A Novel UWB Antenna with Triple Band-Notched Characteristics

Xiao-Lin Yang, Yan Wang, and Gang Chen

School of Physical Electronics
University of Electronic Science and Technology of China, Cheng Du 610054, China
842743945@qq.com, yxlin@uestc.edu.cn, 369780081@163.com

Abstract **─** A novel planar monopole antenna with 3.9/5.5/8 GHz triple band-notched characteristics is proposed. The monopole antenna is composed of microstrip line and radiating patch where the large circle following connects with a small half circle, whereas the ground plane is printed on the other side. By adding a simple T-shaped resonator on the bottom side, two band-notched characteristics in the C-band (3.7-4.2 GHz) and X-band (7.6-8.6 GHz) are obtained at the same time. The band-notched characteristic in the WLAN (5-6 GHz) is obtained by etching spline curved strip in the radiating patch. The measured results are roughly consistent with the simulated. The proposed antenna is printed on a 22 mm × 32 mm, polytetrafluoroethylene (PTFE) substrate with relative permittivity of 2.65 and substrate thickness of 0.5 mm.

Index Terms - Band-notched, monopole antenna, T-shaped.

I. INTRODUCTION

Ultra-wideband (UWB) communication systems have attracted great attention in the wireless world due to the many advantages, such as high speed data rate, low probability of intercept and low cost. However, over the released UWB operation bandwidth (3.1~10.6 GHz), there are some bands occupied by the existing wireless systems. For example, C-band, WLAN networks and some satellite service systems operating in 3.7-4.2 GHz, 5-6 GHz and 7.6-8.6 GHz, respectively [1-2], which will be caused interference with UWB systems. In order to get rid of the interferences of these bands, many methods have been reported, such as using different shape slot on the radiating patch or the ground plane [3-7]. Another main approach is introducing parasitic elements using split ring resonator, or the combination of these methods. Generally, only one or two notched bands can be achieved by the antennas mentioned above. Recently some antennas with triple-band have been studied [8-11], but its band-notches are controlled, respectively and their dimensions are relatively large. A recent trend in band notched UWB antenna design is to impose the multi-band notched characteristics. This article offers a new design strategy on the ways of band control and triple band-notched Characteristics addressing three merits as follows:

i. The proposed antenna has simple and miniaturized structure. The structure has relatively small dimension (22 mm×32 mm) comparing with the antenna dimension (46 mm×48 mm) [12].
ii. In this letter, the measured peak value of the antenna's VSWR in the stop bands are 6.8, 7 and 14; all higher than 6.5, which is even better than the ones achieved by the structures proposed in [13-15] (lower than 5, 4.2 and 5.6 in, respectively). Higher and sharper band rejection achieved for each of the notches makes the avoidance of interference more effective.
iii. By adding a simple T-shaped resonator on the bottom side, as well as adding a spline curved strip parasitic element in the radiating patch aimed for the triple desired band rejections function at C-band (3.4- 4.2 GHz), X-band (7.6-8.6 GH-z) and WLAN (5-6 GHz). T-shaped structure has a simpler optimization due to the lower number of degrees of freedom and can control two stop bands. Moreover, the segmenting structure that brings on band notched characteristic could

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probably be applied to other monopole patches with various patch shapes.

II. ANTENNA DESIGN AND PARAMETER STUDY

A. Antenna configuration

The geometry of the proposed antenna is described in Fig. 1 (a). The antenna is printed on substrate of PTFE with thickness of 0.5 mm, relative permittivity of 2.65. The radiating patch and a 50 Ω microstrip line are printed on the top layer and the ground plane is printed on the bottom layer. A photograph of the fabricated antenna is presented in Fig. 1 (b).

