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A COMPACT UWB ANTENNA WITH SHARP DUAL BAND-NOTCHED CHARACTERISTICS FOR LOWER AND UPPER WLAN BAND

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Abstract—A compact dual band-notched Ultra-Wideband antenna with sharp band-notched characteristics and controllable notched bandwidths is presented. The antenna consists of a spade-shaped microstrip-fed Ultra-Wideband planar monopole antenna and two sets of band-notched structures. The band-notched structures are employed to generate the desired lower and upper rejection bands with good frequency selectivity and sufficient rejection bandwidths. Moreover, the bandwidth of the lower and upper rejection bands can be independently adjusted by changing the size of the band-notched structures. Finally, a UWB antenna is successfully designed with the dual notched bands for the lower WLAN band (5.15–5.35 GHz) and upper WLAN band (5.725–5.825 GHz). A good impedance match is obtained in 3.1–10.6 GHz frequency range ($|S_{11}| < -10$ dB), except the lower and upper WLAN band ($|S_{11}| > -5$ dB). The ratios of the notched bandwidths between -5 dB and -10 dB in the two stop bands are greater than 0.73.

1. INTRODUCTION

After the release of the frequency band 3.1–10.6 GHz for Ultra-Wideband communication by the Federal Communications Commission (FCC) [1], short-range and short-pulses UWB Wireless Communications have developed rapidly. As the key components of the UWB systems, the ultra-wideband (UWB) antennas have been studied widely from both academic and industrial areas. However, over the entire UWB frequency bands, there are some other existing narrow

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band systems, such as the wireless local area network (WLAN) systems in the lower WLAN band (5.15–5.35 GHz) and the upper WLAN band (5.725–5.825 GHz), which may interfere with the UWB systems. To solve the problem, lots of researches have been done recently, including adding band-rejected structure to UWB antenna [2–11] and cascading stop filters with UWB antenna [12]. The methods of adding band-rejected structure mainly include cutting slots of different shapes in the radiator [2–7], inserting slots on the feed line [8] or adding folded parasitic strips near the feed line or around the ground [9, 10]. However, using each of above rejection approaches only created one single filtering frequency and the selectivity is not so good. To achieve better selectivity in the stop-band, higher order band-stop filter can be used in the UWB antenna.

There are lots of researches on UWB antennas with dual or multiple rejection bands [4–6, 13], but how to obtain high efficient band-notched characteristic is still a challenging issue. The main problem of the band rejected function design is the difficulty of controlling bandwidth of the notched band, and few band-notched UWB antennas with controllable rejection band width have been presented. Some designs of multiple rejection bands are with a notched bandwidth more than 2 GHz. However, the needed band-notches are 0.2 GHz for the lower WLAN band and 0.1 GHz for the upper WLAN band.

In order to achieve good selectivity in the entire WLAN band without increasing the dimensions, two sets of band-notched structures are used to form a compact dual band-notched ultra-wideband antenna. One band-rejected structure for the lower WLAN band is realized by inserting two half wavelength C-shaped slots with the same resonant frequency in the radiator patch. The two C-shaped slots are coupled together to form a sharp band rejection. Another band-rejected structure is realized by coupling two half-wavelength U-shaped inverted resonators along with the feed-line, which can be equivalent to be a two-order band-stop filter. The filter is cascaded with the radiating patch of UWB antenna, and the improved band-notched characteristics can be achieved. The design guidelines of UWB antenna and the principles of the two sets of band-notched structures are demonstrated in Section 2. The size of the designed antenna is 30 mm $\times$ 34 mm. Both in the lower WLAN band and in the upper WLAN band, $|S_{11}| > -5\,\mathrm{dB}$, keeping the impedance matching in good condition in the pass-band ($|S_{11}| < -10\,\mathrm{dB}$). The ratios of $-5\,\mathrm{dB}$ notched bandwidth to $-10\,\mathrm{dB}$ notched bandwidth in the two stop bands are greater than 0.73.

