Progress In Electromagnetics Research M, Vol. 81, 117–126, 2019

A Practical CPW-Fed UWB Antenna with Reconfigurable Dual Band-Notched Characteristics

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Abstract—A practical coplanar waveguide (CPW) fed ultra-wideband (UWB) antenna with reconfigurable dual band-notched characteristics is proposed in this paper. A cup-shaped branch is added to the grounding plate and a step impedance resonator (SIR) added to the microstrip line, which realize notch characteristics in 5.1 $\sim$ 5.9 GHz and 7 $\sim$ 7.8 GHz bands and realize double notch function with good radiation direction characteristics. The antenna bandwidth is extended by using CPW feeding, ranging from 3 GHz to 16 GHz with the relative bandwidth of 137%. The notch band reconfigurability is realized by integrating three switches into the cup-shaped branch and SIR. In addition, the proposed antenna has a compact size of 24 mm $\times$ 32 mm $\times$ 1.5 mm and can provide omnidirectional radiation pattern, which is suitable for UWB communication applications.

1. INTRODUCTION

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 working band [1]. In this band, there are also narrowband communication systems such as WLAN (5.15 $\sim$ 5.825 GHz) and X-band downlink frequency band (7.25 $\sim$ 7.75 GHz) of satellite communications. In order to avoid the interference caused by the above narrowband, the research of UWB antenna with notch function has become a hot topic in recent years, considering the need of miniaturization and integration of the system.

In recent years, with the development of notch antenna, 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 bandgap (EBG) [9, 10], in radiation unit, feeder or grounding plate. In [11], a CPW feed antenna with triple band-notched characteristics is proposed. The antenna achieves triple band-notched characteristics by etching a U-shaped slot on the radiation patch and adding two pairs of L-shaped parasitic side-branch structures on the surface of the antenna. [12] realizes the notch function by adding an SRR structure on the back of antenna to couple it with the front microstrip line. In [13], the notch function is realized by slotting on the microstrip line and adding a J-patch to form a resonant cavity. In [14], two EBG structures are loaded symmetrically on two sides of the microstrip line to realize the single notch function, and the antenna structure is relatively simple. However, these antennas are not flexible, so reconfigurability characteristics become another attractive method for designing multi-band-notched UWB antennas. A reconfigurable band-notched antenna combines the characteristics of multi-band and notched-band. It can be used as a dual-notched UWB antenna, single-notched UWB antenna, and UWB antenna [15, 16]. A practical CPW-fed UWB monopole antenna with dual band-notched characteristics is proposed in this paper. By connecting cup-shaped branches above the ground plate and etching SIR in the CPW transmission line, dual band-notched characteristics can be realized, and the corresponding center frequencies of these notch bands can be controlled by

Received 5 April 2019, Accepted 22 May 2019, Scheduled 28 May 2019
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adjusting the size of cup-shaped branches and SIR. By integrating three switches into the cup-shaped branch and SIR, reconfigurable characteristics can be realized. From the simulation and measurement results, it can be seen that the proposed reconfigurable dual-band notch UWB antenna can operate in the range of 3 to 16 GHz, with VSWR less than 2 except for notch bands.

2. DESIGN OF THE ANTENNA

Figure 1(a) shows the schematic diagram of the CPW UWB antenna. In the design, an FR4 substrate with a relative dielectric constant of 4.4 and thickness of 1.6 mm is employed. The antenna consists of a hexagonal radiation patch and a CPW grounding plane etched with a circular groove. The bandwidth of UWB antenna is $3 \sim 16$ GHz, and the relative bandwidth is 137%. By observing the surface current distribution, the position of WLAN band and X band is determined, and notch processing is carried out on it. The cup-shaped branches are added on the ground plate to realize the notch characteristics of WLAN band, while the X-band notch is implemented by SIR embedded in the microstrip feed line.