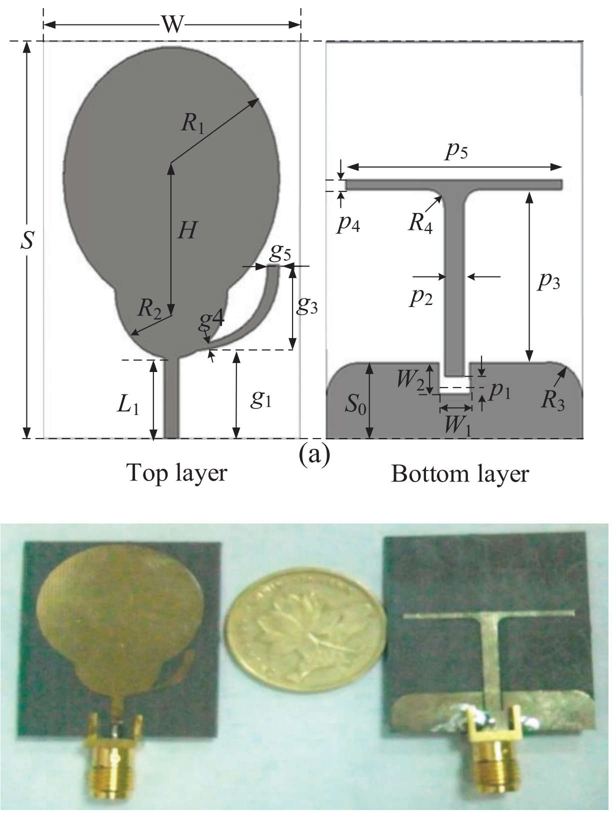

Fig. 1. (a) Geometry of the proposed antenna, (b) photograph of the fabricated proposed antenna; units (mm).

B. Parametric optimization

The width of the microstrip line is 1.4 mm to achieve characteristic impedance of 50 Ω from 2.8-10.6 GHz. The optimizing values of each parameter are as follows: w=22, s=32, L1=6.5, R1=10.5, R2=5.5, R3=3, H=9, w1=2.5, w2=3 and S0=6.2, all units with mm. The impedance band is from 2.8-10.6 GHz. In this study, by cutting a rectangular slot in the ground plane the characteristics at the higher frequency can be enhanced. The rectangular slot acts as an impedance matching element to control the impedance bandwidth of the proposed antenna because it creates additional surface current paths in the antenna. Therefore, additional resonance is excited and hence much wider impedance bandwidth can be produced [16], especially at the higher band. The gap between the radiating patch and ground plane (S_0) affects the band dispensation because it acts as a matching network [17]. The optimum UWB impedance bandwidth from 2.8-10.6 GHz is obtained with S_0=6.2 mm. The simulated VSWR of monopole antenna with and without a rectangular slot is shown in Fig. 2. Obviously, the property of frequency band from 8-10 GHz has been improved.

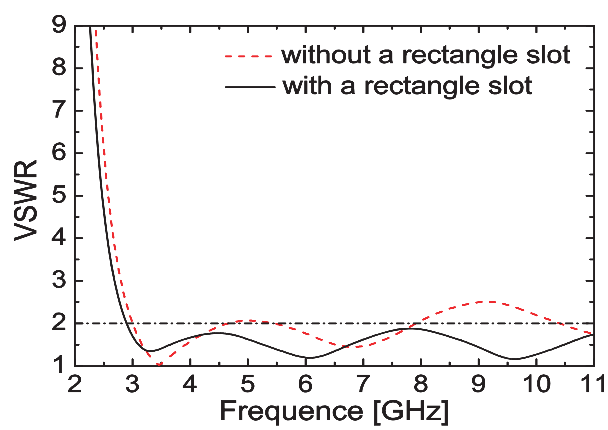

Fig. 2. Simulated results of the antenna; with and without a rectangle slot.

