A Novel Compact Ultra-Wideband Antenna with Quad Notched Bands Based on S-SCRLHs Resonator

Article *in* Wireless Personal Communications · August 2017

DOI: 10.1007/s11277-017-4744-8

Wireless Pers Commun (2017) 97:4667–4679
DOI 10.1007/s11277-017-4744-8

A Novel Compact Ultra-Wideband Antenna with Quad Notched Bands Based on S-SCRLHs Resonator

Yilin Zhao[1] · **Chunhua Wang**[1,2] · **Yawen Deng**[1] · **Changming Xie**[1]

Published online: 5 August 2017

Abstract In this paper, a novel compact ultra-wideband (UWB) antenna with a quad band-notched function using S-SCRLHs (splited simplified composite right/left-handed) resonator is presented. The S-SCRLHs resonator, which exhibits quadruple resonance, is realized by coupling double S-SCRLH resonator. Then, the S-SCRLHs resonator is integrated into a UWB antenna consisting of modified circular patch. The proposed UWB antenna operates under the frequency range of 3.0–10.7 GHz. This proposed antenna displays a VSWR < 2(the voltage standing wave ratio) across the entire UWB band and compact dimensions of $25 \times 20\ \text{mm}^2$, which is 0.2λ (free space) at 3.0 GHz. By changing the dimension of S-SCRLHs resonator, the notched frequencies can be adjusted appropriately in four bands of 3.6–3.8 GHz (WiMAX), 4.5–4.9 GHz (C-band), 5.6–6.0 GHz (WLAN), and 7.2–7.6 GHz (X-band). The antenna can be applicable in the UWB receiver systems where the four kinds of interference signals corresponding to the four bands can be suppressed. The gain varies from 2.1 to 4.5 dBi with gain values of −2.8, −2.6, −1.5 and −2.4 dBi at respective four notch frequencies. The radiation efficiency is no less than 84% throughout the operational bandwidth. The proposed antenna achieves omnidirectional radiation patterns while also providing rejection at desired notches.

Keywords UWB antenna · Quad notched bands · Compact size · S-SCRLHs

✉ Chunhua Wang
wch1227164@hnu.edu.cn

1 College of Information Science and Engineering, Hunan University, Changsha 410082, People's Republic of China

2 College of Computer Science and Electronic Engineering, Hunan University, Changsha 410082, People's Republic of China

1 Introduction

In 2002, UWB technology gained lots of attention from the researchers as FCC permitted the civil use of 3.1–10.6 GHz band for low-power and high-data rate communication [1]. Since then, UWB Antenna, as an essential component of the UWB system, has been a hot topic in recent years [2–6]. It should be noted that UWB system is inevitably interfered by existing wireless network (e.g., 3.6–3.8 GHz WiMAX, 5.6–6.0 GHz WLAN, 4.5–4.9 GHz C-band and 7.2–7.6 GHz X-band satellite communication), which will cause significant impact on system performance. Therefore, a UWB Antenna with multiple notch bands is highly required. To achieve notch characteristics, researchers etch different shaped slots, such as U-shaped, H-shaped, C-shaped in the radiator portion or ground plane of UWB antenna [7–10]. Nevertheless, methods in Ref. [7–10] can only achieve one notch band. In order to realize multiple notch bands, different design schemes are adopted [11–16]. In Ref. [11], a SCRLH resonator is employed to introduce dual notch bands and the relative stopped bandwidth (RSB) of notch band is about 5.7%. In Ref. [12], an elliptical slot and G-shaped slot was introduced to attain dual band-notched function in 3.3–3.8 GHz for WiMax, 5.15–5.85 GHz and compact size of 35 $\times$ 30 mm^2. In Ref. [13], two arc shaped elliptical slots, single elliptical split ring slot and a pair of rectangular single split ring resonators were introduced to attain triple band notched function in 3.3–3.8 GHz for WiMax, 5–6 GHz, 7.1–7.9 GHz and compact size of 35 $\times$ 30 mm^2. In Ref. [14], a pair of C-shaped slot is etched to obtain triple band notched characteristics in 3.3–3.7 GHz for WiMax, 5.15–5.85 GHz, 7.1–7.76 GHz and compact size of 31 $\times$ 20 mm^2. However, there are some disadvantages found in the current work, as shown in the following: (1) the number of notched band frequencies does not exceed three; (2) large dimensions and complex structures; (3) the notched frequencies cannot well changed by altering the resonator dimensions, so the selectivity of the UWB antenna needs to be improved.

Therefore, in this paper, we propose a novel compact UWB antenna with quad band-notched function using double splited simplified composite right/left-handed (S-SCRLHs) resonator. The antenna has good notched characteristics, good selectivity and compact size (25 $\times$ 20 mm^2). By adjusting the parameter of the proposed structure, we could easily change the notched frequency in four important bands: 3.6–3.8 GHz WiMAX, 4.5–4.9 GHz C-band satellite communications, 5.6–6.0 GHz WLAN and 7.2–7.6 GHz X-band satellite communications. Compared with the antenna in [11–14], the proposed antenna has the advantages of four band-notched functions, small size and good selectivity.