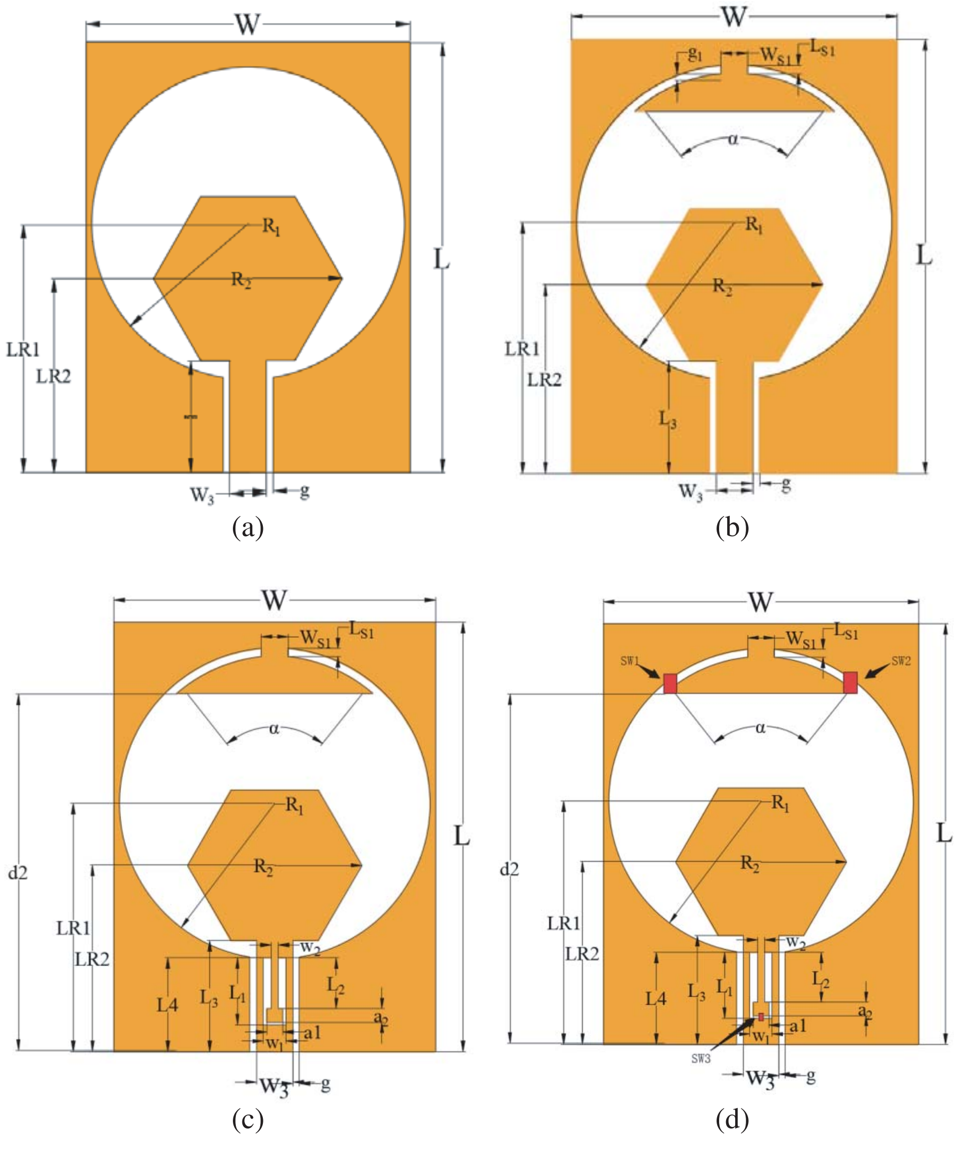


Figure 1. Design evolution and geometry of the proposed antenna, (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, (d) Antenna 4.

According to empirical formulas (1)–(3) [17], the slot length is generally half of the wavelength corresponding to the central frequency of the required notch band.

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

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

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

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. However, in practical engineering design, only an initial value is obtained by empirical formula, and the slot length is needed to optimize by HFSS for obtaining an optimal size.

In this paper, a cup-shaped branch is added on the ground plate to realize the notch in the range of 5.15 $\sim$ 5.825 GHz. The cup-shaped branch forms a resonant cavity through the gap between the cup-shaped branch and ground plate. The resonant frequency band of the resonant cavity is changed by adjusting the arc length of the cup-shaped branch to achieve the effect of band-stop filter.

On the basis of Antenna 2, SIR is inserted into the microstrip feeder to realize the notch in the frequency range of 7.25 $\sim$ 7.75 GHz. As shown in Figure 2, the basic principle of SIR is as follows: the slot in the transmission line is equivalent to a resonant cavity, while L_2 and a are equivalent to a resonant circuit in series with capacitors and inductors, which constitutes a band-stop filter. The notch frequency is changed by adjusting the lengths of L_2 and a and the width of slot W_1. When L_2 increases, the corresponding resonance point decreases, while W_1 affects the bandwidth of notch band. The larger the W_1 is, the larger the notch band bandwidth is [6]. Combining Equations (2) and (3) with HFSS simulation analysis, the size parameters of SIR are obtained as follows: $a = 1.2$ mm, $L_1 = 5.5$ mm, $L_2 = 3.6$ mm, $W_1 = 1.7$ mm, $W_2 = 0.5$ mm.

The antenna is shown in Figure 1(c). The size of the dual band-notched UWB antenna designed in this paper is optimized as shown in Table 1.

To improve the efficiency of the antenna and adapt to different working environments, the notch

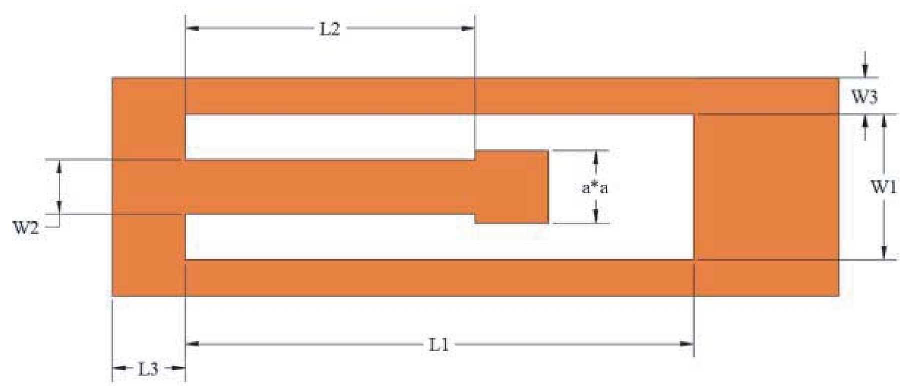


Figure 2. Embedded stepped impedance resonator.