C. Antenna with spline curved strip parasitic element

By adding a spline curved strip parasitic element in the radiating patch of the antenna, a frequency band notched for WLAN is achieved. The band-notch frequency mainly depends on the length of the strip. By comparing Figs. 3 (a) and (c), we can see that at the radiating frequency 3 GHz the surface current concentrated on the edges of the radiating patch, as well as the ground plane as shown in Fig. 4 (a); while at the notch frequency, the surface current concentrated on the edge of the interior and exterior of the spline curved strip parasitic element as shown in Fig. 3 (c). The reason is the spline curved strip perturbs the resonant response at the band-notch frequency. The frequency given by the dimensions of the WLAN band-notch feature can be formulated as [10]:

$$f_{WLAN\_notch} = \frac{c}{4(g_3 + g_4)\sqrt{\varepsilon_{eff}}}. \quad (1)$$

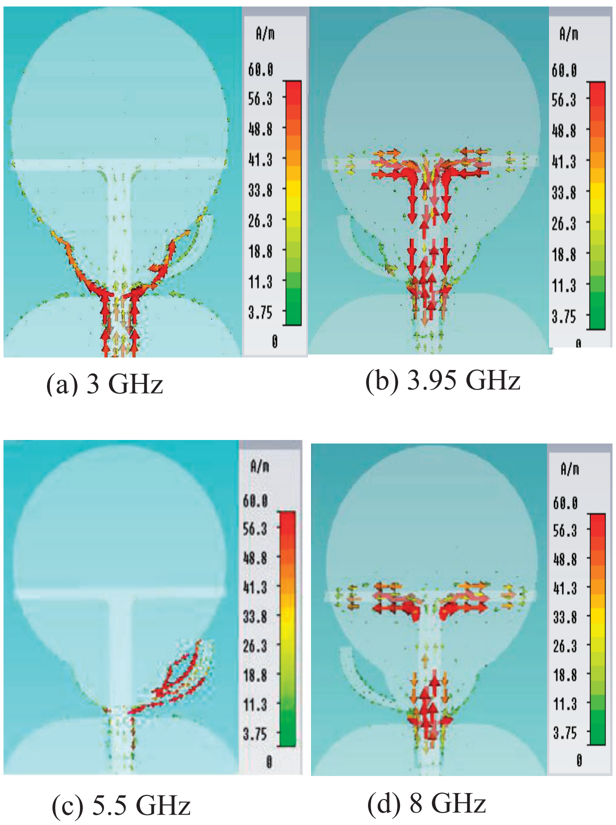

Fig. 3. Simulated results of the surface current distributions at frequency: (a) 3 GHz, (b) 3.95 GHz, (c) 5.5 GHz and (d) 8 GHz.

The various band-notch characteristics can be achieved by carefully choosing the parameters for the spline curved strip element. Figure 4 exhibits simulated band rejection characteristics against various g_1, g_2 and g_3 of the parasitic element with fix g_4= 0.7 mm and g_5=1.2 mm. It can be seen that as g_2 and g_3 increase, the WLAN notched-band shifts toward low frequency, while g_1 is as inverse. The reason is that g_1 increase lead to the length of the strip decrease. These results correspond with the caculated formula (1). Ultimately, the optimal parameters of the spline curved strip are as follows: g_1=7.16 mm, g_2=10.5 mm, g_3=7 mm, g_4=0.7 mm and g_5=1.2 mm.

