Progress In Electromagnetics Research Letters, Vol. 87, 59–66, 2019

CPW-Fed Miniaturized Isosceles Triangular Slot UWB Planar Antenna with Triple Band-Notched Characteristics

Mourad Elhabchi[1, *], Mohamed N. Srifi[2], and Rajae Touahni[1]

Abstract—In this paper, a compact triangular defected ground plane monopole antenna with 5G, WLAN, and downlink/uplink of X-band notched characteristics for UWB applications is presented. The initial design consists of a CPW rectangle-shaped patch with a triangular, slotted ground plane to obtain ultra-wideband feature. The 3.3–3.7 GHz for the 5G band is eliminated by inserting dual symmetrical T-shaped slots at the upper edge of the ground plane. Further, a metamaterial as dual symmetrical single split ring resonator slits is etched at the bottom edge of the ground plane to suppress electromagnetic interference at IEEE upper WLAN band from 5.72 to 5.84 GHz. To restrict the interferences with the existing downlink and uplink for X-band signals from 7.1 to 8.39 GHz, we load a single I-slot to the radiator patch. The small size of the presented triple band eliminated antenna makes it a candidate suitable for recent communication systems.

1. INTRODUCTION

As the research and evolution of communication and information technologies have drawn great attention in the past few years, various electronic devices using wireless communication technologies are being manufactured to cover short range frequency spectrum. UWB antenna has several attractive characteristics such as easy manufacture and uses in single chip, omnidirectional radiation pattern, high processing gain, good radiation efficiency and so on. The existing licensed bands like 5G, WLAN, and X-band can provide interferences with ultra-wideband (UWB) systems [1]. It is still a challenge to conceptualize small and efficient UWB antennas.

Several microstrip patch antennas have been developed to overcome this problem and to design band-notched characteristics. Quite a few elements are reported and studied in [2, 3]. Gong et al. used a metamaterial as a complementary split ring resonator (CSRR) and loaded it in a regular hexagonal shape radiation patch to eliminate the lower and upper WIMAX bands and a pair of inverted T-shaped conductor-backed planes loaded in the upper edge of the ground plane to suppress downlink of X-band signals [4]. Bong et al. published a dual-band filters antenna using a split ring-shaped slit to reject 5G band and a V-shaped slot to suppress the licensed WLAN band [5]. Xi et al. loaded a UWB antenna with two resonators and used a capacitor to obtain tunable dual band notched features [6]. Hammache et al. integrated three C-shaped slots in the hexagonal part of the design to eliminate triple band features [7]. Several other methods have been reported to create a UWB range with eliminated properties such as switched band rejected using double inverted S-shaped slots [8], modified H-shaped resonator embedded in UWB antenna [9], using electromagnetic band gap structures [10], using DGS and a semi-arc shaped slot [11].

In this letter, a triangular shape [12] triple band-eliminations UWB structure with double symmetrical inverted T-shaped slots and dual Split Ring Resonator (SRR) metamaterial slits are

Received 22 July 2019, Accepted 29 August 2019, Scheduled 10 September 2019
* Corresponding author: Mourad Elhabchi (mouradelhabchi@hotmail.fr).
[1] LASTID Laboratory, Department of Physics, Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco. [2] Electronics and Telecommunication Systems Research Group, National School of Applied Sciences (ENSA), Ibn Tofail University, Kenitra, Morocco.

perforated in the top and bottom edges of the ground plane to suppress respectively the 5G (3.3–3.7 GHz) and WLAN (5.72–5.84 GHz) bands. In order to avoid the problem of interference with the existing downlink and uplink for X-band spectrums from (7.1–8.39 GHz), a single I-shaped slot is embedded as a slot in the rectangular radiator of the antenna. The simulated and measured results show that this proposed UWB antenna can offer an operating frequency from 2.93 GHz to 10.04 GHz with 10 dB return loss bandwidth, except the mentioned three notched bands. The simulated and measured results are quasi-consistent. The proposed antenna can be a good candidate to fulfil the recent developments in wireless UWB applications.

