Design and Implementation of a Compact CPW-Fed Planar UWB Antenna with Quadruple Band Notched Characteristics

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Abstract

A novel coplanar waveguide ()-fed planar UWB antenna with quadruple band-notched property is presented. The quadruple band rejection is achieved by etching a M-shaped slot on the radiation patch and a U-shaped slot on the feed line, and adding two L-shaped parasitic strips near radiator patch and two split ring resonators (SRRs) on the back surface of the substrate. The voltage standing wave ratio (VSWR) results show that the proposed antenna exhibits good wideband performance over an UWB frequency range from 3 to 11.8 GHz with VSWR less than 2, except for four stop-bands at 3.3~3.75GHz, 5.15~5. 85GHz, 7. 2~7.76GHz, 8~8.55GHz respectively. It also demonstrates a nearly omnidirectional radiation pattern and available gain. The fabricated antenna has a tiny size, only 34mm× 31mm× 0.508mm. The simulated results are compared with the measured results and good agreement is obtained. The simple structure, compact size and good characteristics make the antenna an excellent candidate for UWB applications.

Keywords: *quadruple notched band, UWB antenna, parasitic strip, split ring resonators, omnidirectional pattern*
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1. INTRODUCTION

Ultra-wideband (UWB) is specified in the Federal Communication Commission (FCC) in 2002 as frequency band which ranges from 3.1 to 10.6 GHz [1]. UWB communication systems have recently obtained a great deal of attention because of its planar configuration, small size and fast data transmission rate. Among them, UWB antennas with filtering properties are in great demand due to coexistence of UWB communication systems with other wireless frequency bands such as the World Interoperability for Microwave Access (WiMAX) system bands in the 3.5GHz (3.3~3.7GHz), Wireless Local Area Network (WLAN) bands in the 5.25GHz (5.15–5.35 GHz) and 5.75 GHz (5.725–5.825GHz), X-band downlink satellite communication system operating at the band of 7.25–7.75GHz and International Telecommunications Union (ITU) operating at the band of 8.01–8.5GHz, respectively. As one of promising candidates, CPW-fed planar antenna has been investigated and reported [2]. However, in order to design UWB antennas with band-notched functions, several methods have been proposed including etching various kinds of slots and adding some elements. One method is etching various types of slots such as C-shape [3-5], T-shape [6-8], H-shape [9-11], U-shape [12-16] and E-shape [17,18] and integrating electromagnetic band gap (EBG) structures [16,19-21] on the radiation patch, ground plane and feed line. Another method consists of adding parasitic elements [22-25], T-shaped elements [26,27] and SRRS on the antenna structure [28-31]. In this paper, a novel CPW-fed planar UWB antenna with quadruple band-notched characteristics of 34mm × 31mm × 0.508mm =$532mm^3$is proposed and investigated in detail. To realize a compact UWB system, CPW-fed planar monopole antenna is proposed to cover UWB range. The proposed antenna has a quadruple band-notched characteristics at the center frequency of 3.42GHz, 5.58GHz, 7.38GHz and 8.3GHz. First band-notched characteristic is obtained by etching a M-shaped slot on the radiation patch. Moreover, second band-notched property is obtained by adding another two L-shaped parasitic strips on the ground plane. By etching a U-shaped slot on the feed line, third band-notched property is obtained. Finally, forth band-notched property is obtained by adding SRRs. The simulated and measured VSWR results indicate that proposed quadruple band-notched antenna could operate from 3 to 11.8GHz with VSWR less than 2, except for four stop-bands at 3.3~3.75GHz, 5.15~5.85GHz, 7.2~7.76GHz, 8~8.55GHz respectively. The prototyped antenna with optimal dimensions was fabricated and measured. This paper is organized in the following 5 sections. In Section 2, configuration of the proposed antenna is shown. Parametric study is presented in section 3. Both of the simulated and measured results including voltage-standing wave ratio, current distribution, radiation pattern, realized gain and so on are shown in section 4. A conclusion will be presented in section 5.

2. ANTENNA CONFIGURATION

The proposed quadruple band-notched antenna is based on a CPW-fed planar UWB antenna that covers the UWB frequency range, whose structure is shown in Fig. 1. The proposed antenna is printed on an 0.508mm thick Rogers 4350B substrate. Relative permittivity of this substrate is $\varepsilon_r = 3.66$ and loss tangent is $tan\delta = 0.0037$. The antenna with novel structures has a tiny size of 34mm× 31mm× 0.508mm =532 mm^3. The proposed antenna consists of a circular radiator with a M-shaped slot, two L-shaped parasitic strips on the ground plane, a CPW feed line with a U-shaped slot on the front surface of the substrate and two SRRs on the back surface of the substrate. The proposed quadruple band-notched antenna uses CPW feed line due to its significant advantages compared to microstrip-fed lines. Band-notched characteristics of the proposed antenna are obtained by etching a M-shaped slot and a U-shaped slot, and adding two L-shaped parasitic strips and two SRRs. Geometrical parameters of elements satisfying band-notched characteristics are listed in Table 1.

