Omnidirectional UWB Monopole Antenna with WLAN Notched-band Functionality

Zahra Bastani[1,2], Mohamad Amin Honarvar[3*], Masoud Jabari[4]
1-Department of Engineering and Technology, Fars Science and Research Branch, Islamic Azad University, Shiraz, Iran
2-Department of Engineering and Technology, Shiraz Branch, Islamic Azad University, Shiraz, Iran
Email: bastani_eng@yahoo.com
3-Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
Email:Amin.Honarvar@gmail.com (Corresponding Author)
4-Department of Electrical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran
Email: jabari@miau.ac.ir

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ABSTRACT:
This paper introduces a novel ultra-wideband (UWB) microstrip antenna having wireless local area network band rejection characteristics. The proposed antenna is composed of a lip-shaped radiation patch being fed by a 50 Ω coplanar waveguide (CPW) feed line. The ground vertically continued to the two sides of the radiator. Thus, the substantial extra space adjacent to the radiator can be efficiently saved. The band rejection in the wireless local area networks (WLAN) (5.15-5.825GHz) is secured through etching the two symmetric C-shaped slots on ground plane to preclude interference between UWB and WLAN systems. The proposed antenna is of the size of $30\times30\times1.6mm^3$working within the range of 2.9 to 11.2 GHz with VSWR lower than 2 except in 5.15-5.825GHz band. Finally, the antenna is simulated and fabricated with nearly omnidirectional radiation patterns, stable gain and constant group delay in the operating band.

KEYWORDS: Ultra-wideband (UWB), Coplanar waveguide (CPW), Microstrip antenna, Wireless local area network (WLAN), Voltage standing wave ratio (VSWR).

1. INTRODUCTION

In order to make the ultra-wideband (UWB) technology useful for the community and to prevent possible interference to other existing electronic systems, the Federal Communications Commission (FCC) published the first report and order on February 14, 2002 [1]. The order deals with the employment of UWB systems within the 3.1-10.6 GHz band. Because of such useful characteristics as low cost, unsophisticated structure, ease of construction, low profile, high data rate, and nearly omnidirectional radiation pattern, the UWB microstrip antennas have attracted the attention of both academia and industry [2]. Since conventional antenna theory is based on the narrow band assumption and cannot be used to design UWB antenna, novel techniques and technologies need to be developed for UWB antenna design. Furthermore, within the UWB operation band, existing narrowband communication systems, such as 5.15–5.825 GHz band (IEEE 802.11a) wireless local area networks (WLAN) may cause electro-magnetic interference to UWB applications. To remedy this situation, several band-notched techniques have been proposed in UWB antennas [3-8]. In the present research, an UWB microstrip antenna having WLAN band rejection characteristics is introduced. The design is formed on the basis of a lip-shaped radiation patch. In this paper, we propose a simple and compact CPW-fed UWB antenna with band-notched characteristics in 5-6 GHz. To achieve wide band characteristic, tapered ground plane is used. The WLAN band rejection is achieved through etching two symmetric C-shaped slots on the ground plane. The results emanating from simulation and measurement of the proposed antenna are indicative of the fact that the voltage standing wave ratio (VSWR) is capable of successfully covering the UWB spectrum. Nearly omnidirectional radiation patterns, constant group delay, stable gain and satisfactory agreement between the measured and the simulated results are obtained from this research. The antenna has dimensions of 30×30 mm^2, which is compatible with the requirements imposed by portable systems. The overall size of the proposed structure is smaller than many other researches [9-14]. The proposed antenna operates within the 2.9 to 11.2 GHz frequency band as VSWR < 2 except a stop-band of 5.15-5.825GHz, which is a suitable candidate for UWB communication systems.

2. ANTENNA DESIGN

Fig. 1, depicts the geometric configuration of the proposed antenna whose total size is 30 × 30 × 1.6 mm^3. The antenna is constructed on a 1.6-mm-thick Rogers RT/duroid 5880 (tm) substrate having relative permittivity of 2.2 and loss tangent of 0.0009. The proposed structure is composed of a lip-shaped radiation patch. The lip-shaped patch is fed through a 50 Ω CPW feed line. The ground plane are embedded from the patch's left and right sides on the substrate with each embedded ground having a vertical 30 mm section, a horizontal 15 mm section at the upper and bottom 13.85 mm face, respectively. A pair of C-shaped slots is made on the ground plane to lessen the interference between UWB systems from WLAN systems. The WLAN rejection band frequency range is controlled through changing the dimensions of the C-shaped slots. The lip-shaped radiation patch design skills are presented to obtain UWB band having good impedance matching over the total operating band.

