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Research Article

Design of a Compact UWB Antenna with Triple Band-Notched Characteristics

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A new compact ultra-wideband (UWB) antenna with triband-notched characteristics is presented. The structure of the proposed antenna is simple and symmetric. A modified ground is introduced to obtain a wide impedance bandwidth of 2.9–13.4 GHz with $S_{11} < -10$ dB. By inserting two arc-shaped slots in the radiation patch, two sharp bands of 3.3–3.7 GHz and 5.15–5.35 GHz are notched. The notch band of 7.25–7.75 GHz is achieved by etching a U-shaped slot in the ground plane. The notched bands can be controlled, respectively, while the characteristics of the proposed UWB antenna almost keep completely unchanged at the unnotched frequencies. Equivalent circuit models, surface current distributions, and input impedance are applied to analyze the principle of the proposed UWB antenna. Parametric studies are given. Simulated and measured results show that the proposed antenna has good impedance matching, stable radiation patterns, and constant gain.

1. Introduction

The Federal Communication Commission (FCC) has prescribed 3.1 to 10.6 GHz for commercial ultra-wideband (UWB) communication systems [1]. Since then, several antennas for UWB application have been reported [2–4]. However, the bandwidth of the UWB system includes the frequency bands of 3.3–3.7 GHz (WiMAX band), 5.15–5.35 GHz (WLAN band), and 7.25–7.75 GHz (the downlink of X-band satellite communication systems), which may generate interference with UWB system. Therefore, it is desirable to design UWB antennas with bands notched characteristics. The conventional methods to achieve band-notched function are using parasitic elements [5–10], embedding a slit in the feed line [11], or cutting different kinds of slots in radiation patch and ground plane [12–16]. Recently, several UWB antennas with single [5–7, 11, 13–17], dual [12, 18], and multiple [8, 19] notched band functions have been reported.

In this paper, we propose a simple microstrip-fed UWB antenna with triband notched characteristics. The proposed antenna is simulated and optimized by the high-frequency structure simulator (HFSS). A modified ground with two fillets and three steps is introduced to produce smooth transition from one resonant mode to another as this structure changes the inductance and capacitance of the input impedance. These measures are useful to decrease the discontinuities and the reflections. Hence, the impedance bandwidth can be effectively improved. By etching two arc-shaped slots in the radiation patch, the notched bands of 3.3–3.7 GHz and 5.15–5.35 GHz are produced. A U-shaped slot is cut in the ground plane to generate the third notched band in 7.25–7.75 GHz for the downlink of X-band satellite communication systems. It should be noted that the notched bands can be controlled independently by adjusting the location and length of slots mentioned above. We present equivalent circuit models, surface current distributions, and input impedance to discuss the proposed UWB antenna. Details of the antenna designs are given. The main parameters of the proposed antenna are discussed. The proposed antenna was fabricated and measured with a vector network analyzer Agilent E8363B. Simulated and measured results are given below to illustrate the performance of the proposed antenna.

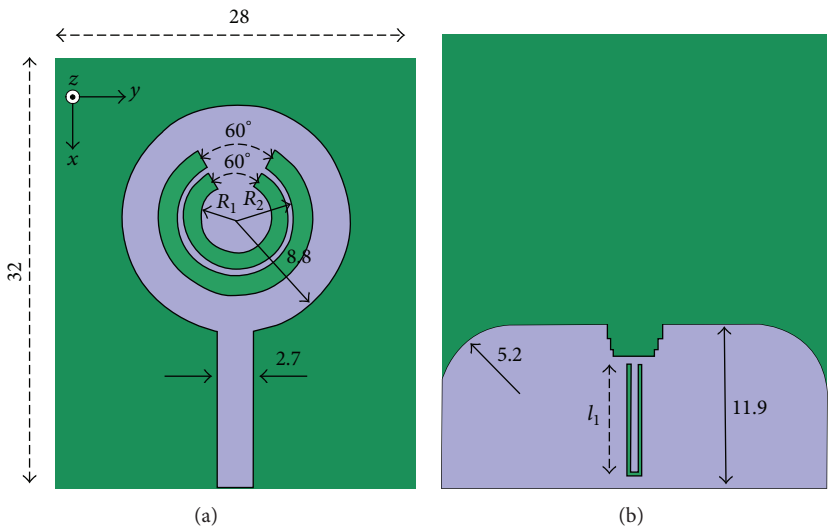

Figure 1: Geometry of the proposed antenna. (a) Top view, (b) bottom view (unit: millimeters).