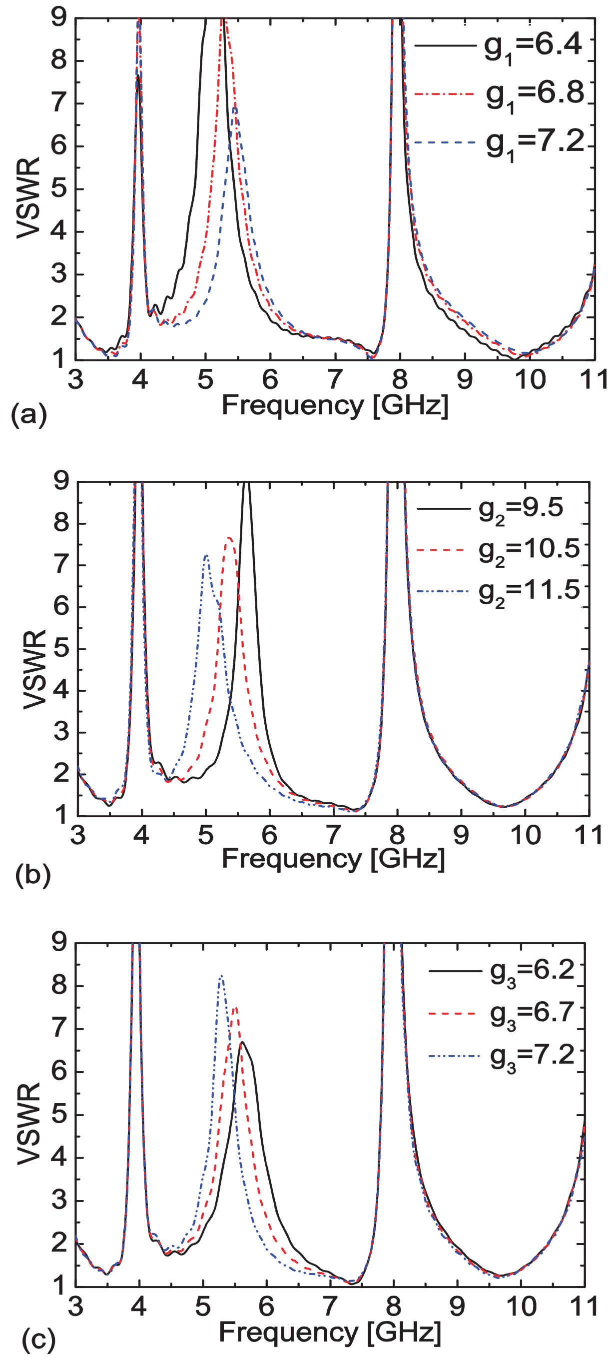

Fig. 4. Simulated band-rejection characteristics of the proposed antenna with notched band for: (a) g_1, (b) g_2 and (c) g_3; units (mm).

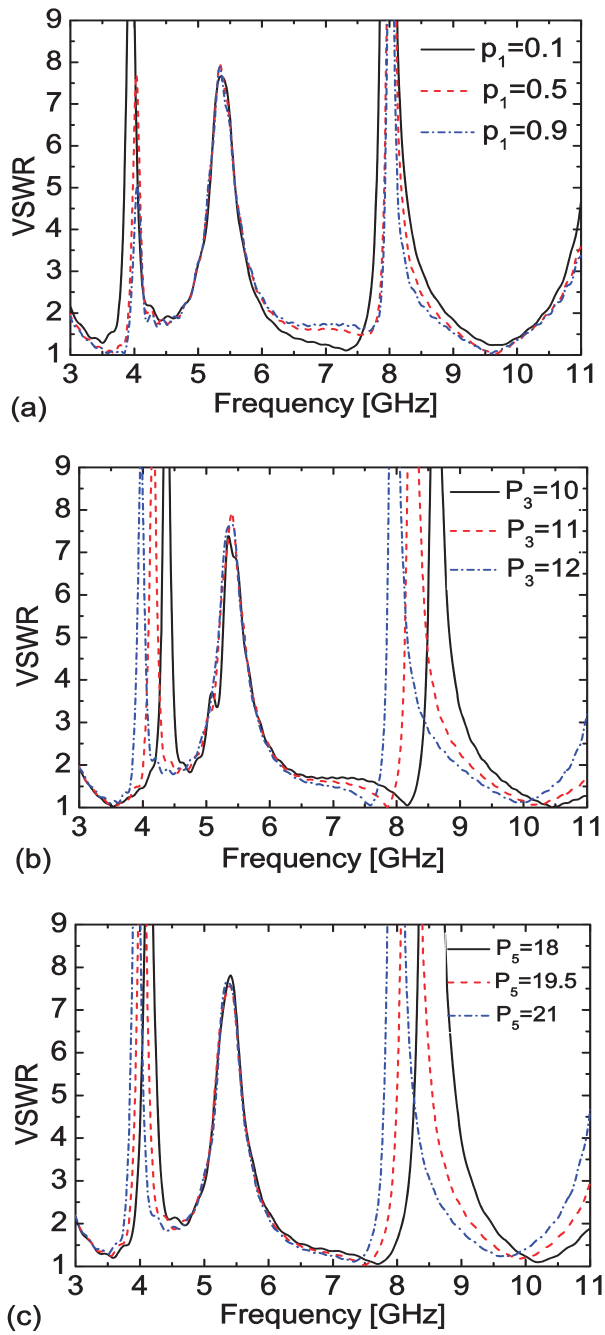

Fig. 5. Simulated band-rejection characteristics of the proposed antenna with varying parameters: (a) p_1, (b) p_2, (c) p_3 and (d) p_5; units (mm).