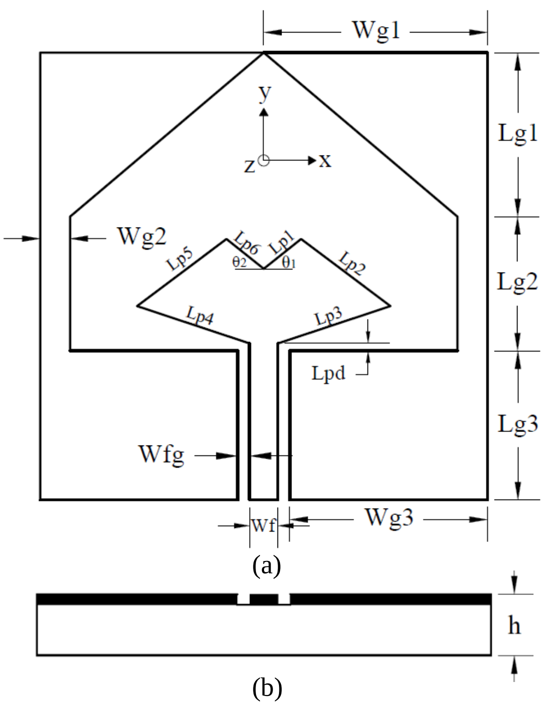

Fig. 1. The geometry and configuration of the proposed UWB microstrip antenna

For explaining the improvement procedure of the proposed antenna design, two prototypes of patches are determined and exhibited in Fig. 2. The base of the radiator is made of a triangle patch, whose dimensions are shown in Fig. 2(a). Fig. 3, shows that the triangle patch reflection coefficient is not able to cover the UWB band. Then patch figure is changing. The Fig. 2(b), shows the change of angle between feed line and side-line from 180° to 162°, but this cannot cover the entire UWB band either. Thus, to obtain UWB band, a slot is made in the patch upper section forming the design of lip-shaped radiation patch. The simulated reflection coefficient of the proposed antenna with lip-shaped radiation patch is shown in Fig. 3. The triangle patches in Fig. 2(a), and Fig. 2(b), are analytically compared in Fig. 3. Fig. 3, shows that Fig. 2(a), representing the worst matching conditions appears over the UWB frequency band. In the case of the patch shown in Fig. 2(b), for the matching condition this is again undesirable across the full UWB band and is not capable of covering the entire UWB band. Thus, the lip-shaped radiation patch in the Fig. 1, can cover the entire UWB spectrum from 3.1 to 10.6 GHz. Table I presents the optimal dimensions of the proposed antenna with lip-shaped radiation patch.

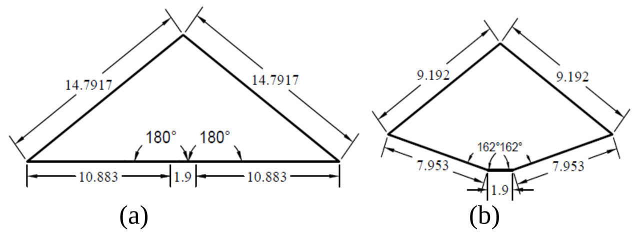

Fig. 2. The different configurations for the triangle patch.

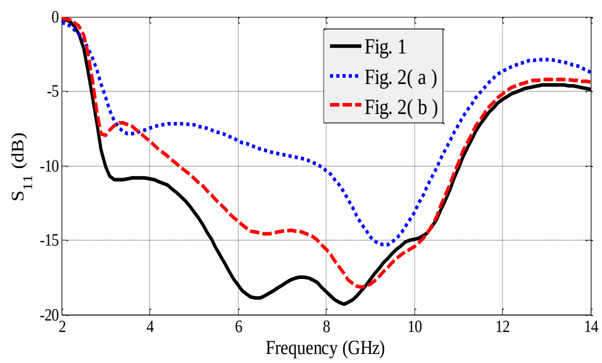

Fig. 3. Simulated reflection coefficient for the proposed UWB antenna Fig. 1, triangle patch Fig. 2(a) and Fig. 2(b), with the same ground plane.