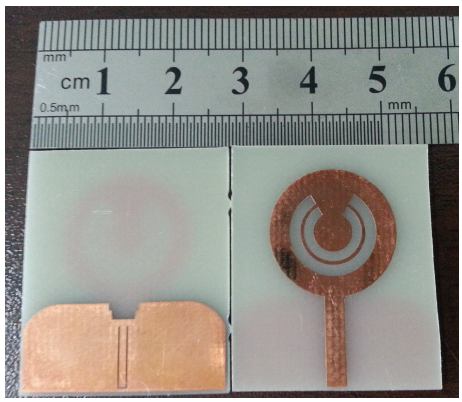

Figure 2: Photograph of the fabricated UWB antenna.

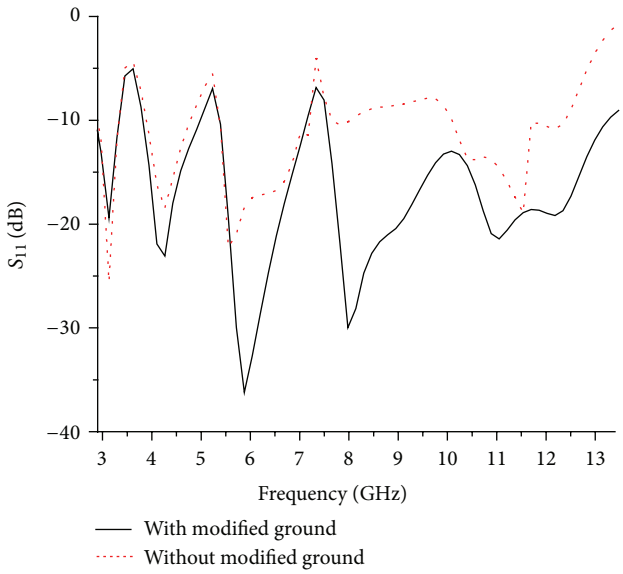

Figure 3: The effect of the modified ground plane.

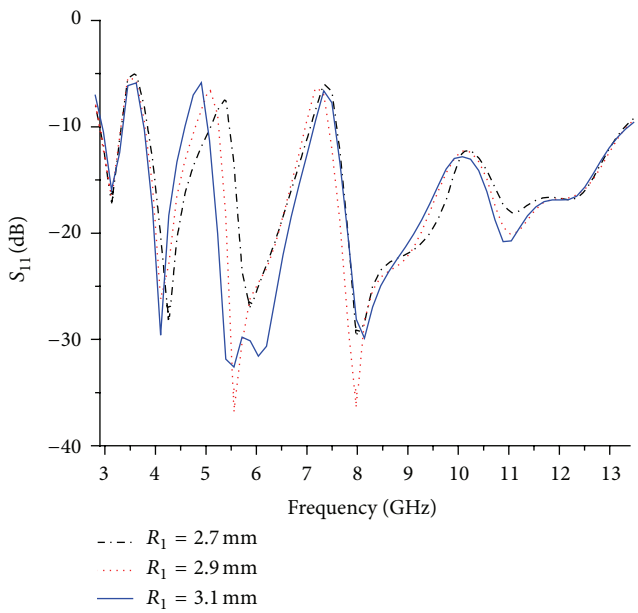

Figure 4: The effect of R_1 on S_{11} of the proposed antenna.

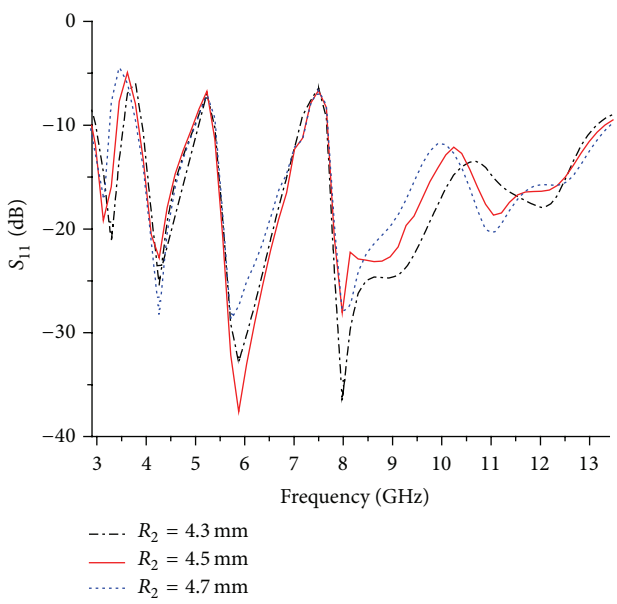

Figure 5: The effect of R_2 on S_{11} of the proposed antenna.