The design procedures are as follows. Firstly, the basic monopole antenna (Ant 1) is created by circular monopole, which is modified by removing three other similar circular structures with the same radii. Secondly, one single S-SCRLH resonator is integrated into the UWB antenna to introduce double band-notched characteristics. Then, by introducing another coupled S-SCRLH, quad band-notched characteristics can be obtained at desired frequencies. Results show that the S-SCRLHS with the advantages of simple structure, compact size, good performance and easy tunable notched band. Finally, the related conclusions are given in brief.

2 Antenna Design

The geometry of the proposed UWB antenna is shown in Fig. 1. The radiator and the feed line are printed on the top side of the substrate, while the ground is printed on the bottom side. All the structure is realized on the substrate FR4 ($\varepsilon r = 4.4$, $h = 1$ mm,

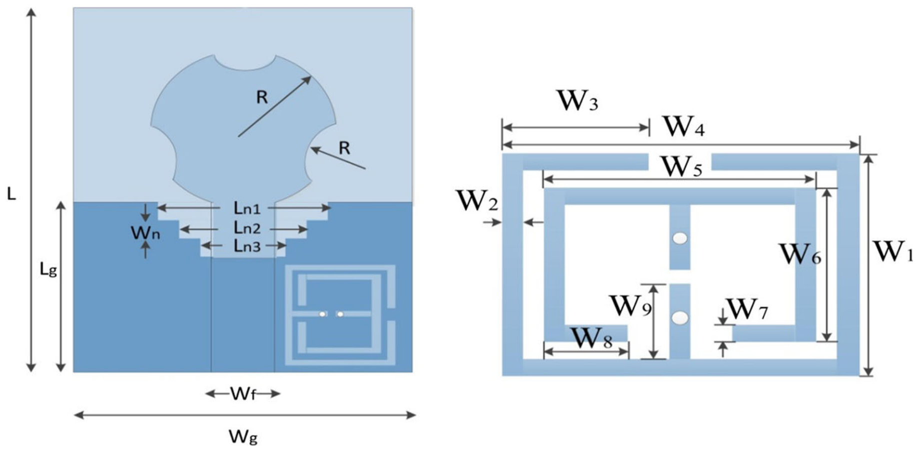


Fig. 1 Geometry of the proposed UWB antenna

tanδ = 0.0023). To have a characteristic impedance of 50 Ω, the feedline was chosen to be 3.2 mm. In addition, the gap between the feedline and the resonator is fixed at 0.1 mm.

The design procedure is as follows:

1. The basic monopole antenna is produced for UWB antenna

The basic monopole antenna (Ant 1) is shown in Fig. 2a. It is created by removing three similar circular structures with the same radii in the circular monopole. The design parameters of the antenna are as follows: L = 25 mm, L_g = 9 mm, W_g = 20 mm, W_f = 3.2 mm, R = 8 mm, L_{n1} = 9 mm, L_{n2} = 6 mm, L_{n3} = 4 mm, W_n = 1 mm. The monopole antenna has wide operating bandwidth (VSWR < 2) from 3 to 11.3 GHz (shown in Fig. 3a).

2. The resonator structure is coupled to the basic monopole antenna to produce dual notch bands

In order to realize notched characteristics, one can introduce a SCRLH resonator and couple it with the UWB antenna to achieve filtering out the interfering signals. It is well known that the concept of the composite right/left-handed transmission line (CRLH TL) has been well studied and widely manufactured various types of microwave devices. Thereafter, the corresponding improved structure (called SCRLH) has been proposed [12].

The SCRLH resonator is composed of high/low impedance short-line and grounded stub with metalized via hole. Compared with conventional CRLH TL unit, the series capacitance C_L is omitted in the SCRLH resonator, so the design process of the resonator is simplified. In our study, the proposed compact structure is designed on the basis of this SCRLH resonator. Figure 2b shows the traditional (H-shaped) SCRLH structure. The geometrical dimensions for the traditional one are as follows: a = 9 mm, b = 1.8 mm, c = 3.4 mm, d = 0.6 mm, e = 2 mm, f = 0.6 mm. The VSWR of the traditional H-shaped resonator is shown in Fig. 3b, which shows that the structure possesses dual notch bands (VSWR > 2) centered at 4.2 and 5.8 GHz.

