A Compact CPW-Fed UWB Antenna with Dual-Band Notched Characteristics for WiMAX/WLAN Applications

Rabah W. Aldhaheri [1], Ibrahim S. Alruhaili [1], Kamili J. Babu [2], and Muntasir M. Sheikh [1]

[1] Department of Electrical and Computer Engineering
King Abdulaziz University, Jeddah 21589, Saudi Arabia
raldhaheri@kau.edu.sa, ibra.s.s@hotmail.com, mshaikh@kau.edu.sa

[2] Department of Electronics & Communication Engineering
St. Ann's College of Engineering & Technology, Chirala, India
jagan_ec@yahoo.com

Abstract **─** A dual-notched bands ultra-wideband (UWB) antenna with coplanar waveguide (CPW) fed is presented in the paper. The two notched bands are selected at 3.5 and 5.8 GHz frequencies to overcome the interference from WiMAX and WLAN bands. The overall size of the antenna is 17.5×17.5 mm^2, which can be considered as one of the smallest UWB antennas in the literature. The developed antenna has an impedance band width ranging from 2.9 to 13 GHz. The measured radiation patterns on E and H planes are nearly omni-directional and stable with acceptable gain over the entire band. The dual-band notched at WiMAX and WLAN is created by embedding I-shaped and C-shaped stubs in the radiation patch of the antenna. Due to the compactness, good radiation patterns and the reasonable stable gain, this antenna is well suited for integration into portable wireless communications devices for UWB applications.

Index Terms **─** CPW fed antenna, dual-band-notched characteristics, Ultra-Wideband (UWB), C-shaped stub.

I. INTRODUCTION

The federal communications commission (FCC) permitted 3.1 GHz to 10.6 GHz band for unlicensed civil applications with a good radiation power [1]. Since then, ultra-wideband (UWB) technology is one of the most promising wireless technologies owing to its high data rate, low power consumption, and increased flexibility to multipath interference. Microstrip feeding with full or partial ground and CPW-fed antenna are widely used for designing UWB Antennas of bandwidth ranging from 3.1 to 10.6 GHz. Over this band, there are several narrow band wireless communication systems, such as WiMAX (3.3–3.7 GHz) and WLAN (5.15–5.875 GHz), and the downlink of X-band satellite system (7.25-7.85 GHz), etc. [2, 3]. So, in order to overcome the interference with these narrow bands, a new UWB antennas design with band-notched characteristics were presented to filter out the interferences caused by the narrow bands wireless systems [2-17]. Many of these techniques used various types of slots in the radiating patch or/and in the ground to create the notch band at certain frequency bands. Some of these designs fail to achieve the desired notched bands and some designs have complex structures to generate notched band at certain bands. In [2], a comprehensive review for achieving band notch characteristics in UWB using different techniques such as etching slots, parasitic element, metamaterials and electromagnetic band gap (EBG) are discussed. In [3 – 6], a single band notched is created by etching certain shapes in the radiating patch or in the ground.

In [7 – 14], dual-band notched UWB antennas were presented where E-shaped, L-shaped, C-shaped or inverted C-shaped, split rings are employed to create notches in in the WiMAX and WLAN bands. In these examples the structures are more complicated and with bigger size. In [9], the overall size is 29 X 20.5 mm^2, but the structure is more complicated than our structure and controlling the notched bands needs more than one factor and it might require a major change in the antenna structure. The antenna proposed in [10] covers the WLAN 2.4/5.8 GHz and the WiMAX band at 3.5 GHz, but the size is 38 X 20 mm^2. In [11], an octagonal-shaped UWB with Minkowski fractal notch and dual C-shaped notch at the either side of the feed line for rejection of the WLAN band is presented and the size of this antenna is 26 X 16.5 mm^2. In [12-14], triangular patch and double rectangular ring-shaped were suggested, but the dimensions are still big and the structures are more complex.

In [15 - 17], triple notch band characteristics are achieved by adding two modified S-shaped cells on either side of Microstrip line as in [15], or etching open-ended L-shaped slot in the ground plane for notching the downlink of the X-band [7.25-7.85 GHz] as in [16], or by adding two separated quarter-wavelength strips in the

Submitted On: October 18, 2020
Accepted On: December 5, 2020
https://doi.org/10.47037/2020.ACES.J.360205
1054-4887 © ACES

patch and etching a half wavelength hook-shaped slot on the ground as in [17].

