

# Quad-Band Notched Small Monopole Antenna with U-shaped Slots and SRRs for UWB Applications

CholHae Ho\*, Tae Il Kim, Yong Chol Ri, Un Chol Kim

## Abstract

*A quad-band notched small monopole antenna with U-shaped slots and SRRs for UWB applications is presented in this study. The quadruple band-notched characteristics can be achieved by embedding three U-shaped slots on the radiation patch and two split ring resonators (SRRs) near feed line, respectively. It has a tiny size, only 17 mm×23 mm×0.508 mm. The experimental and measured results demonstrate that the proposed antenna offers an impedance bandwidth across an ultrawide frequency range from 3.1 to 10.8 GHz, with S11 less than -10 dB, except for the frequency bands of 3.27–3.7 GHz (World Interoperability for Microwave Access system), 3.8–4.8 GHz (C-band satellite communication system), 5.13–5.65 GHz (Wireless Local Area Network), and 7.9–8.5 GHz (International Telecommunications Union). 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. The proposed antenna, featuring rejected band characteristics, has been successfully simulated, prototyped, and tested. The simulated results align well with the measured performance, demonstrating good agreement. 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

Since 2002, after the declaration of unlicensed free frequency band of 7.5 GHz (3.1~10.6 GHz) for ultrawideband (UWB) communication by Federal Communication Commission (FCC) [1], the UWB antenna became more popular. 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) 8 GHz operating at the band of 8.01–8.5 GHz have already been put out [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.

### \*Author for Correspondence

CholHae Ho  
E-mail: dawei\_0220@163.com

Faculty, Department of Physical Engineering, Kim Chaek University of Technology, Kyogu Dong, Central District, Pyongyang, Democratic People's Republic of Korea

Received Date: July 16, 2024

Accepted Date: November 13, 2024

Published Date: December 31, 2024

**Citation:** CholHae Ho, Tae Il Kim, Yong Chol Ri, Un Chol Kim. Quad-Band Notched Small Monopole Antenna with U-shaped Slots and SRRs for UWB Applications. Journal of Communication Engineering & Systems. 2025; 15(1): 21–31p.

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 [21], and SRR-shaped slot [22–24]. Another effective method is adding diverse parasitic elements, such as T-shaped [25, 26] and SRR shaped elements [27–30].

In this study, a novel compact UWB planar monopole antenna of  $17\text{ mm} \times 23\text{ mm} = 391\text{ mm}^2$  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 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, 3.8~4.8, 5.13~5.65, and 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 study is organized in the following four sections: Geometrical structure and design procedure of the proposed antenna; parametric study; current distribution, radiation pattern and realized gain; and finally, the conclusion.

## ANTENNA DESIGN

### Schematic and Dimensions of the Proposed Antenna

Figure 1 depicts the configuration and the fabricated prototype of the proposed antenna. As can be seen from Figure 1, the proposed quad-band notched antenna consists of a radiator with three U-shaped slots, two split ring resonators near the feed line and feedline 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 was fabricated on a Rogers 4350B 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  $17\text{ mm} \times 23\text{ mm} = 391\text{ mm}^2$ . The proposed antenna is simulated using CST MWS software. The optimized parameters listed in Table 1 satisfy both the designated notch bands referred to the VSWR and the desired UWB bandwidth.

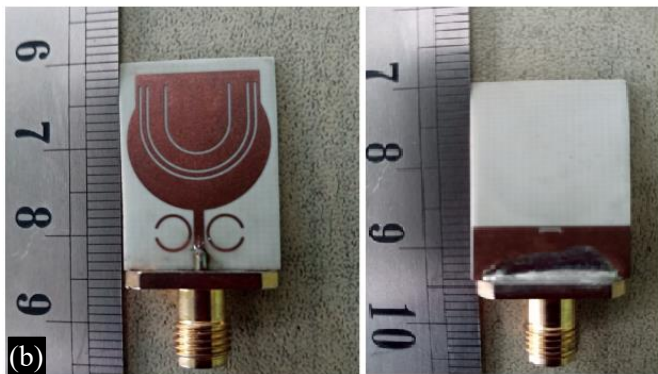
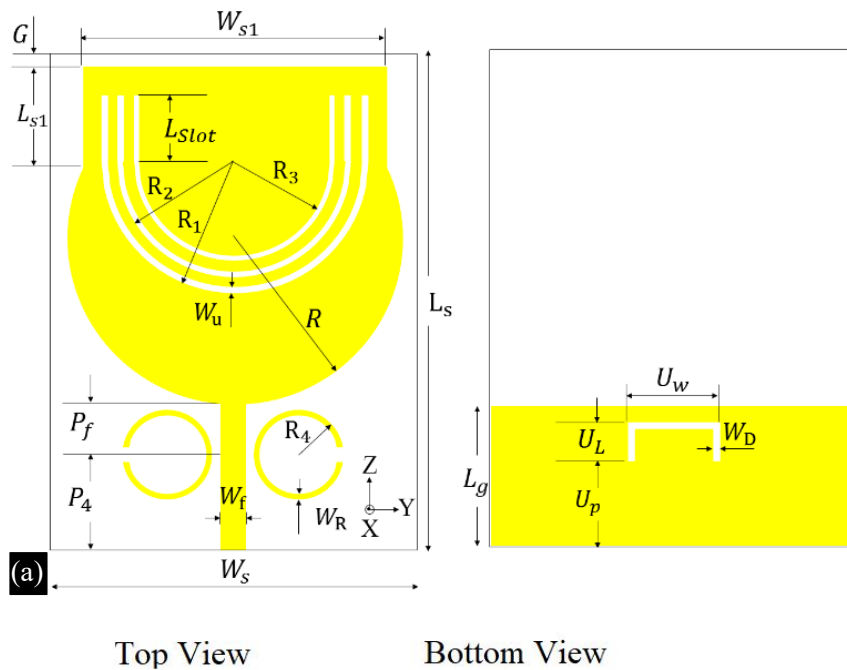
### Design Steps

The design steps are shown 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 Ant 1 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.