2. Antenna Design and Analysis

Figure 1 illustrates the geometry and configuration of the proposed antenna, which is printed on the FR4 substrate with a thickness of 1.4 mm, relative permittivity $\varepsilon_r = 4.4$, and loss tangent $\tan\delta = 0.02$. A circular patch with a radius of 8.8 mm is printed on the top side of the substrate. The circular patch is connected to the microstrip line. To achieve 50 Ω characteristic impedance, the width of the microstrip feed line is fixed at 2.7 mm. On the bottom of the substrate is a modified rectangular ground plane with two fillets and a step-shaped slot.

The outer arc-shaped slot is introduced to achieve the lower notched band of 3.3–3.7 GHz. The inner arc-shaped slot is used to obtain the middle notched band of 5.15–5.35 GHz. To make the design work and discussion much simple, the width and angle of the two arc-shaped slots are set to be 1.4 mm and 60°, respectively. We use the U-shaped slot in the ground plane to perform the higher notched band of 7.25–7.75 GHz band. Figure 2 shows the photograph of the proposed antenna, which is connected to a 50 Ω SMA connector for excitation and measurement.

The main parameters of the proposed antenna are studied by changing one parameter at a time and the others are

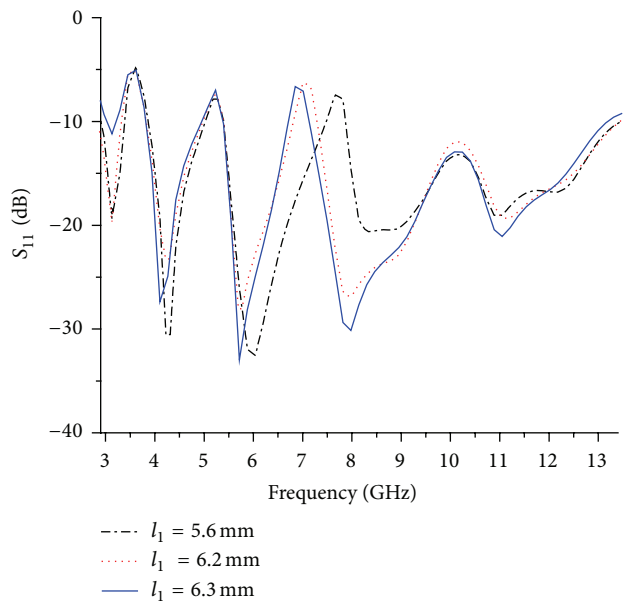

Figure 6: The effect of l_1 on S_{11} of the proposed antenna.

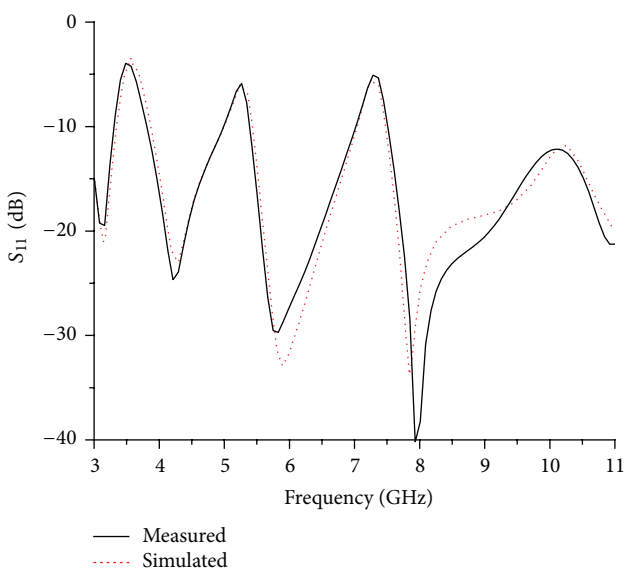

Figure 7: Simulated and measured S_{11} of the proposed antenna.