On the basis of Fig. 2b, we propose modified SCRLH structure as shown in Fig. 2c which can exhibit dual resonance characteristics. Compared with the traditional one, the modified structure has both size and performance advantages, so we choose the modified resonator. The design parameters are as follows: W_1 = 6.3 mm, W_2 = 0.24 mm,

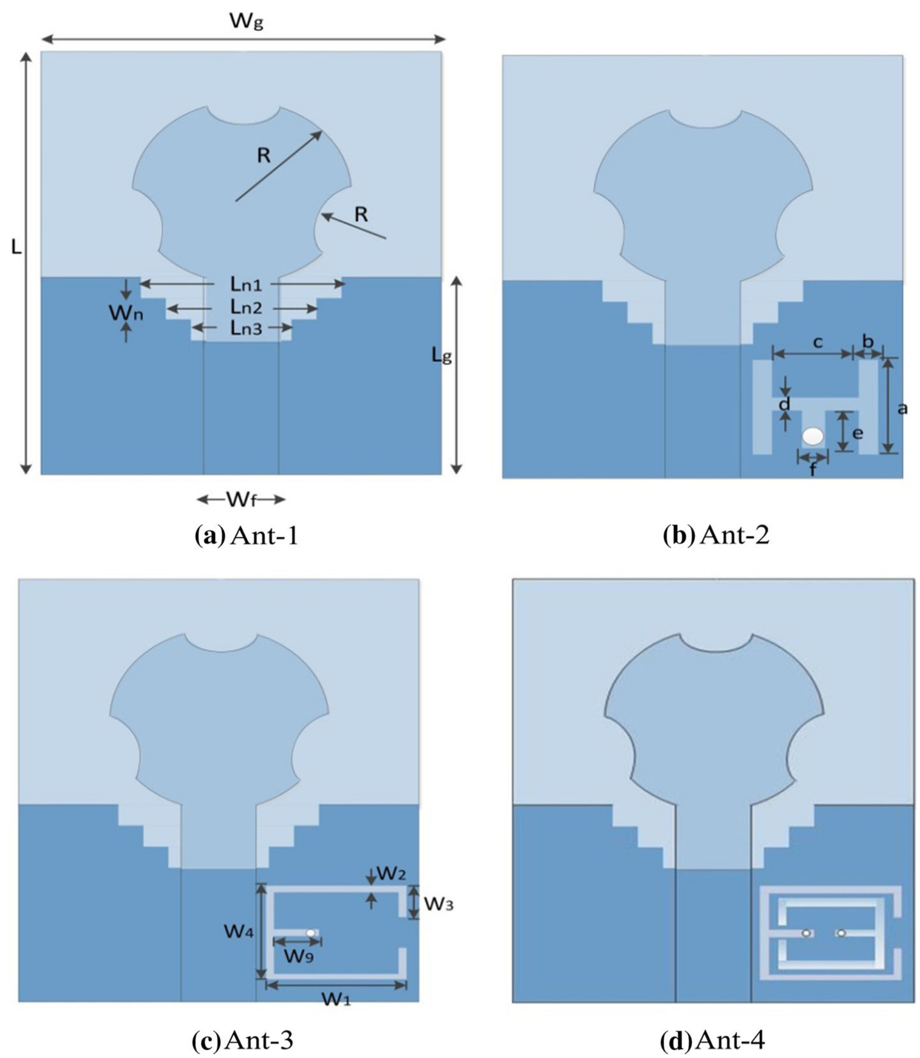


Fig. 2 Evolution of the UWB antenna

$W_3 = 2.6$ mm, $W_4 = 6.6$ mm, $W_9 = 1.7$ mm. As Fig. 3c shows, our modified structure exhibits notch characteristics in the 4.0 GHz, 5.0 GHz.

3. Quad band-notched antenna is produced on the dual band-notched structure

To realize quad band-notched characteristics, we introduce another small modified structure into the above modified dual band-notched structure. This novel structure (called as S-SCRLHs) is simple and flexible for blocking undesired narrow band radio signals appeared in the UWB band. Figure 2d shows the layout of the S-SCRLHs resonator coupled to UWB antenna. Figure 3d shows the corresponding VSWR.

