speed of light.

3. SIMULATION AND ANALYSIS OF THE ANTENNA

Figure 2 shows S_{11} and VSWR curves of the antenna when a rectangular stub and two pairs of quarter-wavelength stubs are loaded on the antenna ground plane. When the rectangular patch is loaded, S_{11} is significantly reduced to meet the requirements of the UWB antenna. When loading two pairs of quarter-wavelength stubs, the antenna achieves the X-band notch characteristic. Figure 3 shows the effect of each parameter on the notch bandwidth and center frequency of the antenna. It can be seen

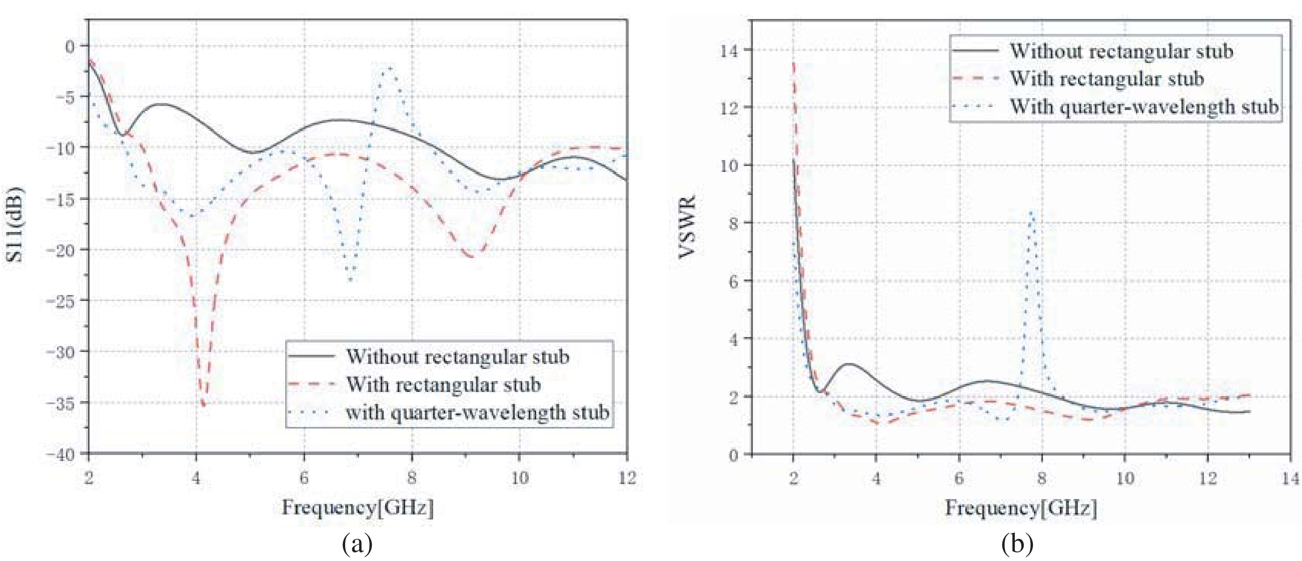


Figure 2. The simulated reflection coefficient and VSWR characteristic of the proposed antenna. (a) S_{11}. (b) VSWR.