fixed. Figure 3 shows the effect of the modified ground plane. We can find that the modified ground plane broadens the impedance bandwidth significantly, particularly in the high frequencies. Figure 4 shows the simulated effects of radius R_1 of inner arc slot on the simulated S_{11} of the proposed antenna. It is observed that the lower notch band shifts toward higher frequencies as R_1 decreases. The simulated S_{11} curves of the proposed antenna with different values of radius R_2 of outer arc slot are illustrated in Figure 5. We can find that the longer the outer arc slot, the lower the middle notch band. The effects of length l_1 on S_{11} of the proposed antenna are shown in Figure 6. It is found that the higher notch band shifts to the lower frequencies with the increase of length l_1. Note that the others almost keep unchanged when we change any of the notched bands. This phenomenon suggests that the slots can be controlled independently for the desired notched bands. The optimum parameter values are $R_1 = 2.8$ mm, $R_2 = 4.6$ mm, and $l_1 = 5.9$ mm. The simulated and measured results of S_{11} are shown in Figure 7. A good agreement between measured and simulated S_{11} results is observed.

3. Results and Discussion

To analyze the principle of the proposed UWB antenna, the surface current distributions at 3.6, 5.2, 7.3, and 8.9 GHz are

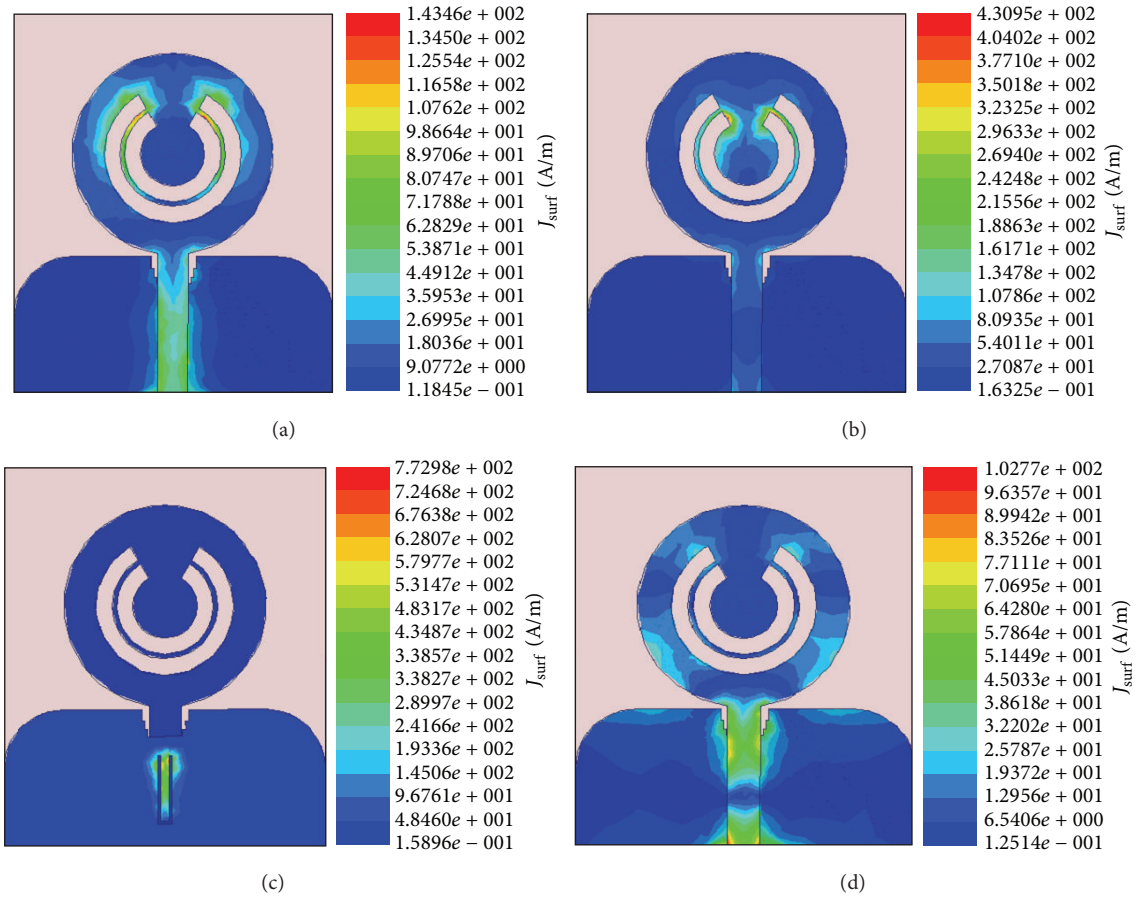

Figure 8: Surface current distributions. (a) The first notched band at 3.6 GHz, (b) the second notched band at 5.2 GHz, (c) the third notched band at 7.3 GHz, and (d) a passband frequency of 8.9 GHz.

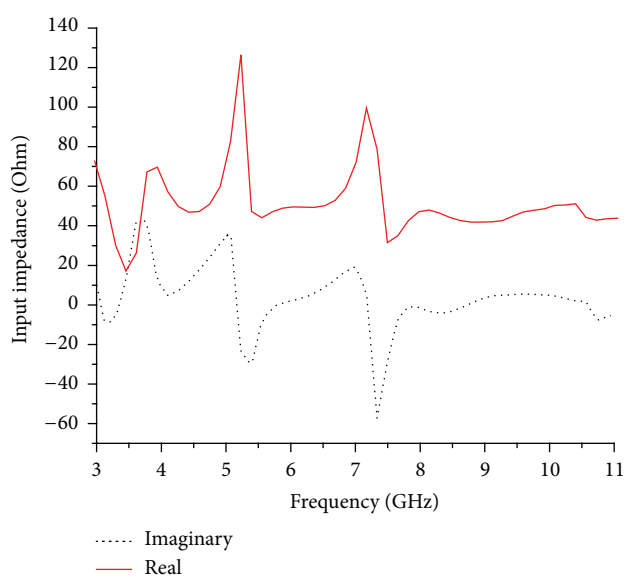

Figure 9: Real and imaginary part of the input impedance of the proposed antenna.

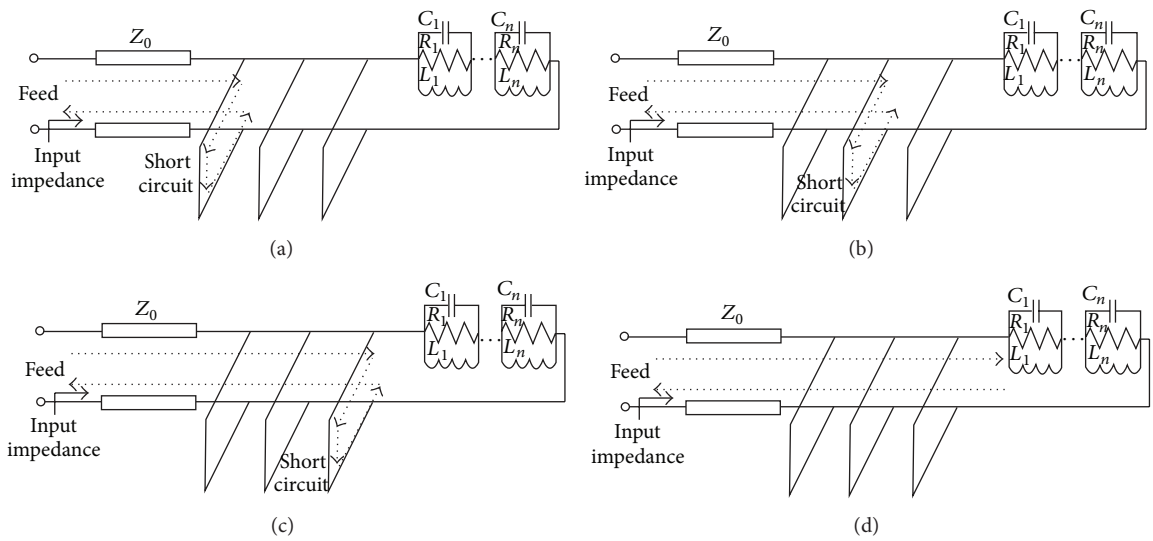

Figure 10: Equivalent circuit models of the proposed antenna. (a) The first notched band, (b) the second notched band, (c) the third notched band, and (d) the unnotched band.