2. ANTENNA DESIGN

2.1. Antenna Design and Discussion

The geometry of the evaluated triple band-eliminated UWB triangular defected ground plane antenna is illustrated Figure 1. The proposed design is fed by a 50 Ω microstrip line with $Wf = 3$ mm and $Lf = 9$ mm, and fabricated on an FR4 substrate with $\varepsilon_{eff} = 4.3$ (permittivity) and $\tan\delta = 0.025$ (loss tangent). The slotted UWB antenna has a size of $26 \times 26 \times 1.6\,\text{mm}^3$, and the radiating element is designed with a rectangle-shaped form. The Computer Simulation Technology (CST) Microwave (MW) parameters of the final obtained optimized antenna designs are: $Ws = 26$ mm, $Ls = 26$ mm, $Wp = 9$ mm, $Lp = 3$ mm, $Wf = 3$ mm, $Lf = 9$ mm, $Wg = 11$ mm, $Lg = 7$ mm, $WS1 = 5$ mm, $Ls1 = 0.7$ mm, $Wr = 9.5$ mm, $Lr = 1.5$ mm, $Wt = 5$ mm, $Lt = 10.5$, $A = 22.5$, $B = 1$, $G = 0.6$ mm, $Gt = 2$ mm. The wanted eliminated signals can be obtained using the following equations [13, 14].

$$f_{filter} = \frac{c}{2 \times L \times \sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

The total length L of all introduced slots and slits at the unwanted frequency bands can be calculated using Equation (2), and c is defined as the velocity of the light in free space. The dielectric is characterized by its constant effective ε_{eff}. Therefore, the eliminated signals can be tuned to the wanted frequency spectrum by optimizing the dimensions of the inserted slots.

The first step in Figure 2(a) depicts the initial design without inserting slots and its reference UWB antenna, and the second step in Figure 2(b) illustrates the design with two inverted T-shaped slots. In the third structure (Figure 2(c)), an open single horizontal I-slot is introduced in the radiating

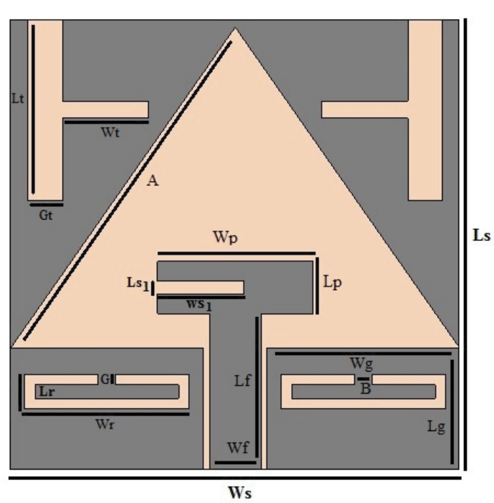
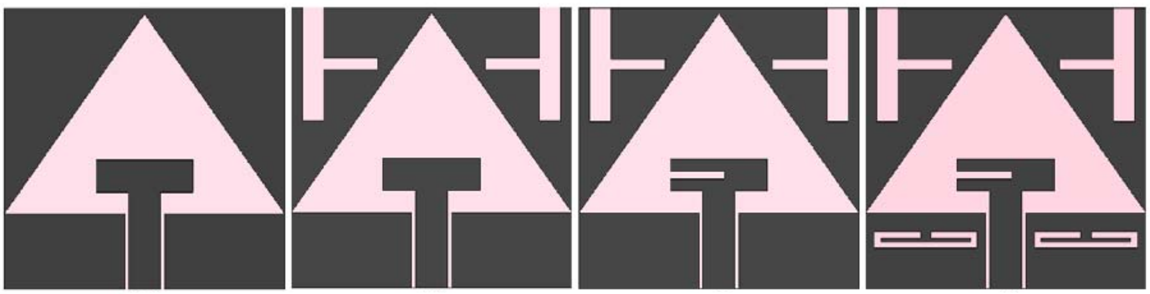


Figure 1. The geometry of proposed triple band antenna.

patch element. Finally, we identically cut two SRRs in the ground plane, and the desired final proposed antenna is obtained (Figure 2(d)).