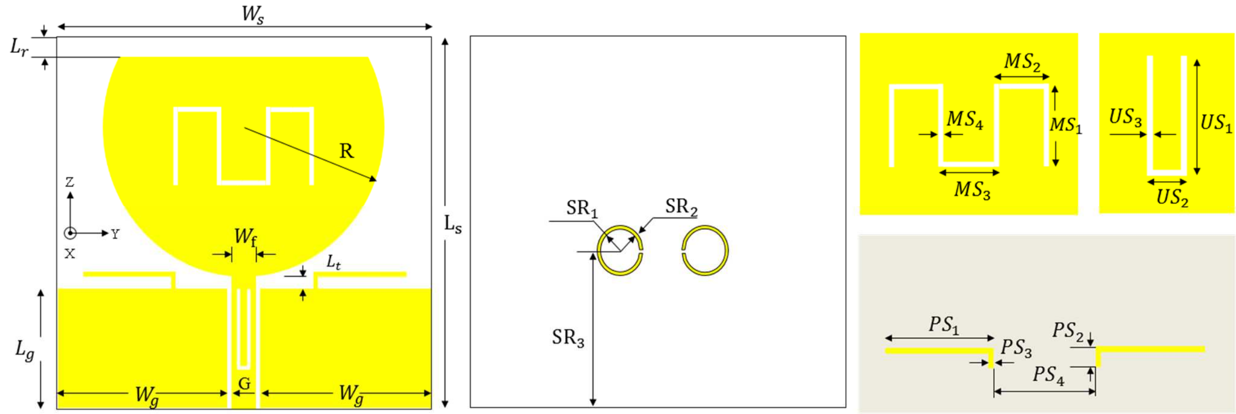


Fig. 1: *Geometrical Structure of the Proposed Antenna*

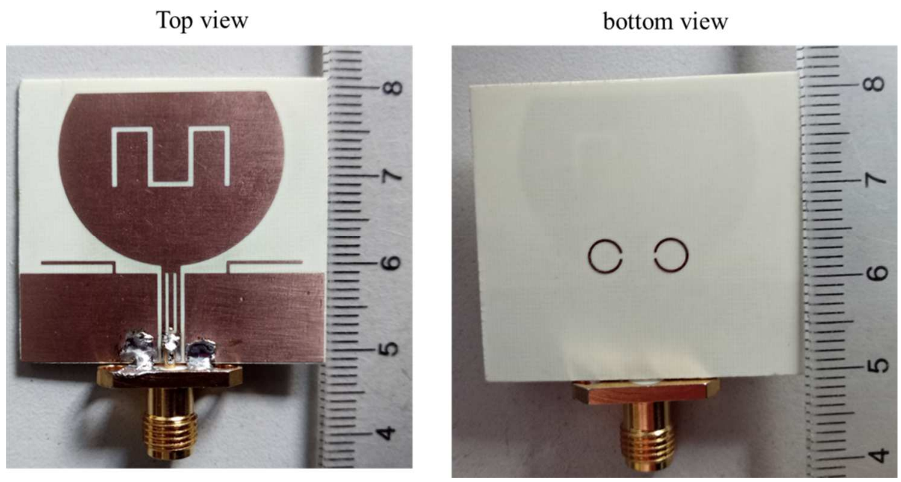


Fig. 2: *Photograph of the Proposed Antenna*

Table 1. *Optimized Parameters of the Proposed Antenna*

Parameters	**W_s**	**L_s**	**W_g**	**L_g**	**G**	**W_f**	**L_t**	**R**	**MS_1**	**MS_2**	**MS_3**	**MS_4**
Values(mm)	34	31	15.5	10	0.4	2.2	0.85	12.5	6.5	3.5	5	0.5
Parameters	**US_1**	**US_2**	**US_3**	**PS_1**	**PS_2**	**PS_3**	**PS_4**	**SR_1**	**SR_2**	**SR_3**	**L_r**	
Values(mm)	6.4	1.2	0.3	8.75	1.4	0.4	12.4	1.59	0.25	13	1	

3. PARAMETRIC STUDY

A parametric study of the proposed quadruple band-notched UWB antenna was carried out in order to control band rejection operation. It is necessary to control notched bandwidths by changing parameters in practical application to obtain an effective band-notched UWB antenna. A study of rejected band based on the dimensions of the corresponding notched band structure was carried out. Band-notched characteristics of a M-shaped slot, a U-shaped slot, two L-shaped parasitic strips can be obtained by adjusting total length. In case of SRRs, band-notched characteristic is obtained by adjusting radius and position of rings. In this section, influences of each parameter on the proposed antenna will be studied.

