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A New UWB Antenna with Band-Notched Characteristic

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Abstract—A new coplanar waveguide (CPW) fed ultra-wideband (UWB) antenna with band notched characteristic is proposed in this paper. In order to achieve sharp and controllable notch-band characteristic, one pair of half-wave-length stubs and slits is introduced inside the tapered slot and circular patch, respectively, on the basis of a UWB antenna. Simulated and measured results show that the antenna has a reflection coefficient (S_{11}) less than -10 dB in the range of 3.0 to 11 GHz, which can meet the requirements of a UWB communication system. It shows a good notch characteristic in 5.0∼5.8 GHz, which can cover the operating band of wireless local area network (WLAN) well. The antenna has a stable gain and good radiation characteristics in the pass band. It is simple in structure and easy in fabrication. Moreover, it has broad application prospects.

1. INTRODUCTION

Since the ultra-wideband (UWB) system has shown many advantages such as wide bandwidth, fast transmission speed, low power dissipation, and high processing gain, more and more attention has been paid to UWB antenna designs in wireless communication field [1]. However, because of its wide operating bandwidth (3.1∼10.6 GHz) and even covering other communication systems, such as Wireless Local Area Networks (WLAN) (5.15∼5.825 GHz) [2], compatibility issues between spectrums must be solved. An easy solution is to add a band-stop filter to the UWB communication system, but this will make the system more complicated. A UWB antenna with band-notched characteristic is a good choice to solve this problem [3].

Band-notched characteristics can be achieved mainly in two ways. The first way is to insert various slits or slots on the patch or the ground. The surface current on the antenna can be changed due to the introduction of the slit or slot, which can produce a notch-band. There are many types of embedded slits or slots, such as Split Ring Resonator (SRR) slots, fractal slots, L-shaped slits, and U-shaped slits. The second way is to load different parasitic elements on the antenna. For example, we can load a stub on the patch or a split ring resonator (SRR) near the feed line [4–12]. The basic principle of the above methods can be summarized as loading a series or parallel resonant circuit on the radiation element of the antenna, equivalently [8].

Many UWB antennas with band-notched characteristic have been proposed in recent years. [1, 3, 9] provided UWB antennas with good band-notched characteristic. Since the antennas in [1, 3, 9] use only one type of resonator at a notch frequency, the notch band is uncontrollable. [12–14] provided UWB antennas with a single notch band, but none of them have sharp selectivity in the notch band. The antenna proposed in [15] had a sharp notch band; however, parameter S_{11} is not satisfactory on high frequency. [16] provided a UWB antenna with good notch characteristic, but the configuration to realize the band notch characteristic was complicated. [17] proposed a compact band notched UWB antenna. To achieve the notched frequency band for WLAN, an inverted L-slit was embedded at the edge of the

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radiating patch. Despite having fairly compact dimension, the proposed antenna completely rejected the entire 4.85 ∼6.04 GHz frequency band, though the desired notched-band for WLAN is 5.15∼5.825 GHz.

A new CPW-fed band-notched UWB antenna with sharp selectivity is proposed in this paper. In order to achieve sharp and controllable notch-band characteristic, one pair of stubs is introduced inside the tapered slot, symmetrically, and slits are etched on a circular patch, on the UWB antenna. The combination of the stubs and slits is equivalent to the introduction of two resonators [18], resulting in a sharp notch band finally. The configuration to realize the band notch characteristic is simple. Results show that the antenna achieves an impedance bandwidth of 3 GHz to 11 GHz for $S_{11} < -10$ dB, except the rejected band 5.0 GHz∼5.8 GHz. It can avoid the working band of WLAN successfully, and the VSWR in the pass-band is lower than 2. In addition, simulated results show that the proposed antenna has high and stable gain and good radiation characteristics in the passband.

