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NOVEL CIRCULAR SLOT UWB ANTENNA WITH DUAL BAND-NOTCHED CHARACTERISTIC

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Abstract—In this paper, a novel circular slot UWB antenna with dual notched frequency band is presented and investigated. A C-shaped slot is inserted into the fed element, and a parasitic strip is printed in the circular slot, so that the proposed antenna achieves dual band-notched characteristics, respectively. The measured and simulated results show that the proposed antenna meets the requirement of wide working bandwidth of 3.1–10.6 GHz with VSWR < 2, while avoiding the interference with the 3.5 GHz WiMAX and 5.5 GHz WLAN band. Study of transfer function (amplitude of S_{21}/group delay) and time domain characteristic (radiated pulses/power spectrum density (PSD)) correspond well with the VSWR, which indicate the dual band notched characteristic of the antenna.

1. INTRODUCTION

The ultra-wideband (UWB) communication systems have gained much attention due to their many advantages including the low-spectral-density radiated power and potential for accommodating higher data rate. Several antennas for UWB application have been reported so far [1–8]. However, over the designed bandwidth of the UWB system, there are existing narrow bands used by WiMAX operating in the 3.3–3.7 GHz band and IEEE 802.11a wireless local area network (WLAN) in the frequency range of 5.15–5.825 GHz. Thus, any electromagnetic interference caused from use of the IEEE802.11a WLAN and WiMAX system should be avoided to ensure the UWB transmitter performance. To fulfill this requirement, a dual band-notch filter in the UWB system is necessary. However, the use of a filter will increase the complexity

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of the UWB system. Therefore, it is desirable to design the UWB antenna with notched bands which can cover the two bands to minimize the potential interference. Several antennas with the band-notch characteristic have been reported [9–16].

In this paper, we propose a novel circular slot UWB antenna with dual band-notched function. The band-notched characteristic is achieved by inserting a C-shaped slot into the fed element and printing a parasitic strip in the circular slot. By adjusting the location and length of the slot and strip, the designing of notched frequency band can be realized. Experimental and simulated results of the constructed prototype are presented, and the transfer function and time domain characteristics are also studied to evaluate the antenna.

2. ANTENNA DESIGN AND RESULTS

Figures 1(a) and 1(b) show the top view and bottom view of the proposed antenna, respectively. The proposed circular slot antenna is fabricated on a substrate with the relative dielectric constant of $\varepsilon_r = 4.4$ and the thickness of $h = 1.4\,\text{mm}$ with width and length of W and L. As shown in Figure 1(a), the fed element is a circular arc which is fed by microstrip line. The circular arc has a width of W_c and outer radius of R_1. The width of the microstrip feed line is fixed at W_1 to achieve $50\,\Omega$ characteristic impedance. To achieve the 3.5 GHz band-notched operation, a C-shaped circular slot with a radius of R_s, a width of W_{s1} and a flare angle of θ is notched on the fed element. Bottom view of the antenna is shown in Figure 1(b), it is seen that the ground have a same size as the substrate and the inner profile of the ground is a circular cut with radius of R_2. A parasitic strip with a length of $L_{s1} + 2L_{s2}$, a width of W_{s2} is inserted to the ground plane so that the antenna obtains the 5.5 GHz band-notched operation. The C-shaped circular slot and parasitic strip destroy the excited surface current, so that the antenna makes negative response at the notched frequency (3.5 GHz/5.5 GHz). Location and length of the slot/strip is adjusted so that the wideband circular slot antenna achieves a dual band-notched characteristic at the designed frequency separately. The photograph of the fabricated antenna is shown in Figure 2.

The simulation of antenna is taken by using CST Microwave Studio software based on the method of finite integration technology (FIT), and the measurement is achieved by using Agilent E8363B Vector Network Analyzer. Table 1 shows the optimized dimensions of the proposed antenna, and the prototype is constructed and investigated. Figure 3 shows comparison of the measured and simulated VSWR for the constructed prototype. Ii it is observed that