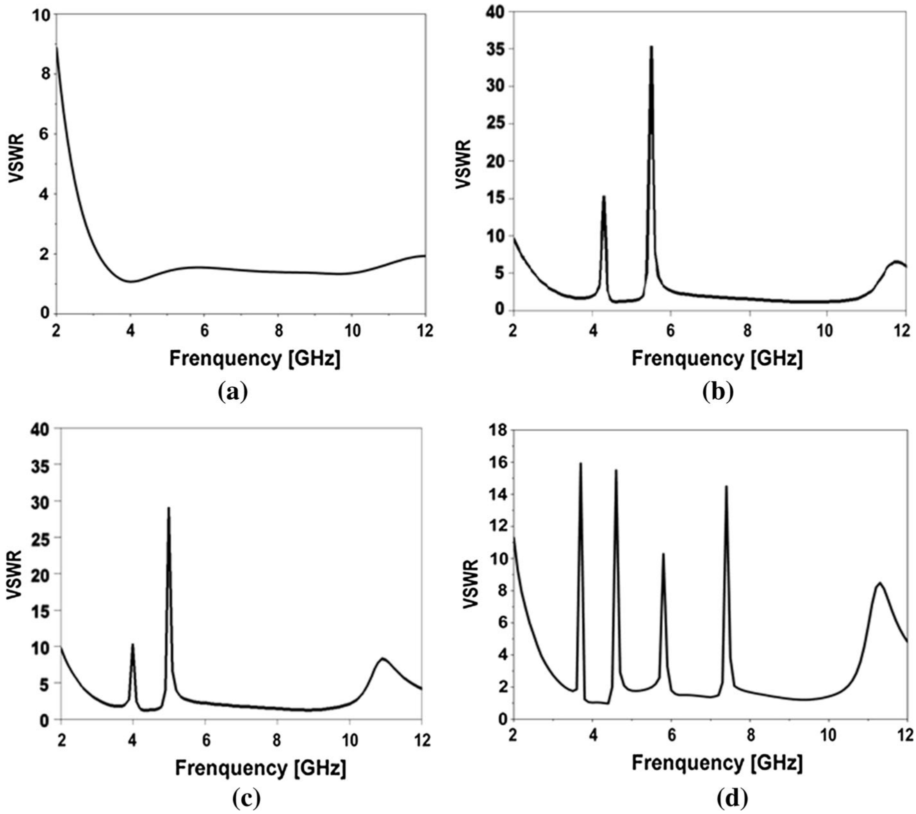


Fig. 3 **a** VSWR of the basic monopoly antenna **b** VSWR of the H-shaped resonator **c** VSWR of the modified SCRLH resonator **d** VSWR of the proposed S-SCRLHs resonator

3 The Optimization of Size

The S-SCRLHs structure shows quadruple resonance characteristics in the 3.7/4.7/5.8/7.4 GHz frequency bands. Figure 4 shows the simulated VSWR of the proposed structure with three different values of W_6, W_8, where f_1, f_2, f_3 and f_4 are the center frequencies of the first, second, third, and fourth notch bands, respectively.

It can be seen from Fig. 4 that f_3 changes dramatically by altering W_6. And f_4 changes dramatically by altering W_8. The design parameters of the proposed structure are as follows: $W_1 = 6.3$ mm, $W_2 = 0.24$ mm, $W_3 = 2.6$ mm, $W_4 = 6.6$ mm, $W_5 = 5.4$ mm, $W_6 = 5$ mm, $W_7 = 0.15$ mm, $W_8 = 1.7$ mm, $W_9 = 1.7$ mm.

Thus, by appropriately altering the S-SCRLHs dimensions, four resonance frequencies can be achieved at desired places. Additional, the final size (5.5×7 mm^2) is smaller than the H-shaped resonator.

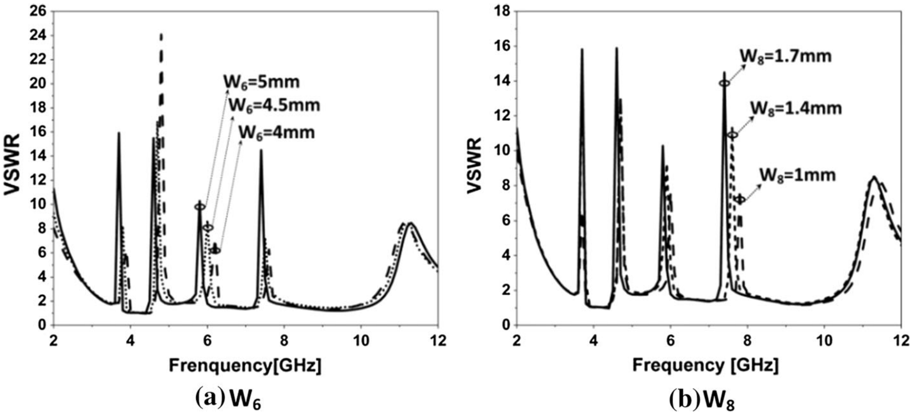


Fig. 4 VSWR of the S-SCRLHs resonator for various dimensions W_6 and W_8

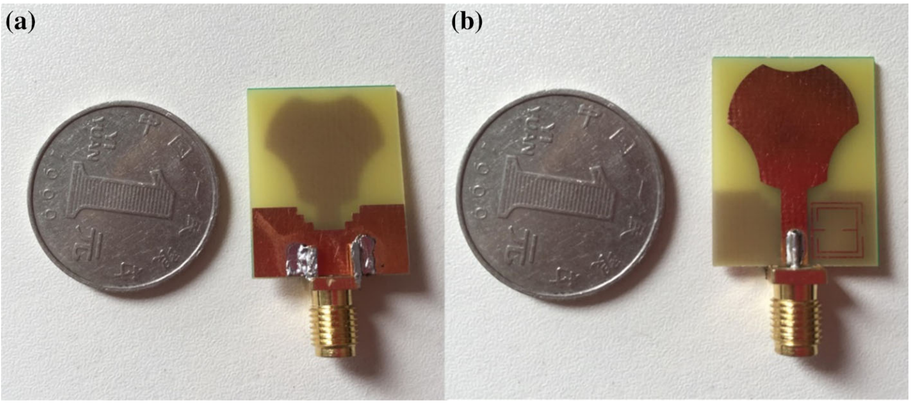


Fig. 5 **a** Top view and **b** bottom view of the fabricated UWB antenna

4 Results and Discussion

In this section, we successfully fabricated the optimized antenna prototype and investigated its characteristics. Figure 5 shows the top and bottom views of the fabricated prototype of the proposed UWB antenna. In particular, we are interested in the UWB signal in the microwave receiving system application. A vector network analyzer E5071C is used for measurement.