2. GEOMETRY OF UWB ANTENNA

The UWB antenna is printed on one side of a substrate having a dielectric constant of 2.55, loss tangent of 0.0019, and thickness of 0.8 mm. The dimensions of the antenna ($W_0 \times L_0$) is 30×28 mm^2. The UWB antenna consists of a circular patch and a tapered slot ground, and the circular patch is connected with a coplanar waveguide feed-line. A rectangular part is cut from the circular patch to improve impedance matching. This is equivalent to introducing an impedance matching element to improve impedance characteristic [19]. The gradually changing structure on the ground can generate several resonant modes and provide smooth transition within these modes [20], and the impedance characteristics of the antenna are further improved. The geometry of the antenna is shown in Figure 1. The parameters in Figure 1 are optimized using ANSYS HFSS 13.0 which is based on the method of finite element method. Several parameters are optimized in the following discussion.

Parameters of the UWB antenna are listed in Table 1.

Table 1. Parameters of the UWB antenna (see Figure 1).

Parameter	W_1	W_2	W_3	L_1	L_2	L_3	g_0	h_0	Ra	Rx	Ry
Value/mm	19	3	2.2	5	2.5	2.8	0.8	0.5	5	5	5

Figure 2 shows the simulated S_{11} of the UWB antenna. Results show that the impedance bandwidth of the antenna is 3 GHz∼11 GHz. Reflection coefficient is less than −10 dB in the range, which can meet the requirements of the UWB communication system. It proves that the slotting method we take can improve impedance matching effectively.

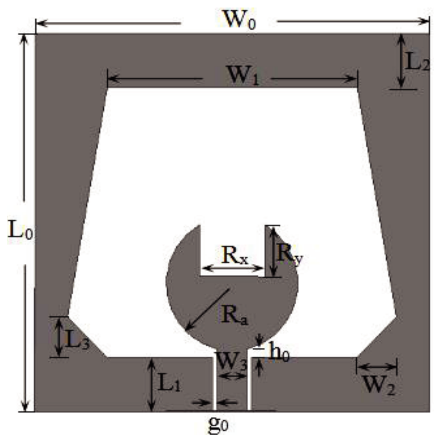


Figure 1. Schematic diagram of the UWB antenna.

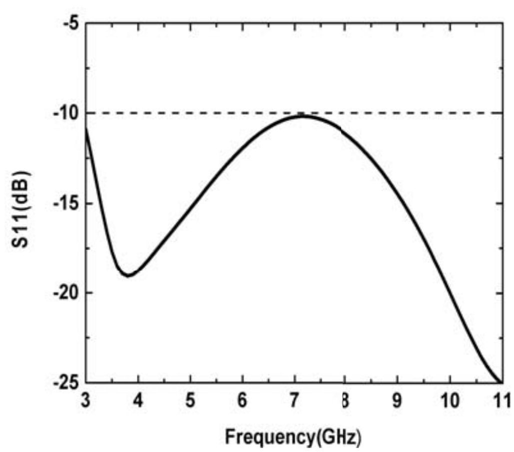


Figure 2. The simulated S_{11} of the UWB antenna.

Figure 3 shows the effect of rectangular part which is cut from the circular patch. It shows that the impedance matching in the low frequency band (3.5 GHz$\sim$6 GHz) is obviously improved when the rectangular slot is introduced. The dimensions of the rectangular slot are optimized in Figure 4. It shows that when $R_x = 5.0$ mm and $R_y = 5.0$ mm, the antenna can cover the entire UWB of 3 $\sim$11 GHz.