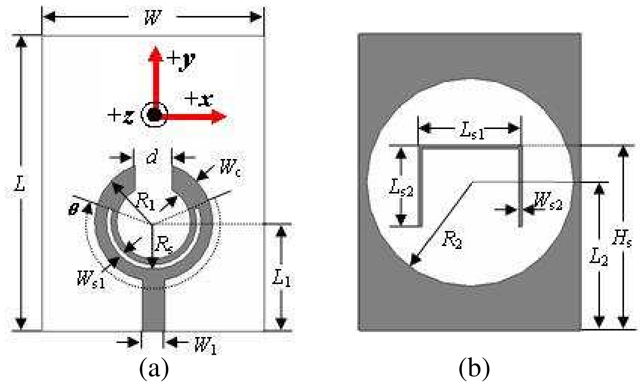

Figure 1. The geometry of the proposed antenna. (a) Top view. (b) Bottom view.

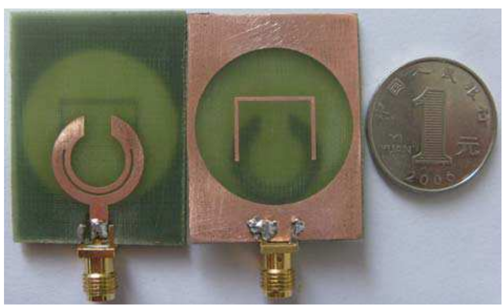

Figure 2. The photograph of the proposed antenna.

Table 1. The dimensions of the proposed antenna. All dimensions are in millimeters except that the unit of θ is in degree.

Parameter	W	L	W_1	L_1	L_2	R_1	R_2	W_c
Value	30	40	3	14.8	20	8	14	3
Parameter	d	W_{s1}	θ	R_s	H_s	L_{s1}	L_{s2}	W_{s2}
Value	5	0.6	216	5.8	25	14	11	0.5

the simulation and measurement VSWR agree well with each other. Both the measured and simulated VSWR has notched characteristic in 3.5 GHz and 5.5 GHz band. The measured bandwidth for VSWR < 2 has good agreement with simulations, which covers the frequency range of 3.1–10.6 GHz except in 3.15–3.90 GHz and 5.10–5.95 GHz.

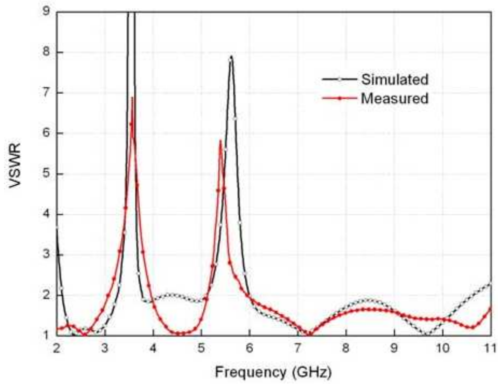

Figure 3. The measured and simulated VSWR of the proposed antenna.

The measured notched band for return VSWR $>$ 2 is a little wider than the simulated one in 3.5 GHz notched band. This difference is mainly caused by the fabrication error, the SMA connector, and numerical error. Both the measured and simulated results are suitable for UWB antenna with 3.5 GHz and 5.5 GHz notched band. Therefore, the potential interferences between UWB system and the two wireless communication systems can be suppressed effectively.

3. PARAMETRIC STUDIES FOR THE NOTCHED BAND

3.1. Study of 3.5 GHz Notched Band

In order to study the 3.5 GHz band-notched characteristic of the antenna, the parameters R_s, θ, and W_{s1} which define the dimension of C-shaped circular slot are studied. It can be seen from Figures 4(a) and 4(b) that with the length of the slots increasing, the centre frequency of the corresponding notched band will become smaller. Figure 4(c) shows that the bandwidth of the notched band is mainly depend on the width of the slot. Parameter study shows that the 3.5 GHz band-notched characteristic is obtained by changing parameters of the C-shaped circular slot, while it has little influence on 5.5 GHz notched band.