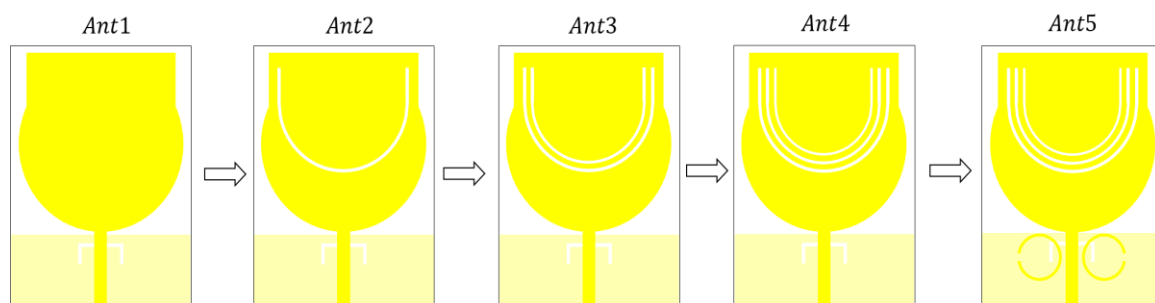
Then the first U-shaped slot is etched on the radiation patch to create Ant 2 which is to design the first rejected band at 3.5 GHz WiMAX band. And also, the second U-shaped slot is etched on the radiation patch to construct Ant 3 which is to design the second notched band at C-band satellite communication band. Then, the 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 GHz WLAN band. Lastly, we add two SRRs near the feed line to construct Ant 5 which is to provide the forth notched band at ITU band.

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

|             |       |       |          |            |       |       |       |       |       |       |       |
|-------------|-------|-------|----------|------------|-------|-------|-------|-------|-------|-------|-------|
| Parameters  | $W_s$ | $L_s$ | $W_{s1}$ | $L_{s1}$   | $G$   | $W_f$ | $P_f$ | $R$   | $R_1$ | $R_2$ | $R_3$ |
| 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   |       |



**Figure 1.** Geometrical structure and photograph of the proposed Antenna: (a) Geometrical structure, (b) Photograph.



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

## EXPERIMENTAL RESULTS

### Parameter Analysis

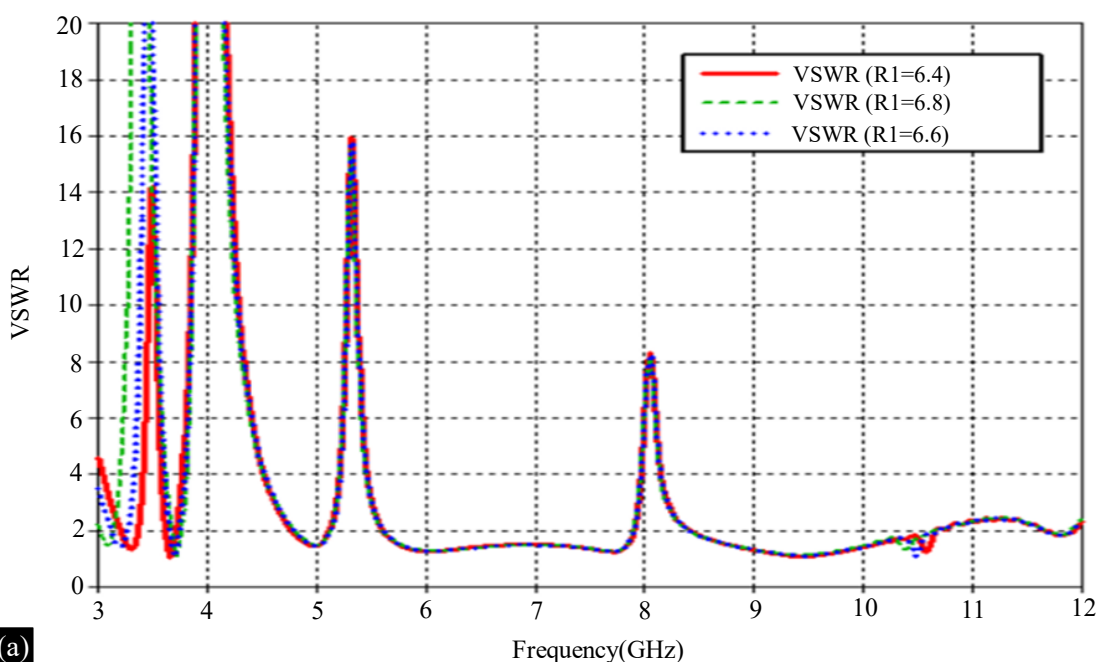
We will investigate parameter effects on the VSWR. Here, the parameters  $R_1$ ,  $R_2$ ,  $R_3$  and  $R_4$  are selected for evaluating the effects on the proposed quadruple band-notched UWB antenna. Figure 3(a) shows that  $R_1$  has important effects on the 3.47 GHz frequency center band. As shown in the Figure 3(a), by increasing  $R_1$  from 6.4 to 6.8 mm, the first notched frequency is shifted from 3.54 to 3.38 GHz. It could be observed that the tuning of parameter  $R_1$  has little affection on the other notched bands.