Table 1. Parameters of the dual band-notched UWB antenna.

Parameter	L	W_2	L_1	L_2	L_3	L_{r1}	L_{r2}	W_1	R_1
Value/mm	32	24	5.5	3.6	8.3	18.5	13.9	1.7	11.6
Parameter	W_2	W_3	W_{s1}	W_{s2}	S_1	g	g_1	a	R_2
Value/mm	0.5	2.7	2	0.6	14	0.5	0.5	1.2	6.5

frequency reconfigurability of the antenna is realized by loading three switches on the basis of antenna 3. Frequency reconfigurable antenna changes the physical structure of the antenna in a special way, which changes the current distribution on the radiation surface of the antenna to change the working frequency band of the antenna. Loading radio frequency (RF) switch in the antenna is a typical design method. At two ends of the cup-shaped branch, SW_1 and SW_2 are loaded to control the notch characteristics of the $5.15 \sim 5.825$ GHz band through controlling the switch. Load SW_3 to connect the SIR, which can reconstruct the notch characteristics of $7 \sim 7.8$ GHz band. In order to process SW_1, SW_2, and SW_3 conveniently, three metal bridges are used instead of RF switches, as shown in Figure 1(d).

3. SIMULATION AND ANALYSIS OF THE ANTENNA

Figure 3 shows the effect of each parameter on the notch frequency of the antenna. It can be seen from Figure 3 that the value of α determines the size of the cavity formed by the cup-shaped branch and ground plate. When α is 77°, the WLAN notch band shows the best performance. Changing the values of L_2 and a will change the center frequency of the notch structure. When $L_2 = 3.6$ mm and $a = 1.2$ mm,