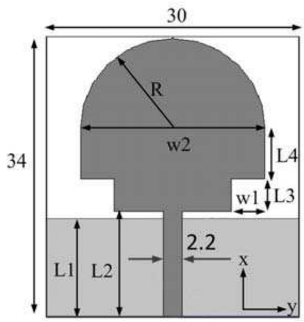

Figure 1. Geometry of the proposed UWB antenna (Unit: mm)

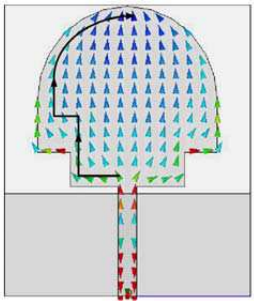

Figure 2. The current distributions at 3.1 GHz.

2. UWB ANTENNA DESIGN FOR SINGLE BAND-NOTCHED

2.1. UWB Antenna Design

The geometry of the proposed UWB antenna is illustrated in Figure 1. The microstrip-fed UWB antenna's radiating patch is spade-shaped. The antenna is designed on a substrate with thickness of 0.8 mm and relative permittivity of 2.55. A semicircle structure is adapted in the front side of radiating patch, which results in a smooth transition from one resonant mode to another and ensures good impedance match over a broad frequency range. Two rectangles are cut off from bottom patch separately, which improve the characteristic of the high frequency band. The half-wavelength of the lowest resonant frequency in UWB band ($f = 3.1$ GHz) can be calculated with Expression (1).

$$\frac{\lambda_p}{2} = \frac{c}{2f\sqrt{\varepsilon_r}} \tag{1}$$

where λ_{p} denotes the corresponding phase wavelength of the resonator; f represents frequency; ε_r is the effective dielectric constant of the substrate; c is the speed of the light in free space.

The current distribution at 3.1 GHz is shown in Figure 2. The length of the current loop L can be calculated with Expression (2).

$$L = R + L_3 + L_4 + \frac{2\pi R}{4} \tag{2}$$

where the parameters are marked in Figure 1.

To simplify the analysis, supposing that

$$L_3 + L_4 = R \tag{3}$$

Because the longest path of current in radiating element is approximately equal to half wavelength at the minimum frequency, so

$$\frac{\lambda_p}{2} = L \tag{4}$$

It can be figured out from the above expression that R is equal to 8.7 mm. The initial value of L_3 is given for 2 mm. Then, $L_4 = R - L_3 = 6.7$ mm. So the initial value of the parameters about radiating patch are: $w_1 = L_3 = 2$ mm, $L_4 = 6.7$ mm, $R = 8.7$ mm. The electromagnetic software Ansoft HFSS V_{11} is employed to perform this design and optimization. The high frequency band can be controlled by adjusting the L_3 and the matching characteristic of entire frequency band can be controlled by adjusting radio of L_4 and R. The final antenna parameters are given as follows: $w_1 = 4$ mm, $w_2 = 22$ mm, $L_1 = 12$ mm, $L_2 = 12.8$ mm, $L_3 = 4$ mm, $L_4 = 6$ mm, $R = 11$ mm. The radiating element occupies a size of 21 mm × 22 mm. The simulated return loss of the UWB antenna without band-rejection is presented in Figure 3. The 10 dB impedance bandwidth is from 3.0 GHz to 12.6 GHz, which can cover the entire UWB operating band (3.1–10.6 GHz).

2.2. Band-notched UWB Antenna for Lower WLAN Band

The geometry of the proposed band-notched UWB antenna for the lower WLAN band is illustrated in Figure 4. Two C-shaped slits are embedded in the radiator patch. It is well known that band-notched response can be achieved by etching a slit in the radiator. The slit resonates at the frequency where its electrical length is equal to half

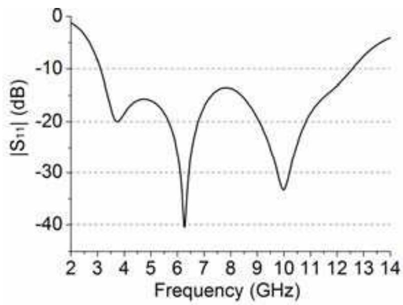

Figure 3. Return loss of the UWB antenna without band-rejected structure.