Table 1. Design parameters of the proposed UWB microstrip antenna shown in Fig. 1.

Parameters	$L_{P1} = L_{P6}$	$L_{P2} = L_{P5}$	$L_{p3} = L_{p4}$
Unit (mm)	3.2	7.5	7.953
parameters	L_{pd}	W_{g1}	W_{g2}
Unit (mm)	0.5	15	2
parameters	W_{g3}	W_f	W_{fg}
Unit (mm)	13.85	1.9	0.2
parameters	L_{g1}	L_{g2}	L_{g3}
Unit (mm)	11	9	10

2.1. Variation of Lip-Shaped Patch Parameters

Fig. 4, shows the simulated VSWR curves of the proposed antenna with different values of $L_{P1} = L_{P6}$ length, from 0.5 to 4.72 mm with $\theta_1 = \theta_2$ angle, from

11° to 58°. As can be observed, by decreasing values of $L_{P1} = L_{P6}$ length, from 4.72 to 0.5 mm there is a mismatch between the impedance of the radiating patch and the input impedance at the lower frequencies. Thus, it is decided that $L_{P1} = L_{P6} = 3.2$mm with $\theta_1 = \theta_2 = 39^{\circ}$ as the optimum conditions with the bandwidth from 2.9 to 11.2 GHz covering the UWB band.

Fig. 5, depicts the simulated VSWR results of the proposed UWB microstrip antenna with $L_{P2} = L_{P5}$ length, from 5.02 to 9.22 mm with $\theta_1 = \theta_2$ angle, from 39° to 58°. Nonetheless, it can be observed that $L_{P2} = L_{P5} = 7.5$mm and $L_{P2} = L_{P5} = 9.22$mm have the VSWR<2 bandwidth at the UWB band, but there is a mismatch between the impedance of the radiating patch and the input impedance at the $L_{P2} = L_{P5} = 9.22$mm upper frequencies of the UWB. Thus, the optimum conditions are $L_{P2} = L_{P5} = 7.5$mm with $\theta_1 = \theta_2 = 39^{\circ}$ with the bandwidth from 2.9 to 11.2 GHz.

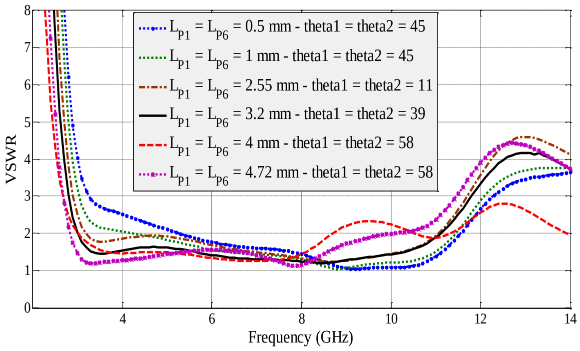

Fig. 4. Simulated VSWR curves of the proposed antenna with different values of $L_{P1} = L_{P6}$ length and $\theta_1 = \theta_2$ angle; other parameters are the same as listed in Table 1.

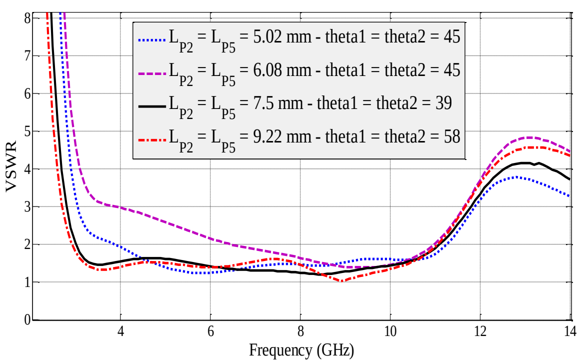

Fig. 5. Simulated VSWR curves of the proposed antenna with different values for $L_{P2} = L_{P5}$ length and $\theta_1 = \theta_2$ angle; other parameters are the same as outlined in Table 1.

Fig. 6, shows the simulated results of the proposed antenna with $L_{P3} = L_{P4}$ length, from 6.02 to 7.43 mm with $\theta_1 = \theta_2$ angle, from 39° to 45°. It can be observed that $L_{P3} = L_{P4} = 7.953$mm with $\theta_1 = \theta_2 = 39^{\circ}$ have VSWR<2 bandwidth at the UWB band. As a result, the optimum conditions are $L_{P3} = L_{P4} = 7.953$ mm with $\theta_1 = \theta_2 = 39^{\circ}$ resulting in the bandwidth from 2.9 to 11.2 GHz. The final angles and dimensions of the lip-shaped patch are $\theta_1 = \theta_2 = 39^{\circ}$ with parameters outlined in Table 1.