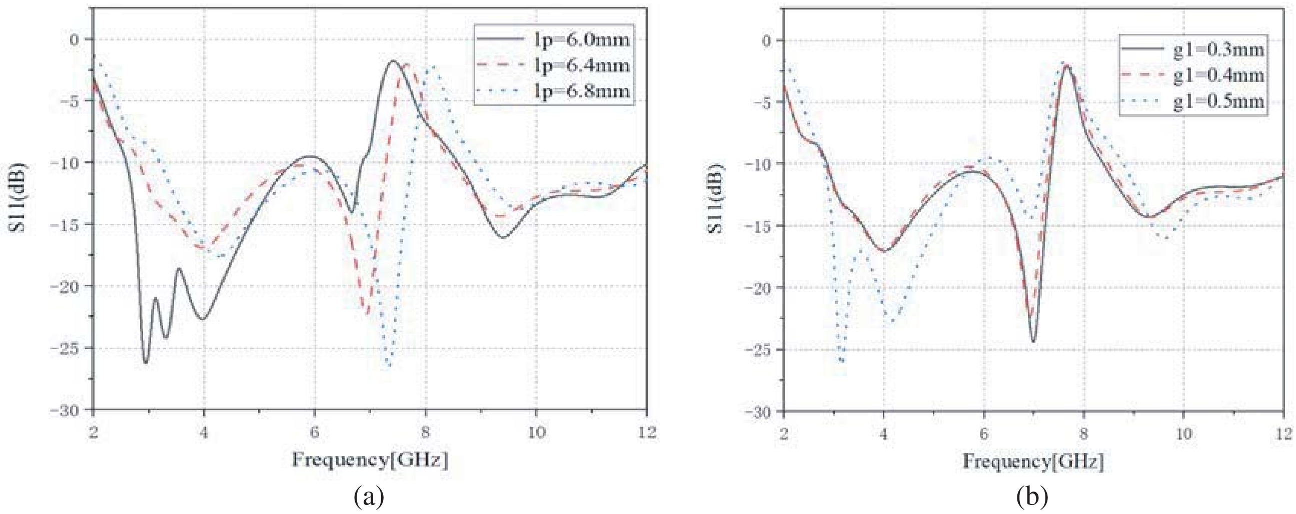


Figure 3. The influence of each parameter on the notch frequency.

from Figure 3 that the value of L_p determines the center frequency of the notch band, and changing the value of L_p makes the center frequency of the notch adjustable. The value of g_1 determines the notch bandwidth. As the value of $g1$ decreases, the notch bandwidth of the antenna decreases. When $L_p = 6.4\,\text{mm}$, $g_1 = 0.4\,\text{mm}$, the X notch band shows the best performance.

Figure 4 shows the isolation comparison results of the antenna before and after loading the band-notched structure. It can be seen from the figure that the band-notched structure can reduce the isolation of the working band of the antenna, increase the isolation of the notch band, and make the band-notched characteristic better.

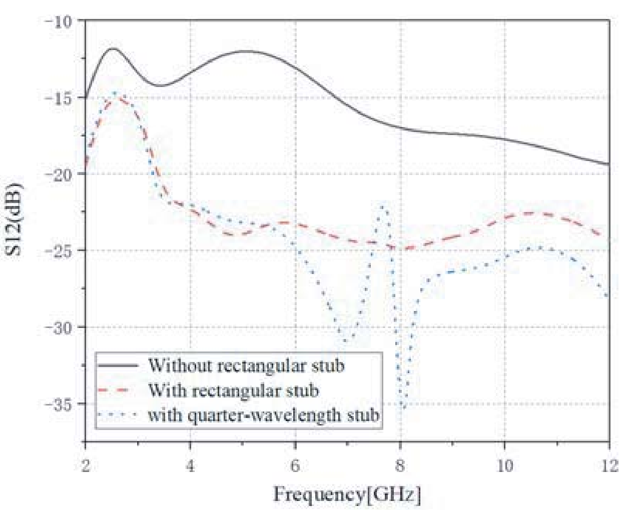


Figure 4. Isolation of the proposed antennas.