shown in Figures 8(a)–8(d). From Figure 8(a)–8(c), we can find that the majority of the currents flow around the arc-shaped slots and the U-shaped slot at the notched frequencies, respectively. It implies that the impedance of the radiation patch is quite small, just like about shorted, at the notched bands. It can be seen in Figure 8(d), at a passband frequency of 8.9 GHz, that the currents mainly concentrate on the feed line and the edge of radiation patch, whereas, the currents around the arc-shaped slots and the U-shaped slot are weak. This suggests that the slots do not have a large impact on the proposed antenna performance at the unnotched bands.

For further discussion, the microstrip feed line given the dimensions can be expressed as a transmission line with characteristic impedance Z_0 (50 Ω). As mentioned above, the proposed antenna is connected to a 50 Ω SMA connector for excitation, so we can select the feeding point as the reference plane. Based on the transmission line theory, the input impedance given the reference plane is

$$Z_{\text{in}} = Z_0 \frac{1+\Gamma}{1-\Gamma}, \tag{1}$$

where Z_0 is the characteristic impedance, and Γ is the reflection coefficient.

As is shown in Figure 7, at the notched frequencies, the S_{11} of the proposed antenna is much higher, and at the unnotched frequencies the S_{11} is small. That means the reflection coefficient Γ is large (close to 1) at the notched frequencies and small (nearly 0) at the unnotched frequencies. Inserting the Γ in formula (1), the input impedance should be about 50 Ω at the unnotched frequencies and a big difference to 50 Ω at the notched frequencies. Figure 9 shows the input impedance of the proposed antenna. We can find the input impedance changes around 50 Ω at the unnotched band. It is also observed that the input impedance changes greatly at the notched frequencies. This demonstrates the principle discussed above.

It is also observed from Figure 7 that the wide matching bandwidth is the result of several resonances at 4, 6, and 8 GHz and each one can be represented by an RLC circuit. Based on the S_{11} curves and the input impedance, the radiation patch can be seen as several RLC cells in series at passband frequency. On the other hand, the currents mainly concentrate on the half-wavelength slots and the input impedance is singular at the notched bands. This is equal to reflection coefficient Γ closing to 1 in formula (1). So the radiation patch can be modeled as short circuit at the notched band. The introduced equivalent circuit model is shown in Figure 10.

Figure 11 shows the radiation patterns at 4.5, 6.0 and 8.9 GHz. The antenna displays a good omnidirectional radiation pattern in the H-plane (yz-plane) and bidirectional radiation pattern in the E-plane (xz-plane). The radiation pattern is rather stable.

Figure 12 shows the antenna gain of the proposed antenna. At the notched band, the gain of the proposed antenna drops sharply, which implies the effectiveness of band-notched feature of the proposed antenna. However, the gain keeps stable at the un-notched frequencies.

Time-domain characteristics are also investigated as flat group delay and small signal distortion is a primary requisite for UWB communication systems. In order to obtain time domain characteristics, a pair of proposed antennas is placed face-to-face with a distance of 30 cm. Figures 13(a) and 13(b) show the measured group delay and magnitude of transfer function (S_{21}). As is shown in Figure 13(a), the group delay is nearly constant in the entire UWB band except at the triple notched bands. The variation of group is less than 1 ns in the operating frequency, and the maximum group delay is about 7 ns at 3.5 GHz. It is observed in Figure 13(b) that the magnitude of S_{21} is relatively flat in the UWB band except in the notched bands, which indicates a fairly good dispersion behavior. Good phase linearity and low dispersion make it