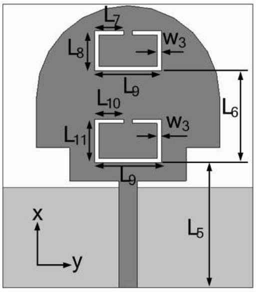

Figure 4. Configuration of the band-rejected UWB antenna for lower WLAN band.

wavelength. By adjusting the length of the slit to be about half-wavelength at the desired notched frequency, a destructive interference can take place [5]. Current is concentrated around the edges of the slit, which leads to an impedance mismatch at the antenna feed. But the sharp band-notched response using only one slit can not be obtained in the entire desired narrow band. In order to produce sharp edge band-notch in desired narrow band, two C-shaped slits with the same resonant frequency are embed in the patch. When the two slits are about a quarter of wavelength apart, these two notched frequencies are coupled together. A second-order band-stop filter is formed [14], and an improved notch-band structure with sufficient rejection bandwidth and sharp skirt response is obtained.

According to the above discussion, a band-notched UWB antenna for lower WLAN band is designed. The total length of each slit can be calculated with Expression (5).

$$f_{slit} = \frac{c}{2L_{slit}\sqrt{\varepsilon_{re}}} \tag{5}$$

The band-rejected antenna etched one C-shaped slit is compared with the antenna etched two ones in Figure 5. It can be concluded from Figure 5 that two coupling C-shaped slits give a good enhancement in the rejection sharpness. Figure 6 shows the simulated return losses at various distances between two slits. Here, all of the parameters are the same except the distance (L_6 in Figure 4), and λ_0 represents corresponding phase wavelength. It is found that when the distance is equal to a quarter of corresponding wavelength, the best band-notched characteristic can be achieved.

As for the proposed antenna, the transverse length of the slot (L_9) and the width of the slot (w_3) are the most important parameters of

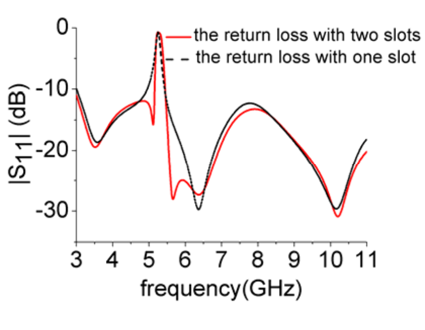

Figure 5. Simulated $|S_{11}|$ with one and two slots.

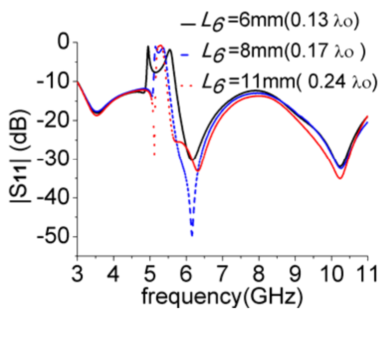

Figure 6. Simulated $|S_{11}|$ with different L_6.

the notched bandwidth. Figure 7 shows the simulated return loss at various L_9. Here, all of the parameters are fixed except L_9, L_8 and L_{11}. When L_9 varies from 7 mm to 11 mm, L_8 and L_{11} are changed properly, keeping the center frequency of stop band almost unchanged. It can be seen that the band-notched bandwidth is widened obviously as L_9 becomes longer. Figure 8 presents the simulated return loss for the width of the slot w_3 varied from 0.3 to 0.8 mm. In this case, the other parameters are kept almost unchanged. It is seen that, a larger value of w_3 generates a wider rejection bandwidth. From the discussion above, the notched bandwidth of the lower rejection band can be independently adjusted by changing L_9 and w_3.

The final antenna parameters are optimized and given as follows: $w_3 = 0.5$ mm, $L_5 = 15$ mm, $L_6 = 11$ mm, $L_7 = 3$ mm, $L_8 = 4.8$ mm, $L_9 = 7$ mm, $L_{10} = 3$ mm, $L_{11} = 5.2$ mm. The ratio of -5 dB notched bandwidth to -10 dB notched bandwidth is 0.73.

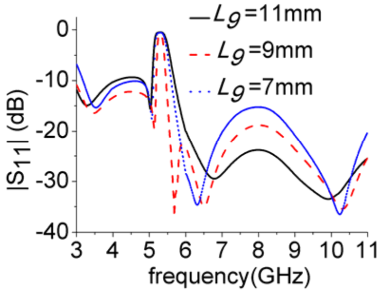

Figure 7. $|S_{11}|$ with different L_9.