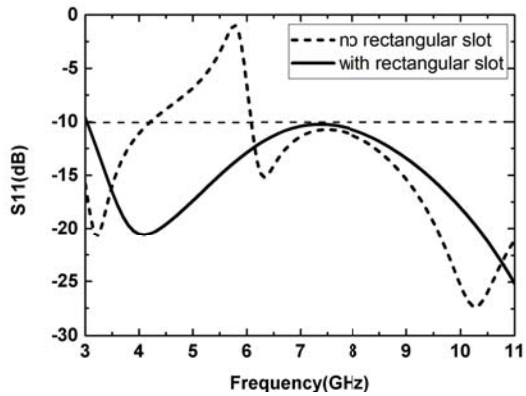
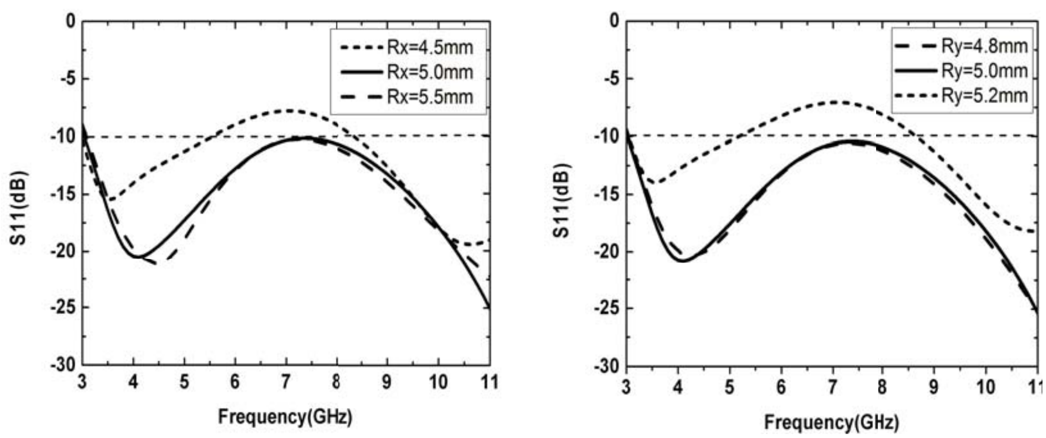


Figure 3. The effect of the rectangular slot for S_{11} of the UWB antenna.



(a) (b)

Figure 4. Optimization of rectangular slot dimensions.

3. DESIGN OF THE BAND-NOTCHED UWB ANTENNA

In order to avoid interference of WLAN (5.15 GHz$\sim$5.825 GHz) signals to the UWB system, a UWB antenna with a notch band from 5.0 GHz to 5.8 GHz is required. The simulated current distribution of the above UWB antenna shows that the current is strongly concentrated near the connection of the circular patch and feed line and two sides of the tapered slot. Figure 5 shows the surface current distribution of the UWB antenna. The resonant structure introduced in a place where current energy is dense can make the resonance effect more obvious [17–20], so one pair of stubs is introduced inside the tapered slot, symmetrically, and slits are etched on the circular patch, on the UWB antenna. The band-notched antenna is shown in Figure 6. One pair of stubs is parallel to the edge of the tapered slot on both sides. The total length of the stubs and slits is half of the wavelength of the start frequency 5.0 GHz and stop frequency 5.8 GHz, respectively. In fact, the half-wavelength stubs and half-wavelength slits serve as two resonators at the desired notched frequencies 5.0 GHz and 5.8 GHz, which will make impedance mismatched seriously [20].

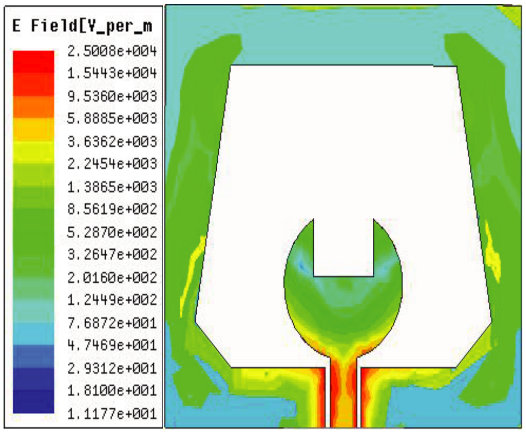


Figure 5. Surface current distribution of the UWB antenna.