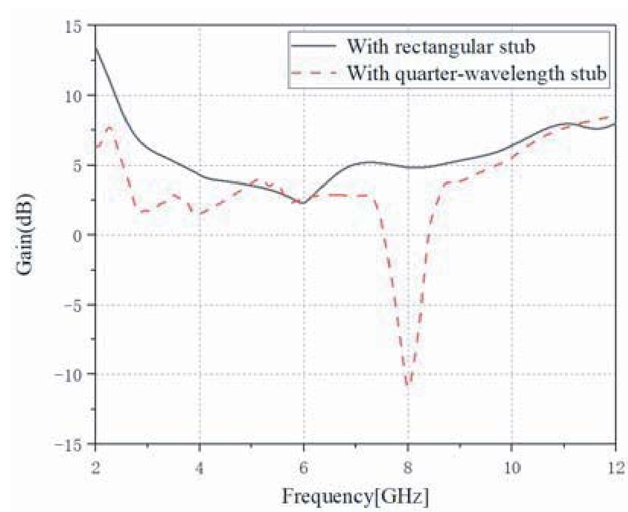
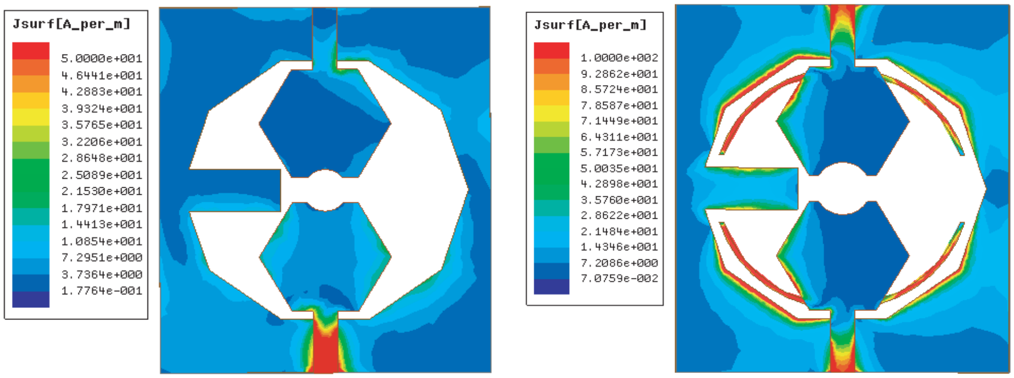


Figure 5. Gain of the proposed antennas.

Figure 5 shows the gain of antenna 2 and the proposed antenna. It can be seen that the gain of the antenna is more than 4 dB in the non-notch band and increases with the increase of the frequency. In notch band, the antenna's gain decreases significantly and is less than 0 dB, which shows better band-notched characteristic.

In order to better understand the principle and characteristic of the band-notched structure, the surface currents of antenna 2 and the proposed antenna are analyzed by HFSS. Figure 6 shows the



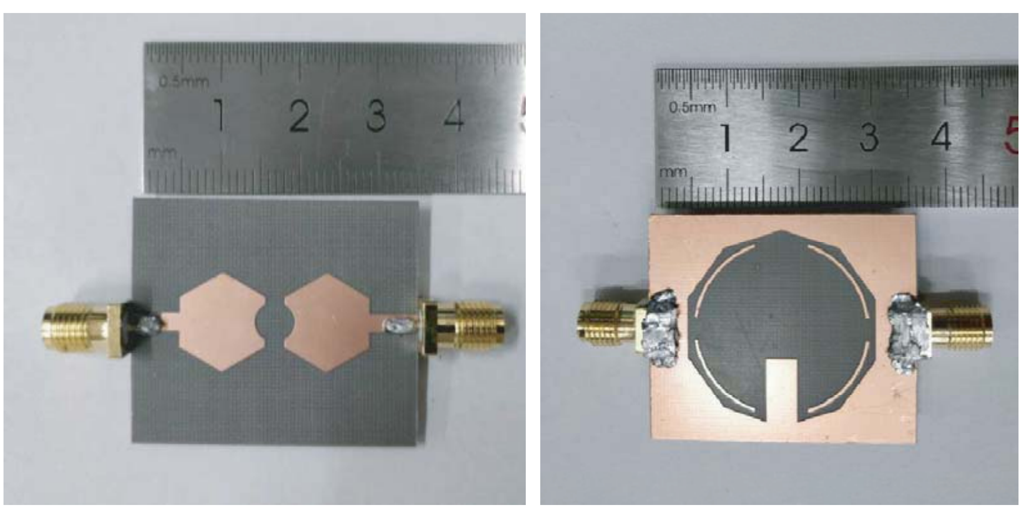
(a) (b)

Figure 6. Surface current distribution of the proposed antennas.

current distribution of antenna 2 and the proposed antenna at a center operating frequency of 7.6 GHz. It can be seen from the figure that in the notch band, the current is concentrated near the quarter-wavelength stub. This means that the energy is limited to the band-notched structure in the X notch band, and there is no normal radiation. This also shows that the antenna achieves the band-notched characteristic in the X-band.