In this paper, a very compact, simple and low cost CPW-fed UWB antenna design is presented and analyzed. The characteristic of this antenna is investigated numerically and experimentally. A dual-band notched at WiMAX and WLAN is created by embedding I-shaped and C-shaped stubs in the radiation patch of the antenna. The center frequency and the band of the WLAN is controlled by the length and width of the I-shaped stub, while the center frequency and the band of the WiMAX is controlled and adjusted by the minor and the major radii of the elliptic C-shaped stub. The overall size of this antenna is 17.5 × 17.5 × 1.5 mm^3, which is very compact to be integrated in hand-held high-speed wireless devices.

II. ANTENNA STRUCTURE

The schematic view of the proposed antenna is shown in Fig. 1. The design and optimization of the proposed antenna dimensions are carried out using ANSOFT HFSS electromagnetic simulator [18]. An FR4 substrate with a relative permittivity of 4.4 having a substrate thickness of 1.5 mm and a loss tangent of 0.02 is used for the antenna design. A coplanar waveguide CPW-fed of a trapezoidal shape of width, F_w and P_{L3} with a gap distance of g_1 and g_2 are used to feed the antenna in order to achieve a 50 Ω input impedance matching. The antenna consists of trapezoid ground planes symmetrically around the CPW feed line. The bottom plane dimensions are taken with a width of G_W, a lower length of G_{LL} mm and an upper length of G_{UL} as shown in Fig. 1. The dimensions of the two trapezoids are *C1* and *C2* respectively, and the lengths of the bottom and top parallel sides are P_{L1}, P_{L2} and P_{L3}.

The elliptic slot of major and minor radii of *A* and *B* is etched from the radiating area to insert the C-shaped and the I-shaped resonators which are using for controlling the band notched characteristics for the WiMAX and WLAN, respectively.

III. DESIGN PROCEDURE

Three antennas are presented in Fig. 2 to analyze the evolution process of the final designed antenna. As in traditional antenna design procedures, design starts by initial theoretical calculation to estimate dimensions of Antenna 1 as illustrated in Fig. 2. The first antenna has two trapezoid shapes fed by a 50-Ω CPW-line surrounded by symmetrical ground planes in both sides with optimized dimensions as given in Table 1. The current distribution of Antenna 1 at 3.5 GHz is shown in Fig. 3, where it can be seen that the current distribution is minimum at the middle portion of the patch at this particular frequency. Hence, this portion is removed and an elliptic slot is etched at the middle portion as shown in Antenna 2 and this elliptical slot is responsible in achieving the wideband with notch characteristics as explained below. In the next step, an I-shaped monopole resonator is incorporated with length L_I as shown in Fig. 2 to achieve band-notched characteristic at WLAN.

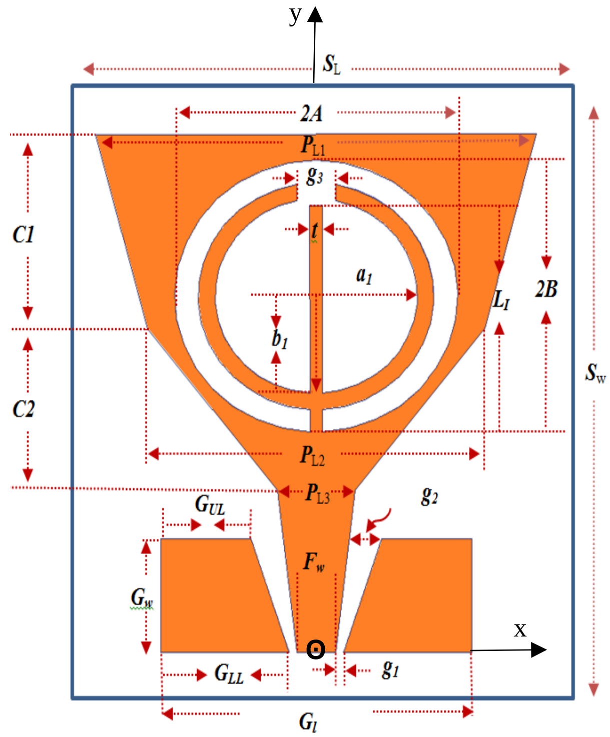


Fig. 1. Geometry of proposed antenna.