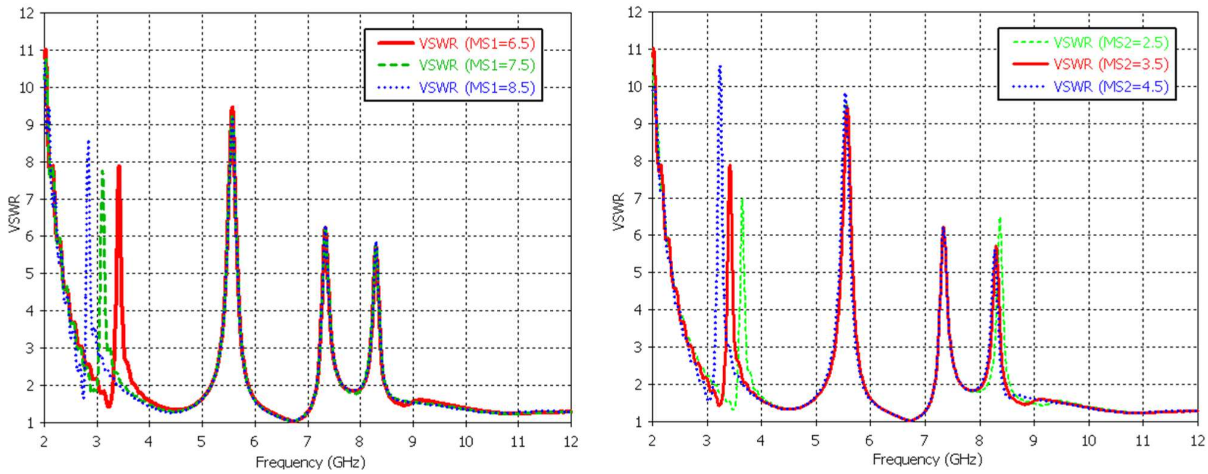
3.1 Controlling the first rejected band generated by M-shaped slot.

Fig. 3*a* and *b* show the simulated VSWR with changing MS_1 and MS_2 on the 3.42GHz frequency center band. When MS_1 increases, center of the first notched band shifts slightly for lower frequencies side: from 3.42GHz for MS_1 = 6.5 mm to 2.84 GHz for MS_1 =8.5 mm. We observe the same effect when MS_2 increases: center of the first notched band shifts slightly from 3.65GHz for MS_2 = 2.5mm to 3.24 GHz for MS_2 =4.5 mm. The first notched band width is decided by MS_1 and MS_2. On the other hand, we can observe that the parameters MS_1 and MS_2 have small influences for three other notched bands 5.58GHz, 7.38 GHz and 8.3GHz.

3.2Controlling the second rejected band generated by two L-shaped parasitic strips.

Fig. 4 shows the simulated VSWR with changing PS_1 on the 5.58GHz frequency center band. When PS_1 increases, center of the second notched band shifts slightly for lower frequencies side: from 5.76GHz for PS_1 = 8.35 mm to 5.36 GHz for PS_1 =9.15

mm. On the other hand, we can observe that the parameter PS_1 has small influences for three other notched bands 3.42GHz, 7.38 GHz and 8.3GHz.



a b

Fig. 3: *The Simulated VSWR of the Proposed Antenna with Changes of MS_1 and MS_2 (a) MS_1, (b) MS_2*