4. ANTENNA PROCESSING AND TESTING

In order to verify the proposed differential-fed UWB antenna with single band-notched characteristic, the proposed antenna is processed and then tested by N5234APNA-L vector network analyzer. The fabricated prototype of the proposed antenna is shown in Figure 7. Figure 8 shows the comparison of the test and simulation results of main parameters of the antenna. As can be seen from Figure 8, the simulation and test results are basically the same. The proposed antenna achieves UWB performance with $S_{11} < -10$ dB from 3 GHz to 11 GHz, and it can effectively avoid the interference of the X-band signal to the UWB system. The deviation is due to the accuracy of the HFSS simulation software, the test environment, and the working frequency band of the SMA connector and its welding.



(a) (b)

Figure 7. Fabricated sample of the proposed antenna. (a) Radiation patch. (b) Grounding plate of the proposed antenna.

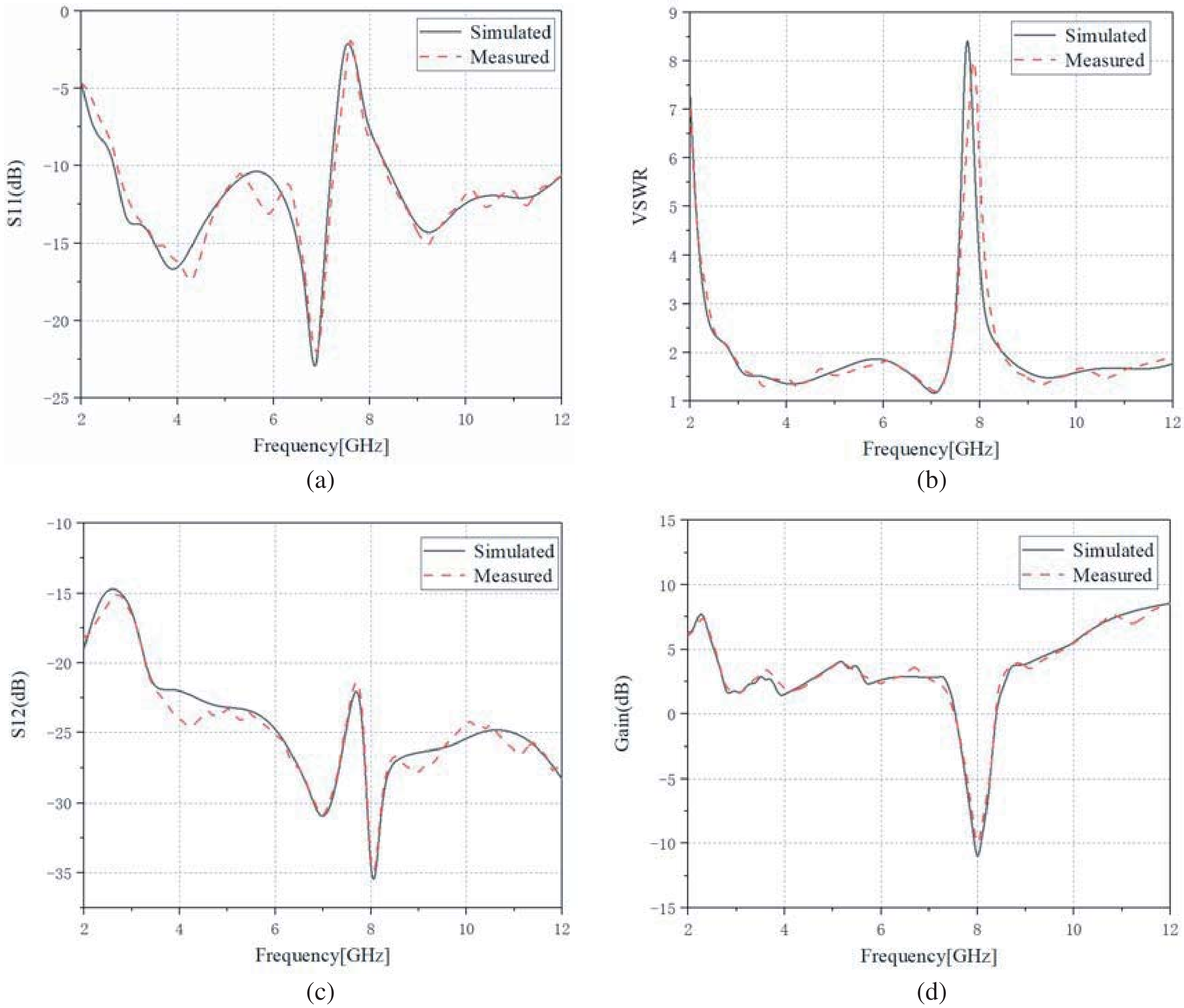


Figure 8. Simulated and measured of the proposed antenna, (a) S_{11}. (b) VSWR. (c) S_{12}. (d) Gain.

Figure 9 shows the simulated and measured radiation patterns at 4 GHz, 6 GHz, and 9 GHz. It can be seen that the antenna has an omnidirectional radiation characteristic in the H-plane and dipole-like radiation characteristic in the E-plane. The radiation pattern slightly deteriorates at high frequency,

Table 2. Comparison between existing and proposed band-notched UWB antennas.

Antenna	***Size (mm^3)***	***Rejected band (GHz)***	***Technique***
[4]	$38 \times 32 \times 1.6$	3.27–3.86/5.13–5.95	U-shaped Slot, Parasitic strip
[6]	$50 \times 50 \times 1.6$	7.2–7.9	2-SRR elements
[8]	$70 \times 50 \times 1.6$	7.33–8.37	6-CSRR elements
[10]	$40 \times 38 \times 1.0$	5.20–5.72/5.99–6.23	2-EBG elements
[17]	$31 \times 30 \times 0.8$	4.9–6.5	CSRR, dynamic resonance
Proposed	$35 \times 30 \times 0.8$	7.2–8.4	Coupling stubs