Another notch band rejecting WiMAX band is realized by embedding a C-shaped stub at the center of the ellipse resulting the final antenna structure as indicated in Fig. 2, Antenna 3.

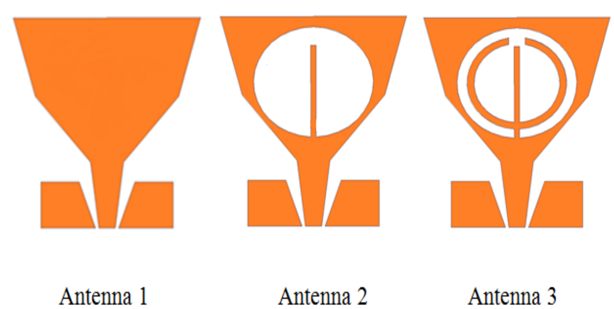


Fig. 2. Evolution of the Proposed Antenna.

The numerical reflection coefficients of the three designed antennas without, with one-notch at 5.8 GHz and with 2 notches at 3.5 GHz and 5.8 GHz are shown in Fig. 4.

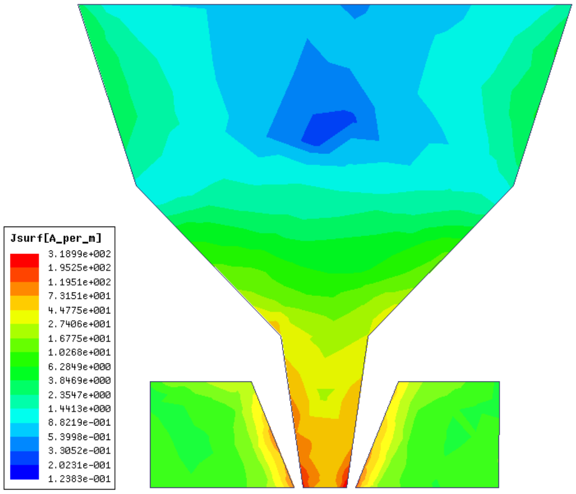


Fig. 3. Current distribution of Antenna 1 at 3.5 GHz.

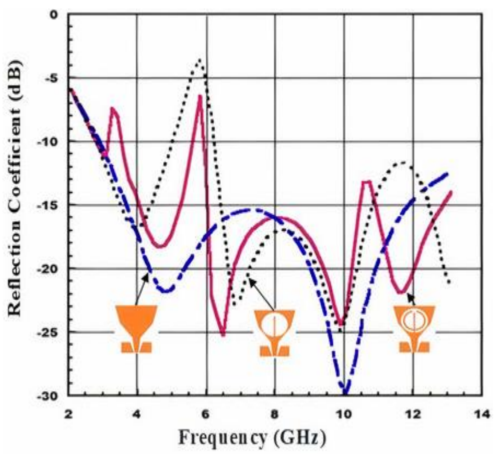


Fig. 4. Simulated reflection coefficient of Antenna 1, Antenna 2 and Antenna 3.

IV. DUAL-BAND NOTCH DESIGN PARAMETERS

Antenna 1 covers the entire UWB band. For obtaining band-notch for WLAN frequency (5.8 GHz), a monopole I-shaped quarter-wavelength stub, L_I is inserted on radiating part as shown in Antenna 2. The length of I-shaped slot is given approximately by Eq. (1), [3, 6]:

$$L_I = \frac{c}{4f_{5.8}\sqrt{(\varepsilon_r+1)/2}}, \qquad (1)$$

where L_I is the length of the I-shaped stub for WLAN band, *c* represents light speed, ε_r is dielectric permittivity constant 4.4 and $f_{5.8}$ represents center frequency of WLAN band (5.8 GHz). After exhaustive simulation studies, it is found that the practical length of L_I is 7.55 mm compared with 7.87 mm obtained by Eq. (1). The value of L_I is critical in determining the center frequency of rejected band of WLAN. By inserting C-shaped stub, we can generate the second notched band at 3.5 GHz to reject WiMAX band. The length of C-shaped stub acting as a half-wavelength resonator [6, 10] as given by Eq. (2):