D. T-shaped parasitic element

To achieve the other two band-notched characteristics for C-band and X-band, a T-shaped stub is printed on the bottom layer. This structure changes the reactance of the input impedance. The T-shaped strip coupled to the ground plane with the rectangular slot, which act as the stop filter at a certain frequency. In order to explain the band-notched function of the proposed structure, the surface current distribution was analyzed. Figures 3 (b) and 3 (d) illustrate the simulated surface current distribution of notched-band frequencies 3.9 GHz and 8 GHz, respectively. It can be seen that at band-notched frequency the current distribution is clustered along the edges of the T-shaped strip. The resultant radiation fields cancel out and sharp attenuation near the notch frequency is produced. Hence, the antenna does not radiate efficiently and the stop band is achieved. The notched center frequency and the bandwidth can be controlled by adjusting the dimensions of the T-shaped parasitic strip. The parameters of the proposed antenna are studied by changing one parameter at a time and fixing the others. The sensitive parameters for various p_1, p_3 and p_5 of the T-shaped strip with p_2=1.9 mm, p_4=0.8 mm and R_4=1.5 mm, are given in Fig. 5. It is observed that the p_1 determines the notched bandwidth. As p_1 increases, the notched bandwidth increases. While the p_3 and p_5 mainly determine the location of notched band. As p_3 and p_5 increase, the center frequency of the notched band shifts toward the low frequency. Therefore, it can be concluded that the rejected band can be easily obtained by tuning these parameters. Lastly, the optimized parameters are listed as follow: p_1=0.1 mm, p_2=1.9 mm, p_3=15 mm, p_4=0.8 mm, p_5=21 mm and R_4=1.5 mm.

III. RESULTS AND DISCUSSIONS

A prototype of the proposed antenna was fabricated and the VSWR was measured with an Agilent E8363B vector network analyzer. Figure 6 (a) shows the performance of the measured and simulated VSWR of UWB antenna with triple band-notched characteristics. The measured results showed that the proposed antenna exhibits a wide impendence bandwidth from 2.8 GHz to 11 GHz; while it achieved triple stop band of 3.7-4.2 GHz, 5-6.2 GHz and 8.1-9 GHz, respectively. Comparing to simulated results, the measured center frequency of the band-notched shifts toward higher and the gain also has the frequency shift, as shown in Fig. 6 (b). The reasons maybe led by the deviation substrate relative permittivity between simulated and fabricated. The losses of the coaxial line and coaxial connectors are possible reason of the disagreement between the simulated and the measured peak gain.