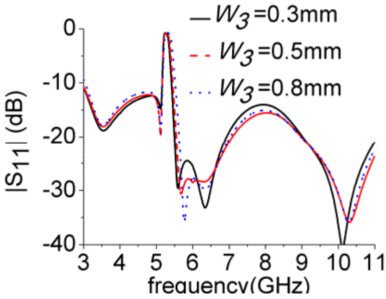

Figure 8. $|S_{11}|$ with different w_3.

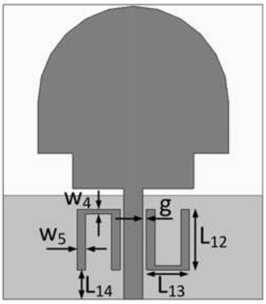

Figure 9. Configuration of the band-rejected UWB antenna for upper WLAN band.

2.3. Band-notched UWB Antenna for Upper WLAN Band

The geometry of the proposed band-notched UWB antenna for upper WLAN band is illustrated in Figure 9. The band-rejected structure comes from a traditional two-order micro-strip band-stop filter. As shown in Figure 10 [14], two half-wavelength open-circuit U-type resonators are located at the same side of a micro-strip line with a quarter wave-lengths apart. The notched bandwidth of the filter can be effectively controlled by adjusting the width of the resonators and the gap between the feed-line and the resonators. But the filter may be too large if it is applied into a notch band UWB antenna. If the two U-type resonators are located at the same point of a micro-strip feed line at the different side and one of the U-type resonators is inverted as shown in Figure 11, an interesting phenomenon can be found that the properties remain unchanged for the two filters.

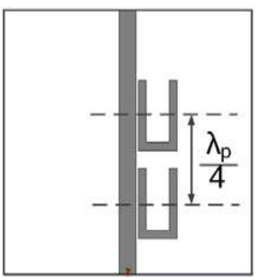

Figure 10. Traditional structure of two order band-stop filter.

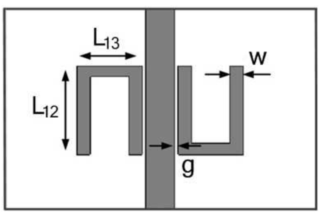

Figure 11. Geometry of the proposed band-stop filter.

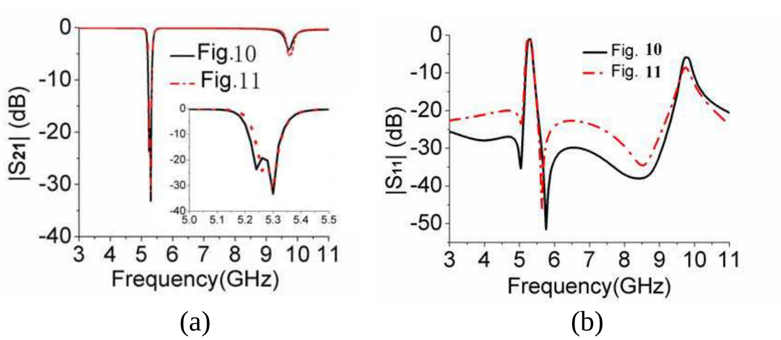

Figure 12. The S parameters of the filter in Figure 10 and the filter in Figure 11. (a) $|S_{21}|$ for Fiure 10 and Figure 11. (b) $|S_{11}|$ for Figure 10 and Figure 11.

Figure 12 exhibits the transmission coefficient and reflection coefficient of the two filter structures. The design parameters are $L_{12} = 8\,\mathrm{mm}$, $L_{13} = 5\,\mathrm{mm}$, $w = 1\,\mathrm{mm}$, $g = 0.3\,\mathrm{mm}$. Based on the above equivalent concept, a compact filter structure equivalent to the one shown in Figure 10 is presented. The total length of each resonator, L_u, is half-wavelength at the center frequency of the desired stop band. The stop band width is decided by L_{12}, g, w. The size of the new structure is reduced about a quarter wave-lengths.