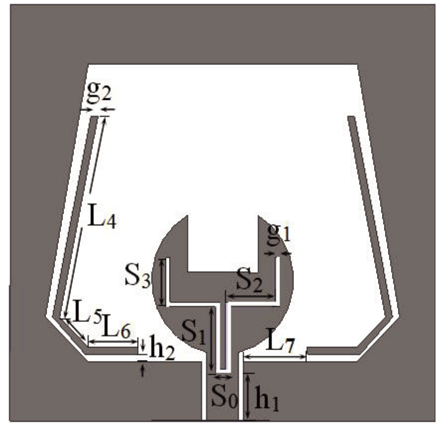


Figure 6. Schematic diagram of the band-notched UWB antenna.

Formulas for the total length of the stubs and slits are given below [21].

$$L_{stub} = \frac{c}{2f_1 \cdot \sqrt{\varepsilon_{eff}}} \tag{1}$$

$$L_{slit} = \frac{c}{2f_2 \cdot \sqrt{\varepsilon_{eff}}} \tag{2}$$

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

where c is the speed of the light in free space, ε_{eff} the effective dielectric constant of the substrate, and f_1 and f_2 are the resonant frequencies of the half-wavelength stubs and half-wavelength slits, respectively [21]. To cover the band of WLAN, we set f_1 as 5.0 GHz and f_2 as 5.8 GHz. The parameters in Figure 6 are optimized and listed in Table 2.

Table 2. Parameters of the band-notched UWB antenna.

Parameter	L_4	L_5	L_6	L_7	g_1	g_2	S_0	S_1	S_2	S_3	h_1	h_2
Initial Value/mm	7.1	2.5	2.5	5	0.2	0.3	0.8	3.6	3.16	3.14	2.5	0.8
Final Value/mm	7.2	2.7	2.3	5.2	0.3	0.5	1	3.5	3.2	3.2	3	0.5

For frequency f_1, the theoretically calculated value $L_{stub} \approx 24.36$ mm, and the practical length of the stub is $2(L4 + L5 + L6) = 2(7.2 + 2.7 + 2.3) = 24.4$ mm. For frequency f_2, the theoretically calculated value $L_{slit} \approx 20.68$ mm, and the practical length of the slit is $S_0 + 2(S1 + S2 + S3) = 1 + 2(3.5 + 3.2 + 3.2) = 20.8$ mm. The comparison of the theoretically calculated and simulated results shows that our design theory matches the practice. The inaccuracies between the theory and practice mainly come from the errors of calculating the effective dielectric constant.

4. SIMULATION AND ANALYSIS OF BAND-NOTCHED ANTENNA

Figure 7 shows surface current distribution of the band-notched UWB antenna at a notch frequency 5.4 GHz. It can be seen that the surface current on the circular patch mainly flows along the slits, and the current on the ground gathers near the stubs, which can generate a standing wave effect and a rejected band [22]. Since the current is concentrated near the stubs and slits, it leads to impedance

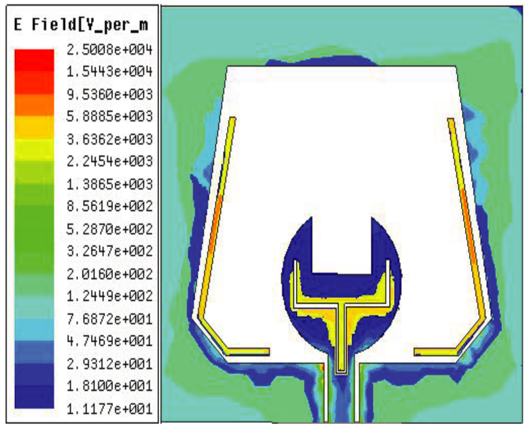


Figure 7. Surface current distribution of the band-notched UWB antenna at 5.4 GHz.