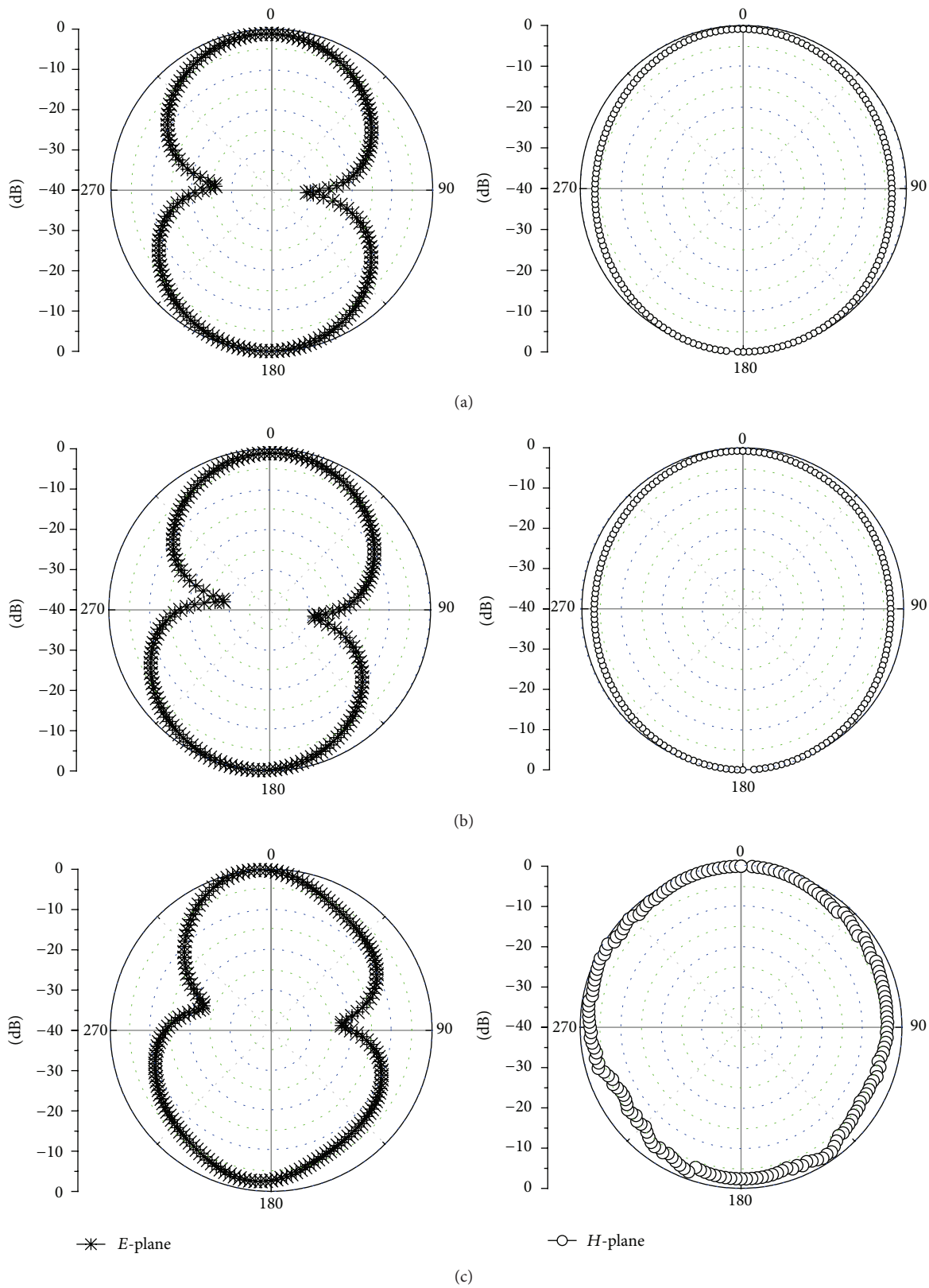

Figure 11: The measured radiation patterns in the H-planes and the E-planes (a) at 4.5 GHz, (b) at 6.0 GHz, and (c) at 8.9 GHz.

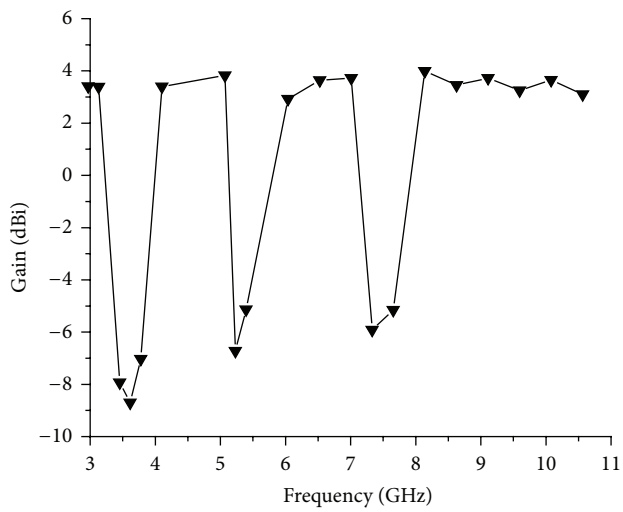

Figure 12: Measured maximum gain of the proposed antenna.

