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A Miniaturized Quadruple Band Notched UWB Antenna Using U-Shaped Slots and SRRs

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Abstract

In this paper, a novel planar Ultra-Wideband (UWB) antenna with quadruple band-notched characteristics is proposed and investigated. The quadruple band-notched characteristics can be achieved by embedding three U-shaped slots on the radi ation patch and two Split Ring Resonators (SRRs) near feed line, respectively. The proposed antenna was successfully simulated and manufactured. It has a tiny size, only 17 mm × 23 mm × 0.508 mm. The proposed antenna exhibits good wideband performances over an UWB frequency range from 3.1 to 10.8 GHz with S11 less than -10 dB and with the exception of 3.27~3.7 GHz, 3.8~4.8 GHz, 5.13-5.65 GHz, 7.9~8.5 GHz frequency bands. Good agreement is obtained between the simulated results and measured results. The miniaturized structure and good characteristics make the suggested antenna a good candidate for UWB applications.

Keywords: Quadruple notched band; Split ring resonators; Miniaturized structure; Omnidirectional pattern; UWB antenna

Introduction

UWB communication system operates in the frequency band of 3.1 up to 10.6 GHz which has been approved by the U.S. Federal Communication Commission (FCC) in 2002 [1]. Antenna is an indispensable component of wireless device. The optimal performance of the radio communication system depends on the efficient design of antenna in great measure. Therefore, many studies on efficient design of UWB antennas which provide good wideband characteristics have been performed. However, before the approval of UWB, some narrow band communication systems, such as the World Interoperability for Microwave Access (WiMAX) system operating in the 3.5 GHz (3.3~3.7 GHz), C-band satellite communication system operating at the band of 3.8–4.2 GHz, Wireless Local Area Network (WLAN) operating in the 5.25 GHz (5.15–5.35 GHz) and 5.75 GHz (5.725–5.825 GHz), and International Telecommunications Union (ITU) operating at the band of 8.01–8.5 GHz have already existed [2,3]. Therefore, frequency band for UWB communication systems will cause interference to existing narrow band systems. One solution to this problem is to insert band-stop filter to the RF front-end. But this method would increase complexity, cost and size of system. The other better method is to design UWB antennas which incorporate integrated band-notched characteristics. Various techniques have been applied to achieve band-notched properties. One common method focuses on etching various kinds of slots, such as C-shape [4-7], T-shape [8-10], H-shape [11-13], U-shape [14-18], E-shape [19,20], arc-shaped slots, and SRR-shaped slot. Another effective method is adding diverse parasitic elements, such as T-shaped and SRR shaped elements. In this paper, a novel compact UWB planar monopole antenna of 17 mm × 23 mm=391 mm^2 is presented and fabricated. The initial design of the proposed UWB antenna includes a rectangular patch adding on the circular patch at the top of the dielectric substrate and a defected ground structure at the bottom of the dielectric substrate. The proposed antenna can operate from 3.1 to

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10.8 GHz to cover entire UWB range with VSWR less than 2. By etching three U-shaped slots on the radiation patch and adding two SRRs near the feed line, the proposed antenna can produce quadruple notched bands at 3.27~3.7 GHz, 3.8~4.8 GHz, 5.13~5.65 GHz, 7.9~8.5 GHz to give resistance to the interferences from narrow band communication systems. The proposed antenna was manufactured and measured with optimal dimensions. This paper is organized in the following 4 sections. Geometrical structure and design procedure of the proposed antenna are shown in section 2. In section 3, parametric study is presented. In addition, current distribution, radiation pattern and realized gain are shown. Finally, section 4 presents the conclusion.

Materials and Methods

Antenna Design

Schematic and dimensions of the proposed antenna: The proposed quadruple band-notched antenna is based on a planar monopole UWB antenna. Figure 1 depicts the configuration and the fabricated prototype of the proposed antenna. As you can see from Figure 1, the proposed antenna consists of aradiator with three U-shaped slots, feedline and two SRRs near the feed line on the front surface of the substrate. On the back surface of the substrate, there is a defected ground structure with inverted U-shaped slot. The proposed antenna is printed on a Rogers 4350 B substrate with relative permittivity of 3.66, loss tangent of 0.0037 and thickness of 0.508 mm. The total size of the antenna is 17 mm × 23 mm=391 mm^2. The proposed antenna is optimized by CST on the basis of the principle of the proposed quadruple band-notched UWB antenna. The optimized parameters listed in Table 1 satisfy both the designated notch bands referred to the VSWR and the desired UWB bandwidth.