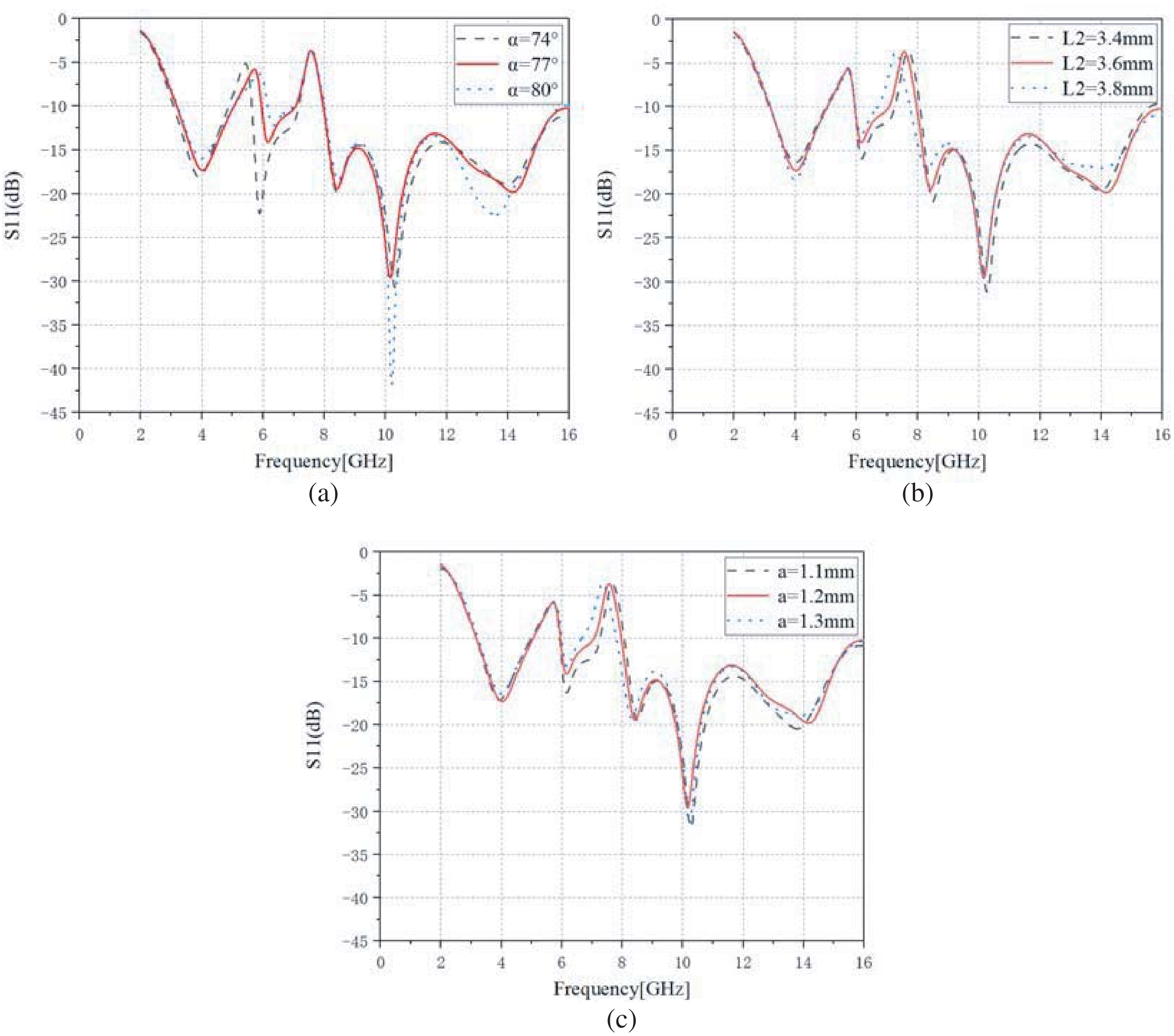
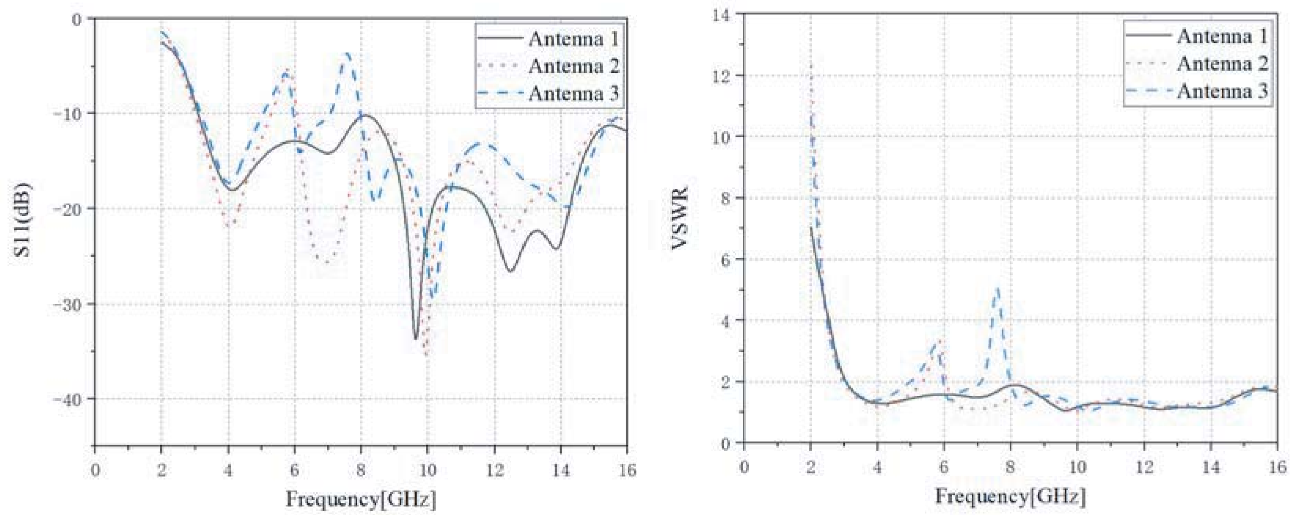


Figure 3. The influence of each parameter on the notch frequency.



(a) (b)

Figure 4. The simulated reflection coefficient and VSWR characteristic of the proposed antenna.

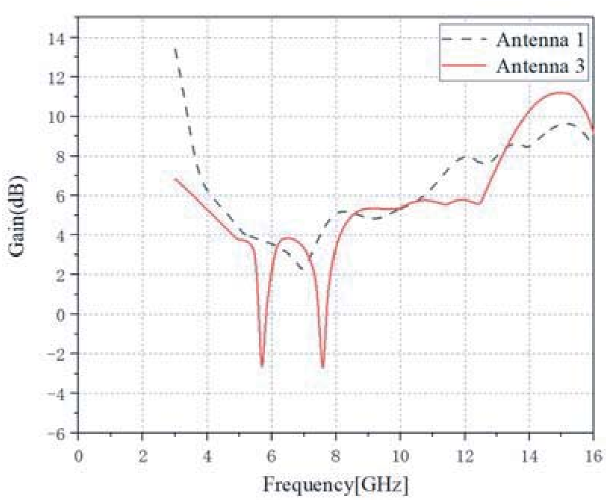


Figure 5. Gain of the proposed antennas.