Figure 3(b) shows that  $R_2$  makes a great impact on the 4.1 GHz frequency center band. It is observed that, when the parameter  $R_2$  increases from 5.6 to 5.9 mm, the center frequency of the second notched band shifts slightly for lower frequencies side: from 4.17 to 4.04 GHz. And the parameter  $R_2$  has little effect on the other notched bands: 3.47, 5.33 and 8.1 GHz. Figure 4(a) shows that  $R_3$  affects greatly on the 5.33 GHz frequency center band. Increasing the value of the parameter  $R_3$  from 3.5 to 3.7 mm changes the center frequency of the third notched band from 5.51 to 5.33 GHz. On the other hand, the parameter  $R_3$  has small influences on three other notched bands: 3.47, 4.1, and 8.1 GHz. Figure 4(b) 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 to 2.13 mm, center of the fourth notched band shifts slightly for lower frequencies side: from 8.21 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, 4.1 and 5.33 GHz.

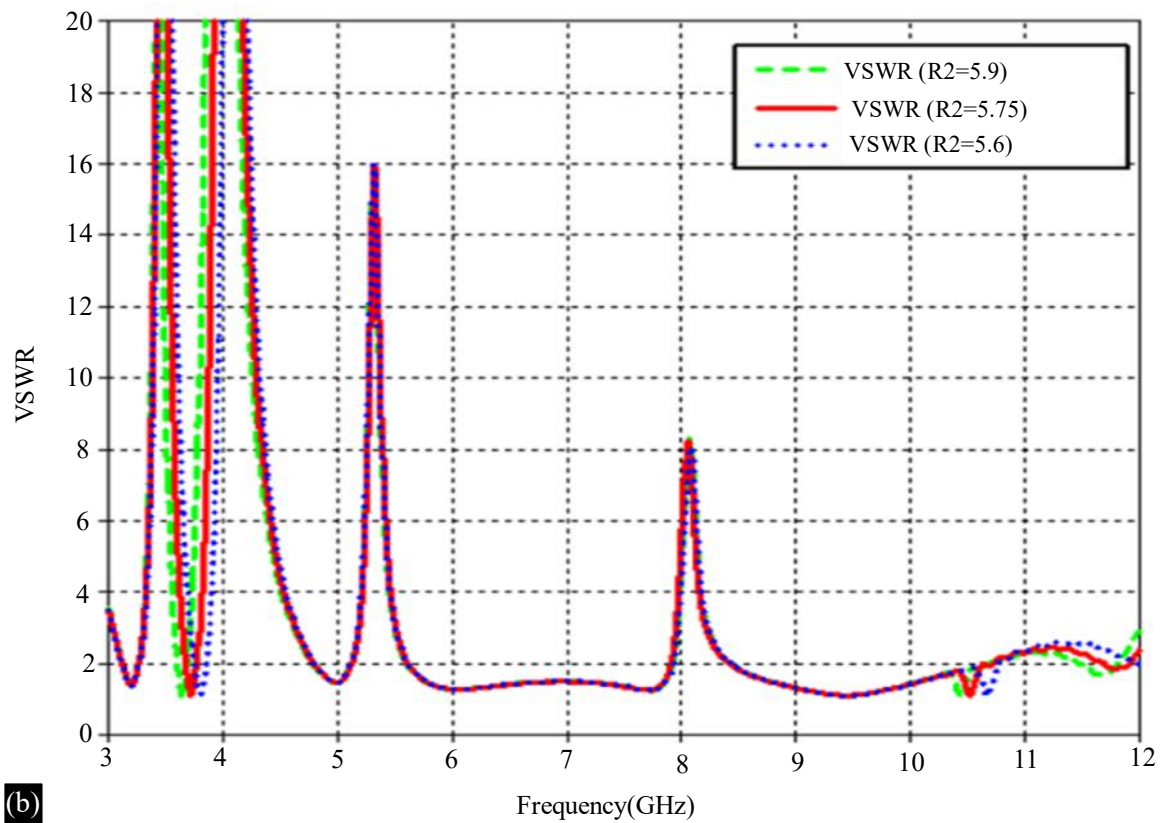
To confirm the effectiveness of the proposed antenna, the optimized antenna is manufactured and its VSWR is measured by using AgilentField Fox N9918A vector network analyzer. Figure 5 shows comparison between the measured and simulated VSWR results of the proposed antenna. As can be seen from Figure 5, 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%). Simulation results and measurements show that the WiMAX system, WLAN, C-band satellite communication system and ITU are effectively suppressed. Simulation results and measurements show that the WiMAX system, WLAN and ITU system are effectively suppressed. And it includes the entire UWB operating range.