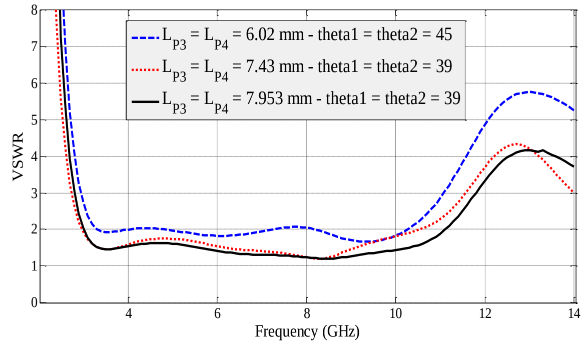

Fig. 6. Simulated VSWR curves of the proposed antenna with different values of $L_{P3} = L_{P4}$ length and $\theta_1 = \theta_2$ angle; other parameters are the same as outlined in Table I.

2.2. Variation of Overall-Size Ground Plane

Fig.7, presents the simulated results of the proposed antenna with overall size of ground structure, from 25 mm to 30 mm. By increasing overall size of ground plane, the proposed antenna can cover UWB band with VSWR<2. Therefore, it is decided to take overall size of ground plane 30 × 30 mm^2 as the optimum, with minimum mismatch at the entire frequency of UWB band. Fig. 8, shows the input impedance S_{11} of the proposed antenna from 3.1 to 10.6 GHz.

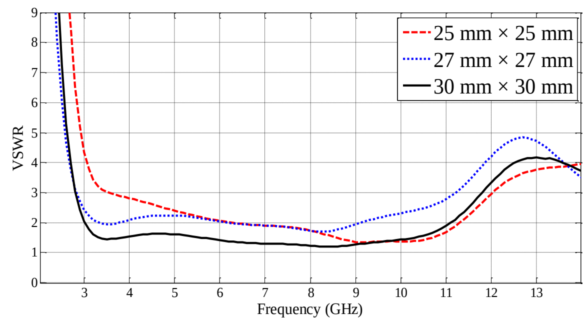

Fig.7. The simulated VSWR for the proposed UWB microstrip antenna with various ground size.

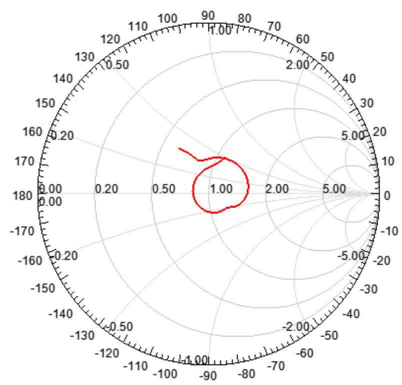

Fig. 8. The simulated S_{11} of the proposed antenna

3. NOTCH BAND CHARACTERISTICS

Two C-shaped slots are used to reject WLAN band from the UWB band. Fig. 9, shows the geometry and configuration of the C-shaped slots of proposed structure. The notched-band is obtained through adjustment of the C-shaped slots to about half wavelength at the notched frequency with the wavelength being $\lambda_g = \lambda_0/\sqrt{\varepsilon_{eff}}$ and $\varepsilon_{eff} = (\varepsilon_r + 1)/2$, where λ_0 represents the free-space wavelength. Analysis of the effect of the length, the width, and the position, of the C-shaped slots in the ground plane, makes it possible to obtain the optimized configuration of the slots and the WLAN band rejection.

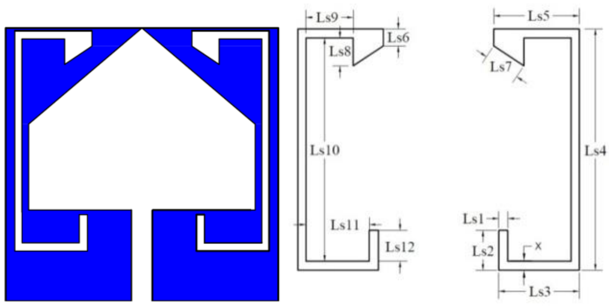

Fig. 9. The geometry and configuration of the two C-shaped slots on the ground plane.