Four traces of the reflection coefficient for the mentioned steps are shown in Figure 3. Trace 1 represents a UWB spectrum (3 GHz to 11 GHz) with a return loss less than −10 dB (antenna 1). Trace 2 depicts S_{11} of the prototype antenna with a single suppressed band in the frequency range of 5G applications (antenna 2). X-band signals are rejected when an open single I-shaped slot is inserted into the patch, and this case is shown in trace 3 (antenna 3). In the last step, the WLAN band is rejected by the integration of two SRR metamaterial slots [15]. This last trace illuminates the behavior of the final combined proposed structure (antenna 4), which consists of novel triple band filtered 5G, WLAN, and X-band signals.



(a) (b) (c) (d)

Figure 2. The evolution process step by step of the presented antenna.

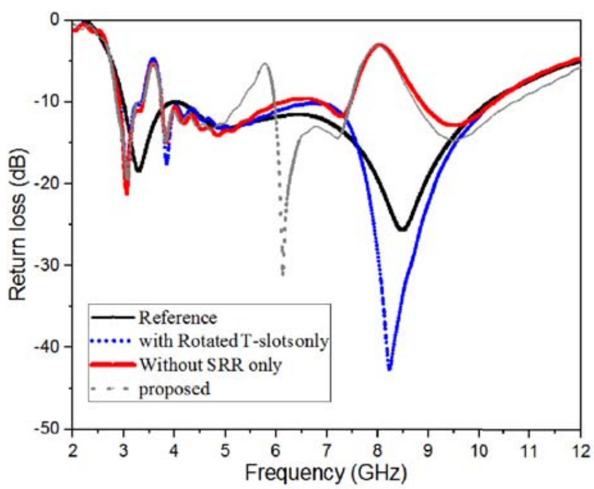


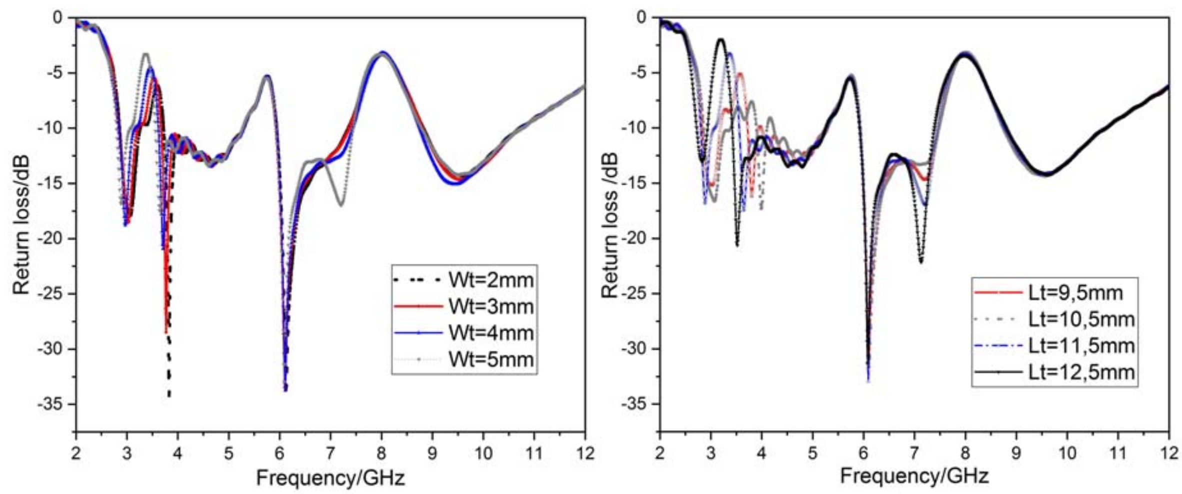
Figure 3. Variation of the S-parameter with frequency for the fourth cases in Figure 2.