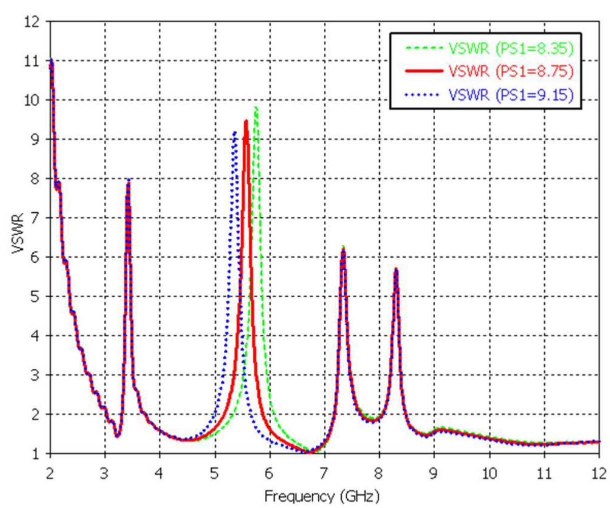


Fig. 4: *The Simulated VSWR of the Proposed Antenna with Changes of PS_1*

3.3 Controlling the third rejected band generated by U-shaped slots.

Fig. 5*a* and *b* show the simulated VSWR with changing US_1 and US_2 on the 7.38GHz frequency center band. When US_1 increases, center of the third notched band shifts slightly for lower frequencies side: from 7.56GHz for US_1 = 6.2 mm to 7.13GHz for US_1 =6.6mm. We observe the same effect when US_2 increases: center of the third notched band shifts slightly from 7.38GHz for US_2 = 1mm to 7.26 GHz for US_2 =1.4 mm. The third notched band width is decided by US_1 and US_2. On the other hand, we can observe that the parameters US_1 and US_2 have small influences for three other notched bands 3.42GHz, 5.58 GHz and 8.3GHz.

3.4 Controlling the forth rejected band generated by SRRs.

Fig. 6*a* and *b* show the simulated VSWR with changing SR_1 and SR_2 on the 8.3GHz frequency center band. When SR_1 increases, center of the forth notched band shifts slightly for lower frequencies side: from 8.71GHz for SR_1 = 1.49 mm to 8.3 GHz for SR_1 =1.59 mm. We observe the same effect when SR_2 increases: center of the forth notched band shifts slightly from 8.45GHz for SR_2 = 0.15mm to 8.16GHz for SR_2 =0.35 mm. On the other hand, we can observe that the parameters SR_1 and SR_2 have a little influence for three other notched bands 3.42GHz, 5.58 GHz and 7.38GHz. Therefore, the center frequency of the forth rejected band is got by varying the parameters SR_1 and SR_2. In summary, the longer the length of slots and parasitic strips gets, the lower the notched band frequency becomes.

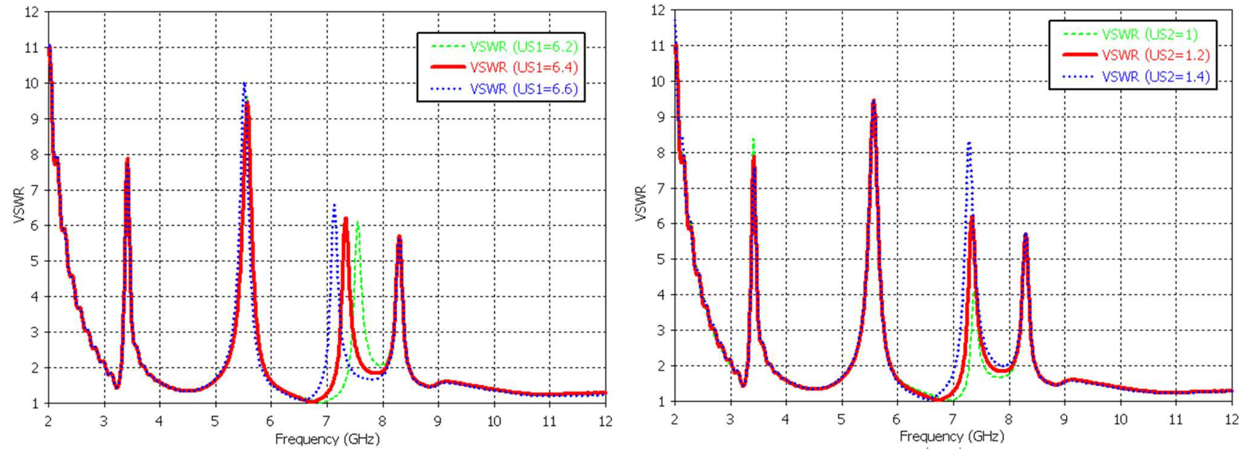


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Fig. 5: *The Simulated VSWR of the Proposed Antenna with Changes of US_1 and US_2 (a) US_1, (b) US_2*