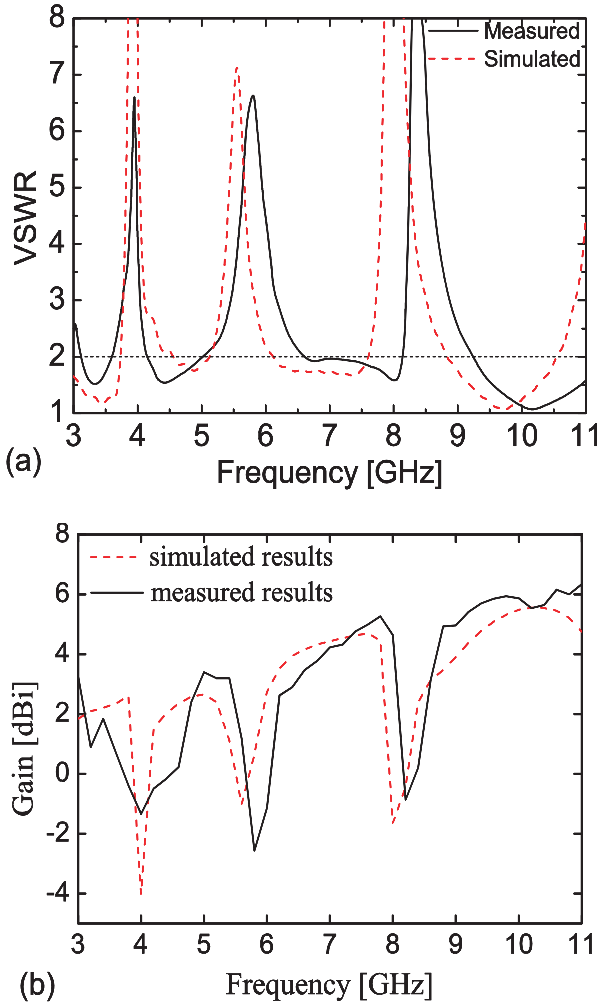

Fig. 6. (a) Measured and simulated VSWR of the proposed UWB antenna with triple band-notched function, (b) measured and simulated the peak gain of the proposed UWB antenna with triple band-notched function.

Figure 7 illustrates the measured radiation pattern in the E-plane and H-plane at the frequencies of 4.5, 6.4 and 8 GHz. It can be seen that the radiation patterns in the H-plane for the three frequencies are nearly omnidirectional.

IV. TRANSFER FUCTION STUDY

On UWB antenna designing, it is crucial to evaluate the system transfer function. In order to suppress the signal distortions, it should make the group delay as sharp as possible in notch-band and a constant outside of the notch-band.

The simulated group delay of the proposed antenna is presented in Fig. 8 (a). It can be seen that in operating band the variation of the group delay is within 1, while in notched band the group delay is sharp change.

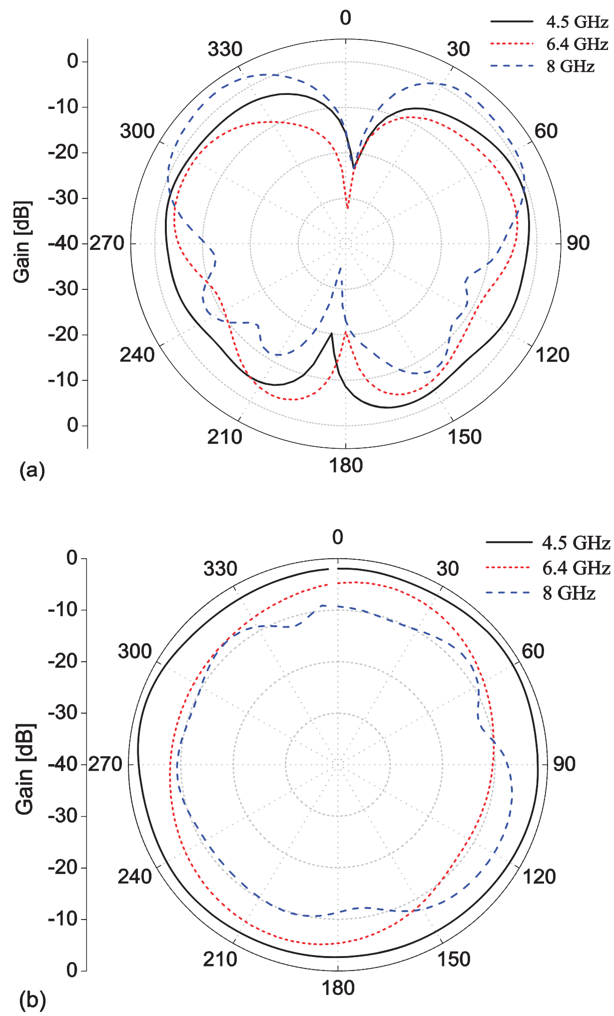

Fig. 7. Measured radiation patterns at: (a) E-plane and (b) H-plane.