3.2. Study of 5.5 GHz Notched Band

The 5.5 GHz notched band is achieved by the parasitic strip inserted in the ground plane, so that the parameters H_s, L_{s1}, L_{s2}, and W_{s2} which

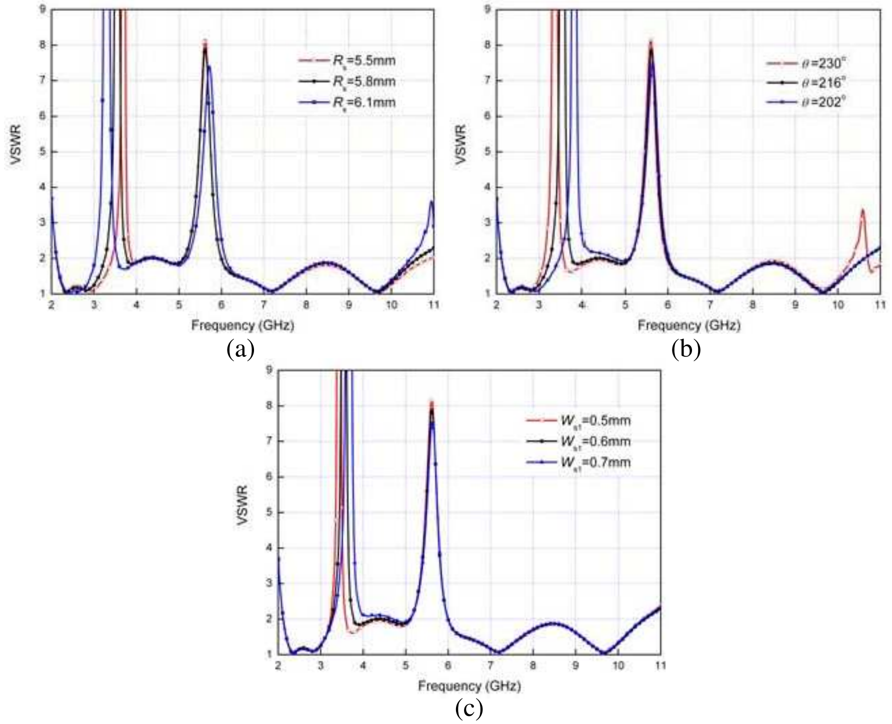

Figure 4. The effect of changing parameters on the VSWR at 3 GHz notched band. (a) R_s, (b) θ, (c) W_{s1}.

define the dimension of the parasitic strip are studied in this segment. Figure 5(a) shows the effect of varying the location of the strip in the ground plane. Both the bandwidth and the centre frequency of the notched band change when the location of the slots is different, and the notched band will get smaller if the slot is closer to the feed line. The influence of strip length on VSWR is shown in Figures 5(b) and 5(c), it is observed that the notched frequency of the proposed antenna decrease by increasing the length of parasitic strip, which shows a similar result as study of 3.5 GHz notched band. Figure 5(d) shows the effect of changing strip width on the notched band. It is seen that the center of notched band increase while the wide of strip becoming wider. The reason is that the length of strip is decrease with increasing of strip width. Both the 3.5 GHz and 5.5 GHz notched band study show that the two notched bands have little effect on each other, they can be adjusted respectively.