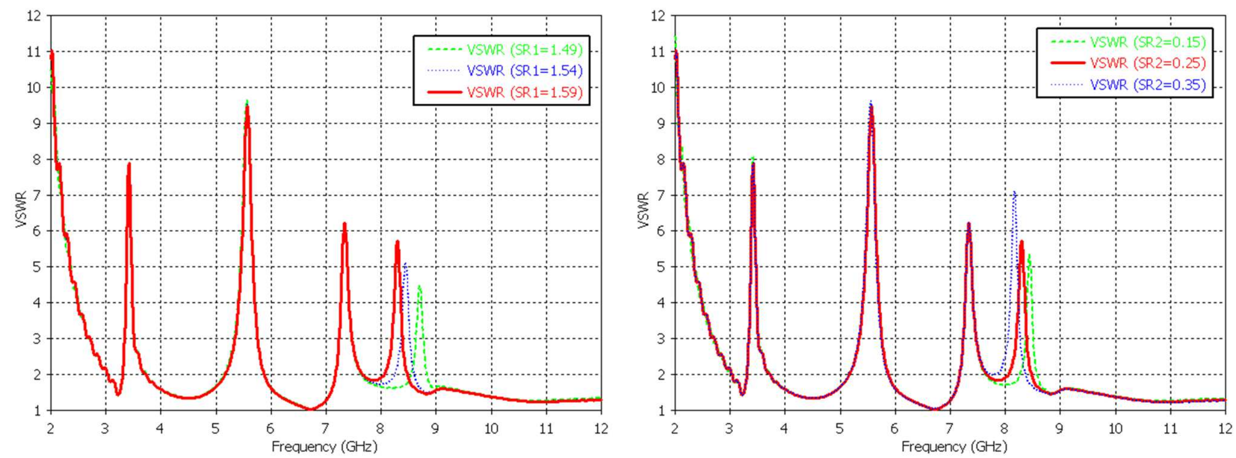

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Fig. 6: *The Simulated VSWR of the Proposed Antenna with Changes of SR_1 and SR_2 (a)SR_1, (b)SR_2*

4. RESULTS AND DISCUSSIONS

The quadruple band-notched antenna is successfully fabricated and measured with optimized size shown in Table 1. Photograph of the antenna is printed in Fig. 2 and the measurement is taken with an Agilent Field Fox N9918A vector network analyzer.

4.1 VSWR Measurement

The measured and simulated VSWR results for the proposed antenna with quadruple band- notched characteristics are shown in Fig. 7. It can be seen that the measured notched frequencies and bandwidths of the proposed antenna are very suitable for rejecting the interference from WLAN, WiMAX systems, X-band downlink satellite communication system and ITU. The measured frequency range covers commercial UWB band (3.1–10.6GHz) and rejects four frequency bands of 3.3– 3.75GHz (12.8%), 5.15-5.85GHz (12.7%), 7.2–7.76GHz (7.5%), and 8-8.55GHz (6.7%). There is a little disagreement between the simulated and measured results and this is maybe because of tolerance in manufacturing and interference of connector and feeding cable in the measurement.

4.2 Current distribution

Fig. 8*a* illustrates the simulated surface current distributions at the stop band center frequencies of 3.42GHz, 5.58GHz, 7.38GHz and 8.3GHz. We can observe that surface current is highly concentrated at the M-shaped slot at 3.42GHz, at L-shaped parasitic strips at 5.58GHz, at the U-shaped slot at 7.38GHz and at two SRRs at 8.3GHz. This means that a large portion of electromagnetic energy has been stored around the slot or parasitic strips so that the radiation efficiency decreases at the notched bands. As can be seen in Fig .8*b*, the surface current at the pass band center frequencies of 4.5GHz, 6.5 GHz, 7.88 GHz and 9GHz is slightly concentrated close to M-shaped slot, U-shaped slot, L-shaped parasitic strips and SRRs while it is highly concentrated around the edge of the main radiator. Thus, signal is propagated.