The return loss of the new band-stop filter at the center frequency of 5.5 GHz for different parameters is illustrated in Figure 13–16. In this condition, only the discussed parameter is changed, and the other parameters are kept unchanged. It can be seen from Figure 13 that when L_u varies from 18 mm to 20 mm, the center frequency of the stop band decreases from 6.2 GHz to 5.2 GHz while the bandwidth almost remains unchanged. It is observed from Figure 14 that when the gap g decreases from 0.5 mm to 0.2 mm, -5 dB notched bandwidth increases. The notched bandwidths for the different w of the resonator are shown in Figure 15. W varies from 0.2 to 1 mm and L_{13} is change

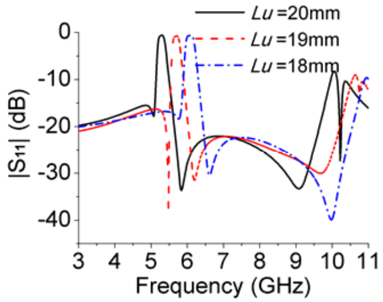

Figure 13. $|S_{11}|$ for different L_u.

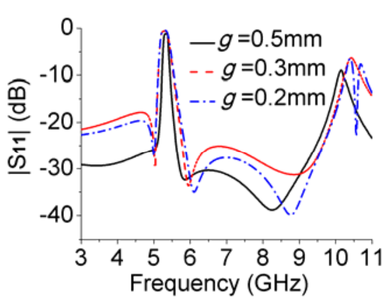

Figure 14. $|S_{11}|$ for different g.

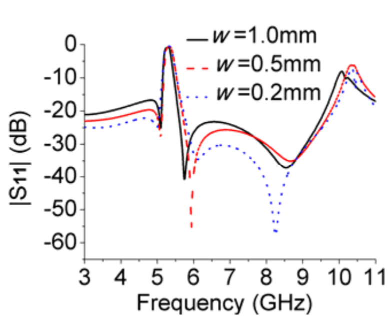

Figure 15. $|S_{11}|$ for different w.

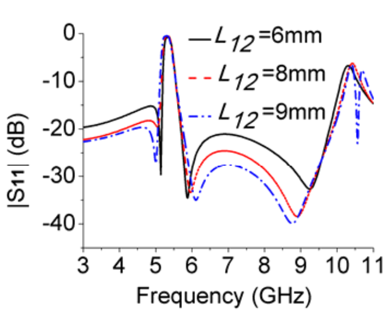

Figure 16. $|S_{11}|$ for different L_{12}.

properly, keeping the center frequency of the stop band unchanged. It can be found that -5 dB notched bandwidth decreases. The notched bandwidths for the different coupling lengths (L_{12}) of the resonators are shown in Figure 16. L_{12} increases from 6 mm to 9 mm and L_{13} is change properly, keeping the center frequency of stop band unchanged. It is found that -5 dB notched bandwidth increases. From the discussion above, the notched bandwidth of the upper rejection band can be independently adjusted by changing L_u, L_{12}, g and w.

In Summary, the center frequency of the stop-band is determined by the total length of each resonator L_u: the longer the length of resonator gets, the lower the stop-band frequency becomes. The stop-band width is decided by L_5, g, w. The smaller the distance between resonators and micro-strip feed line becomes, the wider the bandwidth is; the narrower the width of resonator gets, the wider the bandwidth is; the longer the length of coupling length, the wider the bandwidth; and vice versa.

It should be paid attention that the first parasitic stop-band of the filter is within 10 GHz. If the filter is connected with the antenna directly, the property of the high frequency band will be worse. For this reason, the Stepped Impedance Resonator (SIR) is applied, which is illustrated in Figure 17. The parasitic stop band can be removed out of the UWB band by changing the ratio of impedance [15]. The band-stop filter of this paper covers the upper WLAN band of 5.725–5.825 GHz. According to the above analysis, the design steps of band-stop filter are as follow:

Step 1. In order to have relatively strong magnetic coupling, L_{12}, w_5 are fixed to be 8 mm, 0.6 mm respectively.

Step 2. The appropriate impedance ratio can be achieved by adjusting w_4. According to the formula of literature [15] and the center

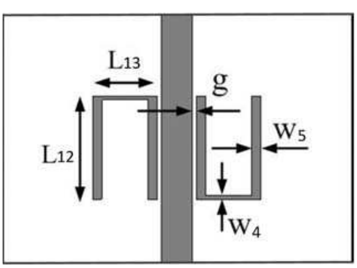

Figure 17. Two order band-stop filter with SIR structure.