Fig. 10, depicts the simulated VSWR results of two C-shaped slots of the proposed antenna having the length $L_{S6} = 0.9$ mm, and 1.7 mm. It is found that $L_{S6} = 1.7$ mm leads to a good notched band at 5.15-5.825GHz frequencies WLAN band. As a result, the optimum condition is represented at $L_{S6} = 1.7$ mm. This being the case, the C-shaped slots are designed with a taper in the C-shaped slots upper section.

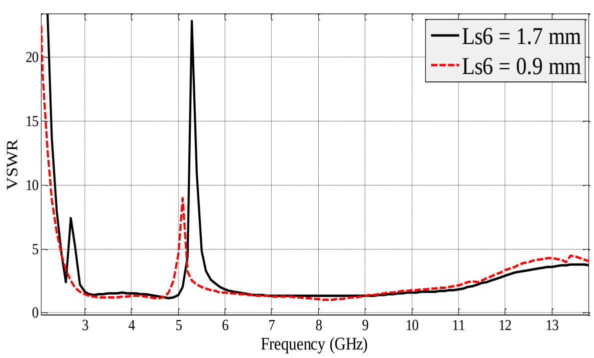

Fig. 10. Simulated VSWR for the C-shaped slots of the proposed antenna with different values of L_{S6}.

Fig.11, shows that as the length L_{S10} increased from 21 to 24mm, the notched band moves to the lower frequency. It can be observed that the $L_{S10} = 22.4$ mm can result in the band rejection function at the WLAN band. Accordingly, it was decided to consider $L_{S10} = 22.4$ mm as the optimum. Fig. 12, depicts the influence of the C-shaped slot width X on the simulated VSWR of the antenna. As can be observed, increases in X move the notched band to the higher frequency where X = 0.9 mm can reject WLAN band from UWB band. Table 2 shows the optimal dimensions of the C-shaped slots.

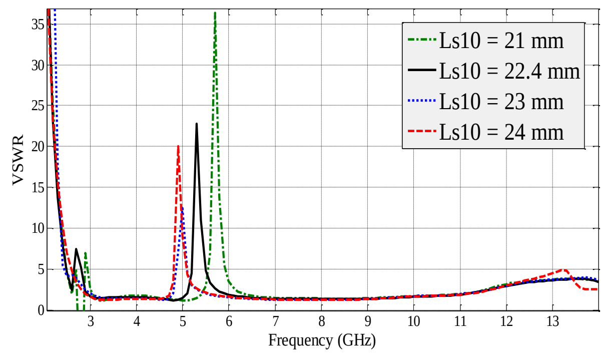

Fig. 11. Simulated VSWR for the C-shaped slots of the proposed antenna with different values of L_{S10}.

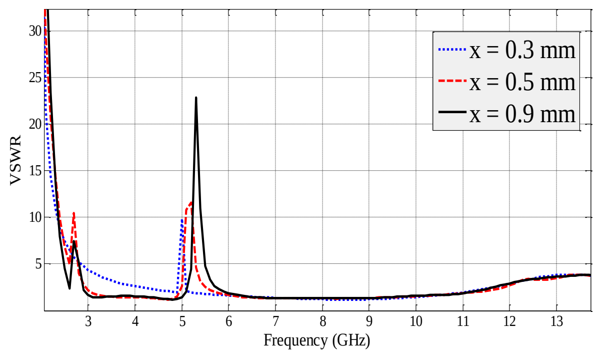

Fig. 12. Simulated VSWR for the C-shaped slots of the proposed antenna with different values of X.

Table 2. Design parameters of the two C-shaped slots on the ground plane Fig. 9.

Parameters	L_{S1}	L_{S2}	L_{S3}	L_{S4}
Unit(mm)	0.9	4	8	24.2
Parameters	L_{S5}	L_{S6}	L_{S7}	L_{S8}
Unit(mm)	8.5	1.7	3	2.8
Parameters	L_{S9}	L_{S10}	L_{S11}	L_{S12}
Unit(mm)	4.7	22.4	6.3	3.1

4. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed UWB microstrip antenna is simulated and optimized using the High-Frequency Structure Simulator (HFSS). Fig.13, shows the fabricated antenna. The parameter voltage standing-wave ratio (VSWR) of the proposed structure is measured using the Agilent 8722ES vector network analyzer. Fig.14, shows the measured and simulated VSWR curves of the proposed antenna with WLAN band rejection characteristics. As shown in Fig. 14, the simulated and the measurement results are in good agreement with the small difference between the measured and the simulated results being due to the introducing of the