### Current Distribution

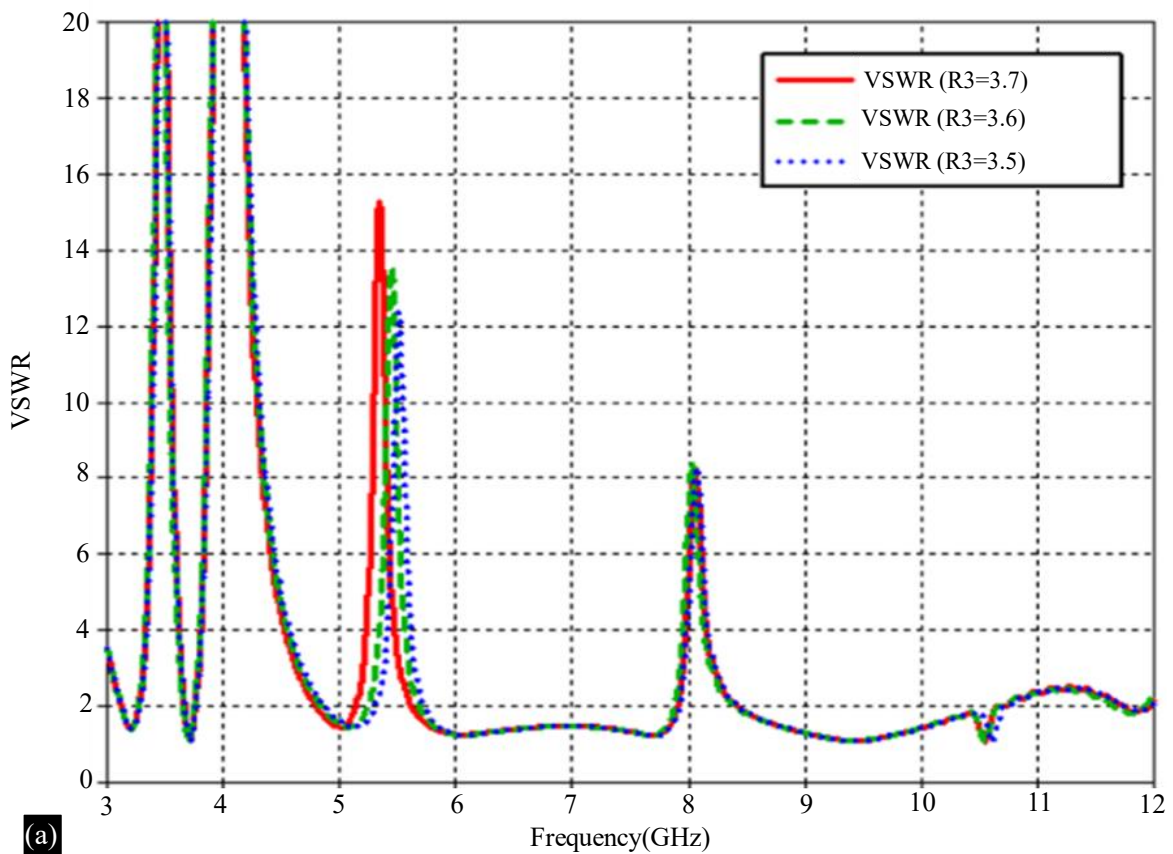
The current distribution of the proposed antenna is investigated and explained in Figure 6. As can be seen in Figure 6(a), current density is highly concentrated at three U-shaped slots at 3.47, 4.1, and 5.33 GHz respectively and at two SRRs at 8.1 GHz. This means that a large part of electromagnetic 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 6(b), surface current at the pass band of 3.75, 5, 6.7 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.

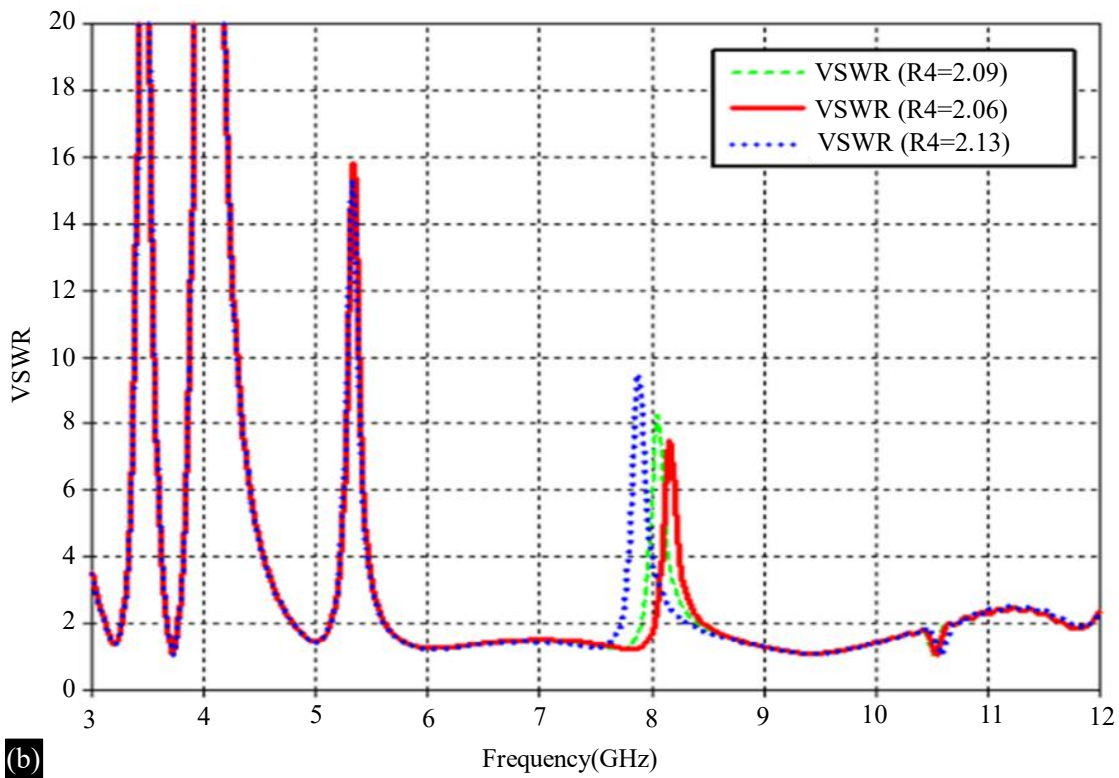


(a)