2.2. Parametric Study for the Rejected Bands

2.2.1. The WIMAX and WLAN Eliminated Bands

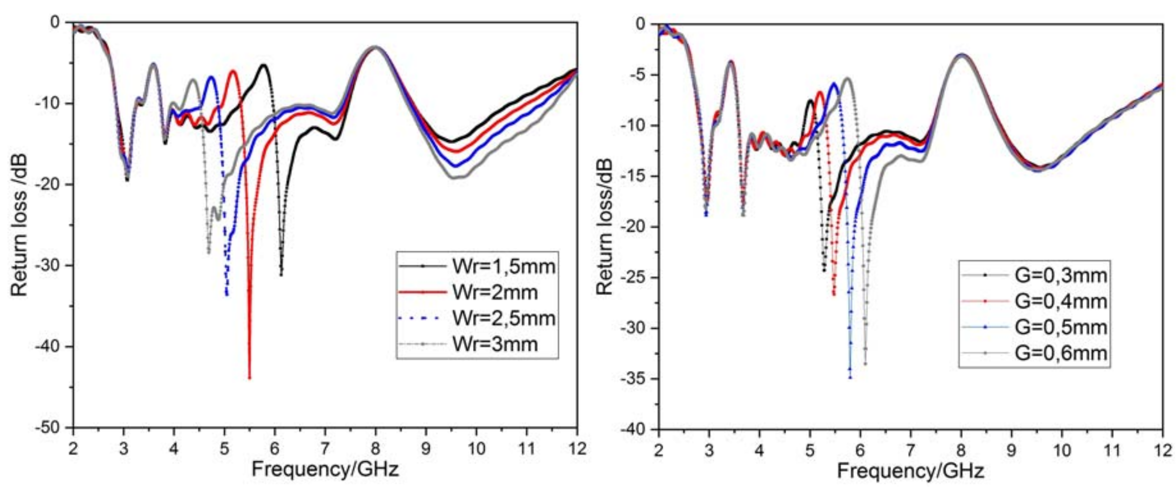
Figures 4(a) and 4(b) present influences of the double inverted T-shaped slot dimension on the return loss versus frequency trace. As seen in this figure, the unwanted signal is moved from 4 to 3.2 GHz when the length Lt of the T-shaped slot is improved from 9.5 to 12.5 mm by a step of 1 mm, and the reject in 5G spectrum is centred at 3.5 GHz with S_{11} value of −3.5 dB (Figure 4(a)). However, to ensure a good 5G band elimination, the return loss value changes from 6.5 dB to 3 dB when varying the width Wt from 2 to 5 mm of inserting T-shaped slot (Figure 4(b)).

Figures 5(a) and 5(b) depict effects of the dual symmetrical SRR slot dimension on S_{11} function of the frequency trace. As observed, the filtered signal increases from 4.5 to 5.8 GHz when the width Wr of SRR slot decreases from 3 to 1.5 mm. The notch in WLAN band is centred at 5.8 GHz with a reflection coefficient value of -4.5 dB (Figure 5(a)). Moreover, for a better WLAN signal suppression, the S_{11} value changes from 7 dB to 5 dB when varying the gap G of the dual SRRs from 0.3 to 0.6 mm by a step of 0.1 mm (Figure 5(b)).



(a) (b)

Figure 4. Simulated S_{11} traces for: (a) different Wt values, (b) different Lt values.



(a) (b)

Figure 5. Simulated S_{11} traces for: (a) different Wr values, (b) different G values.