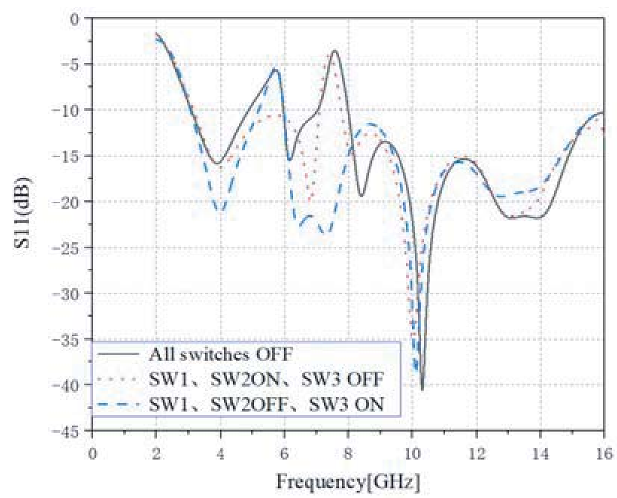


Figure 6. Reflection coefficient comparison chart of the antenna 4.

the X notch band shows the best performance. Figure 4 shows the reflection coefficients (S_{11}) and VSWRs of antennas 1, 2, and 3. It can be seen from Figure 4 that $S_{11} < -10$ dB and VSWR < 2 in the working band of the antenna 1 and $S_{11} > -10$ dB and VSWR > 2 in the $5.15 \sim 5.825$ GHz notch band of antenna 2. It shows that antenna 2 achieves good notch characteristics in this band. Compared with antenna 2, antenna 3 achieves $7 \sim 7.8$ GHz notch.

Figure 5 shows the gain of antenna 1 and antenna 3. 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 gain decreases significantly and is less than -2 dB, which shows better notch characteristics.

Figure 6 shows a comparison of the reflection coefficient of the frequency reconfigurable dual band-notched antenna. The notch frequency can be reconfigured by controlling the working state of the switch of antenna 4. When $SW1$, 2 is ON and $SW3$ OFF, it is equivalent to short-circuit the cup-shaped branch. The band-pass characteristics of $5.1 \sim 5.9$ GHz band will be realized with the independence of the notch characteristics of $7 \sim 7.8$ GHz band. When $SW1$, 2 is OFF and $SW3$ ON, the short circuit