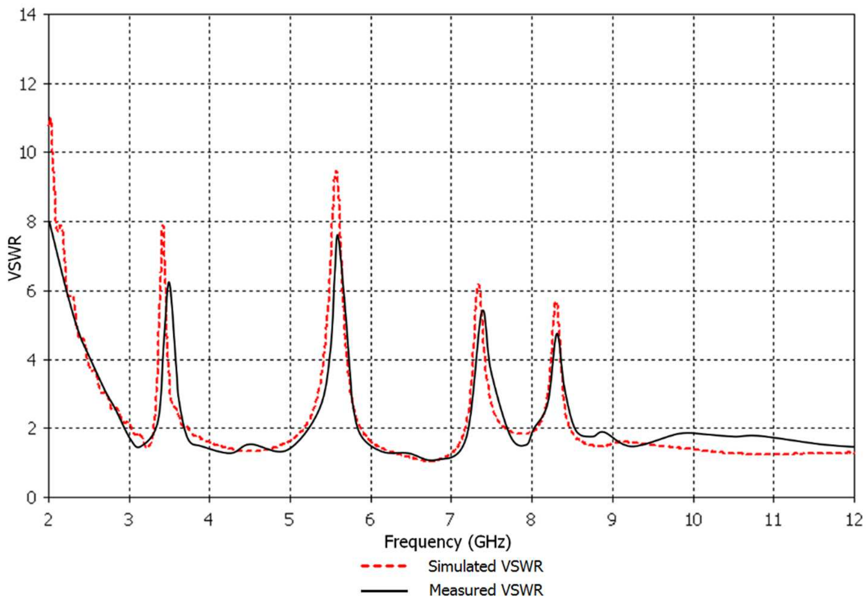

Fig. 7: *Simulated and Measured VSWR of the Proposed Antenna*

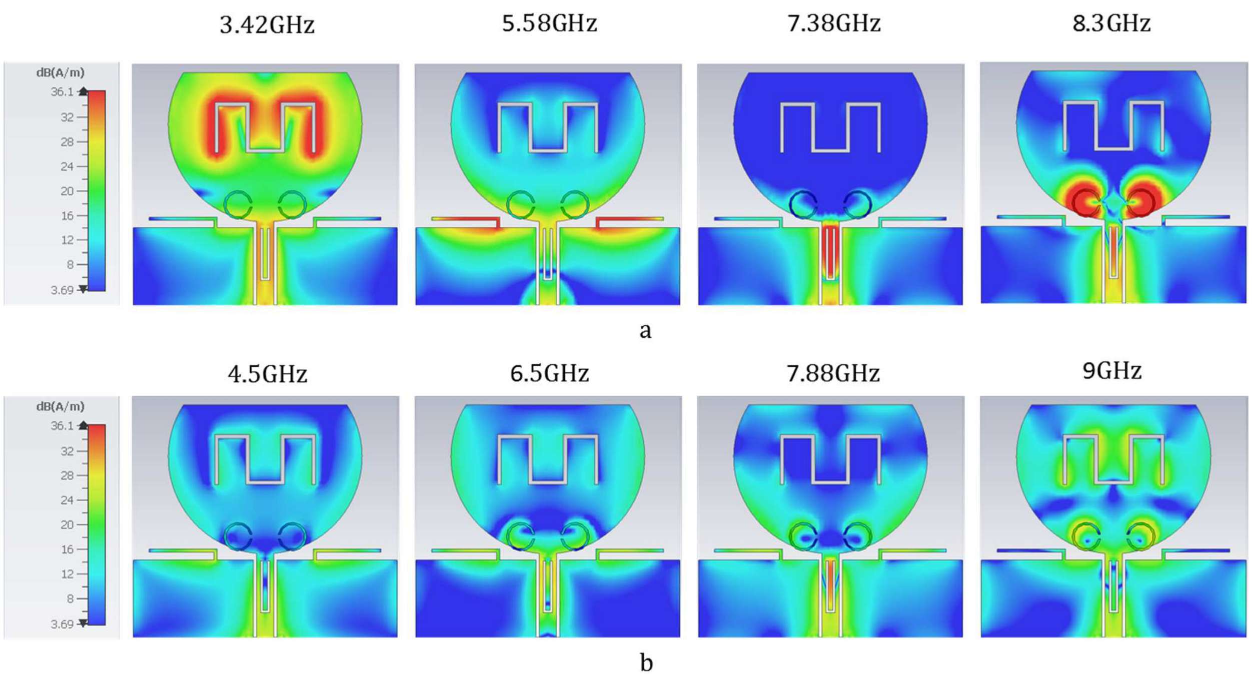

Fig. 8: *The Current Distribution of the Proposed Antenna*
(a) stopband, (b) passband

4.3 Radiation Pattern

Fig. 9 shows radiation patterns in E-plane(X-Z plane) and H-plane(X-Y plane) at the four notched frequencies of 3.42GHz, 5.58GHz, 7.38GHz and 8.3GHz and pass band frequencies of 4.5GHz,6.5GHz,7.88GHz and 9GHz. For the proposed antenna, E-plane radiation patterns are bidirectional at lower frequencies while at higher ranges, the radiation patterns are faintly distorted. H-plane radiation patterns conserve nearly omnidirectional characteristics at low frequencies and as frequency becomes higher, they vary a little.