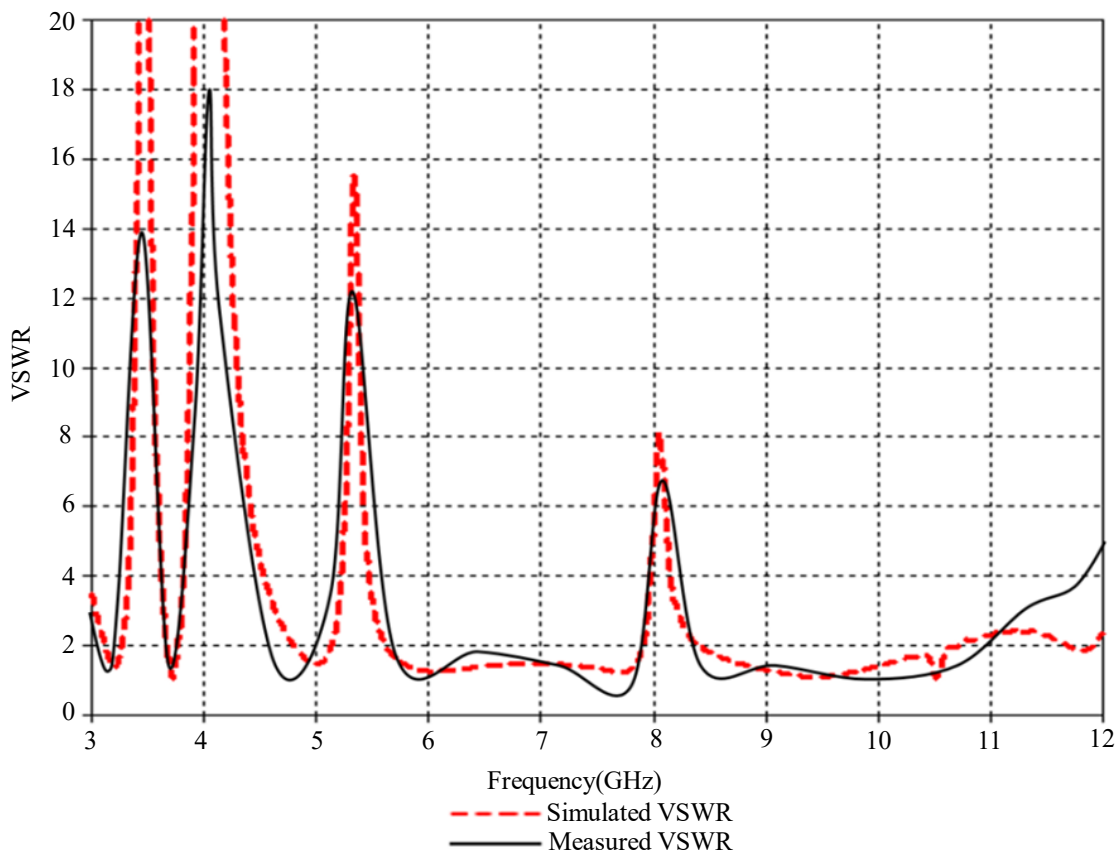


**Figure 3.** The simulated VSWR of the proposed antenna with changes of  $R_1$  and  $R_2$ . (a)  $R_1$ , and (b)  $R_2$ .

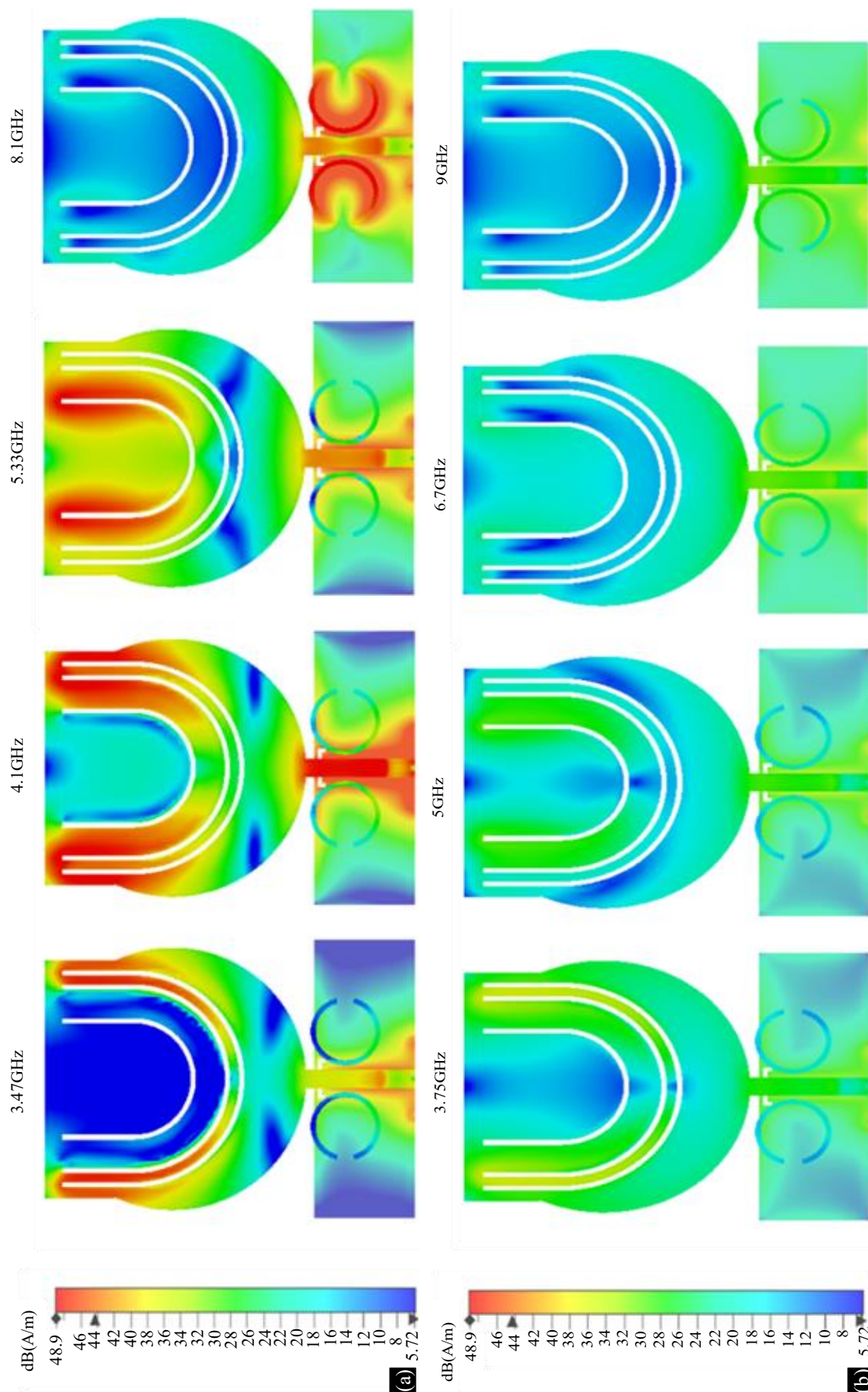




**Figure 4.** The simulated VSWR of the proposed antenna with changes of  $R_3$  and  $R_4$ : (a)  $R_3$ , and (b)  $R_4$ .