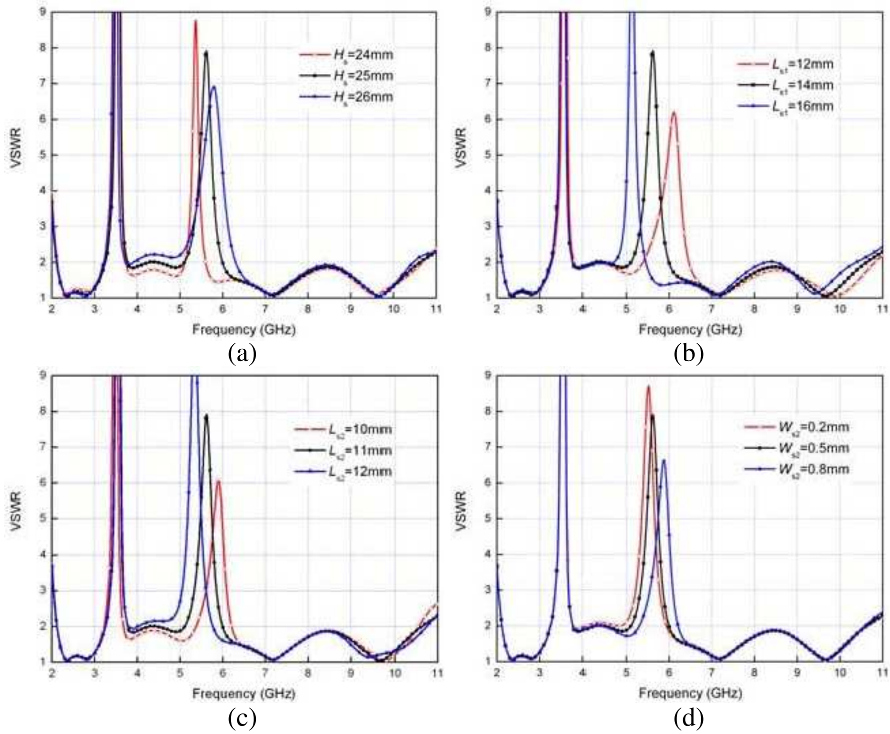

Figure 5. The effect of changing parameters on the VSWR at 5 GHz notched band. (a) H_s, (b) L_{s1}, (c) L_{s2}, (d) W_{s2}.

3.3. Parameter Study of 3.3 GHz and 5.5 GHz Notched Band

Parameter study of notched bandwidth and center frequency is investigated in this segment. The length of C-shaped slot and parasitic strip is calculated by formula (1) and (2), respectively. Table 2 shows the effect of bandwidth at 3.5 GHz and 5.5 GHz notched band. The notched bandwidth increase from 360 MHz to 1300 MHz while W_{s1} increasing from 0.5 mm to 0.7 mm. The width of parasitic strip $Ws2$ shows a less influence on notched bandwidth than W_{s1}. The result is also shown in Figure 6(a). The designed 3.5 GHz bandwidth is 510 MHz when $W_{s1} = 0.6$ mm and the 5.5 GHz bandwidth is 880 MHz when $W_{s2} = 0.5$ mm.

Table 3 and Table 4 show the influence of slot/strip length on notched center frequency at 3.5 GHz and 5.5 GHz band, respectively. It is seen that with the increasing of slot/strip length, the notched center frequency decreases. The relation between slot/strip length and notched center frequency is also explained in Figures 6(b) and 6(c). With the changing of L_{s1} or L_{s2}, a liner relation between length of strip and notched center frequency is observed from Figure 6(c).

$$L_{slot} = 2\pi \left(R_s + \frac{W_{s1}}{2} \right) \frac{\theta}{360} \tag{1}$$

$$L_{strip} = 2L_{s2} + (L_{s1} - W_{s1}) \tag{2}$$

Table 2. The effect of bandwidth at 3.5 GHz and 5.5 GHz notched band.

Approach	W_{s1}			W_{s2}		
Value (mm)	0.5	0.6	0.7	0.2	0.5	0.8
Notched band (GHz)	3.23–3.59	3.26–3.77	3.30–4.60	4.93–5.93	5.11–5.99	5.31–6.20
bandwidth (MHz)	360	510	1300	1000	880	890

Table 3. The effect of slot length at 3.5 GHz notched band.

Approach	R_s (mm)			θ (degree)		
Value	5.5	5.8	6.1	230	216	202
Length of slot (mm)	21.8655	22.9965	24.1274	24.4870	22.9965	21.5059
Notched center frequency (GHz)	3.69	3.55	3.30	3.37	3.55	3.83

Table 4. The effect of strip length at 5.5 GHz notched band.

Approach	L_{s1}			L_{s2}		
Value (mm)	12	14	16	10	11	12
Length of strip (mm)	33.5	35.5	37.5	33.5	35.5	37.5
Notched center frequency (GHz)	6.11	5.62	5.13	5.9	5.62	5.34