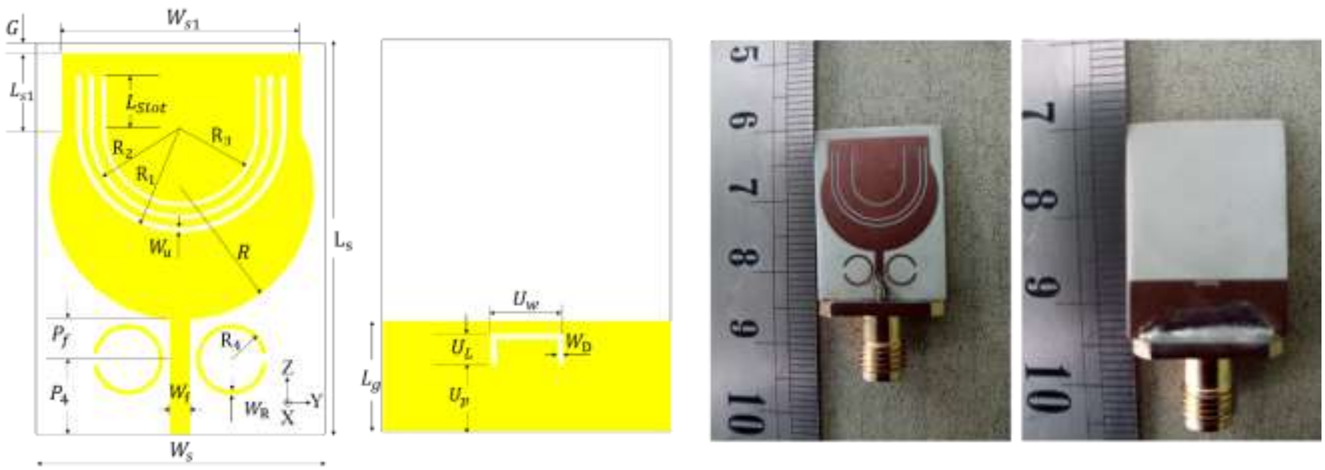


FIG. 1. **Geometrical structure and photograph of the proposed antenna (a) Geometrical structure, (b) Photograph.**

TABLE 1. **Optimized parameters of the proposed antenna.**

Parameters	**W_s**	**L_s**	**W_{s1}**	**Ls_1**	**G**	**W_f**	**P_f**	**R**	**R_1**	**R_2**	**R_3**
Values(mm)	17	23	14.5	4.1	0.9	1.1	2.4	8	6.6	5.75	3.7
Parameters	R_4	P_4	L_g	L_{slot}	U_p	U_L	U_w	W_u	W_R	W_D	
Values(mm)	2.05	4.15	6	4.3	5.3	0.5	2.4	0.25	0.25	0.3	

Design procedure of the proposed antenna: The design procedure of the proposed antenna is described in Figure 2. We will show how to design the proposed quadruple band-notched antenna step by step. Firstly, we used a UWB antenna which is denoted Ant1 for designing the proposed antenna. Ant 1 covers UWB band 3.1-10.6 GHz. The upper frequency of impedance bandwidth is affected by an inverted U-shaped slot in the ground plane. Therefore, by adjusting the length of an inverted U-shaped slot, we can control impedance bandwidth. Then the first U-shaped slot is etched on the radiation patch to create Ant 2 which is to design the first rejected band at 3.5 GHzWiMAX band. And also the second U-shaped slot is etched on the radiation patch to construct Ant 3 which is to design the second notched band at C-band satellite communication band. Then, third U-shaped slot is etched on the radiation patch to create Ant 4 which is to design the third notched band at 5.25 GHzWLAN band. Last, we add two SRRs near the feed line to construct Ant 5 which is to provide the forth notched band at ITU band.