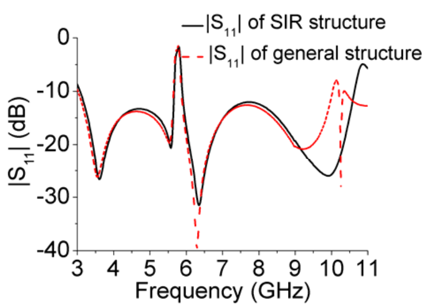

Figure 18. Simulated $|S_{11}|$ with UR and SIR structure.

frequency of stop-band, L_{13} can be calculated.

Step 3. And then by adjusting g, the desired bandwidth of stop-band can be obtained.

Step 4. The final parameters are achieved, which are $L_{12} = 7\,\mathrm{mm}$, $L_{13} = 5\,\mathrm{mm}$, $L_{14} = 3.4\,\mathrm{mm}$, $w_4 = 0.5\,\mathrm{mm}$, $w_5 = 1\,\mathrm{mm}$, $g = 0.4\,\mathrm{mm}$.

The return losses of using uniform resonator (UR) and using Stepped Impedance Resonator (SIR) are shown Figure 18. It can be seen that: while connected with SIR band-stop filter, a good impedance matching is obtained in 3.1–10.6 GHz frequency range ($|S_{11}| < -10\,\mathrm{dB}$), except the upper WLAN band of 5.725–5.825 GHz ($|S_{11}| > -5\,\mathrm{dB}$). Moreover, the parasitic stop band of filter is removed out of the ultra-wideband frequency band because of the SIR structure, and the characteristic of the high frequency band is improved. The ratio of $-5\,\mathrm{dB}$ notched bandwidth to $-10\,\mathrm{dB}$ notched bandwidth is 0.73.

3. UWB ANTENNA DESIGN FOR DUAL BAND-NOTCHED

3.1. Geometry of Dual Band-notches UWB Antenna

According to the above discussion, the overall design procedure for the proposed dual band-notched antenna can be summarized as follows. Firstly, design a UWB antenna to cover the whole UWB operating band (3.1–10.6 GHz). Secondly, two C-shaped slits with the same resonant frequency are embedded in the patch, and the two slits are about a quarter of wavelength apart. Then an improved notch-band structure with sufficient rejection bandwidth and sharp skirt response for the lower WLAN band is obtained. Thirdly, two half wavelength U-shaped inverted resonators are added around the feed-line and a notch-band structure with sharp band-notched characteristic for the upper WLAN band is obtained. Finally, based on the design procedures, an improved UWB antenna with dual band-rejected filtering properties in the entire WLAN band is successfully design. The design parameters have been optimized and discussed in the Section 2.

The photograph of the proposed antenna is shown in Figure 19. It is fabricated on a substrate with thickness of 0.8 mm and relative permittivity of 2.55. The antenna occupies a size of $30\,\mathrm{mm} \times 34\,\mathrm{mm}$.

3.2. Results of the Dual Band-notched UWB Antenna

The measurement is taken by Agilent N5230A vector network analyzer and the South China University of Technology's Antenna Test System. The simulated and measured return losses of the proposed antenna are

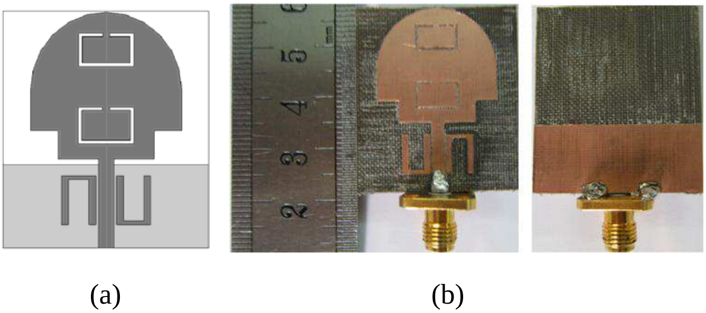

Figure 19. The geometry of the proposed antenna. (a) Schematic diagram. (b) Fabricated sample of top and bottom view.