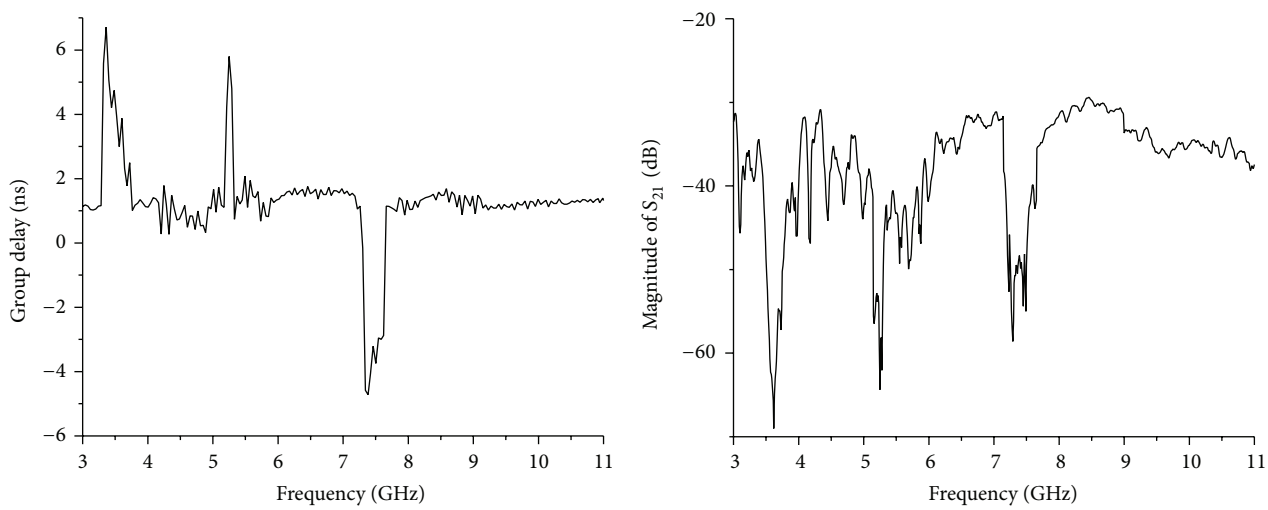

Figure 13: Time domain characteristics of the proposed antenna. (a) Group delay, (b) magnitude of the transfer function.

possible for the proposed antenna to communicate with good UWB pulse preserving capabilities.

4. Conclusion

To minimize potential interferences between the UWB communication systems and the existing narrowband systems, a compact triple band-notched antenna is designed, fabricated, and measured. The controllable notched bands are obtained by embedding half-wavelength slots on the radiation patch and ground plane. An equivalent circuit model based on input impedance, reflection coefficient Γ, and current distributions is introduced to discuss the mechanism of the proposed UWB antenna. Small profile, low cost, good omnidirectional radiation pattern, stable gain, and low distortion property make the proposed antenna a good candidate for UWB communication systems.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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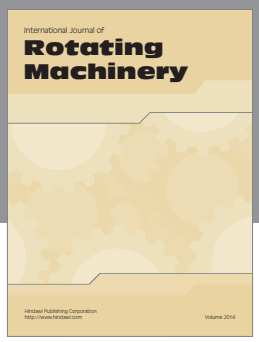

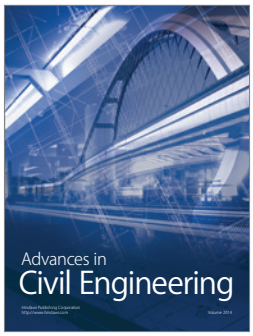

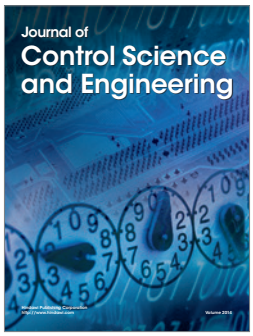

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