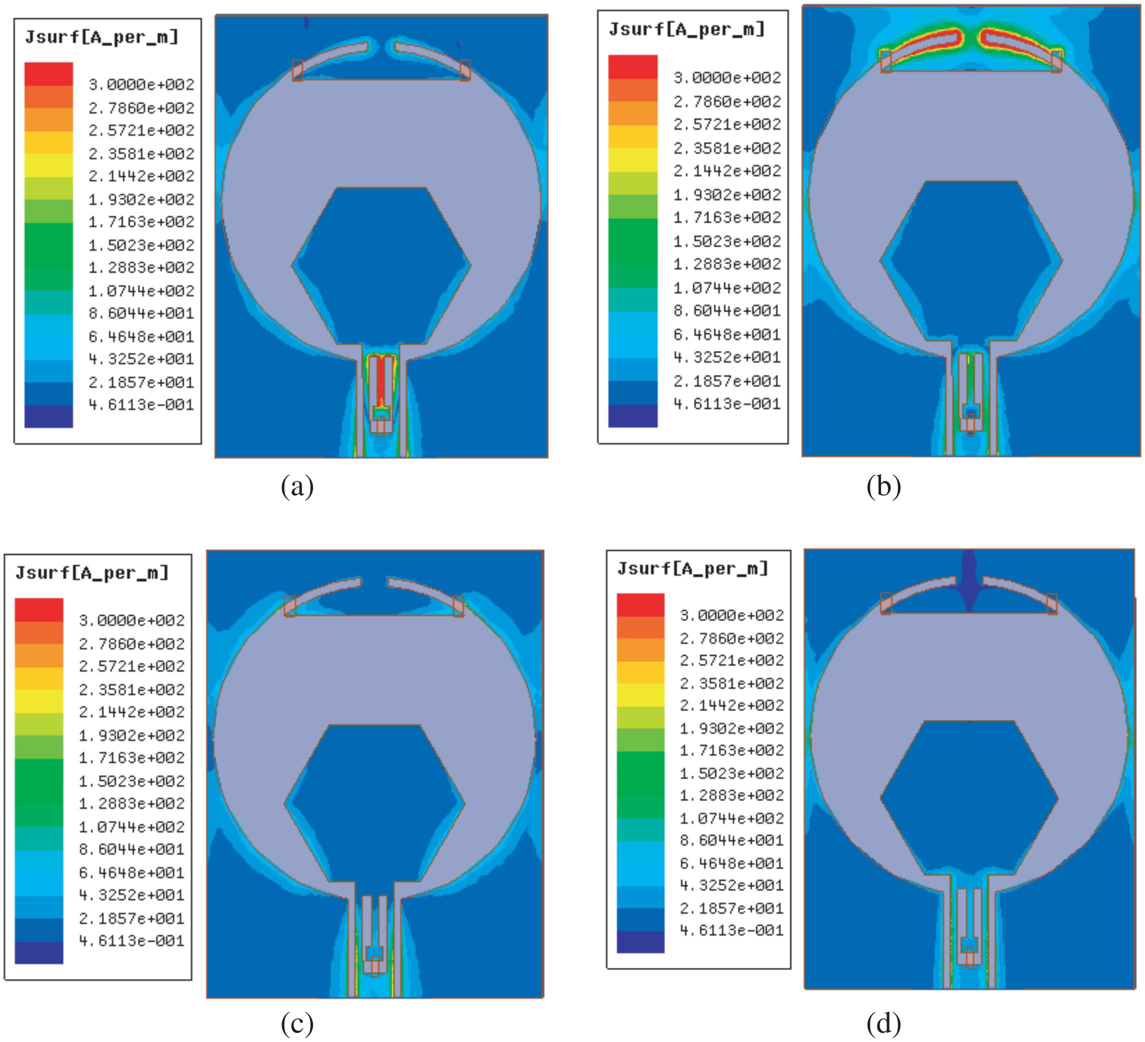
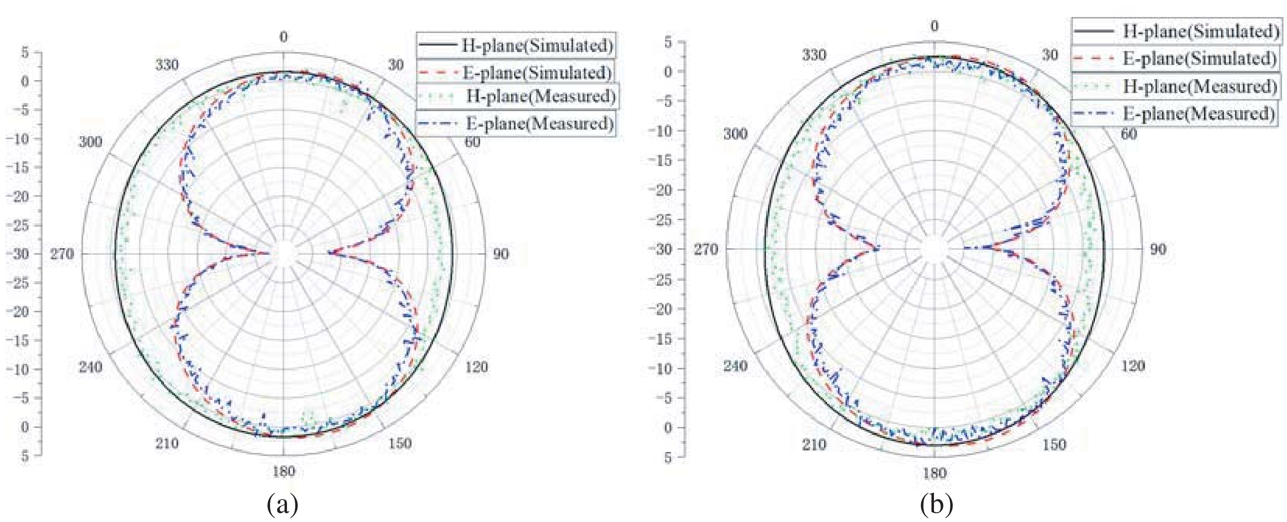
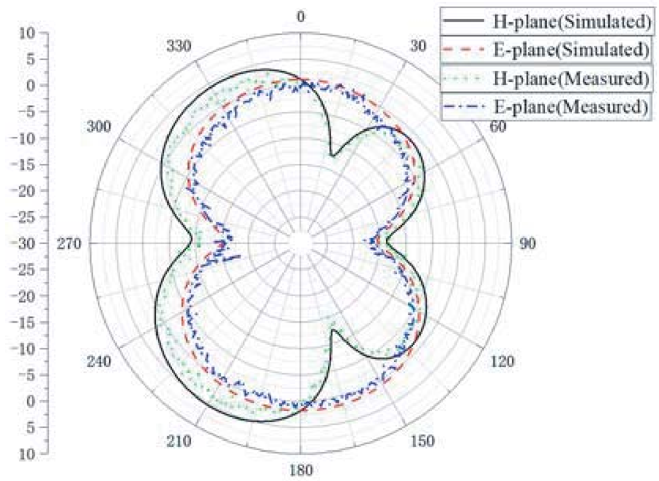


Figure 7. Surface current distribution of the proposed reconfigurable dual band-notched antenna, (a) 5.5 GHz with all switches OFF, (b) 7.5 GHz with all switches OFF, (c) 5.5 GHz with all switches ON, (d) 7.5 GHz with all switches ON.