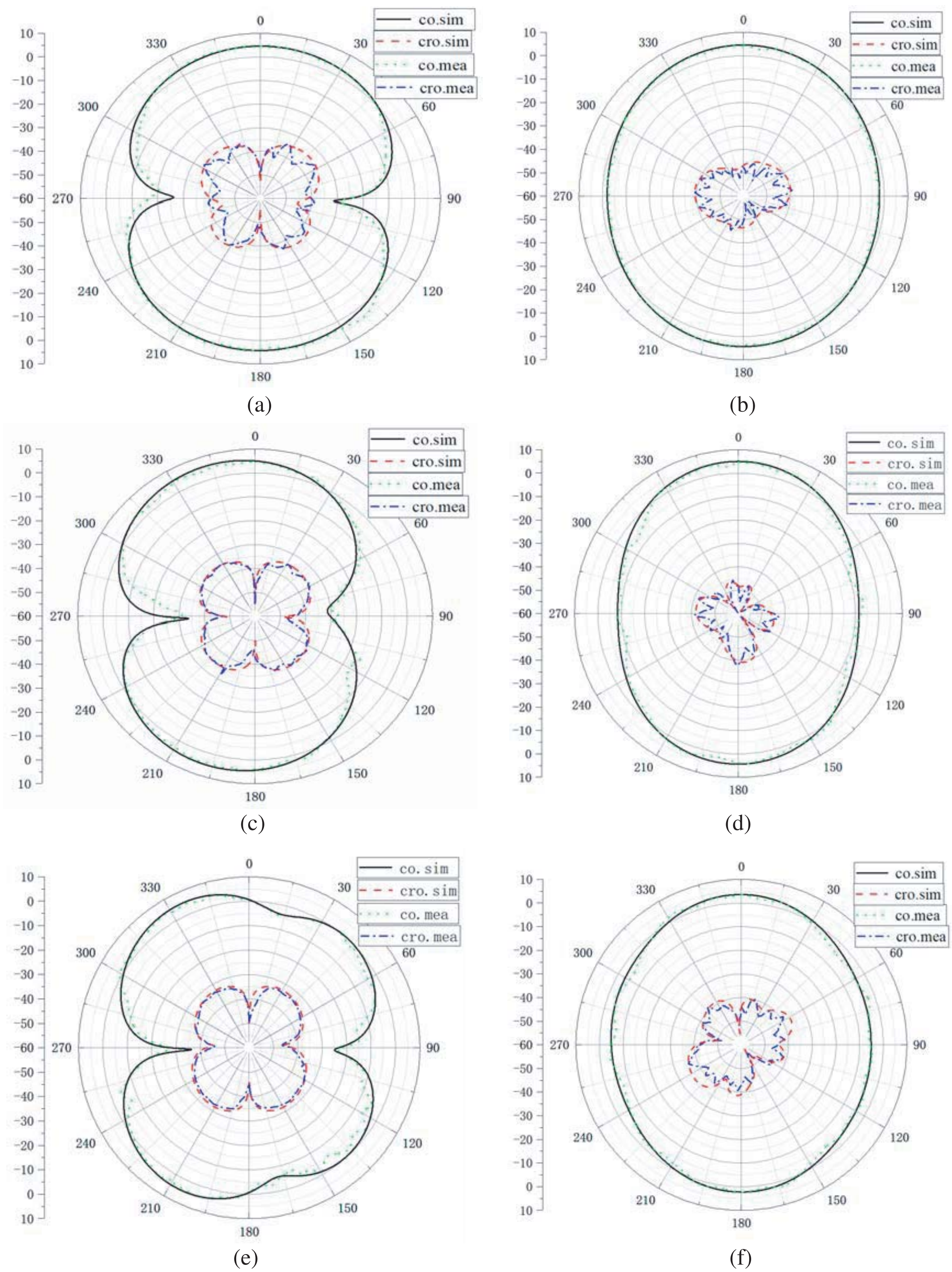


Figure 9. Radiation pattern of the E-plane and the H-plane. (a) E-plane at 4 GHz. (b) H-plane at 4 GHz. (c) E-plane at 6 GHz. (d) H-plane at 6 GHz. (e) E-plane at 9 GHz. (f) H-plane at 9 GHz.

and the cross polarization components of the antenna are less than $-35\,\text{dB}$.

Comparisons between the proposed antenna and existing antennas are shown in Table 2, which includes antenna size, rejected band, and design technique. It shows that the proposed antenna has a more compact size, lower cross polarization, and better band-notched characteristic with a quite simple structure.

5. CONCLUSION

This paper presents a differential-fed UWB antenna with X-band notch characteristic. The antenna consists of a ground plane etched with an octagonal groove and two symmetrical hexagonal radiating patches. S_{11} and S_{12} of the antenna reach the desired range by loading a rectangular patch on the ground plane and etching a semi-circular groove on the radiating patch. Two pairs of quarter-wavelength stubs are introduced into the octagonal groove of the antenna. The notch band can be controlled by adjusting the length of the stub. Compared to conventional single feed antennas, the antenna has lower cross polarization and stable gain. The measured impedance bandwidth with $S_{11} \leq -10\,\text{dB}$ is 114% from 3 to 11 GHz covering the whole UWB except the designed notch band, while giving less mutual coupling (S_{12}) of lower than $-35\,\text{dB}$, and the antenna has good practicability.

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