$$L_c = \frac{c}{2f_{3.5}\sqrt{(\varepsilon_r+1)/2}}, \qquad (2)$$

where L_C represents C-shaped stub length, and $f_{3.5}$ is center frequency of WiMAX band (3.5 GHz). L_C is approximately equal to the perimeter of the ellipse of major radius $a = (a_1+t)$ mm and minor radius, $b = (b_1+t)$ mm. The approximate perimeter equation is given by Eq. (3), [6]:

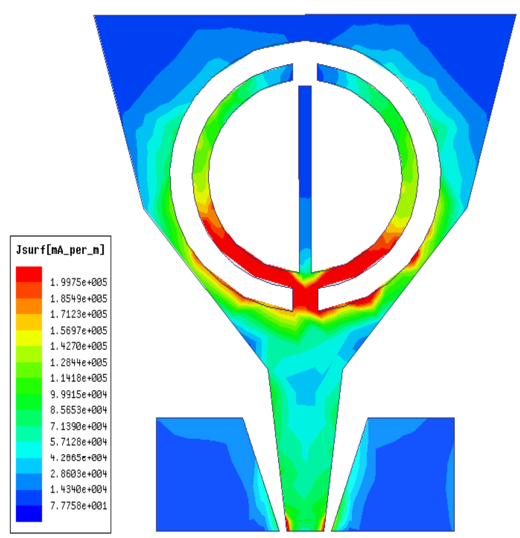
$$\boldsymbol{P} \approx 2\pi\sqrt{\frac{a^2+b^2}{2}}. \qquad (3)$$

Equation (3) gives $\boldsymbol{P} \approx 24.98$ mm while the optimized L_C = 26.06 mm is obtained using Equation (2). By introducing the strip with length of L_C, the desired dual-band notched characteristics with UWB operating band is obtained. Hence, the etched gap (g_3) in the C-shaped stub is to adjust and control the middle frequency of lower notch band of the WiMAX, a compromise result of g_3 = 1.0 mm is obtained.

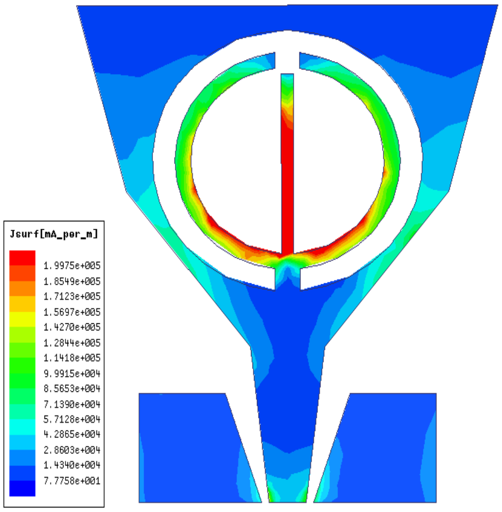
The surface current distributions of the final antenna structure at both the notch frequencies are shown in Fig. 5. From Fig. 5 (a), it is clear that surface current distribution on the C-shaped of the patch at WiMAX frequency is maximum. Similarly, the current distribution presented on I-shaped stub at WLAN frequency is maximum as shown in Fig. 5 (b).

V. PARAMETRIC STUDY

Parametric analyses of the antenna is carried out to compute the optimal parameters of the desired antenna using Ansoft HFSS electromagnetic simulator [18]. The final optimized parameters are listed in Table 1.



(a)



(b)

Fig. 5. Current distribution of Antenna 3 at: (a) 3.5 GHz and (b) 5.8 GHz.