SMA connector and tolerance in manufacturing. The designed antenna can cover the frequency band 2.9–11.2 GHz with (5.15-5.825GHz) WLAN band rejection. Group delay is a significant parameter in the design of the UWB antenna. To achieve optimal pulse transmission, group delay should be almost constant in the UWB band. The simulated group delay result of the proposed structure is represented in Fig. 14. As can be observed, the group delay variation for the proposed antenna is roughly constant for the UWB band except in the (5-6 GHz) WLAN band where the group delay is not constant. The group delay variation is less than 0.1ns in the operating UWB band. The maximum value of group delay is about 3ns at center frequency of the notched band.

Fig. 13. Photograph of the fabricated UWB microstrip antenna.

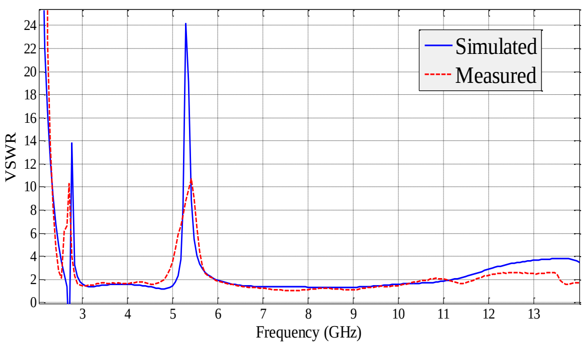

Fig. 14. VSWR for the proposed UWB microstrip antenna with WLAN band rejection characteristics.

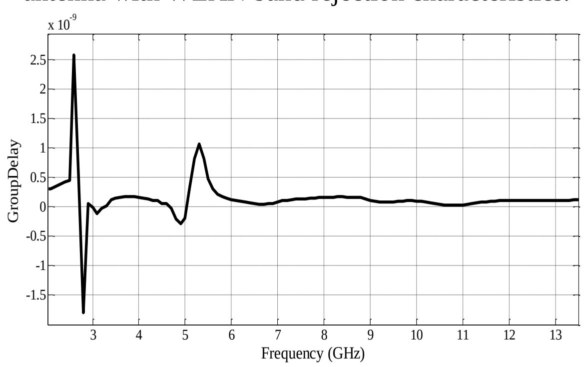

Fig. 15. The group delay of the proposed UWB microstrip antenna with WLAN band rejection characteristics.

Furthermore, the simulated antenna gain with and without rejected band is shown in Fig. 16. Within the operating band, the proposed antenna possesses stable gain. It can also be observed that there is abrupt reduction at the notched band which evidently confirms the signal-rejection capability of the proposed antenna.

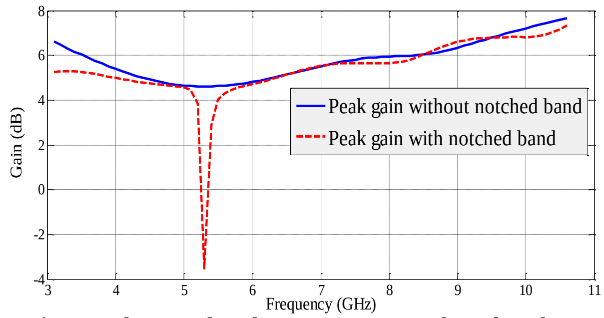

Fig.16. The simulated antenna gain with and without the notched band.

Fig. 17, shows the simulated current distributions of our proposed antenna at frequencies 4, 5.5 and 9.5 GHz for the optimal design. As shown in Fig. 17(b), we can see that the current is mainly distributed on the C-shaped slot, which results in band-stop effect. In Fig. 17(a), and 17(c), weak current distribution on the C-shaped slot is observed. The natural interpretation is that the C-shaped slot is not the major contributor of antenna performance except for the notch frequency.