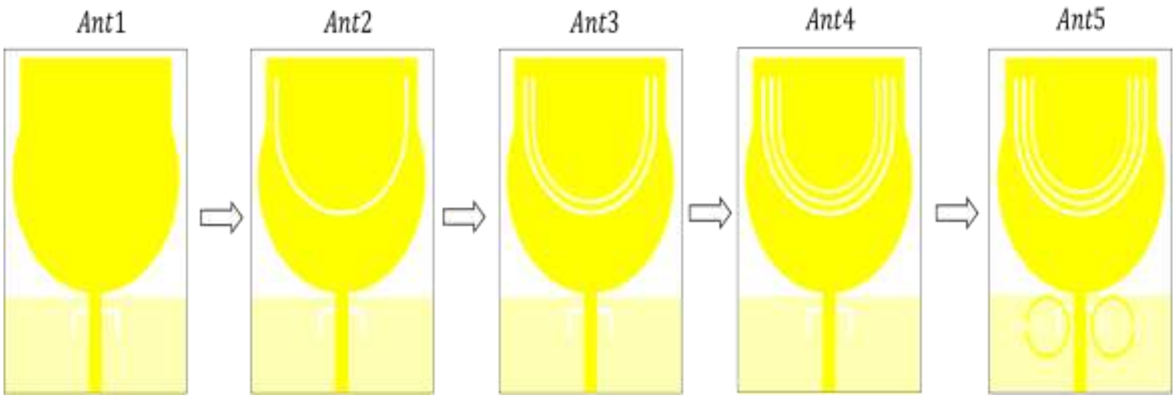
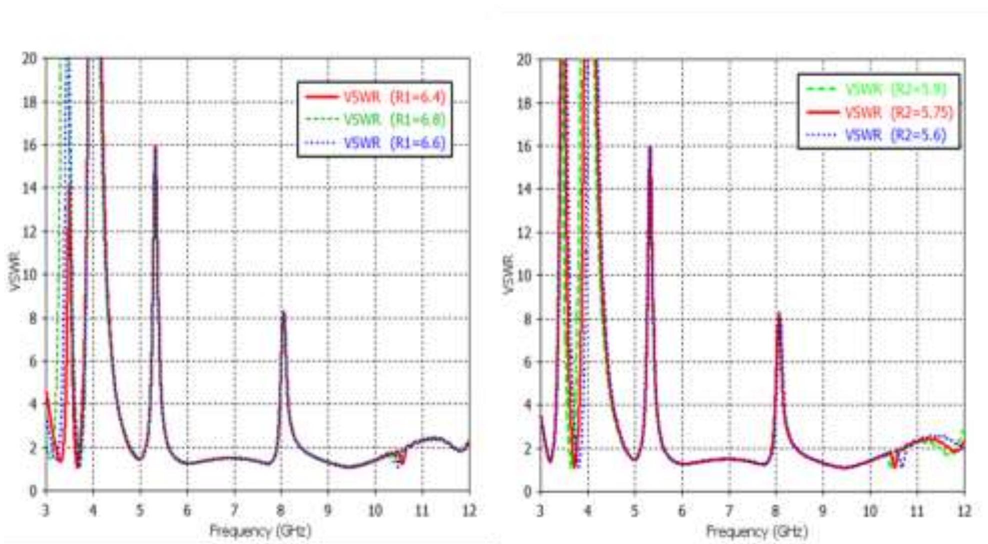