Figure 6 shows the measured and simulated VSWR. It can be clearly seen that a good agreement is achieved between them. The simulated results show the operating bandwidth from 3 to 10.7 GHz with notch frequencies at 3.7/4.7/5.8/7.4 GHz. It is observed that the measured impedance bandwidth is from 3 to 10.7 GHz. However, some discrepancies are observed due to the measurement environment, SMA connector losses and the fabrication tolerances.

Figure 7 shows measured radiation pattern in H-plane (XY plane) and E-plane (YZ plane) at 4, 7, 9 GHz. It can be observed that the radiation pattern of H-plane is nearly omnidirectional for the frequencies while E-plane pattern is bidirectional in nature. The

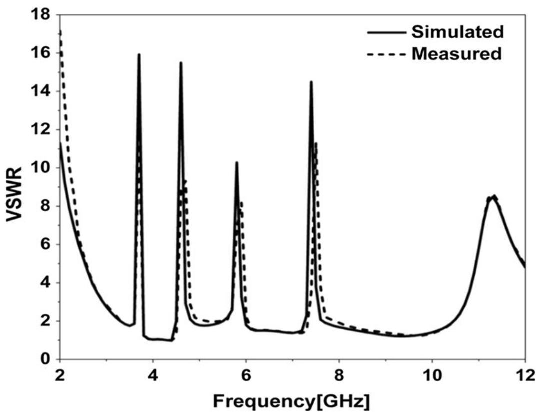


Fig. 6 Simulated and measured VSWR of proposed UWB antenna

measured peak gain in the E-plan is given in Fig. 8, where the dashed line with rectangle tag indicates the gain of the basic monopoly antenna and the short dot line represents the gain of the proposed quad band-notched one. We can clearly see that the antenna exhibits shaped gain decreases at notched frequency, that is, 3.7 GHz, 4.7 GHz, 5.8 GHz and 7.4 GHz. For other frequencies outside the notch band, the antenna gain is similar to the basic one. Thus clearly indicates the effect of the proposed antenna. Figure 9 shows radiation efficiency which is no less than 84% in most of the operational bandwidth. Ohmic losses are not included in the calculated radiation efficiency. The radiation efficiency is substantially high throughout the operational bandwidth of the antenna. Figure 10 shows the measured group delay versus frequency of the proposed UWB antenna. The range of the group delay over the entire UWB spectrum is about 2.75 ns. The large group delay mainly corresponds to the sharp drop in gain at about 7.3 GHz as seen in Fig. 8. The variation of the group delay is relatively stable for the operating frequency, while the variation of the group delay is bigger than 0.4 ns for the notch band.

All parameters of the proposed UWB antenna have been listed in Table 1. The comparison with other reported UWB antennas is shown in Table 2, which depicts the advantages of its compact size. So, the S-SCRLHs have the advantage of compact size, multi-resonance and good selectivity.

5 Example of Antenna Application

As an example, the compact UWB antenna is suitable for UWB receiver systems. The proposed antenna is applied in the UWB receiver architecture [17] as shown in Fig. 11. The proposed UWB antenna operates under the frequency range of 3.0–10.7 GHz. In this frequency range, there exist four important interference bands: 3.6–3.8 GHz (WiMAX signal), 4.5–4.9 GHz (C-band satellite communications signal), 5.6–6.0 GHz (WLAN signal), and 7.2–7.6 GHz (X-band satellite communications signal). By adjusting the parameter of the resonator, we could easily change the notched frequencies corresponding to above four interference bands and remove the above four kinds of interference signals. Previous band-notched antenna can only handle some of these cases, so the UWB system needs extra filter to block out other undesired signal, which could increase the complexity of the whole system. The proposed UWB antenna has four notch