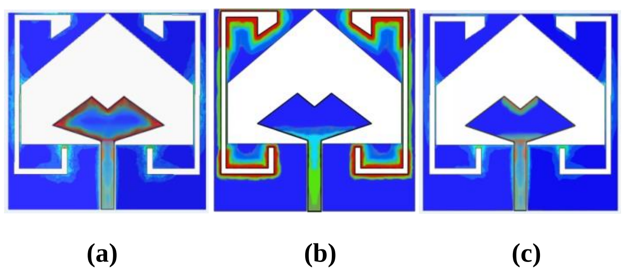

Fig. 17. Surface current distribution of the proposed antenna at (a) 4 GHz, (b) 5.5 GHz and (c) 9.5GHz.

Fig. 18(a)-(c), depicts normalization of the measured far-filed radiation patterns including the co-polarization and cross-polarization of the proposed antenna at frequencies of 3.5, 6.44, and 9.5 GHz in E-plane (yz-plane) and H-plane (xz-plane). It becomes clear that the proposed antenna has omnidirectional radiation pattern in the H-plane over the entire UWB frequency band. At lower frequencies, it is seen that our proposed design exhibits as an omnidirectional profile for the x-z plane and a bi-directional one for the y-z plane. With the increase of frequency, then proposed antenna becomes more directive, but still remains bi-directional.

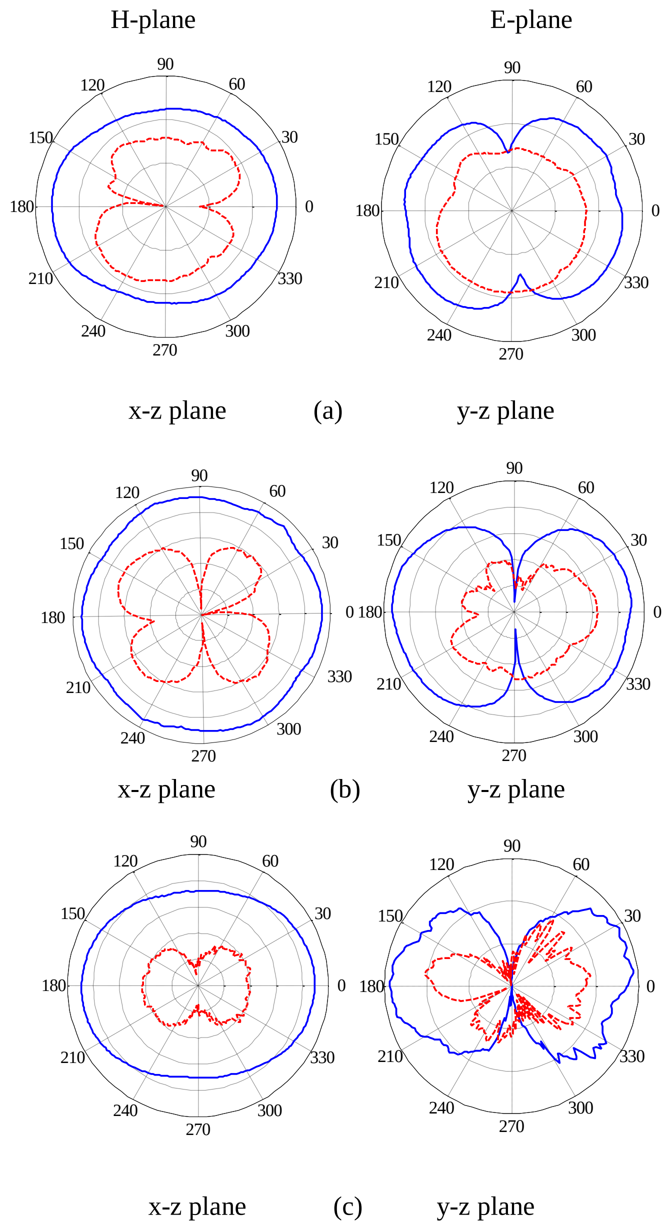

Fig. 18. Radiation patterns of the proposed antenna at frequencies of (a) 3.5, (b) 6.44, (c) 9.5 GHz with co-polar and cross-polar in the E-plane and H-plane.

Comparison of the proposed UWB antenna with other recently reported notch band UWB antenna in Table 3 shows that the proposed antenna is substantially smaller.

Table 3. Comparison of the proposed UWB antenna.