Table 1: Optimized parameters of proposed antenna

Parameters	Unit (mm)
S_L	17.5
S_w	17.5
P_{L1}	17.0
P_{L2}	13.0
P_{L3}	3.0
G_l	12.0
G_w	3.5
G_{LL}	5.85
G_{UL}	3.47
g_1	0.15
g_2	1.23
g_3	1.0
F_w	1.5
a_1	3.9
b_1	3.0
t	0.5
$C1$	6.0
$C2$	5.0
A	5.46
B	4.2

The parametric study of all the parameters is conducted and in the figures below we present some of these studies. Figures 6 and 7 show the reflection coefficients as a function of the ground width and length, G_W and G_l. In Fig. 6, it is observed that as the parameter G_W increases, the center frequency of the WiMAX band increases while the center frequency of the WLAN notch frequency is slightly changed. However, increasing the length, G_l of ground will slightly shift the WLAN and WiMAX notched bands as shown in Fig. 7. Figure 8 illustrates the effect of the minor radius of the inner ellipse of C-shaped, b_1 which mainly controls the center frequency of WiMAX band. The other parameters are studied and the final results are listed in Table 1.

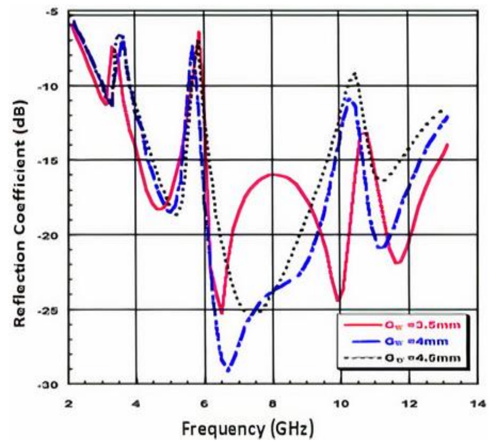


Fig. 6. Parametric analysis w.r.t G_w.

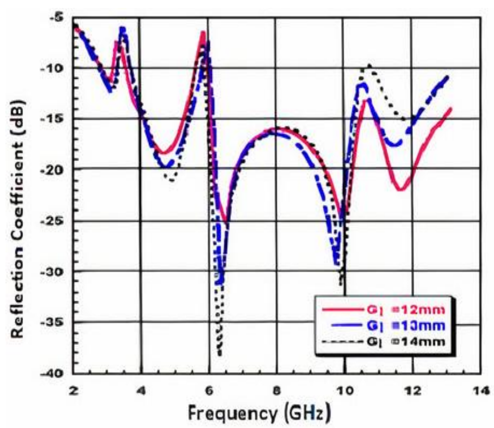


Fig. 7. Parametric analysis w.r.t *Gl*.

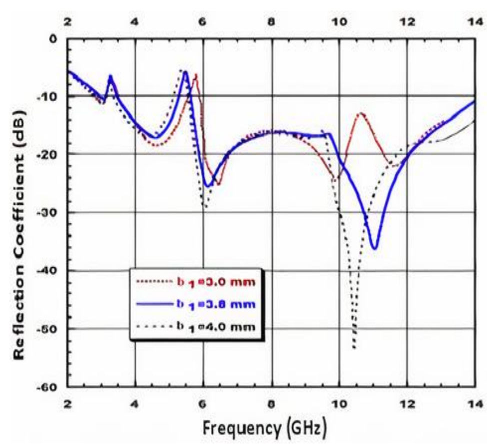


Fig. 8. Parametric analysis w.r.t b_1.

VI. RESULTS AND DISCUSSION

To evaluate the performance of the optimized antenna, the proposed antenna is fabricated and tested. The photograph of the final version of the fabricated antenna is shown in Fig. 9. Vector Network Analyzer (VNA) N5225A is used to carry out the measurements of the reflection coefficient, gain and radiation patterns of the designed antenna. Figure 10 gives the simulated and measured results of the reflection coefficients. As shown from the figure, a good agreement between the measured and simulated reflection coefficients is observed. The slight variation between the results is due to the fabrication tolerances and the SMA connector soldering to the feeder, which is included in the measurements but not taken into account in the simulated results. As seen, the developed antennas rejects both the WiMAX and WLAN bands, while covering the entire UWB band.

Fig. 9. Fabricated antenna.