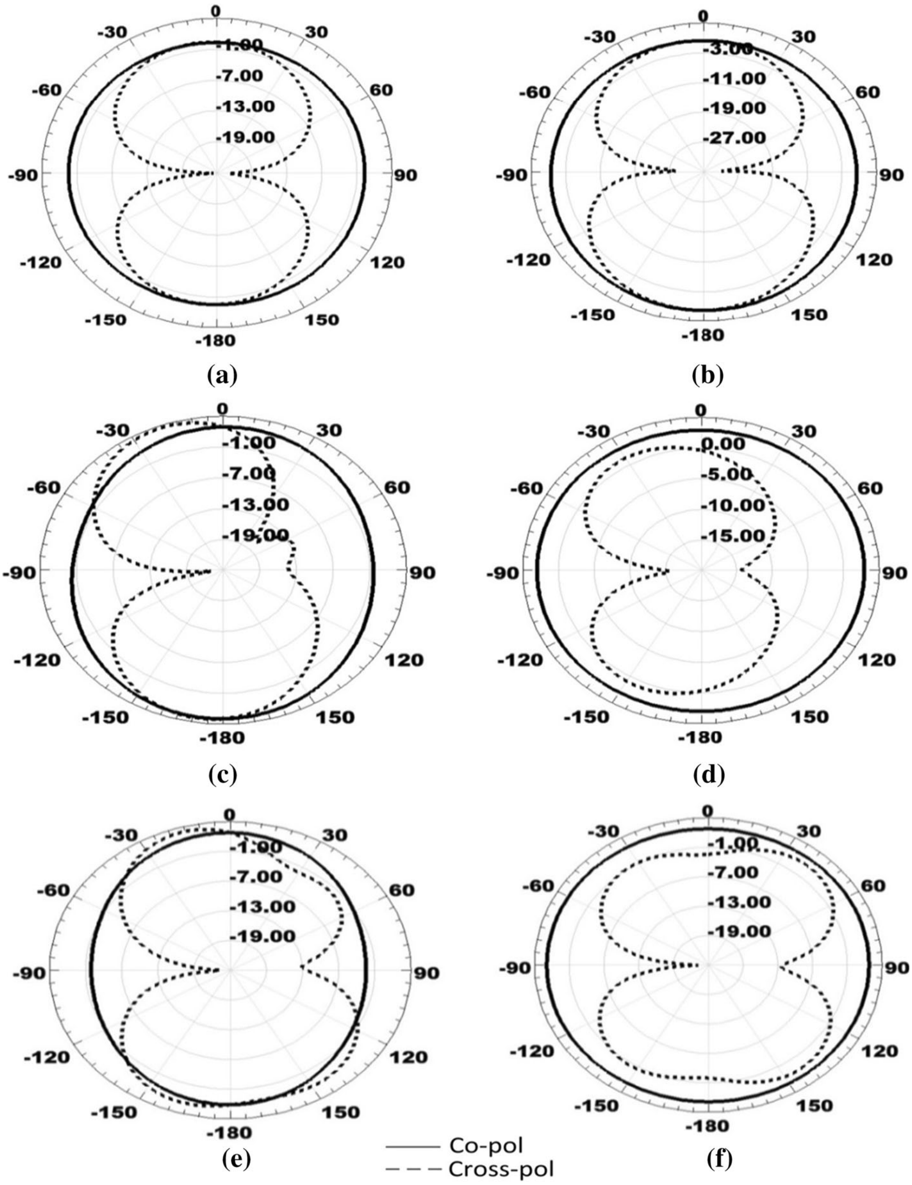


Fig. 7 Measured radiation pattern of proposed UWB antenna **a** E-plane (4 GHz), **b** H-plane (4 GHz), **c** E-plane (7 GHz), **d** H-plane (7 GHz), **e** E-plane (9 GHz), **f** H-plane (9 GHz)

bands, it does not need extra filter to block out undesired signal. Therefore, the antenna is compact and can be effectively utilized for integrating with other components of System-On-a-Chip in UWB system. So our proposed antenna has the potential to reduce system complexity and cost when applied into the UWB system, so it may be more practical in the future.