FIG. 2. **Design procedure of the proposed antenna.**

Results

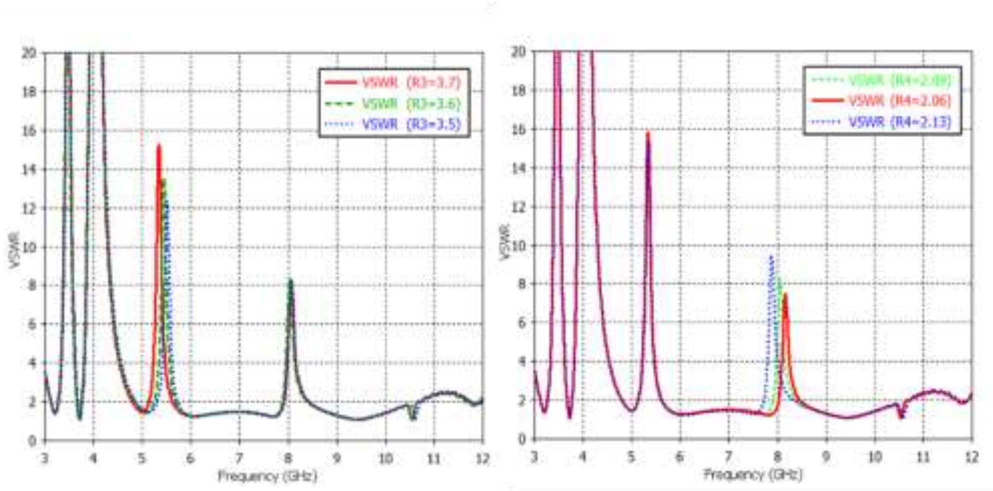
Parameter analysis

We will investigate parameter effects on the VSWR. Here, the parameters R_1,R_2,R_3 and R_4 are selected for evaluating the effects on the proposed quadruple band-notched UWB antenna. Figure 3a shows that R_1 has important effects on the 3.47 GHz frequency center band. By adjusting the value of R_1 from 6.4 mm to 6.8 mm, center of the first notched band shifts slightly for lower frequencies side: from 3.54 GHz to 3.38 GHz. On the other hand, we can observe that the parameter R_1 has small influences for three other notched bands 4.1 GHz, 5.33 GHz and 8.1 GHz. Figure 3b shows that R_2 makes a great impact on the 4.1 GHz frequency center band. By adjusting the value of R_2 from 5.6 mm to 5.9 mm, center of the second notched band shifts slightly for lower frequencies side: from 4.17 GHz to 4.04 GHz. Also, it is found that the parameter R_2 has a little influence for three other notched bands 3.47 GHz, 5.33 GHz and 8.1 GHz. Figure 4a shows that R_3 affects greatly on the 5.33 GHz frequency center band. By adjusting the value of R_3 from 3.5 mm to 3.7 mm, center of the third notched band shifts slightly for lower frequencies side: from 5.51 GHz to 5.33 GHz. On the other hand, we can observe that the parameter R_3 has small influences for three other notched bands 3.47 GHz, 4.1 GHz and 5.33 GHz. Figure 4b shows that R_4 has a great influence on the 8.1 GHz frequency center band. By adjusting the value of R_4 from 2.06 mm to 2.13 mm, center of the forth notched band shifts slightly for lower frequencies side: from 8.21 GHz to 7.86 GHz. On the other hand, we can observe that the parameter R_4 has a little influence for three other notched bands 3.47 GHz, 4.1 GHz and 5.33 GHz.



(a) **(b)**

FIG. 3. **The Simulated VSWR of the Proposed Antenna with Changes of R_1 and R_2 (a)R_1, (b)R_2.**



(a) **(b)**

FIG. 4. **The Simulated VSWR of the proposed antenna with changes of R_3 and R_4 (a) R_3, (b) R_4.**

To confirm the effectiveness of the proposed antenna, the optimized antenna is manufactured and its VSWR is measured by using Agilent Field Fox N 9918A vector network analyzer. Figure 5 shows comparison between the measured and simulated VSWR results of the proposed antenna. As you can see from Figure 5, the measured notched frequencies and impedance bandwidth of the proposed antenna are very suitable for suppressing the intrusion from WiMAX system, WLAN, C-band satellite communication system and ITU. The measured frequency range covers commercial UWB band (3.1–10.6 GHz) and has four notched frequency bands of 3.27–3.7 GHz (12.34%), 3.8-4.8 GHz (23.3%), 5.13–5.65 GHz (9.65%), and 7.9-8.5 GHz (7.3%). There is a little discrepancy between the measured and simulated results, which may be caused by fabrication tolerance and interference of connector and feeding cable in the measurement.

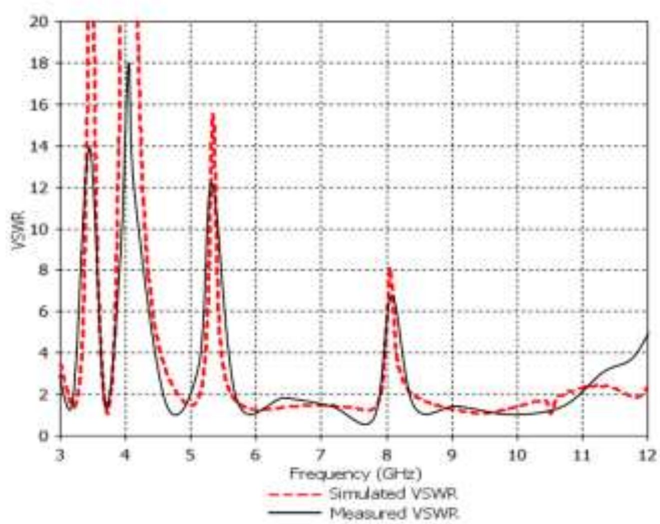


FIG. 5. **Simulated and measured VSWR of the proposed antenna**.