2.2.2. The X-Band Eliminated Signals

Figures 6(a) and 6(b) illuminate effects of the open I-slot dimension on S_{11} versus frequency plot. It is shown that as the width $Ws1$ of I-slot value increases from 4 to 5.5 mm, the rejected signal shifts from 9.5 to 7.5 GHz. The reject in X-band spectrums is centred at 8 GHz with a reflection coefficient value of -3 dB (Figure 6(a)). Finally, for a good X-band signal suppression, the reflection coefficient value is enhanced from 5.5 dB to 2.5 dB when varying the length $Ls1$ of I-slot from 0.4 to 1.3 mm with a step of 0.3 mm (Figure 6(b)).

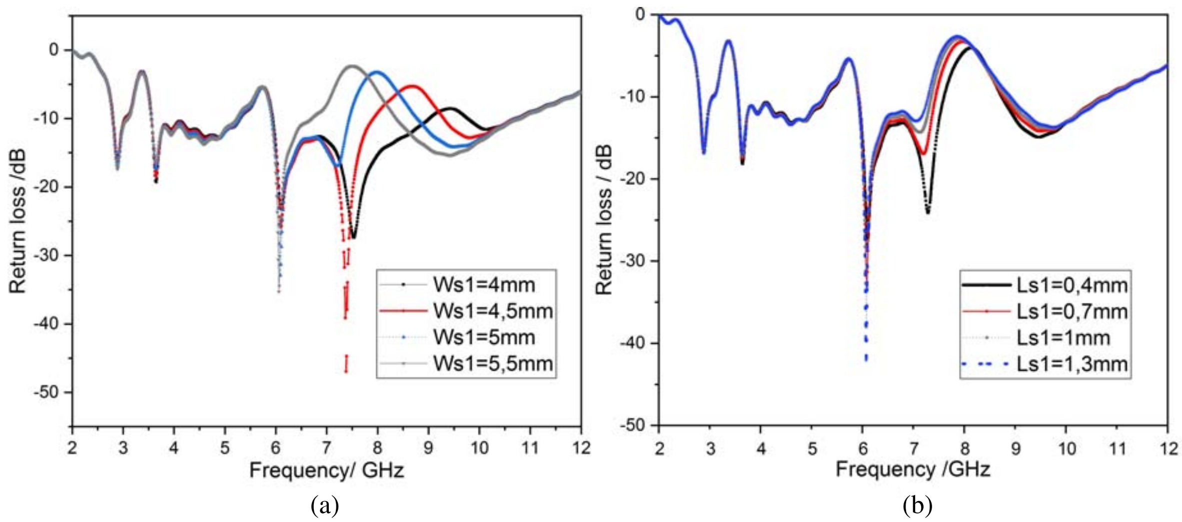


Figure 6. Simulated S_{11} traces for: (a) different $Ws1$ values, (b) different $Ls1$ values.

2.3. Simulated Current Distribution, Realized Gain and Radiated Efficiency

In order to elucidate the generation of filter band frequencies. The surface current distribution density of the proposed triple band isosceles triangular antenna, at 3.5, 5.8, 8, and 9 GHz, is shown in Figure 7 respectively. At the first mentioned frequency 3.5 GHz, strong current density is concentrated around the double rotated T-slots to reject 5G band while a small current flows around the rest parts of the structure. At the second notched band (5.8 GHz), the current largely flows around the dual symmetrical split ring resonator to filter WLAN signals. Therefore, its density is high in the open I-slot to filter the third band (8 GHz) while the current at 9 GHz is uniformly distributed in the patch elements. Thus, these slots prove that the production of the eliminating waves is caused by resonating at the filtered frequencies [15].