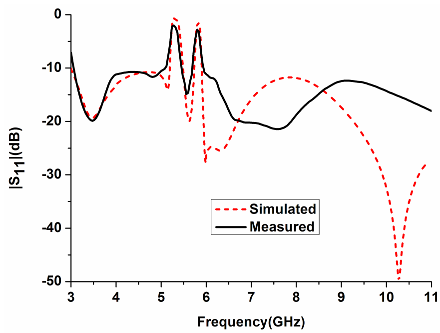

Figure 20. The simulated and measured return losses of the proposed antenna.

matched well as shown in Figure 20. It can be concluded from Figure 20 that the proposed antenna can satisfy the UWB band (3.1–10.6 GHz) for $S_{11} < -10$ dB, except the rejection for the 5.15–5.35 GHz of the lower WLAN band and the 5.725–5.825 GHz of the upper WLAN band. The ratios of -5 dB notched bandwidth to -10 dB notched bandwidth in the two stop band are greater than 0.7.

The measured radiation patterns of the proposed antenna in the E-plane (xoz-plane) and H-plane (yoz-plane) for three different frequencies (3.1, 6.5 and 9.5 GHz) are shown in Figure 21. The patterns in the H-plane are quite omni-directional as expected. In the E-plane, the radiation patterns remain roughly a dumbbell shape like a small dipole leading to bidirectional patterns. The measured gain of the proposed antenna is shown Figure 22. The gain increases slowly as the frequency increase, and the gain is 2–6 dB. Sharp gain decreases occur in the vicinity of the WLAN band and gain decreases to -4 dB obviously, which suppresses the interference with WLAN effectively.

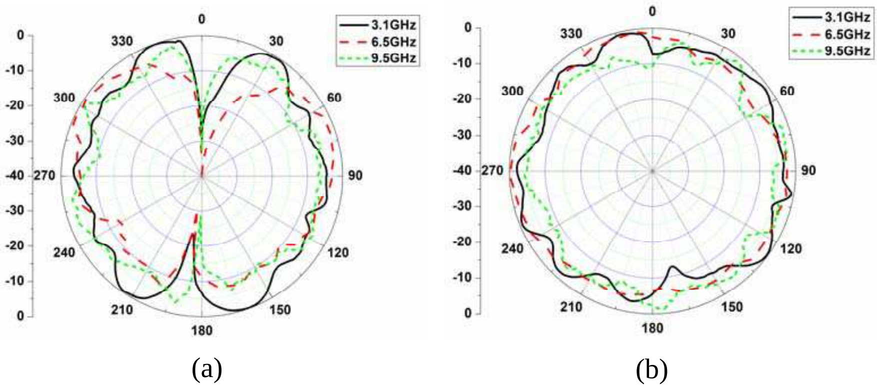

Figure 21. Measured radiation patterns of the proposed antenna at 3.1, 6.5 and 9.5 GHz. (a) E-plane (xy). (b) H-plane (yz).

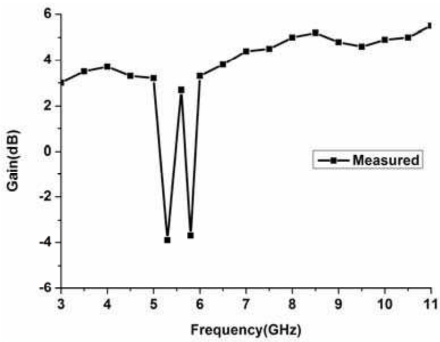

Figure 22. Measured Gain of proposed antenna.

4. CONCLUSION

In this paper, two sets of band-notched structures have been used to form a compact dual band-notched ultra-wideband antenna. One set of band-rejected structure with two C-shaped slots has been adopted for the lower WLAN band and another one with two SIR resonators has been employed for the upper WLAN band. The notched bandwidths of the lower and upper rejection bands can be independently adjusted by changing the size of the band-notched structures. Both in the lower WLAN band and in the upper WLAN band, $|S_{11}| > -5\,\text{dB}$, keeping the impedance matching in good condition in the pass-band ($|S_{11}| < -10\,\text{dB}$). The E-plane radiation patterns remain roughly a dumbbell shape and the H-plane radiation patterns are quite omni-directional. And the ratios between −5 dB notched bandwidth and −10 dB notched bandwidth in the two stop bands are greater than 0.73.

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