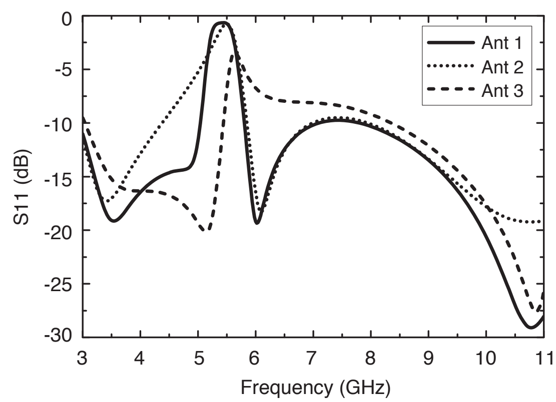


Figure 8. Reflection coefficient (S_{11}) comparison of the band-notched antennas.

mismatch, which causes a band-notched characteristic. Adjusting the length of the slits and stubs can make the antenna to generate a notch-band at the desired frequency.

The reflection coefficient (S_{11}) of the band-notched UWB antenna is shown in Figure 8. It shows that only stubs are introduced in the tapered slot(antenna 2), or only slits are etched on the circular patch(antenna 3), and the band-notched characteristic is not good. When the stubs and slits are introduced together (antenna 1), their notch bands can couple, and a notch band from 5.0 GHz to 5.8 GHz with good selectivity is obtained. In addition, adjusting the length of the stubs and slits can change the range of the notch band to meet the requirements of different communication systems.

The results indicate that the -10 dB impedance bandwidth of the proposed antenna is in the frequency range from 3 to 11 GHz, which covers the bandwidth of the UWB communication systems. A rejected band with good selectivity is generated at 5.0 GHz to 5.8 GHz.

Figure 9 shows the influence of different parameters on the notch band. It shows that s_o makes great influence on high frequencies of the notch band, and when g_1 is 0.3 mm, the notch band shows the best performance. By optimizing some parameters and choosing the optimal values for these parameters, a band with good notched characteristic can be achieved.

Figure 10 shows the simulated VSWR characteristic of the band-notched UWB antenna. It shows that the antenna has a voltage standing wave ratio of less than 2 in the UWB (3.0 GHz to 11 GHz) except for the rejected band.

Figure 11 shows the simulated gain of the proposed antenna. It is easy to see that the gain of the antenna ranges from 2.5 dBi to 7 dBi within 4–11 GHz except for the rejected band (5.0 GHz–5.8 GHz) where the gain decreases even to -12.5 dBi. The antenna has stable gain in the passband and cannot

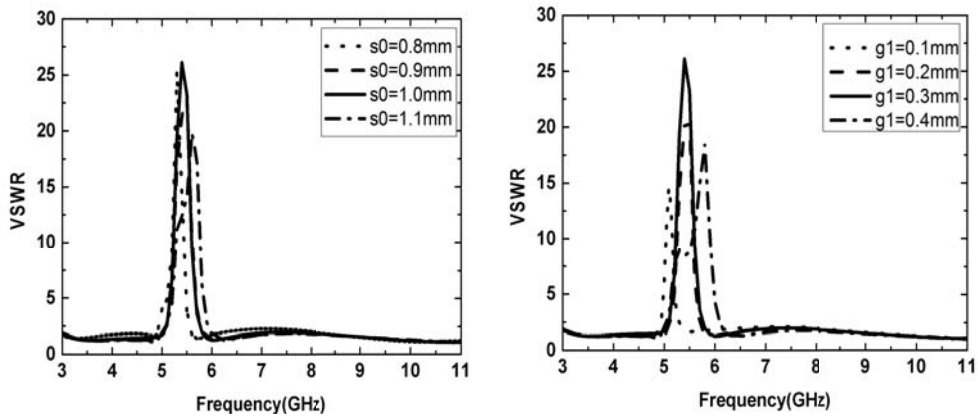


Figure 9. The influence of different parameters on the notch band.

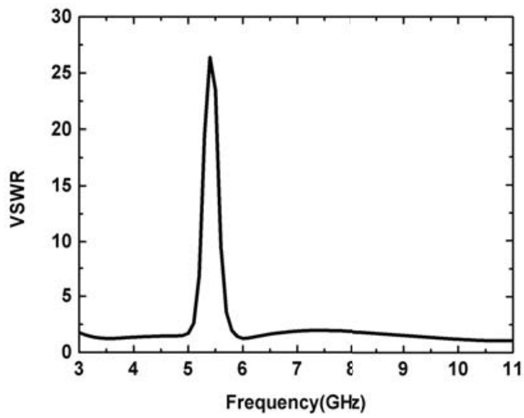


Figure 10. The simulated VSWR characteristic of the band-notched UWB antenna.