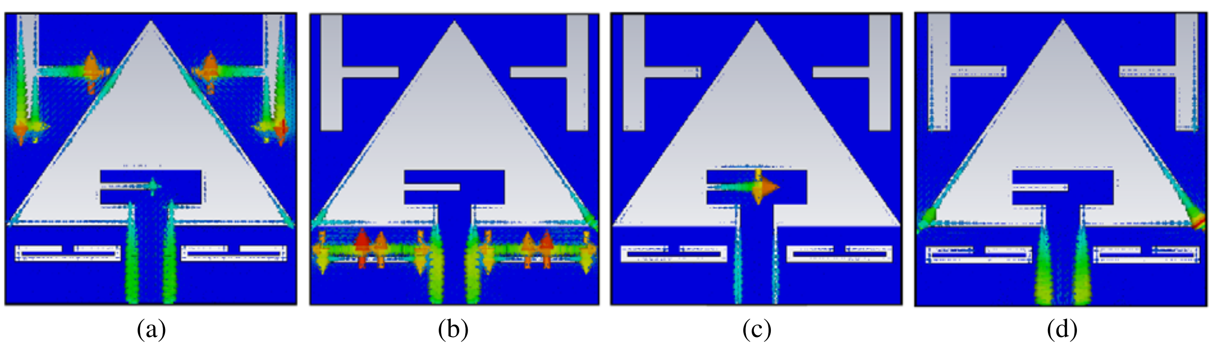


Figure 7. Current distributions at (a) 3.3 GHz, (b) 5.8 GHz, (c) 8 GHz, and (d) 9.5 GHz.

Figure 8 illuminates the simulated realized gain and radiated efficiency of the triple band notched antenna. A stable and positive realized gain and radiated efficiency are found in the UWB range [16] with maximum gain value of 4 dB except in the notched frequency spectrums, and the value of the gain is reduced to become negative.

3. MEASUREMENT RESULTS AND DISCUSSION

Simulated and measured reflection coefficient parameters as well as a photograph of the proposed antenna are presented in Figure 9. The prototype of isosceles triangular three band notched antenna

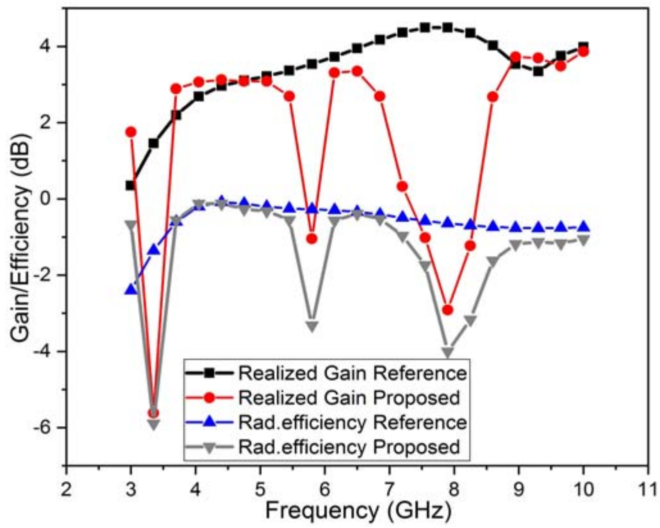


Figure 8. Simulated realized gain and radiated efficiency of the UWB antenna without and with three notched bands.