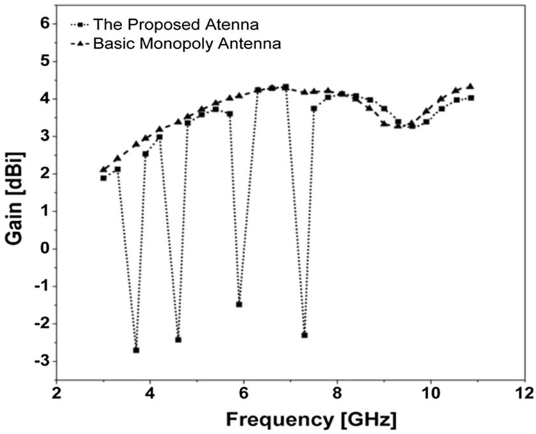


Fig. 8 Peak gain of the proposed UWB antenna with and without notched elements

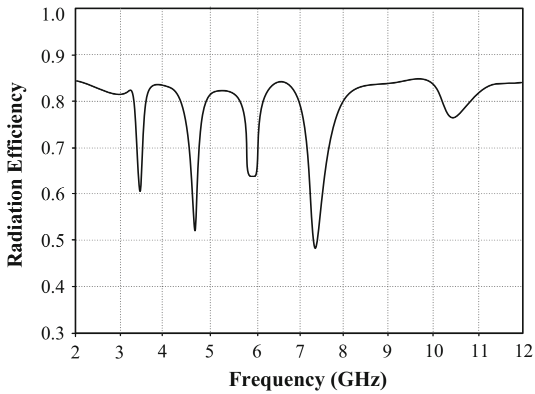


Fig. 9 Efficiency of quad notched bands antenna

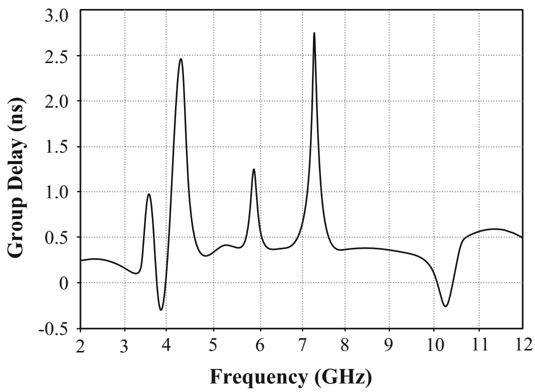


Fig. 10 Measured group delay versus frequency of the proposed UWB antenna

Table 1 Design parameters of the proposed antenna

Parameters (mm)	L	L_g	W_g	W_f	R	L_{n1}	*Dimensions*	*Electrical size*
	25	9	20	3.2	8	9	25 × 20 mm^2	0.2λ
	L_{n2}	L_{n3}	W_n	W_1	W_2	W_3	*RSB*	*Peak gain*
	6	4	1	6.3	0.24	2.6	5.4% (f1) 8.5% (f2)	−2.8 dBi (f1) −2.6 dBi (f2)
	W_4	W_5	W_6	W_7	W_8	W_9	6.9% (f3)	−1.5 dBi (f3)
	6.6	5.4	5.0	0.15	1.7	1.7	5.4% (f4)	−2.4 dBi (f4)

Table 2 Comparisons with some current proposed UWB antennas with notched band

Reference	Size (mm^2)	Passband (GHz)/gain (dBi)	No. of notch bands	Notch RSB (%)	Notch peak gain (dBi)	Notch frequency (GHz)/peak VSWR
[11]	68 × 42	2.2–12.0 > –	2	5.7/8.5	–	3.5/5.8 > 10
[12]	25 × 20	2.8–12.0 > 3.6	2	14.1/12.0	−4.0/−5.4	3.5/5.5 > 5
[13]	35 × 30	2.8–11.4 > 4.0	3	14.1/18.1/10.7	−2.2/−1.9/−3.0	3.5/5.5/7.5 > 4.3
[14]	31 × 20	3.1–10.6 > 2.0	3	11.4/12.0/8.9	−5.8/−2.6/−2.0	3.5/5.5/7.5 > 6.8
This work	25 × 20	3.0–10.7 > 2.1	4	5.4/8.5/6.9/5.4	−2.8/−2.6/−1.5/−2.4	3.7/4.7/5.8/7.4 > 10

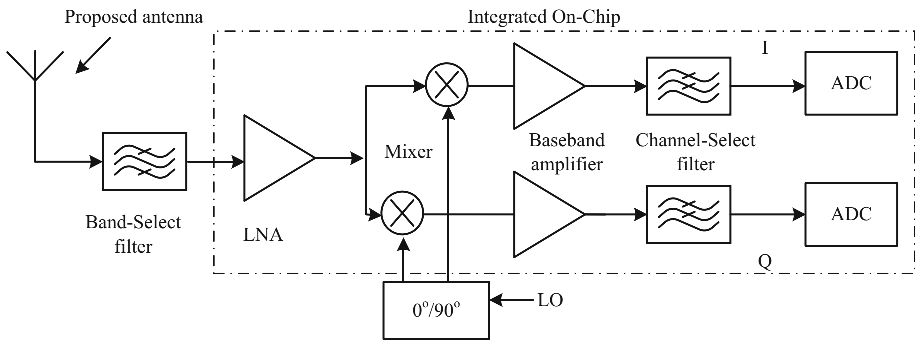


Fig. 11 UWB receiver architecture

6 Conclusion

In this paper, a novel compact ultra-wideband (UWB) antenna with quad band-notched characters is presented. To obtain band rejection characteristics in the notch bands, a S-SCRLHs, which coupled two splited simplified composite right/left-handed (S-SCRLH) resonator, is designed and integrated into a UWB antenna. The proposed UWB antenna has a compact size of 25 × 20 mm^2, it can achieves an ultra-wide bandwidth ranging from 3 to

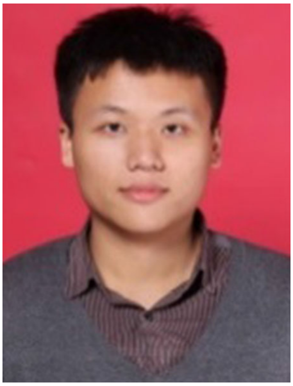
10.7 GHz and suppresses four kinds of interference signals which are 3.6–3.8 GHz WiMAX signal, 4.5–4.9 GHz C-band satellite communications signal, 5.6–6.0 GHz WLAN signal, 7.2–7.6 GHz X-band satellite communications signal. In the pass band, the antenna shows good performance and efficiency with VSWR < 2 and gain from 2.1 to 4.5 dBi. In the stop band, the antenna shows good notched characteristics with VSWR > 10 and antenna gain being $-2.8, -2.6, -1.5$ and -2.4 dBi, respectively. Besides, by altering the dimension of S-SCRLHs resonator, the notched frequencies can be adjusted appropriately. Therefore, the proposed antenna exhibits good characteristics such as compact size, good performance, multi-stop band and good selectivity. Due to these four reasons, the proposed antennas are expected to be good candidates for use in various UWB systems.