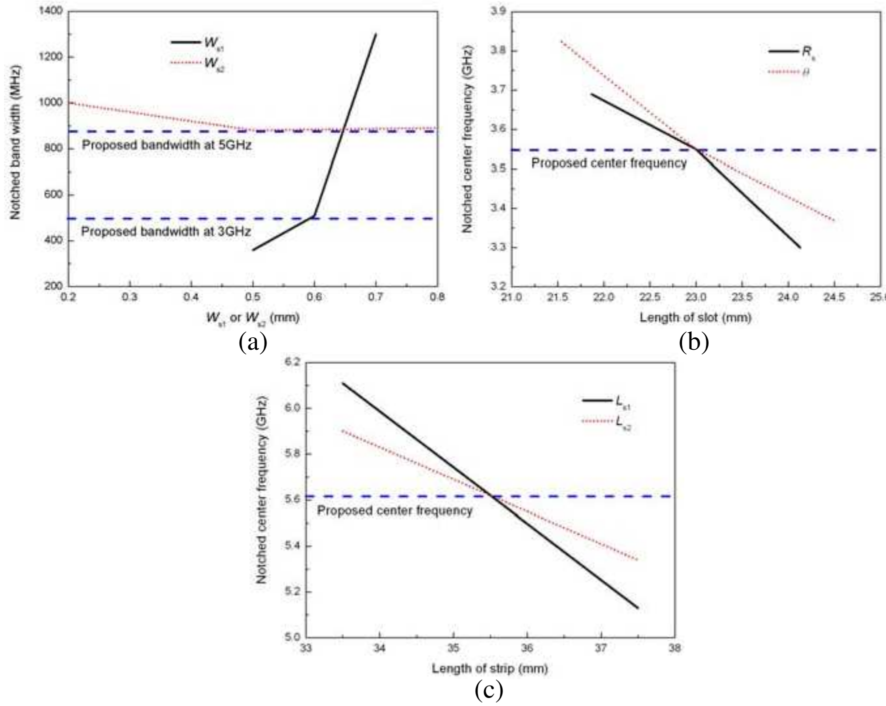

Figure 6. Parameter study of 3.3 GHz and 5.5 GHz notched band. (a) The effect of bandwidth at 3.5 GHz and 5.5 GHz notched band. (b) Influence of center frequency at 3 GHz notched band. (c) Influence of center frequency at 5 GHz notched band.

3.4. Radiation Pattern and Antenna Gain

The simulated radiation patterns in the x-y plane, y-z plane, and x-z plane are plotted in Figures 7(a), 7(b) and 7(c), respectively. It can be seen that the E-plane (x-y plane, y-z plane) radiation patterns at 4 GHz are about the same as that of a dipole antenna, while it become butterfly-shaped at 7 GHz and 10 GHz. So the E-plane pattern is monopole-like, and the number of lobes rises with the increase of frequency which means the antennas get more directional. The H-plane (x-z plane) radiation patterns are approximately omni-directional over the entire operation frequencies, and the radiation is relatively stable.

Figure 8 shows the peak gain of proposed antenna with/without notched bands against frequency. For the proposed antenna without notched bands, the peak gain is relatively flat over the operation band

and the variation is from 2.82 dBi to 6.36 dBi (3–11 GHz). Peak gain of the proposed antenna with notched bands is similar to antenna without notched bands, while two large drops in the notch-frequency band is observed. The lowest gain in notched bands is −10.38 dBi at 3.6 GHz and −4.41 dBi at 5.6 GHz. The antenna gain corresponds well with the VSWR, which presents that the proposed antenna is successfully performed with the rejection in 3.5 GHz and 5.5 GHz notched band.