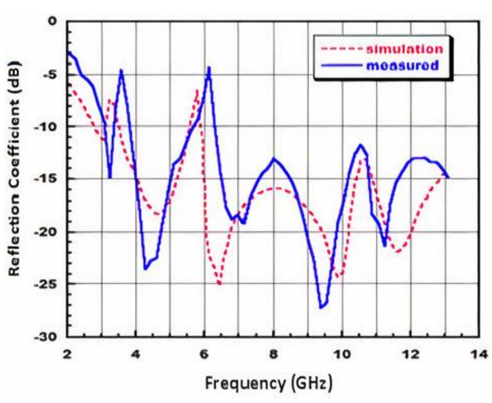
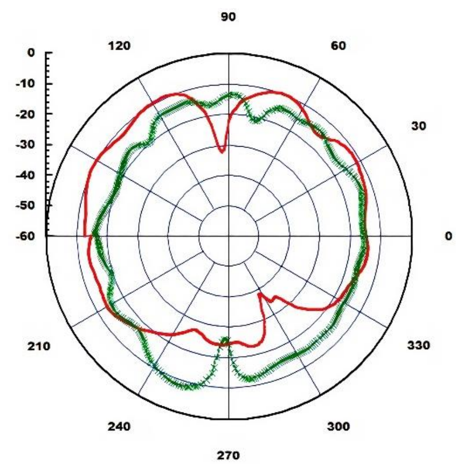
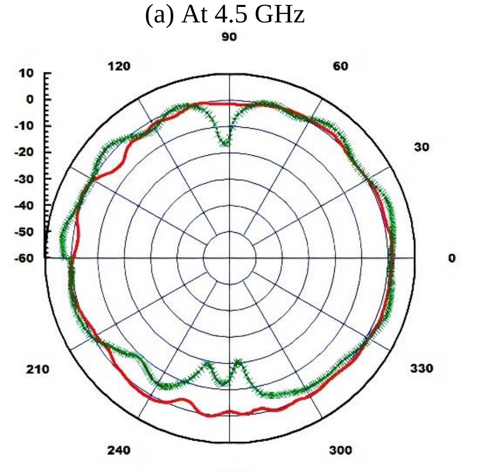


Fig. 10. Comparison of simulated and measured results.

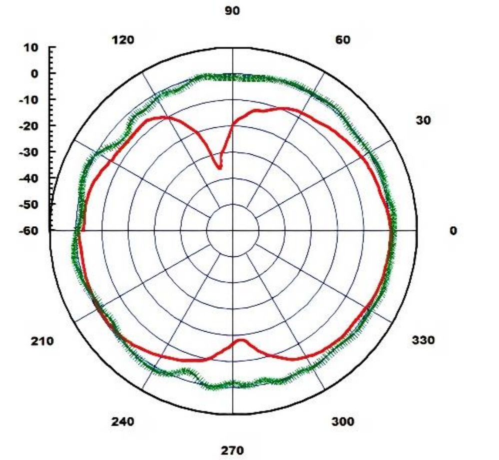
At different frequencies like 4.5 GHz, 7.0 GHz, and 10.0 GHz the measured radiation patterns in the E and H planes are displayed in Fig. 11. From this figure, it is observed that the radiation patterns in the H-plane (x-z plane) are nearly omni-directional for the three frequencies. In the E-plane (y-z plane), they are approximately omnidirectional at 7 GHz and bidirectional at the other two frequencies. Hence, the developed compact antenna has a good radiation patterns over the operating bands. The measured gain of the antenna is given in Fig. 12. It is clearly seen that the proposed antenna exhibits a moderate gain response with gain variation between 2.4 dBi and 5.2 dBi throughout the desired UWB frequency band and except at the notched bands, a sharp reduction of the gain to -1.1 and -2.3 dBi, respectively is observed at WiMAX and WLAN notched bands which shows that the antenna performed well in these bands.



(a) At 4.5 GHz



(b) At 7 GHz



(c) At 10 GHz

Fig. 11. Measured E-plane (red) and H-plane (green) of the proposed antenna at: (a) 4.5 GHz, (b) 7.0 GHz, and (c) 10 GHz.

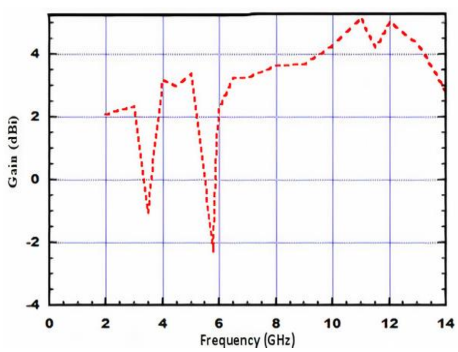


Fig. 12. Measured gain of the proposed antenna.