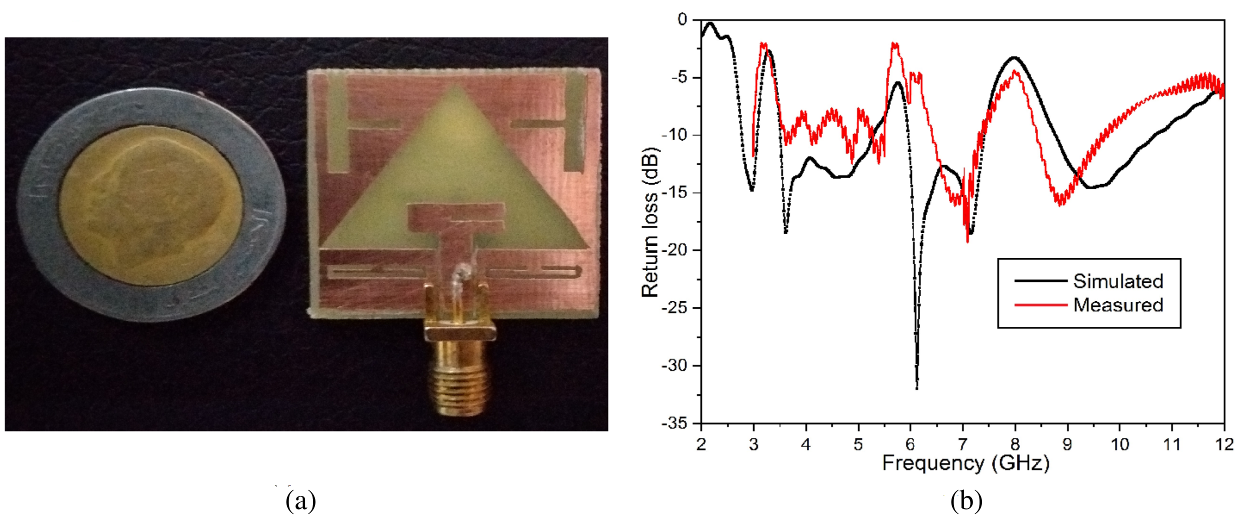


Figure 9. (a) The photograpy of the proposed antenna. (b) Simulated and measured S_{11} parameters.

is manufactured, and S_{11} parameters are tested using the ZVB 20-Vector Network Analyzer 20 MHz–20 GHz. The measured results are in quasi-consistence with the simulated ones. A little shift seen between the optimized and measured results is due to the condition of measurement.

4. COMPARISON WITH RECENTLY PUBLISHED WORKS

Table 1 depicts the comparison between this work and other recently published works in terms of bandwidth, total area, gain, and rejected band number. It can be seen from this comparison that the presented structure has a very compact size of 676 mm^2, is triple band notched, and covers the entire FCC band with acceptable gain features with a maximum value of 4.8 dB compared with other similar works.

Table 1. Comparison with recently developed UWB designs.

Antennas	Bandwidth (GHz)	Dimension (mm)	Total area (mm^2)	Gain (dB)	Number of notched-bands
Ref. [2]	3–6	40 × 40	1600	2.52–4.13	3
Ref. [3]	3.1–11	24 × 35	840	3–6	3
Ref. [4]	3–11	31 × 40	1240	1.5–6.5	3
Ref. [5]	2.7–14.6	75 × 10	750	About 2	1
Ref. [6]	3.1–10.6	42 × 50	2100	N. defined	2
Ref. [7]	2.95–12	30 × 30	900	1.5–5.37	3
Ref. [8]	3–11	35 × 30	1050	About 3	2
Ref. [9]	2.5–10.6	25 × 33	825	2–5	3
Ref. [10]	3–12	42 × 50	2100	About 4	3
Ref. [11]	3.1–11	42 × 24	1008	2.7–3.6	3
Ref. [13]	4–11	20 × 25	500	N. defined	1
Ref. [14]	2.8–12.6	8 × 27	220	Above 2	1
Ref. [15]	3.1–13.12	19 × 21.5	408.5	2–6	2
This paper	3–11	26 × 26	676	2.8–4.8	3

5. CONCLUSION

In this paper, a novel compact triple band controllable band rejected antenna with three differently shaped slots for notched bands has been presented and discussed. To create notched signals for three frequency bands in 5G, upper WLAN band, and X-band, we integrate respectively dual symmetrical T-shaped slots, dual symmetrical single split ring resonator slits, and a single I-slot to generate notched bands. Measured and simulated results have proven the responsibility of slots for filtering frequency at the desired bands without the gain and efficiency in the UWB range. Finally, the presented filtered antenna is formed to eliminate interference, and with these characteristics, the purpose of solving the interference between UWB and the existing 5G, WLAN, and X-band is successfully achieved.