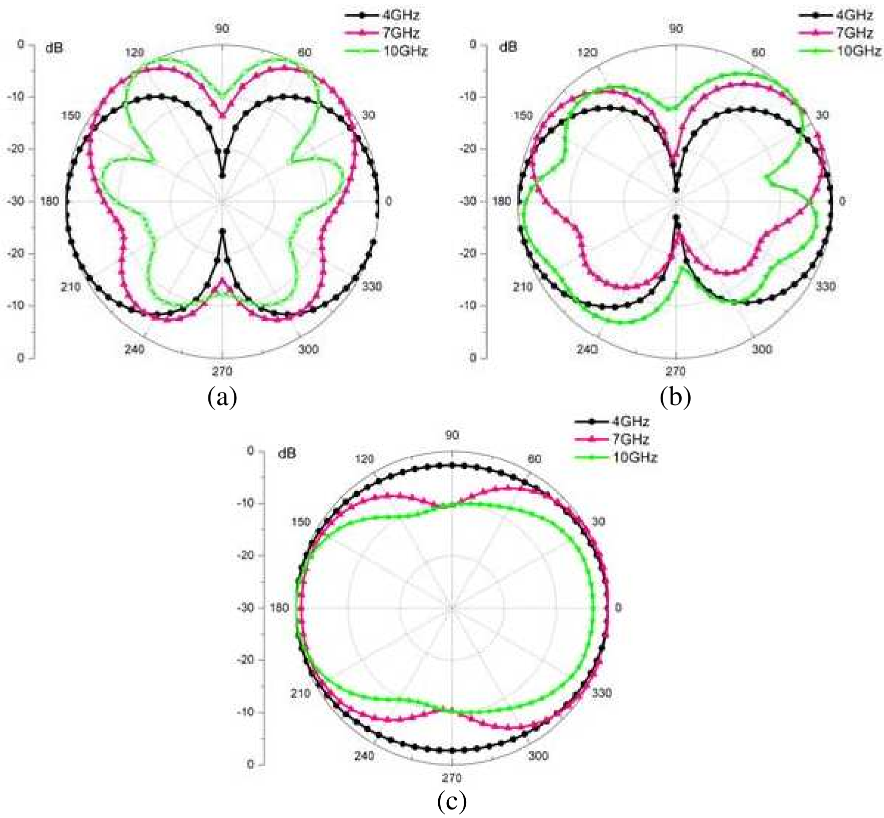

Figure 7. The radiation patterns at different frequencies. (a) x-y plane, (b) y-z plane, (c) x-z plane.

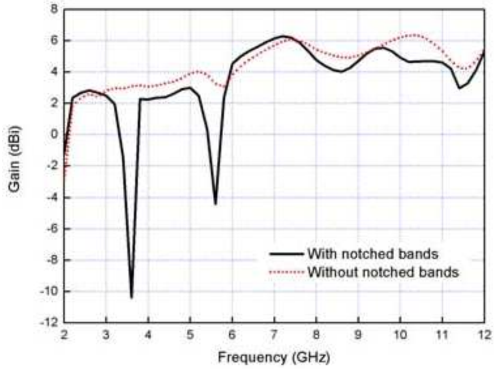

Figure 8. The antenna gain with/without notched bands.

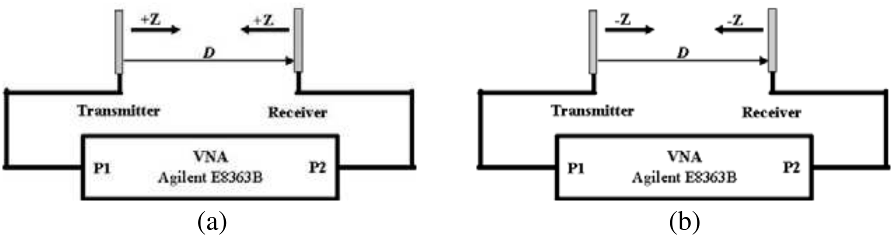

Figure 9. The transfer function measurement set up. (a) Face to face mode. (b) Back to back mode.

4. TRANSFER FUNCTION AND TIME DOMAIN STUDY

4.1. Transfer Function Measurement

Since UWB systems use short pulses to transmit signals, it is crucial to study the transfer function for evaluating the proposed antenna's performance and designing transmitted pulse signals. The UWB antenna can be viewed as a filter with some magnitude (antenna gain) and phase response. The phase response and group delay are related to the antenna gain response. The group delay is able to clearly show any nonlinearity that may be present in the phase response and indicates the degree of the distortion. For UWB applications, the magnitude of the transfer function should be as flat as possible in the operating band. The group delay is required to be constant over the entire band as well.

Agilent E8363B Vector Network Analyzer is used for transfer function measurement and the measurement set up is shown in Figures 9(a) and 9(b). A pair of the proposed antenna is used as the transmitting and receiving antenna. The transmitter and receiver are positioned face to face ($+z$ directions opposite) and back to back ($-z$ directions opposite) with a distance of 15 cm. By considering the antenna system as a two-port network, the transmission scattering parameter S_{21} which indicates the transfer function is measured. It should be noted that the measurement was carried out in a real environment with reflecting objects in the surrounding area.

The measured magnitude of S_{21} is shown in Figure 10. It is observed that the magnitude of S_{21} is relatively flat (variation less than 10 dB) from 3 GHz to 9 GHz in face to face mode, while it has an attenuation of more than 30 dB in the 3.5 GHz notched band and about 20 dB in the 5.5 GHz notched band. The measured magnitude of S_{21} in back to back mode is similar to the result of face to face mode, while it has more distortion from 6 GHz to 9 GHz.