VII. CONCLUSION

In the proposed work, a very compact with a size of 17.5 mm × 17.5 mm UWB antenna with dual band-notch characteristics is designed and studied. The dual-notch characteristics are obtained by simply inserting C-shaped and I-shaped stubs on the antenna to attain dual-notch properties for rejecting the interference of signals at WiMAX and WLAN applications with a wide bandwidth from 2.9 to 13 GHz. The desired notch frequencies can be adjusted and tuned by properly choosing the I-shaped length, L_I, for the WLAN and the major and minor radii of the elliptic C-shaped for the WiMAX. Also, good radiation patterns and stable gain are achieved in the entire operating band. The operation of the antenna with dual-notch band is justified using reflection coefficient and gain values over the UWB except at the two notched bands. The compact size and the good radiation performance of this presented antenna make it appropriate for UWB system applications.

REFERENCES

[1] Federal Communication Commission, "First report and order Revision of part 15 of the Commission's rules regarding ultra-wideband transmission system," Tech. Rep., ET 98-153, FCC Washington, DC, USA, 2002.

[2] K. Gurupreet and K. Rajeev, "A survey on planar ultra-wideband antennas with band notch characteristics: Principle, design, and applications," *AEU International Journal of Electronics and Communications*, vol. 109, pp. 76-98, 2019.

[3] R. W. Aldhaheri, K. J. Babu, A. Syed, and M. M Sheikh, "A novel UWB rectangular slot disk monopole antenna with band-notch characteristics," *Microwave and Optical Technology Letters*, vol. 57, no. 10, pp. 2405-2410, 2015.

[4] R. Azim, A. T. Mobashsher, and M. T. Islam, "UWB antenna with notched band at 5.5 GHz," *Electronics Letters*, vol. 49, no. 15, 2013.

[5] K. J. Babu, B. K. Kumar, B. S. Rao, and A. M. Varaprasad, "Design of a compact elliptical slot printed UWB antenna with band-notched characteristic," *International Journal of Electronics Letters*, vol. 7, no. 4, pp. 448-457, 2020.

[6] R. W. Aldhaheri and I. S. Alruhaili, "A simple and compact CPW-fed UWB antenna with WLAN band rejection," *In: Proceedings of IEEE 19th Mediterranean Microwave Symposium (MMS)*, Hammamet, Tunisia, pp. 1-4, 2019.

[7] L. Chen, Y. Liu, and P. Wu, "Design of compact asymmetric coplanar strip-fed UWB antenna with dual band-notched characteristics," *Progress In Electromagnetics Research Letters*, vol. 47, pp. 103-109, 2014.

[8] C. Liu, T. Jiang, Y. Li, and J. Zhang, "A compact wide slot antenna with dual band-notch characteristic for ultra-wideband applications," *Journal of Microwaves Optoelectronics and Electronics*, vol. 10, no.1, pp. 55-64, 2011.

[9] R. Azim and M. T. Islam, "Ultra-wideband antenna with notched bands at 3.5/5.5 GHz," *Applied Computational Electromagnetics Society Journal*, vol. 31, no. 4, pp. 388-395, 2016.

[10] X. Ren, S. Gao, and Y. Yin, "Compact tri-band monopole antenna with hybrid strips for WLAN/ WIMAX applications," *Microwave and Optical Technology Letters*, vol. 57, no. 1, pp. 94-99, 2015.

[11] S. Tripathi, A. Mohan, and S. Yadav, "A compact UWB antenna with dual 3.5/5.5 GHZ band-notched characteristics," *Microwave and Optical Technology Letters*, vol. 57, no. 3, pp. 551-556, 2015.

[12] S. Hoseyni, J. Nourinia, C. Ghobadi, S. Masumina, and B. Mohammadi, "A compact design and new structure of monopole antenna with dual bad notch

characteristic for UWB applications," *Applied Computational Electromagnetics Society Journal*, vol. 31, no. 7, pp. 797-805, 2016.