Meanwhile, in order to study the level of distortion in the radiated pulses, the fidelity of the signals was computed. The fidelity of the pulses of an antenna can be calculated to assess the quality of the received pulse and select a proper detection template [18]. The definition of the fidelity can be written as:

$$\mathrm{F} = \max_{\tau}\left[\frac{\int_{-\infty}^{+\infty} E_r(t)Ut(t+\tau)}{\sqrt{\int_{-\infty}^{+\infty}\left|E_r(t)^2\right|\mathrm{d}t} \times \sqrt{\int_{-\infty}^{+\infty}\left|\mathrm{U}_t(t)^2\right|\mathrm{d}t}}\right], \quad (2)$$

where E_r refers to the normalized waveform of the received pulse and U_t is the template pulse; which was taken to be the normalized source pulse in this case. The calculated fidelity for the antenna is around 0.75, as shown in Fig. 8 (b). This provides a good time domain performance of the presented antenna and guarantees little distortion of the transmitted and received signals.

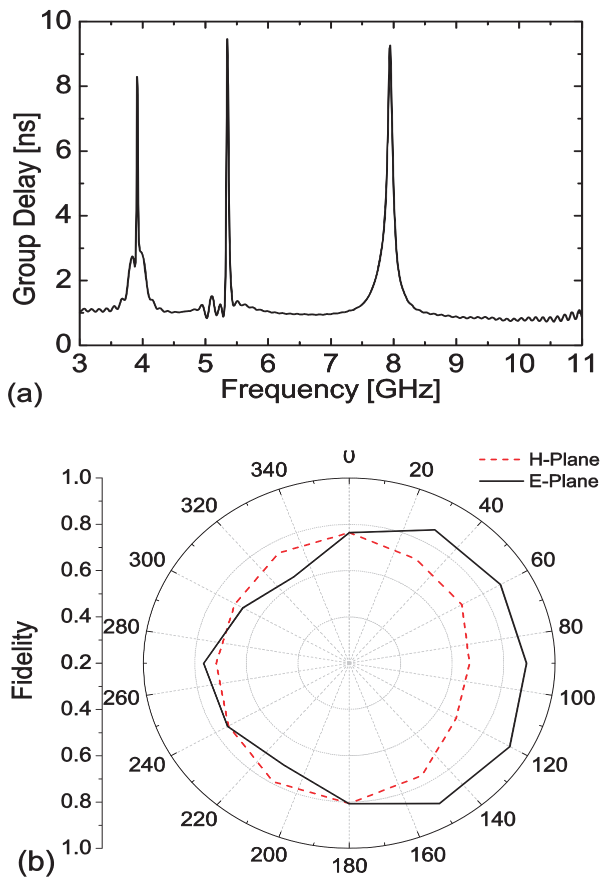

Fig. 8. Simulated results of: (a) group delay and (b) fidelity.

V. CONCLUTION

A novel compact UWB monopole antenna with triple band-notched characteristics is presented and investigated. The proposed antenna covers the frequency band of 2.8 GHz to 10.6 GHz with three rejection bands around 3.7-4.2 GHz, 5-6 GHz and 7.6-8.6 GHz. The radiation patterns in the H-plane are nearly omnidirectional and a typical monopole-like pattern in the E-plane over the entire UWB band. The gain is stable in operating bands, while with a sharp decrease in notched bands. The group delay and fidelity studying indicated that this antenna has good time domain characteristics over the operating bands and notable band-notched properties in required frequencies. Overall, the proposed antenna may be a good candidate for portable UWB systems.

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Xiaolin Yang received his Ph.D. degree in Applied Physics from Lanzhou University, in 2005. He is currently an Associate Professor at the School of Physical Electronics, University of Electronic Science and Technology of China. His current research interests are microwave circuits and systems and Ultra-wideband antenna.

Yang Wang was born in Anhui Province, China. She received her Bachelor degree in Physics from Anqin Teachers College, Anqin, in 2010 and is currently working towards her M.S. degree in Electronic and Communication Engineering at UESTC. Her research interests are in UWB antenna.

Gang Cheng was born in Jiangsu Province, China. He received his Bachelor degree in Optical Information Sciences and Technology from Southwest University of Science and Technology, Mianyang, in 2010 and is currently working towards his M.S. degree in Electronic and Communication Engineering at UESTC. His research interests are in reconfigurable antenna.