Figure 11 shows the measured group delay for the antenna system in face to face mode and back to back mode. In face to face mode, the variation of group delay for proposed antenna is within 2 ns across the whole UWB band except two notched bands, in which the maximum group delay is more than 8 ns in 3.5 GHz notched band and more than 4 ns in 5.5 GHz notched band. In back to back mode, the measured group delay shows a similar result as face to face mode. It can be found that there are two sharp decreases at 3.5 and 5.2 GHz notched band. The measured group delay corresponds well to the magnitude of S_{21}, so it proves that the antenna has a good time-domain characteristic and a small pulse distortion as well.

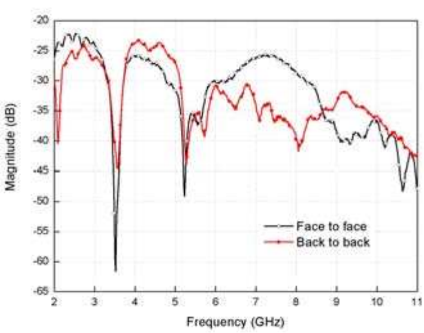

Figure 10. The measured magnitude of S_{21} for the antenna systems.

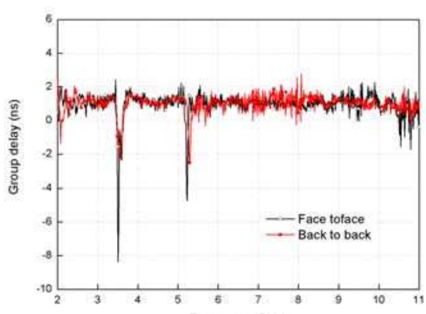

Figure 11. The measured group delay of the antenna systems.

4.2. Time Domain Study

Time domain study based on the waveform of excited pulse, radiated pulse and received pulse. Normalized power spectrum density (PSD) of the pulses is also investigated to explain band-notched characteristic of the proposed antenna. Radiated pulses in x-z plane with different angles is investigated and shown in Figure 12. The curves have already been normalized to their respective maximum values. It is seen that nearly the same radiated waveforms can be observed in different seven directions in x-z plane. So the characteristics of the proposed antenna are very stable with the radiation angles. It also can be observed that the radiated pulses waveforms are distorted as compared to the excited pulse, which is caused by the notched characteristic of the antenna.

The fidelity factor is defined as

$$\rho = \max_{\tau} \left\{ \left| \frac{\int p(t)s(t-\tau)dt}{\sqrt{\int p^2(t)dt}\sqrt{\int s^2(t)dt}} \right| \right\} \tag{3}$$

where τ is a delay which is varied to make the numerator in Eq. (3) a maximum. It determines the correlation between the electric field signals $s(t)$ and $p(t)$. The radiated pulse in $+z$ direction ($\theta = 0°$) is chosen as the reference signal $p(t)$, while the other radiated pulses are set as signal $s(t)$. So the fidelity factor between radiated pulses in x-z plane is calculated, and the result is shown in Table 2. It is observed that the minimized fidelity factor in x-z plane is 0.7361, which shows a stable radiation result.

The waveforms and normalized PSD in $+z$ direction is studied, and the measurement set up is based on Figure 9(a). Figure 13 shows the excited pulse, radiated pulse and received pulse in $+z$ direction. In order to see clearly, the waveforms have been moved parallel along the abscissa. It can be seen that the radiated pulse and received pulse are distorted as compared to excited pulse, so we can study the fidelity and the normalized power spectrum density (PSD) to evaluate the characteristics of pulses.

Figure 14 shows the normalized power spectrum density (PSD) of the excited pulse, radiated pulse and received pulse in face to face mode, respectively. It is seen that all the pulses comply with FCC's emission mask. Reduction of the bandwidth of the radiated

Table 5. Fidelity factor between radiated pulses.