[13] S. Jo, H. Choi, J. Lim, B. Shin, S. Oh, and J. Lee, "A CPW-fed monopole antenna with double rectangular rings and vertical slots in the ground plane for WLAN/WiMAX applications," *International Journal of Antenna and Propagation*, vol. 2015, pp. 1-7, 2015.

[14] R. Shi, X. Xu, J. Dong, and Q. Luo, "Design and analysis of a novel dual band-notched UWB antenna," *International Journal of Antennas and Propagation*, vol. 2014, pp. 1-10, 2014.

[15] Z. Ma, F. Dong, Z. Han, S. Han, and Q. Xue, "Compact UWB antenna with triple band – Notches using C-shaped and S-shaped structures," *Applied Computational Electromagnetics Society Journal*, vol. 31, no. 4, pp. 348-354, 2016.

[16] A. Syed and R. W. Aldhaheri, "A new inset-feed UWB printed antenna with triple 3.5/5.5/7.5 GHz band-notched characteristics," *Turkish Journal of Electrical Engineering & Computer Sciences*, vol. 26, no. 3, pp. 1190-1201, 2018.

[17] L. Cui, H. Liu, C. Hao, and X. Sun, "A novel UWB antenna with triple band-notches for WiMAX and WLAN," *Progress in Electromagnetics Research Letters*, vol. 82, pp. 101-106, 2019.

[18] Ansoft High Frequency Structure Simulation (HFSS), ver. 15, Ansoft Corporation, Pittsburgh, PA, 2013.

Rabah W. Aldhaheri received his Ph.D. degree from Michigan State University in 1988, in Electrical and Computer Engineering. He is currently a Full Professor in the Department of Electrical and Computer Engineering, King Abdulaziz University (KAU), Jeddah, Saudi Arabia. He served as the Head of the Department of Electrical and Computer Engineering at KAU from May 2005 till May 2011. He is currently serving as the Founder and Director of the Microelectronics and RF Circuits Laboratory, FSS and Metamaterial Research Laboratory and the Head of the Communication Systems and Networks Research Group.

Aldhaheri has held Visiting Research Scholar positions with Michigan State University during 1994-1995, and Queensland University of Technology (QUT) in Brisbane, Australia in 2000. His research interests include digital signal processing with application to filter design, and biometric recognition, microelectronics devices; and wireless communications, particularly, antennas design for UWB communication, medical imaging, RFID readers and Frequency Selective Surfaces (FSS).

Ibrahim S. Alruhaili was born in Madinah, KSA 1973. He received his B.Sc. in Electrical and Telecommunication Engineering from King Fahad University for Petroleum and Minerals (KFUPM) Dhahran, KSA, in 1998 and M.Sc. degrees in Electronics and Communication, from King Abdulaziz University, Jeddah, KSA in 2016. His primary research interests are in high speed design, printed circuits boards, signal integrity, RF and antenna design.

Jagadeesh Babu Kamili was born in Chirala, Andhra Pradesh, India in 1978. He received B.Tech. degree from SVH College of Engineering, Machilipatnam in the year 1999, M.Tech. and Ph.D. degrees from Jawaharlal Nehru Technological University, Hyderabad, India in 2006 and 2013 respectively. Presently working as Professor and Head of the Department at St. Ann's College of Engineering & Technology, Chirala, India. Also, he is a Postdoctoral Researcher under Certificate of Excellence in Research program from Indian Institute of Technology Kharagpur, India.

He received Travel Grant from SERB, Department of Science and Technology (DST), India to attend International Conference PIERS-2017 in Singapore. He received Best Researcher Award from JNTUK University in 2018. He is senior member of IEEE and life member of IE and ISTE, India. His research areas include printed antennas, meta-materials, Ground penetrating Radar and Characteristic Mode Analysis.

Muntasir M. Sheikh received his B.Sc. from King Abdulaziz University, Saudi Arabia, in Electronics and Communications Engineering, M.Sc. in RF Communications Engineering from the University of Bradford, U.K., and Ph.D. from the University of Arizona, U.S.A. Since then, he has been teaching in the Electrical and Computer Engineering Dept. in KAU. His research interests are Antenna Theory and Design, Radar applications, and electromagnetic metamaterials.