Ref	operating Bandwidth(GHz)	Notch band frequency (GHz)	Dimension (mm^2)
[9]	3.1 - 10.5	WLAN(5-6)	30×34=1020
[10]	3 - 11	WIMAX(3.3-3.8), WLAN(5-6), X-band(7.9-8.4)	35×35=1225
[11]	2.8 - 11	-	50×50=2500
[12]	3.1 - 10.6	WIMAX(3.3-3.8), WLAN(5-6)	37×34=1258
[13]	2.9 - 12	WIMAX(3.3-3.8), WLAN(5-6)	30×35=1050
[14]	3.1 – 10.6	WIMAX(3.3-3.8), WLAN(5-6)	35×30=1050
This work	2.9 -11.2	WLAN(5-6)	30×30=900

5. CONCLUSION

The present research introduces a novel UWB microstrip antenna having WLAN band rejection characteristics. The proposed antenna possesses a simple structure and an operating frequency band of 2.96 GHz to 11.2 GHz. The measured and the simulated results are in satisfactory agreement. To minimize interference between the UWB systems and the WLAN systems, two C-shaped slots are embedded on the ground plane. The measured and simulated results reveal this factory impedance matching characteristics, stable gain, constant group delay, and nearly omnidirectional radiation patterns within the working band.

REFERENCES

[1] Federal Communication Commission, Washington, DC, USA, **"Revision of part 15 of the Commissions' rule regarding ultra- wideband transmission systems FCC 02–48,"** *First Report and Order*, Feb. 2002.

[2] A. K. Gautam, S. Yadav, and B. K. Kanaujia, **"A CPW-Fed Compact UWB Microstrip Antenna,"** *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, pp. 151–154, 2013.

[3] J. Zang, and X. Wang, **"A Compact C-Shaped Printed UWB Antenna with Band-Notched Characteristic,"** *Progress In Electromagnetics Research Letters*, Vol. 43, 15-23, 2013.

[4] P. Gao, L. Xiong, J. Dai, Sh. He, and Y. Zheng, **"Compact Printed Wide-Slot UWB Antenna with 3.5/5.5-GHz Dual Band-Notched Characteristics,"** *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, pp. 983–986, 2013.

[5] W. Zhiyong, and Zh. Cuiping, **"A Planar UWB Antenna with Triple-Notched Bands,"** *Progress In Electromagnetics Research Letters*, Vol. 52, 99–104, 2015.

[6] U. Chakraborty, A. Kundu, S. K. Chowdhury, and A. K. Bhattacharjee, **"Compact Dual-Band Microstrip Antenna for IEEE 802.11a WLAN Application,"** *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, pp. 407–410, 2014.

[7] Sh. Tripathi, A. Mohan, S. Yadav, **"A Compact UWB Antenna with Dual 3.5/5.5 GHz Band-Notched Characteristics,"** *Microw. Opt. Technol. Lett*, Vol. 57, No. 3, pp. 551–556, 2015.

[8] S. S. Huang, J. Li, and J. Zh. Zhao, **"A Novel Compact Planar Triple-Band Monopole Antenna for WLAN/WiMAX Applications,"** *Progress In Electromagnetics Research Letters*, Vol. 50, 117–123, 2014.

[9] R. A.Sadeghzadeh, M. A. Honarvar, and A. R. Eskandari, **"Coplanar-fed UWB elliptical patch antenna with notched band characteristics**," *PIERS Proceedings, 1225-1228, Xian*, China, Mar. 22-26, 2010.

[10] D. Sarkar, K. V. Srivastava, and KushmandaSaurav, **"A Compact Microstrip-Fed Triple Band-Notched UWB Monopole Antenna,"** *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, pp. 396–399, 2014.

[11] J. Y. Siddiqui, C. Saha, and Y. M. M. Antar, **"A Novel Ultra Wideband (UWB) Printed Antenna with a Dual Complementary Characteristic,"** *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, pp. 1–4, 2014.

[12] F. Fan, Z. Yan, T. Zhang, and Y. Song, **"Ultra-wideband planar monopole antenna with dual stopbands,"** *Microw. Opt. Technol. Lett*, Vol. 52, No. 1, pp. 138–141, 2010.

[13] W. X. Liu, and Y. Z. Yin, **"Dual Band-Notched Antenna with the Parasitic Strip for UWB,"** *Progress In Electromagnetics Research Letters*, Vol. 25, 21-30, 2011.

[14] H. Chen, Y. Ding, and D. S. Cai, **"A CPW-Fed UWB Antenna with WIMAX/WLAN Band-Notched Characteristics,"** *Progress In Electromagnetics Research Letters*, Vol. 25, 163-173, 2011.