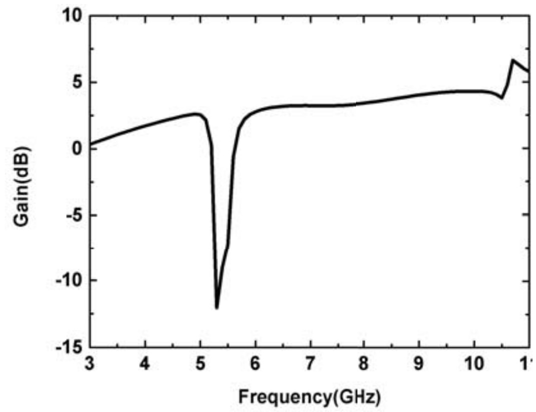


Figure 11. The simulated gain of the band-notched UWB antenna.

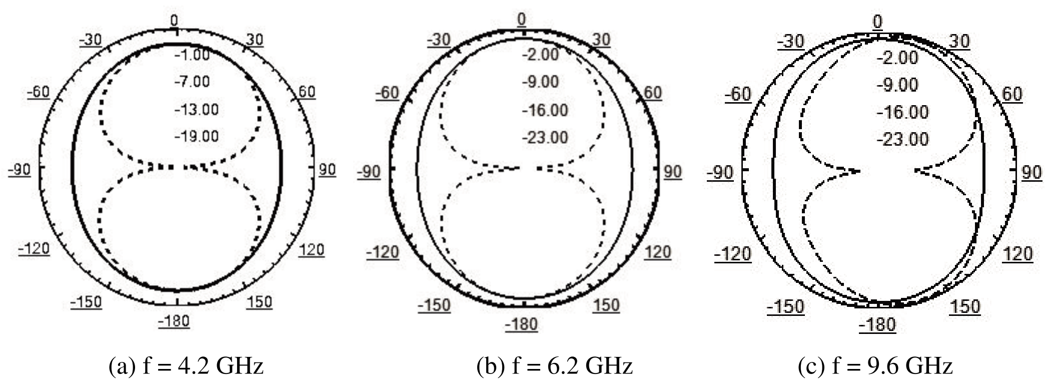


Figure 12. Simulated radiation pattern of the proposed antenna at 4.2, 6.2 and 9.6 GHz.

work normally in the rejected band, which can effectively avoid interference of the WLAN system.

In order to meet the general needs of the application, the radiation characteristics are also an indispensable indicator when the band-notched UWB antenna performs well in working bandwidth, band-notched characteristics, and gain [23]. Figure 12 shows the radiation pattern at three frequency points 4.2, 6.2 and 9.6 GHz, which are selected randomly within the passband (the dotted line represents the x-z plane, and the solid line represents the y-z plane). In the H plane (y-z plane), the proposed antenna shows an omnidirectional radiation characteristic, and it shows bi-directional patterns in the E plane. It can be seen that the antenna has good radiation characteristics at the operating band.

5. ANTENNA PROCESSING AND TESTING

To verify the performance of the proposed antenna, the band-notched UWB antenna was processed and the S_{11} parameter is tested by vector network analyzer. The fabricated sample of the proposed antenna is shown in Figure 13. It is designed on a 0.8 mm-thick Taconic dielectric substrate with dielectric constant 2.55 and loss tangent 0.0019. The dimensions of the antenna are $30\times28\,\mathrm{mm}^2$. The circular patch is connected with CPW feed-line. An SMA is connected to the port of the feed line, and the circular patch and tapered slot ground are on one side of the substrate.