Current distribution

The current distribution of the proposed antenna is investigated and explained in Figure 6. As you can see in Figure 6a, current density is highly concentrated at three U-shaped slots at 3.47 GHz, 4.1 GHz, 5.33 GHz respectively and at two SRR sat 8.1 GHz. This means that a large part of electromagnetic energy has been stored around three U-shaped slots or two SRRs on the front surface of the substrate. So radiation efficiency decreases at the rejected bands. As can be seen in Figure 6b, surface current at the pass band of 3.75 GHz, 5 GHz, 6.7 GHz and 9 GHz is hardly concentrated close to three U-shaped slots and SRRs while it is highly concentrated around the edge of the main radiator. Thus, signal is propagated.

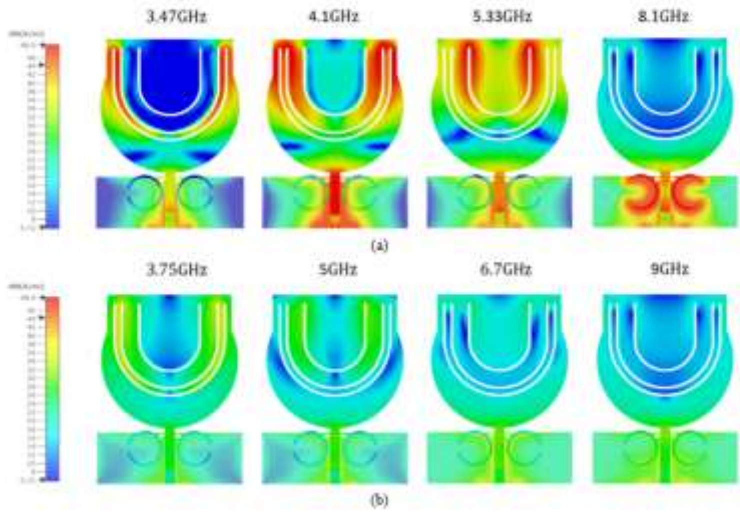


FIG. 6. **The Current Distribution of the Proposed Antenna (a) stopband, (b) passband.**

Radiation patterns and realized gain

Figure 7 illustrates radiation patterns in E-plane (X-Z plane) and H-plane (X-Y plane) at stop bands of 3.47 GHz, 4.1 GHz, 5.33 GHz and 8.1 GHz and at pass bands of 3.75 GHz, 5 GHz, 6.7 GHz and 9 GHz. From Figure 7, we can observe that radiation pattern in E-plane looks like a digit '8'and is faintly distorted as frequency becomes higher. H-plane radiation patterns conserve nearly omnidirectional characteristics at almost every frequency.

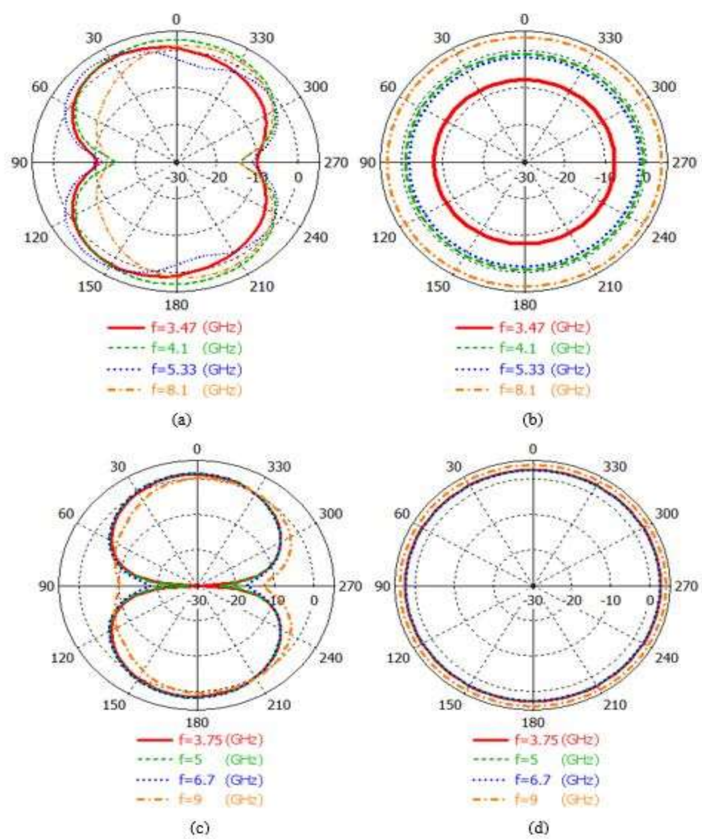


Fig. 7. **Radiation patterns of the proposed antenna. (a) E-Plane (X-Z Plane) at the Stopband Frequencies (b) H-Plane (X-Y Plane) at the stopband frequencies (c) E-Plane (X-Z Plane) at the passband frequencies (d) H-Plane (X-Y Plane) at the passband frequencies.**