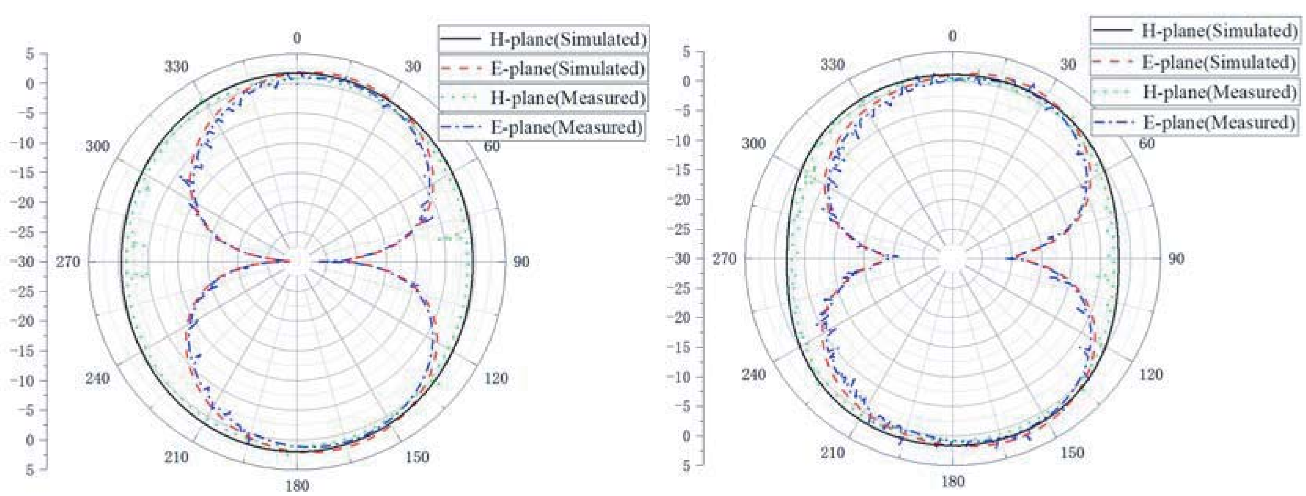
(c)

Figure 8. Radiation patterns of the antenna 4 with all switches OFF, (a) 4.5 GHz, (b) 6.5 GHz, (c) 9.5 GHz.

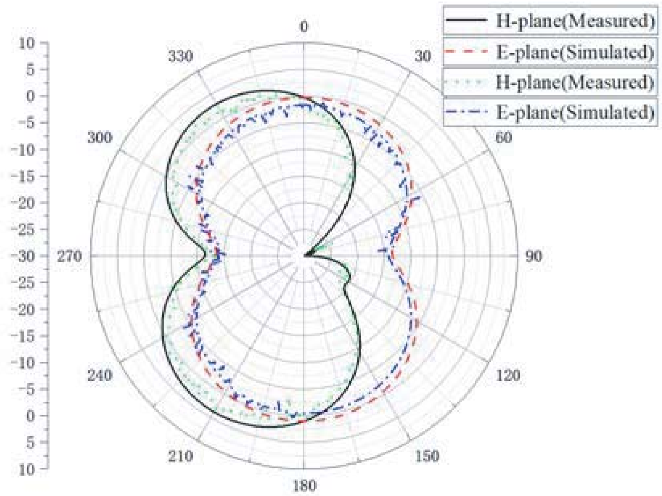
of SIR will realize the band-pass characteristics of 7 $\sim$ 7.8 GHz band, which has no effect on the notch characteristics of 5.1 $\sim$ 5.9 GHz band.

In order to further understand the generation principle and characteristics of notch characteristics, HFSS is used to analyze the surface current near the geometric structure of dual band-notched antenna. Figure 7 shows the current distribution of antenna 3 and antenna 4 at 5.5 GHz and 7.5 GHz. It can be seen from the figure that the antenna current is confined in the vicinity of cup-shaped branch and SIR in notch band. This illustrates that in the above two notch bands, the energy is confined to the notch structure, and radiation is deteriorated. It also shows that the antenna can satisfy the dual notch characteristics at the same time.

Figures 8 and 9 show the radiation patterns of antenna 4 when all switches are OFF and ON respectively. It can be seen that the antenna has omnidirectional radiation characteristics in H plane and bi-directional radiation characteristics in E plane, and the radiation pattern deteriorates slightly at high frequencies. In contrast to the simulated radiation pattern, the measured radiation pattern is the same as the overall shape, but exhibits a zigzag variation in some ranges.



(a) (b)

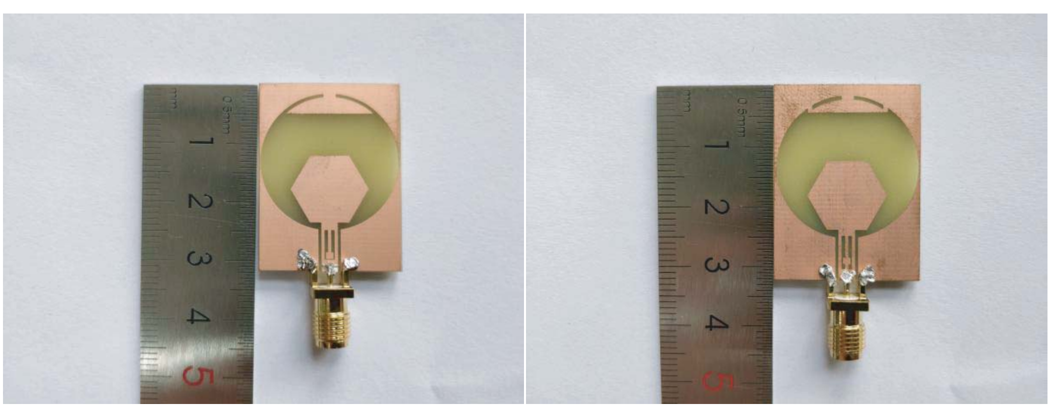


(c)

Figure 9. Radiation patterns of the antenna 4 with all switches ON, (a) 4.5 GHz, (b) 6.5 GHz, (c) 9.5 GHz.