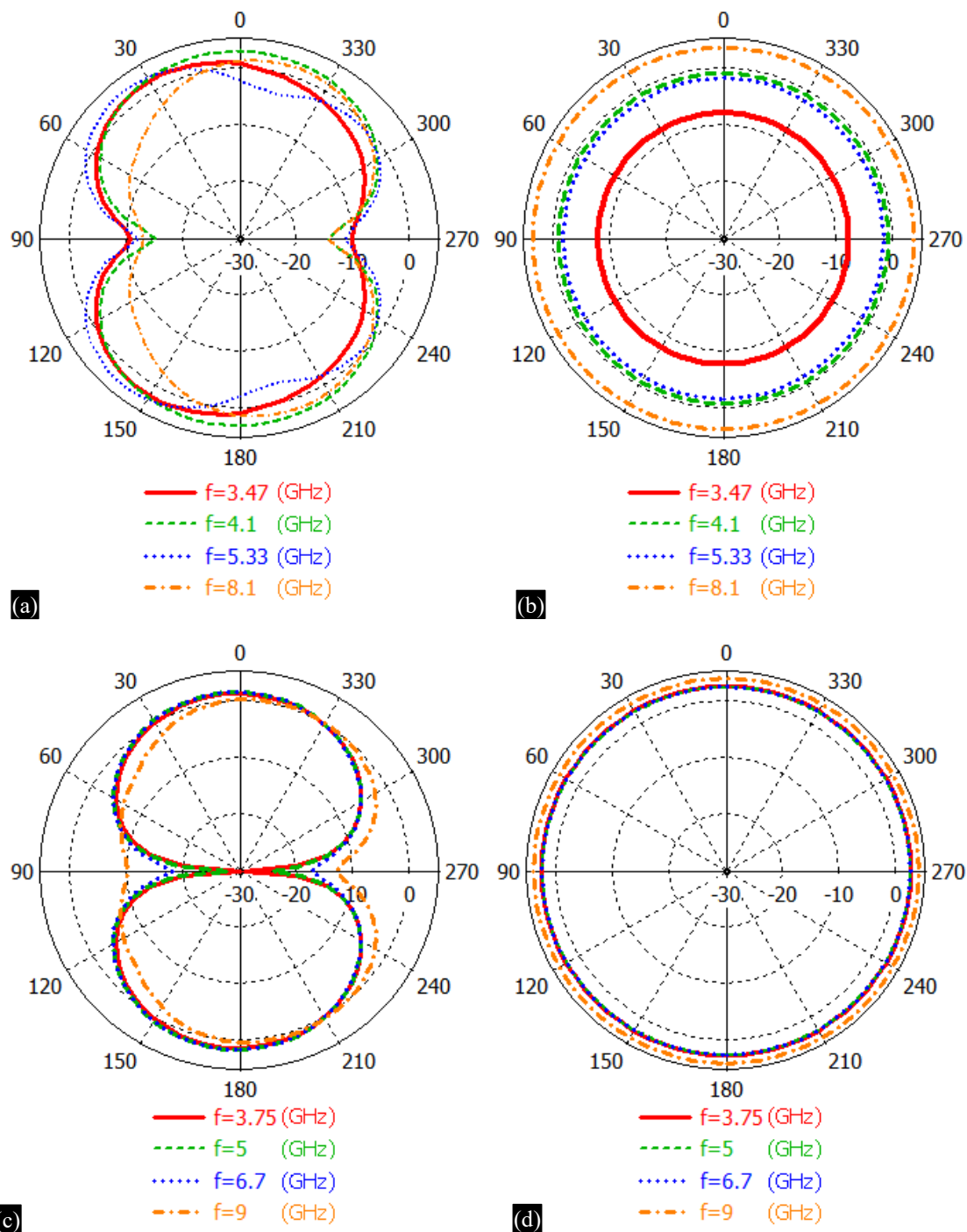
**Figure 5.** Simulated and Measured VSWR of the Proposed Antenna.