Realized gains of the proposed antenna with and without notched band structures are shown in Figure 8. As you can see, antenna gain drops very quickly in the vicinity of four notched band frequencies of 3.47 GHz,4.1 GHz,5.33 GHz and 8.1 GHz. It means that radiation ability of the proposed antenna is strong at UWB band except quadruple notched bands. This clearly illustrates quad band rejection function of the proposed antenna. Table 2 gives comparisons of the proposed antenna with previously introduced band-notched UWB antennas. As you can see from Table 2, many triple or quadruple band-notched UWB antennas have been introduced so far. In NedaRojhani, a miniaturized design of UWB antenna have been introduced but it has achieved only triple notched bands. And also in Chaabane Abdelhalim, not only they provide triple notched bands but also they are fabricated in larger size than this work. In Xiaoyin Li, they provide quadruple notched bands but size of them are bigger than this work. In a word, the proposed UWB antenna provides four notched band, compact size and good band notched properties, making it possible to satisfy the requirements of UWB systems.

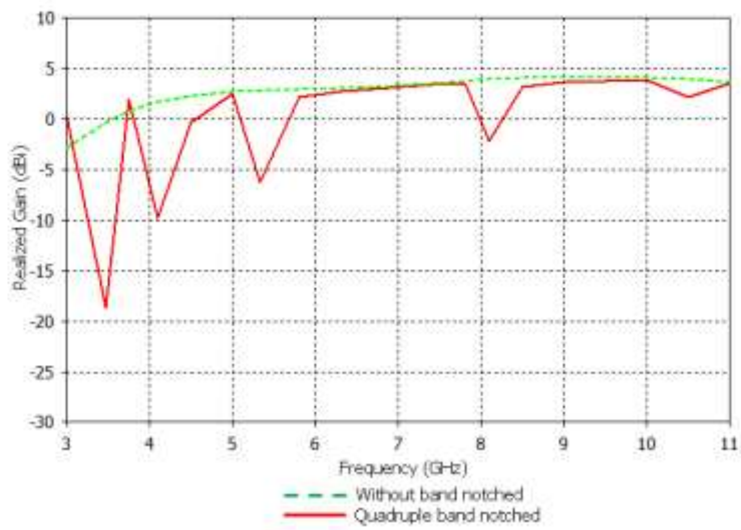


FIG. 8. **Realized gain of the proposed antenna.**

TABLE 2. **Comparisons with proposed band-notched UWB antennas.**

Number of notches	Notched bands, GHz	Bandwidth, GHz	Size, mm^2
4	5.15-5.35,5.75-5.85, 7.25-7.75, 8.01-8.55	3.1-12	26 28
3	1.6-2.66, 3-4, 5.13-6.03	3.1-10.6	31 31
3	2.45-3.0, 3.1-3.7, 3.8-4.3	2.0-10.75	34.9 31.3
4	3.3-3.6, 5.25-5.35, 5.725-5.825, 7.9-8.4	2.94-12	20 35.6
4	3.41-4.07, 4.41-4.76, 5.21-5.64, 6.92-8.63	2.9-12	20 24
3	3.0-3.8, 5.1-6.1, 7.8-8.9	2.8-12.5	20 14
4	3.6-3.8, 4.5-4.9,5.6-6.0, 7.2-7.6	3-10.7	20 25
4	3.27~3.7, 3.8-4.8, 5.13-5.65, 7.9~8.5	3.1-10.8	17 23

Conclusion

This paper presents a study on miniaturized UWB antenna with quadruple band-notched characteristics. Performance of the proposed antenna has been investigated in detail. The quadruple band notched antenna with three U-shaped slots on the radiation patch and two SRRs near the feed line are designed and implemented for suppressing intrusion from WiMAX, C-band satellite communication system, WLAN and ITU band. By simply changing dimensions of corresponding notched band structure, notched-frequency bands can be controlled independently. The proposed antenna shows band rejection at the intended notch frequencies and surface current validates this result. Results show that the antenna has compact size, simple structure and good omnidirectional radiation patterns, making it suitable for UWB communication system.

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