4. ANTENNA PROCESSING AND TESTING

To verify the design of the proposed reconfigurable dual band-notched UWB antenna, antenna 4 was fabricated and then tested by the N5234A PNA-L vector network analyzer. The fabricated sample of the proposed antenna is shown in Figure 10. The switches in the simulation are replaced by metal bridges, and the loaded metal bridge corresponds to the ON state when its absence represents the OFF state. When all switches are ON, the antenna does not have notch characteristics, and when all switches are OFF, the antenna is a dual band-notched UWB antenna. Hence, a reconfigurable dual band-notched UWB antenna can be implemented by controlling the state of the switch. Figure 11 shows the test and simulation results of the S_{11} and VSWR of the antenna, respectively. The fabricated antenna achieves a wideband performance from 3 GHz to 16 GHz for $S_{11} < -10$ dB and a relative bandwidth of 137%. It can effectively avoid the interference of WLAN and X-band signals on the UWB system and has reconfigurable dual band-notched characteristics. The simulation and test results are basically consistent. The deviation is due to the accuracy of the HFSS simulation software, the processing error of the SIR structure, the test environment and the working frequency band of the SMA connector and its welding.



(a) (b)

Figure 10. Prototypes of the fabricated antennas, (a) all switches OFF, (b) all switches ON.

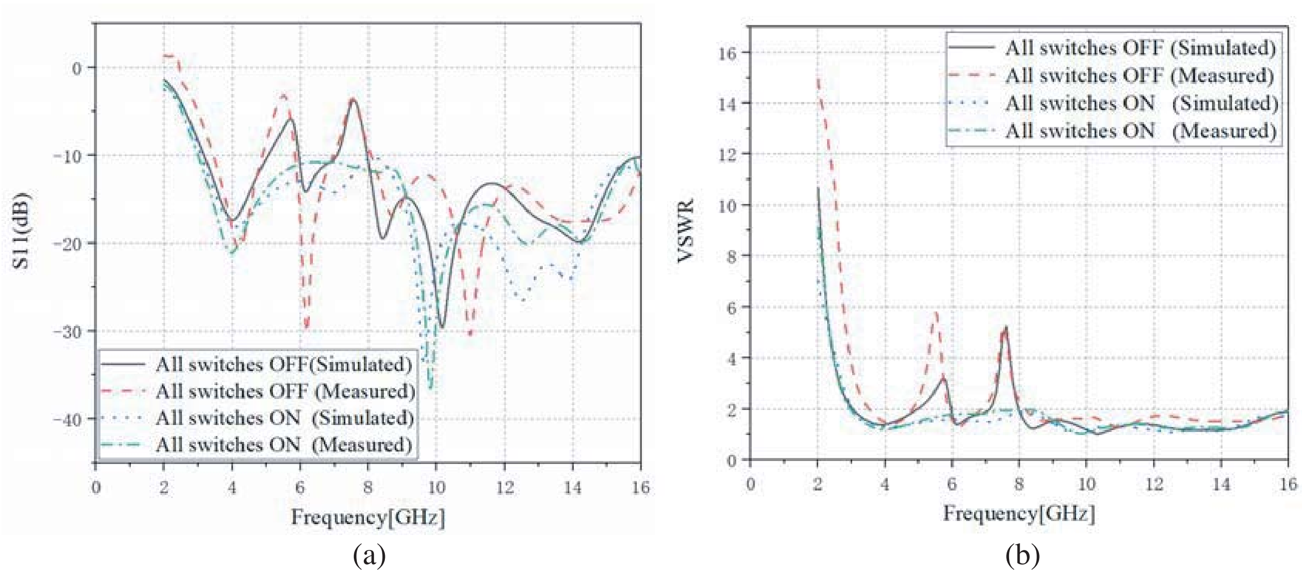


Figure 11. Simulated and measured of the proposed antenna, (a) S_{11}, (b) VSWR.

5. CONCLUSION

In this paper, a practical UWB antenna with reconfigurable dualband-notched characteristics is proposed by loading cup-shaped branches and SIR. Compared with the traditional UWB antenna, the relative bandwidth of the antenna is as high as 137%, and the dual band-notched characteristic is realized. It achieves higher gain in the non-notch band. In addition, the band-notched reconfigurability is realized by integrating three switches into cup-shaped branch and SIR. The antenna has good omnidirectional radiation characteristics in the whole working frequency band, meets the performance requirements of UWB antenna, and has dual-notched and reconfigurable characteristics. It is suitable for UWB applications requiring interference suppression at one or two specified frequencies.

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