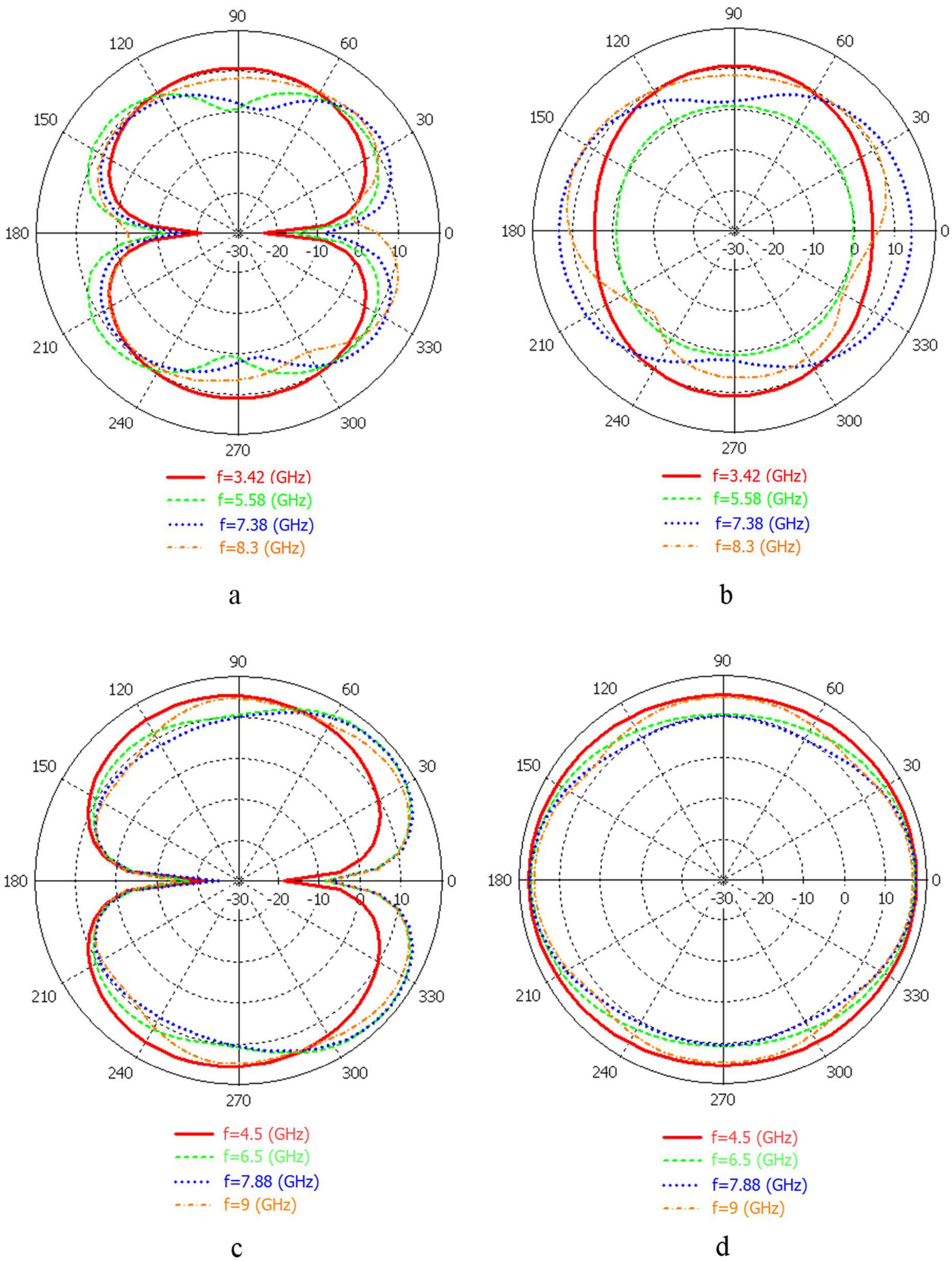

Fig. 9: *Radiation Patterns of the Proposed Antenna*
(a) E-*Plane(*X-Z *Plane) at the Stopband Frequencies* (b) H-*Plane(*X-Y *Plane) at the Stopband Frequencies*
(c)E-*Plane(*X-Z *Plane) at the Passband Frequencies* (d) H-*Plane(*X-Y *Plane) at the Passband Frequencies*

4.4 Realized Gain

Fig. 10 shows the simulated realized gains of the proposed antenna with and without band-notched structures. As we can see, antenna gain decreases sharply in the vicinity of four band-notched frequencies of 3.42GHz, 5.58 GHz, 7.38 GHz and 8.3GHz. The energy at the notched frequency bands is not radiated so realized gain drops at the notched frequency bands. This clearly illustrates the quad band rejection function of the proposed antenna. Table 2 shows many advantages of the proposed antenna in comparison with previously reported band-notched UWB antennas. As we can see from Table 2, most of the antennas only have single, dual and triple notched bands.