REFERENCES

1. Sipal, V., B. Allen, D. Edwards, and B. Honary, "Twenty years of ultrawideband:opportunities and challenges," *IET Commun.*, Vol. 6, No. 10, 1147–1162, 2012.
2. Liu, H. W. and C. H. Ku, "Novel planar triple band monopole antenna for WiMAX/WLAN applications," *Microwave Opt. Technol. Lett.*, Vol. 52, No. 11, 2405–2408, 2010.
3. Deng, J. Y., Y. Z. Yin, Sh. G. Zhou, and Q. Z. Liu, "Compact ultra-wideband antenna with tri-band notched characteristic," *Electron. Lett.*, Vol. 44, No. 21, 1231–1233, 2008.
4. Gong, X., Y. Tong, B. Tian, and B. Gao, "Design of a microstrip-fed hexagonal shape UWB antenna with triple notched bands," *Progress In Electromagnetics Research C*, Vol. 62, 77–87, 2016.
5. Bong, H. U., N. Hussain, S. Y. Rhee, S. K. Gil, and N. Kim,"Design of an UWB antenna with two slits for 5G/WLAN-notched bands," *Microw. Opt. Technol. Lett.*, Vol. 61, No. 5, 1–6, 2019.
6. Xi, L., H. Zhai, Y. Zang, and L. Li, "A novel dual-band tunable band-notched antenna," *Microw. Opt. Technol. Lett.*, Vol. 59, No. 12, 3014–3018, 2017.
7. Hammache, B., A. Messai, I. Messaoudene, and T. A. Denidni, "A compact ultrawideband antenna with three C-shaped slots for notched band characteristics," *Microw. Opt. Technol. Lett.*, Vol. 61, No. 1, 275–279, 2019.
8. Li, B., J. Hong, and B. Z. Wang, "Switched band-notched UWB/dual-band WLAN slot antenna with inverted S-shaped slots," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 572–575, 2012.

9. Sung, Y., "Triple band-notched UWB planar monopole antenna using a modified H-shaped resonator," *IEEE Trans. Antennas Propag.*, Vol. 61, No. 2, 953–957, 2013.
10. Jaglan, N., B. K. Kanaujia, S. D. Gupta, and S. Srivastava, "Triple band notched UWB antenna design using electromagnetic band gap structures," *Progress In Electromagnetics Research C*, Vol. 66, 139–147, 2016.
11. Elhabchi, M., M. N. Srifi, and R. Touahni, "A tri-band-notched UWB planar monopole antenna using DGS and semi arc-shaped slot for WiMAX/WLAN/X-band rejection," *Progress In Electromagnetics Research Letters*, Vol. 70, 7–14, 2017.
12. Sameena, V. A., et al., "A compact CPW fed slot antenna for ultra wide band applications," *AEU-Int. J. Electron Commun.*, Vol. 66, 189–194, 2012.
13. Boopathi, R. R. and S. K. Pandey, "A CPW-fed circular patch antenna inspired by reduced ground plane and CSRR slot for UWB applications with notch band," *Microw. Opt. Technol. Lett.*, Vol. 59, No. 4, 745–749, 2017.
14. Toktas, A. and M. A. Yerlikaya, "A compact reconfigurable ultra-wideband G-shaped printed antenna with band-notched characteristic," *Microw. Opt. Technol. Lett.*, Vol. 61, No. 1, 745–749, 2019.
15. Xu, B., Y. Zhao, L. Gu, and Z. Nie, "Fork-shaped patch printed ultra-wideband slot antenna with dual band-notched characteristics using metamaterial unit cells," *Int J. RF Microw. Comput. Aided Eng.*, Vol. 29, No. 7, e21742, 2019.
16. William, J. and R. Nakkeeran, "Development of CPW-fed UWB printed slot antenna," *National Conference on Communications (NCC)*, 29–31, 2010.