Angle θ (degree)	0	30	60	90	120	150	180
Fidelity	1	0.9928	0.8730	0.7361	0.8543	0.9558	0.9513

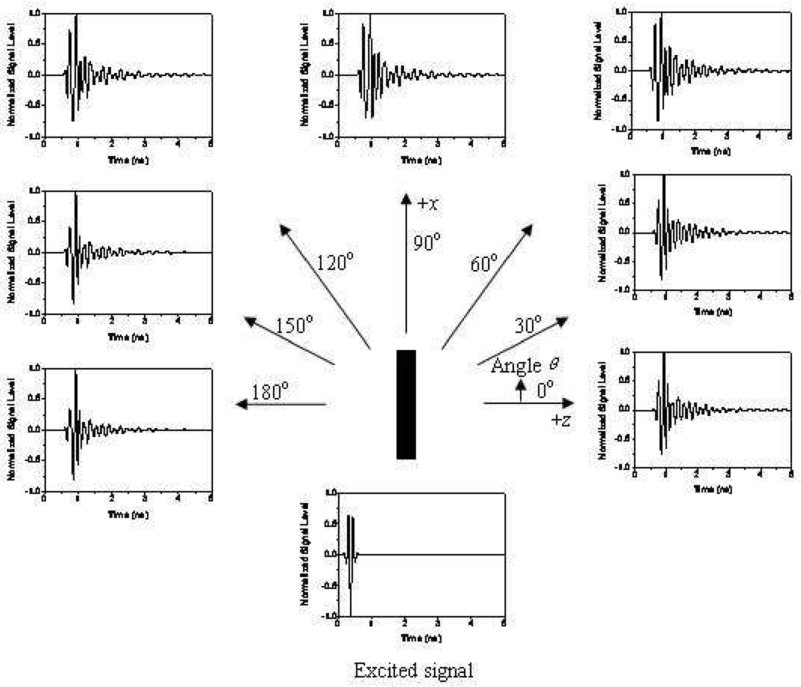

Figure 12. Radiated pulses in x-z plane with different angles.

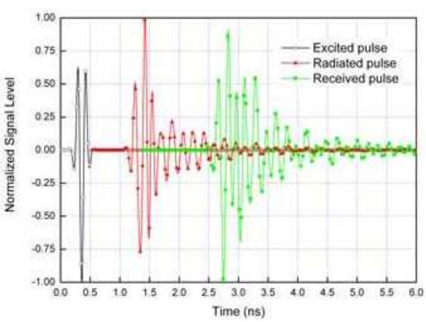

Figure 13. The pulse waveforms for the antenna system in face to face mode.

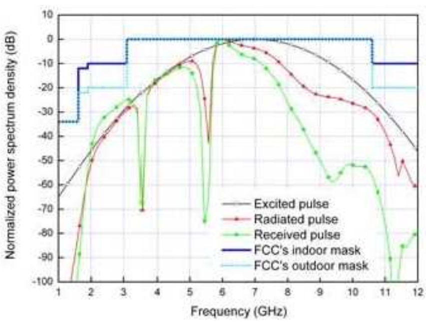

Figure 14. The normalized power spectrum density (PSD) of pulses for the antenna system in face to face mode.

and received pulse's PSD can be seen in comparison with PSD of the excited pulse. The PSD of radiated and received pulse shows a similar result as compared to excited pulse, while both the PSD has two sharp decreases in the 3.5 GHz and 5.5 GHz notched band, which confirms the VSWR and transfer function results. It is also observed that from 7 GHz to 11 GHz, The PSD of radiated/received pulse decreases as compared to the PSD of excited/radiated pulse, which correspond well with the measured amplitude of S_{21} in face to face mode.

5. CONCLUSION

A novel circular slot UWB antenna with 3.5 GHz WiMAX and 5.5 GHz WLAN band notch is investigated in this paper. The study of VSWR and gain show that the proposed antenna achieves dual band-notched characteristic by C-shaped slot and parasitic strip, which are inserted into the fed element and printed in the circular slot. Monopole-like radiation patterns is observed for the antenna. Transfer function (amplitude of S_{21}/group delay) and time domain characteristic (fidelity/power spectrum density (PSD)) results show that the proposed notched antenna has dual band-notched characteristics in the designed bands, which confirms the results of VSWR and gain. The proposed antenna has a compact size, good radiation characteristics, ultra wide bandwidth, and good time-domain behaviors to satisfy the requirement of the current wireless communications systems.

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