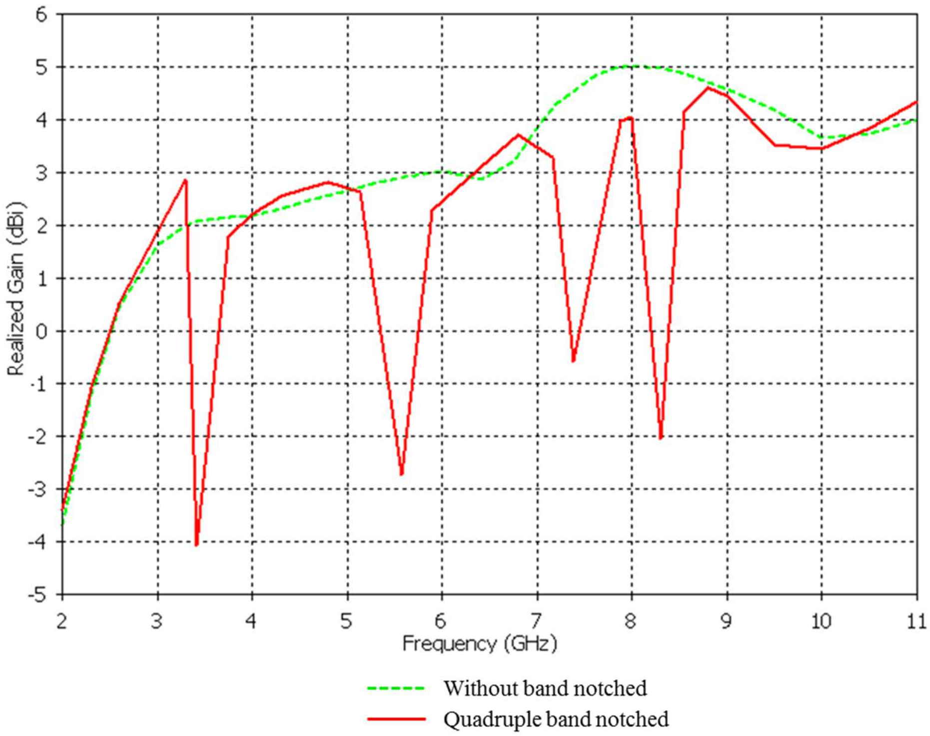

Fig. 10: *Realized Gain of the Proposed Antenna*

In [3,4,6,7,14,26], miniaturized designs of UWB antenna have been introduced but they have achieved only single, dual and triple notched bands. And also in [5,12,31], they not only provide only dual and triple notched bands but also are fabricated in larger size 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.

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

Ref	Number of notches	Notched bands, GHz	Bandwidth, GHz	Size, mm^3	Volumn, mm^3
[3]	2	3.38-3.82, .3-5.8	3.05-10.7	22 × 18 × 1.5	594
[4]	3	1.6-2.66, 3-4, 5.13-6.03	3.1-10.6	31 × 31 × 1.6	1537.6
[5]	2	4.96-5.42, 5.71-5.91	3.1-10.6	38 × 44 × 0.8	1337.6
[6]	2	4.9-5.4, 7.83-8.25	2.8-10.69	22.8 × 15.75 × 0.8	287.28
[7]	2	3.72-4.18, 5.02-5.97,	2.73-13.3	12 × 18 × 1.6	345.6
[12]	3	2.45-3.0, 3.1-3.7, 3.8-4.3	2.0-10.75	34.9 × 31.3 × 1.6	1747.792
[14]	1	3.3-4	2.6-12	30 × 28 × 1.524	1280.16
[26]	3	3.0-3.8, 5.1-6.1, 7.8-8.9	2.8-12.5	20 × 14 × 1	280
[31]	2	3.5, 5.5	3-16	58 × 58 × 0.8	2691.2
This work	4	3.3~3.75, 5.15~5.85, 7. 2~7.76, 8~8.55	3-11.8	34 × 31 × 0.508	535.432

5. CONCLUSION

In this paper, simple, low cost and compacted CPW-fed planar UWB antenna with controllable quadruple band-notched characteristics is proposed and investigated to minimize the potential interferences between the UWB communication systems with WiMAX, WLAN systems and X-band downlink satellite communication system. A M-shaped slot and a U-shaped slot are embedded on the radiation patch and feed line, respectively for rejecting WiMAX and X-band downlink satellite communication band. Two L-shaped parasitic strips and two SRRs are embedded near radiator patch and on the back surface of substrate, respectively for rejecting WLAN band and ITU band. By simply adjusting dimensions of corresponding band-notched structure, notched-frequency bands can be controlled independently. Finally, a UWB antenna with controllable quadruple band rejected characteristics is successfully simulated, fabricated, and measured. It shows a near omnidirectional radiation pattern and available gain over the whole band except in the notched frequency bands. Consequently, simple structure, compact size, easy to fabricate and excellent performances of the proposed antenna make it a good candidate for practical UWB applications.

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