**Figure 6.** The Current distribution of the proposed antenna. (a) Stopband, (b) Passband.

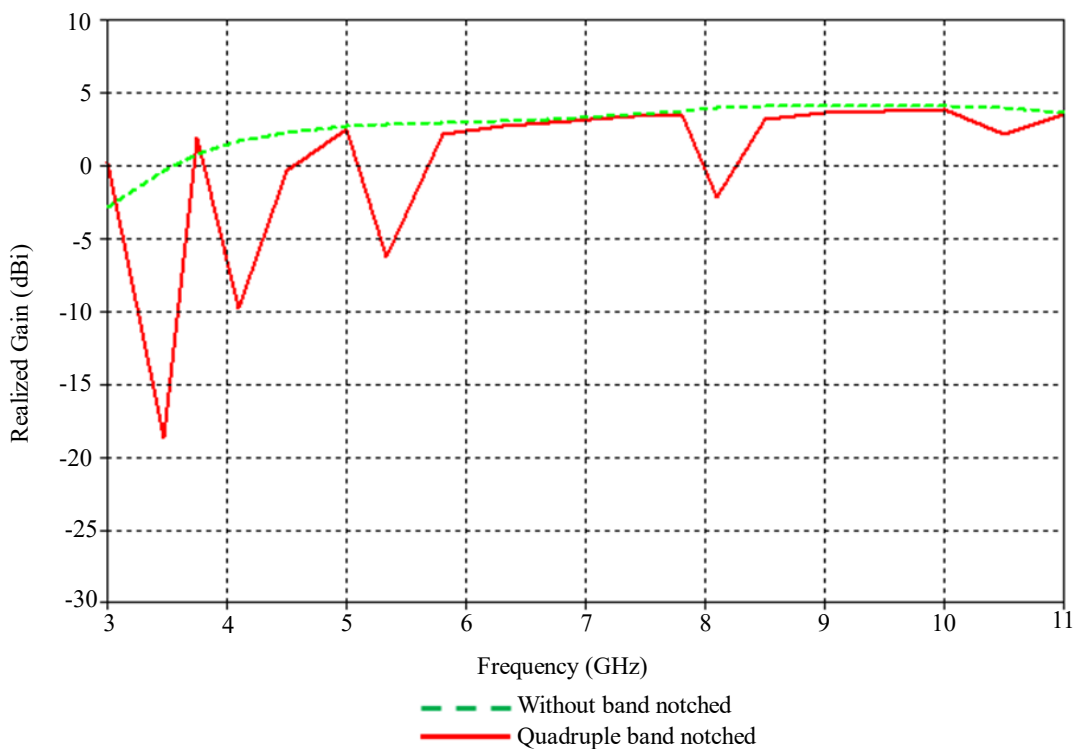
### Radiation patterns and realized Gain

Figure 7 shows far-field radiation patterns in E-plane and H-plane at stop bands of 3.47, 4.1, 5.33 and 8.1 GHz and at pass bands of 3.75, 5, 6.7 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.



**Figure 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; and (d) *H*-Plane (X-Y Plane) at the Passband Frequencies.

From Figure 8, the gain of the proposed antenna drops rapidly at the notched frequencies of 3.47, 4.1, 5.33 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 can be seen from Table 2, many triple or quadruple band-notched UWB antennas have been introduced so far. In the study by Rojhani *et al.*, a miniaturized design of UWB antenna has been introduced but it has achieved only triple notched bands [25]. Also, in other studies, the authors have triple notched band but are larger than the proposed antenna [6, 14]. In their studies, the earlier authors provide quadruple notched bands but size of them are bigger than this work [5, 21, 24, 31]. In a word, the proposed UWB antenna provides four notched bands and compact size and can be used for UWB systems.



**Figure 8.** Realized Gain of the Proposed Antenna.

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

| Ref       | Number of notches | Notched bands (GHz)                        | Bandwidth (GHz) | Size (mm <sup>2</sup> ) |
|-----------|-------------------|--|-----------------|-------------------------|
| [5]       | 4                 | 5.15–5.35, 5.75–5.85, 7.25–7.75, 8.01–8.55 | 3.1–12          | 26×28                   |
| [6]       | 3                 | 1.6–2.66, 3–4, 5.13–6.03                   | 3.1–10.6        | 31×31                   |
| [14]      | 3                 | 2.45–3.0, 3.1–3.7, 3.8–4.3                 | 2.0–10.75       | 34.9×31.3               |
| [21]      | 4                 | 3.3–3.6, 5.25–5.35, 5.725–5.825, 7.9–8.4   | 2.94–12         | 20×35.6                 |
| [24]      | 4                 | 3.41–4.07, 4.41–4.76, 5.21–5.64, 6.92–8.63 | 2.9–12          | 20×24                   |
| [25]      | 3                 | 3.0–3.8, 5.1–6.1, 7.8–8.9                  | 2.8–12.5        | 20×14                   |
| [31]      | 4                 | 3.6–3.8, 4.5–4.9, 5.6–6.0, 7.2–7.6         | 3–10.7          | 20×25                   |
| This work | 4                 | 3.27~3.7, 3.8–4.8, 5.13–5.65, 7.9~8.5      | 3.1–10.8        | 17×23                   |

## CONCLUSION

A new compact UWB antenna with a quad-band notched feature is proposed and analyzed. 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. The notched frequency range can be achieved by simply adjusting the corresponding notched structure, and the individual notched frequencies can be controlled independently. The proposed antenna shows band rejection at the intended notch frequencies and surface current validates this result. The proposed antenna is an excellent candidate for UWB systems because of its compact size, simple structure, good four-band notched characteristics and omnidirectional performance.