Acknowledgements This work is supported by the National Nature Science Foundation of China (No. 61571185), the Natural Science Foundation of Hunan Province, China (No. 2016JJ2030) and the Open Fund Project of Key Laboratory in Hunan Universities (No. 15K027).

References

1. Communications Commission. (2002). *First report and order, revision of part 15 of Commission's rule regarding UWB transmission system FCC02-48.*
2. Ojaroudi, Y., Ojaroudi, S., & Ojaroudi, N. (2015). A novel 5.5/7.5 GHz dual band-stop antenna with modified ground plane for UWB communications. *Wireless Personal Communications, 81*(1), 319–332.
3. Peng, H. J., Wang, C. H., Zhao, L., & Liu, J. (2016). Novel SRR-loaded CPW-fed UWB antenna with wide band-notched characteristics. *International Journal of Microwave and Wireless Technologies, 9*(4), 875–880.
4. Ryu, K. S., & Kishk, A. A. (2009). UWB antenna with single or dual band-notches for lower WLAN band and upper WLAN band. *IEEE Transactions on Antennas and Propagation, 57*(12), 3942–3950.
5. Zhou, H., Wang, C., & Peng, H. (2016). A novel double-incidence and multi-band left-handed metamaterials composed of double Z-shaped structure. *Journal of Materials Science: Materials in Electronics, 27*(3), 1–11.
6. Dikmen, C. M., & Cakir, G. (2013). Miniature crescent shaped UWB antenna. *International Journal of RF and Microwave Computer-Aided Engineering, 23*(4), 494–498.
7. Ojaroudi, M., Ghanbari, G., Ojaroudi, N., Ghobadi, C., et al. (2009). Small square monopole antenna for UWB applications with variable frequency band-notch function. *IEEE Antennas and Wireless Propagation Letters, 8*(4), 1061–1064.
8. Hong, S. J., Shin, J. W., Park, H., & Choi, J. H. (2007). Analysis of the bandstop techniques for ultrawideband antenna. *Microwave & Optical Technology Letters, 49*(49), 1058–1062.
9. Bao, X. L., & Ammann, M. J. (2007). Printed band-rejection UWB antenna with H-shaped slot. In *International workshop on antenna technology: small and smart antennas metamaterials and applications* (pp. 319–322), Cambridge.
10. Chu, Q., & Yang, Y. (2008). A compact ultrawideband antenna with 3.4/5.5 GHz dual band-notched characteristics. *IEEE Transactions on Antennas and Propagation, 56*(12), 3637–3644.
11. Sun, Q., Zhao, Y. J., Li, Q., Liu, B., Wan, J. K., et al. (2010). A planar ultra-wideband antenna with dual notched bands based on SCRLH resonator. In *2010 International Conference on Microwave and Millimeter Wave Technology (ICMMT)* (pp. 380–383).
12. Srivastava, G., & Mohan, A. (2015). A planar UWB monopole antenna with dual band notched function. *Microwave & Optical Technology Letters, 57*(1), 99–104.
13. Srivastava, G., Dwari, S., & Kanaujia, B. K. (2015). A compact triple band notch circular ring antenna for UWB applications. *Microwave and Optical Technology Letters, 57*(3), 668–672.
14. Bakariya, P. S., Dwari, S., & Sarkar, M. (2015). A triple band notch compact UWB printed monopole antenna. *Wireless Personal Communications, 82*(2), 1095–1106.
15. Lin, X. Q., Liu, R. P., Yang, X. M., et al. (2006). Arbitrarily dual-band components using simplified structures of conventional CRLH TLs. *IEEE Transactions on Microwave Theory and Techniques, 54*(7), 2902–2909.

16. Sung, Y. (2013). Triple band-notched UWB planar monopole antenna using a modified H-shaped resonator. *IEEE Transactions on Antennas and Propagation, 61*(2), 953–957.
17. Ranjan, M., & Larson, L. E. (2007). A low-cost and low-power CMOS receiver front-end for MB-OFDM ultra-wideband systems. *IEEE Journal of Solid-State Circuits, 42*(3), 592–601.



Yilin Zhao received the B.S. degree from the College of Computer Science and Communication Engineering, Tianjin University of Technology, Tianjin, China, in 2014. He is studying towards the M.S. degree in the College of Computer Science and Electronic Engineering, Hunan University, Changsha, China. His research interests include wireless communication, RF CMOS integrated circuits, and microwave device.

Chunhua Wang is currently a Professor of College of Information Science and Engineering, Hunan University, Changsha, China. His research interests include current-mode circuit design, filtering, radio frequency circuit and wireless communications.

Yawen Denge received the M.S. degree from the College of Computer Science and Electronic Engineering, Hunan University, Changsha, China, in 2015. Her research includes wireless communication and RF CMOS integrated circuits.

Changming Xie received the M.S. degree from the College of Computer Science and Electronic Engineering, Hunan University, Changsha, China, in 2015. His research includes wireless communication and microwave device.