Figure 14 and Figure 15 show the simulated and measured S_{11} and VSWRs of the proposed antenna. The measured results are slightly different from the simulated ones, but it still meet the requirements of the UWB communication system. The antenna has an S_{11} less than -10 dB in the range of 3 GHz to 11 GHz, and a relative bandwidth of 114%. It can avoid the interference of WLAN signals on the UWB system. The discrepancy between simulation and measurement may be due to the reasons as below:

1. The joining of the SMA connector.
2. The manufacturing precision.
3. The measurement environment.
4. The error of the substrate's relative permittivity and thickness [24–26].

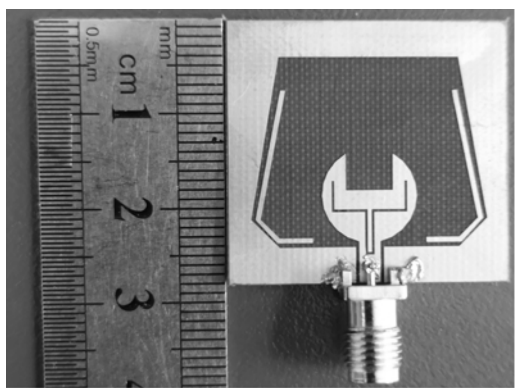


Figure 13. Fabricated sample of the proposed antenna.

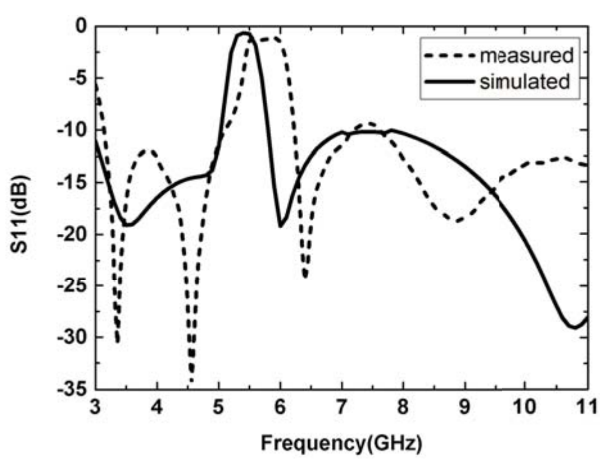


Figure 14. Simulated and measured S_{11} of the proposed antenna.

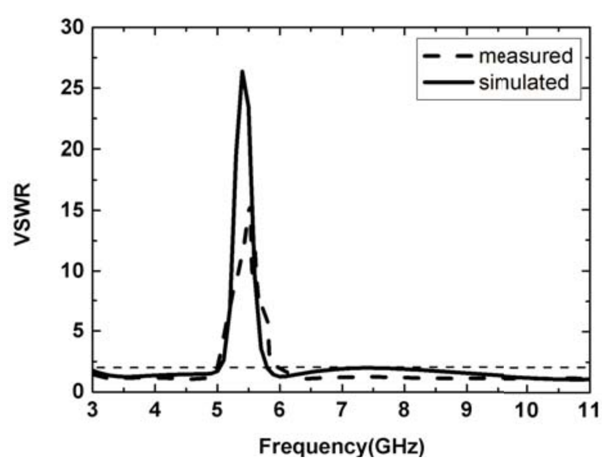


Figure 15. Simulated an measured VSWR of the proposed antenna.

6. CONCLUSION

A new ultra-wideband band-notched antenna with CPW-feed is proposed in this paper. In order to achieve a sharp and controllable notch-band characteristic, two half-wavelength resonators are introduced on the basis of a UWB antenna. It turns out that the notch-band generated by the combination of the stubs and slits has better notch performance and can avoid the interference of the WLAN signal effectively. Since two resonators are introduced, the notch band can be controlled easily to meet different requirements of practical applications, and it can keep good selectivity at the same time. The simulated results show that the antenna has stable gain and excellent radiation direction characteristics. Moreover, the advantages of simple structure and single side print make this antenna a good choice for UWB systems.

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