## REFERENCES

1. Federal Communications Commission. Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems. First Report and Order, Washington, DC, USA, FCC 2 V48, 2002. Available From: <https://www.yumpu.com/en/document/view/49751587/a-2nd-order-tunable-bandpass-sigma-delta-converter-for-material->
2. Azim R, Islam MT, Misran N. Compact tapered-shape slot antenna for UWB applications. *IEEE Antennas Wirel Propag Lett*. 2011 Oct 20; 10: 1190–93.
3. Yadav A, Sethi D, Khanna RK. Slot loaded UWB antenna: Dual band notched characteristics. *AEU-Int J Electron Commun*. 2016 Mar 1; 70(3): 331–35.
4. Xu J, Shen DY, Wang GT, Zhang XH, Zhang XP, Wu K. A small UWB antenna with dual band-notched characteristics. *Int J Antennas Propag*. 2012; 2012(1): 656858(7p).
5. Li X, Yan L, Pan W, Luo B. A Compact Printed Quadruple Band-Notched UWB Antenna. *Int J Antennas Propag*. 2013; 2013(1): 956898(6p).
6. Abdelhalim C, Farid D. A Compact Planar UWB Antenna with Triple Controllable Band-Notched Characteristics. *Int J Antennas Propag*. 2014; 2014(1): 848062(10p).
7. Dong D, Chen S, Liao Z, Liu G. A CPW-Fed Dual-Band-Notched Antenna with Sharp Skirt Selectivity for UWB Applications. *Int J Antennas Propag*. 2014; 2014(1): 629387(7p).
8. Mohammadi B, Valizade A, Nourinia J, Rezaei P. Design of a compact dual-band-notch ultra-wideband bandpass filter based on wave cancellation method. *IET Microw Antennas Propag*. 2015 Jan; 9(1): 1–9.
9. Ojaroudi N, Ojaroudi M, Ghadimi N. Dual band-notched small monopole antenna with novel W-shaped conductor backed-plane and novel T-shaped slot for UWB applications. *IET Microw Antennas Propag*. 2013 Jan; 7(1): 8–14.
10. Draskovic D, Fernandez JR, Briso Rodríguez C. Planar ultrawideband antenna with photonicly controlled notched bands. *Int J Antennas Propag*. 2013; 2013(1): 924768(6p).
11. Ur-Rehman M, Abbasi QH, Akram M, Parini C. Design of band-notched ultra wideband antenna for indoor and wearable wireless communications. *IET Microw Antennas Propag*. 2015 Feb; 9(3): 243–51.
12. Sung Y. Triple band-notched UWB planar monopole antenna using a modified H-shaped resonator. *IEEE Trans Antennas Propag*. 2012 Oct 8; 61(2): 953–7.
13. Shi R, Xu X, Dong J, Luo Q. Design and analysis of a novel dual band-notched UWB antenna. *Int J Antennas Propag*. 2014; 2014(1): 531959(10p).
14. Sarkar D, Khan T, Talukdar FA. Multi-adaptive neuro-fuzzy inference system modelling for prediction of band-notched behaviour of slotted-UWB antennas optimised using evolutionary algorithms. *IET Microw Antennas Propag*. 2020 Oct; 14(12): 1396–403.
15. Rai VK, Kumar M. Tunable inverted u-shaped dual band notch monopole antenna for ultrawideband applications. *IETE J Res*. 2023 Sep 7; 69(7): 4451–60.
16. Tak V, Garg A, Pareek DK. Butterfly shaped single band notch monopole antenna for UWB application. *International Journal of Electrical Engineering & Technology (IJEET)*. 2020; 1(11): 15–25.
17. Manohar M, Kshetrimayum RS, Gogoi AK. A compact dual band-notched circular ring printed monopole antenna for super wideband applications. *Radioengineering*. 2017 Apr 1; 26(1): 64–70.
18. Babu PR, Ramakrishna D, Ensermu G. Triple Band-Notch UWB Antenna Embedded with Slot and EBG Structures. *Wirel Commun Mob Comput*. 2023; 2023(1): 3461751(12p).

19. Mehranpour M, Nourinia J, Ghobadi C, Ojaroudi M. Dual band-notched square monopole antenna for ultrawideband applications. *IEEE Antennas Wirel Propag Lett*. 2012 Feb 3; 11: 172–5.
20. Zhu XF, Su DL. Symmetric E-shaped slot for UWB antenna with band-notched characteristic. *Microw Opt Technol Lett*. 2010 Jul; 52(7): 1594–7.
21. Kong Y, Li Y, Yu W, Yu K. A quadruple band-notched UWB antenna by using arc-shaped slot and rotated E-shaped resonator. *Appl Comput Electromagn Soc J (ACES)*. 2016; 31(11): 1315–21.
22. Yan B, Jiang D, Xu R, Xu Y. A UWB Band-Pass Antenna with Triple-Notched Band Using Common Direction Rectangular Complementary Split-Ring Resonators. *Int J Antennas Propag*. 2013; 2013(1): 934802.
23. Kumar P, Urooj S, Alrowais F. Design and implementation of quad-port MIMO antenna with dual-band elimination characteristics for ultra-wideband applications. *Appl Sci*. 2020 Mar 2; 10(5): 1715.
24. Babu SR, Dinesha PG. Design and development of a miniaturized highly isolated UWB-MIMO diversity antenna with quad band notch characteristics. *Prog Electromagn Res C*. 2023 Apr 1; 131: 197–208.
25. Rojhani N, Akbari M, Sebak A. Controllable triple band-notched monopole antenna for ultra-wideband applications. *IET Microw Antennas Propag*. 2015 Mar; 9(4): 336–42.
26. Sharma P, Vyas K, Yadav RP. Design and analysis of miniaturized UWB antenna with tunable notched band. *Int J Microw Wirel Technol*. 2017 Apr; 9(3): 691–6.
27. Yadav A, Agrawal S, Yadav RP. SRR and S-shape slot loaded triple band notched UWB antenna. *AEU-Int J Electron Commun*. 2017 Sep 1; 79: 192–8.
28. Chandran AA, Thankachan S. Triple frequency notch in UWB antenna with single ring SRR loading. *Procedia Comput Sci*. 2016 Jan 1; 93: 94–100.
29. Shaik LA, Saha C, Siddiqui JY, Antar YM. Ultra-wideband monopole antenna for multiband and wideband frequency notch and narrowband applications. *IET Microw Antennas Propag*. 2016 Aug; 10(11): 1204–11.
30. Abbas A, Hussain N, Lee J, Park SG, Kim N. Triple rectangular notch UWB antenna using EBG and SRR. *IEEE Access*. 2020 Dec 25; 9: 2508–15.
31. Zhao Y, Wang C, Deng Y, Xie C. A novel compact ultra-wideband antenna with quad notched bands based on s-sCRLHs resonator. *Wirel Pers Commun*. 2017 Dec; 97: 4667–79.