



An Octagonal Shaped Monopole Antenna for UWB Applications with Band Notch Characteristics

Narinder Sharma¹ · Sumeet Singh Bhatia² · Vipul Sharma³ · Jagtar Singh Sivia²

Published online: 23 November 2019

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Abstract

This article presents a microstrip-fed octagonal shaped monopole antenna with dual band notched characteristics for UWB applications. Partial ground plane has been employed in the geometry of proposed antenna to improve the VSWR bandwidth over the entire range of UWB (3.1–10.6 GHz). Initially, the proposed antenna exhibits the VSWR bandwidth of 9.06 GHz (121.28%) with a frequency range of 2.94–12.0 GHz and after introducing C-shaped slot and complementary split ring resonator on the geometry of octagonal shaped radiating patch, dual band notched function has been acquired at Wi-MAX (3.5 GHz) and upper WLAN (5.8 GHz) frequency bands. The overall dimensions of proposed UWB antenna are 30 mm × 30 mm. The proposed antenna is designed and simulated using Ansys HFSS V13 simulator, its fabricated prototype is also tested to validate the simulated results with experimental ones. Both the results are in reasonable agreement with each other. An experimental result also reveals that the proposed antenna depicts nearly omni-directional pattern like dipole antenna.

Keywords Wi-Max · WLAN · Band notch · CSRR · Monopole antenna · UWB

✉ Narinder Sharma
narinder.acet@gmail.com

Sumeet Singh Bhatia
sumeet.bhatia8@gmail.com

Vipul Sharma
vipul.s.sharma@gmail.com

Jagtar Singh Sivia
jagtarsivian@gmail.com

¹ Department of Electrical and Electronics Engineering, Amritsar College of Engineering and Technology, Amritsar, Punjab 143001, India

² Electronics and Communication Engineering Department, Yadavindra College of Engineering and Technology, Punjabi University Guru Kashi Campus, Talwandi Sabo, Bathinda, Punjab, India

³ Department of Electronics and Communication Engineering, Gurukula Kangri Vishwavidyalaya, Haridwar, India

1 Introduction

Day-by-day wireless technology is expanding exponentially, with this; a remarkable growth has been noticed in the wireless communication system and its applications. Indeed, it has created a massive demand for antenna which can operate for shorter range and exhibit multiband characteristics [1, 2]. Specifically, an antenna with less complexity, high precision ranging, low profile, low cost, compact size, light weight, low power spectral density, ease of implementation, high data transmission rate, less power consumption etc. is the need of modern communication system [3, 4]. With the advent of time various techniques like beveling [5], use of shorting pins [6], combining beveling and shorting [7], offset feed [8], double feed [9], trident-shaped feed [10], notching [11], Ultra Wide Band (UWB) etc.; have been applied to attain the aforementioned characteristics of antenna. UWB became most promising technology which is equally useful for indoor as well as outdoor short range wireless communication. It has also created the lot of interest among the distinct telecommunication industrialist as well as academicians because of its unique characteristics, they have designed PCB antennas which are lighter in weight, compact in size and effortlessly embedded into handheld/portable devices or integrated with other Radio Frequency circuits [12]. PCB based antenna consists of patch and a ground plane, and feed line is applied to excite it [13]. Microstrip or CPW feed line can be used for the UWB antenna. These antennas may use various monopole configuration as circular [14], elliptical [15] or octagonal [16]. As every technology, which can has its own pros and cons, UWB is not an exception. The major cons of the UWB antenna which exhibits multiple band notch functions are the space restrictions, mutual coupling of multiband rejection elements and the presence of a part of the frequency band of the UWB application in the rejected interference band. In the design of UWB MIMO antenna the mutual coupling between the band rejected antennas can be reduced by applying distinct techniques which also ensure good isolation between adjacent elements [17]. The distinct techniques used by researchers to reduce the aforesaid effects are introduction of Slits into the patch, insertion of Open-end slit into antenna structure, Electromagnetic Band Gap, Defected Ground Structure, modification in Ground Plane, and accumulation of parasitic elements have been applied. However, Crescent slot [18], Circular ring slot [19], U-slot [20] and the Compact Coplanar Waveguide (CPW) resonant cell (CCRC) [21] have been introduced to realize the antenna which can operate around 5.5 GHz but reported antenna is not physically compact [22] as per the requirement. Though, present era is a witness of unceasing enhancement in the field of antenna designing especially for the UWB applications but interference is all the time the vital issue faced by UWB technology. The noteworthy involvement of interference is noticed because of X-band (satellite communication), WLAN, Wi-MAX etc. Numerous techniques and methods have been suggested by various researchers and scientists to rectify this interference. Kim et al. [23] validated the UWB antenna with SRR slots to attain dual band rejection characteristics. The various types of methods and techniques have been suggested by Li et al. [24–29], to acquire band notch characteristics like reconfigurable notch antenna using switching techniques [25–27] [29], radial stub loaded technique [28] and contour fractal techniques [24]. Sarkar et al. [30] expounded the small sized UWB antenna with dual band notched characteristics at WLAN and Wi-MAX. Two annular slots with splits have been employed in the proposed antenna geometry to achieve the desired band notch filter. Yang et al. [31] revealed an antenna which can exhibit dual band notch characteristics and useful

for automotive communications. In the proposed antenna design, quasi U-shaped Slots, four stubs and stepped ground plane has been introduced to get desired band notched characteristics.

In this paper, octagonal shaped antenna with dual band notched characteristics has been designed to avoid the interference of Wi-MAX and upper WLAN from UWB pass band. Initially, octagonal radiating patch without notch filters has been designed which exhibits VSWR bandwidth of 9.06 GHz with a frequency range of 2.94–12.0 GHz, which lies in the range of UWB (3.1–10.6 GHz). Further, the C-Shaped slot and CSRR has been employed in the geometry of proposed antenna to obtain dual band rejection characteristics. The detailed design of proposed antenna and optimized results has been discussed in Sects. 2, 3 and 4 in this manuscript.

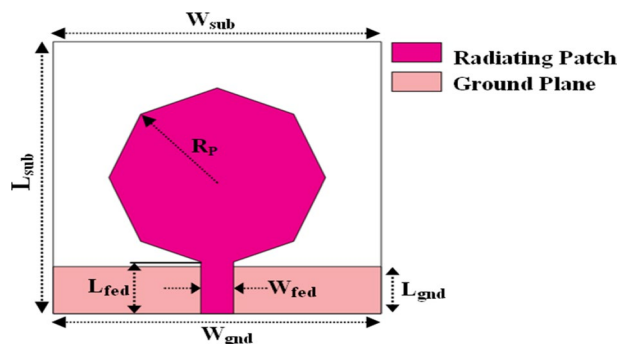
This manuscript contains four distinct Sections. Section 1 is an introduction. Section 2 elaborates the design of proposed octagonal antenna and also enlightens the effect of partial ground plane on the performance of designed antenna. Section 3 adorns the consequences of optimized parameters of CSRR and C-shaped slot on the performance of antenna. This section also elucidates the optimized final geometry and results of proposed antenna with dual band notched filter. At the end, Sect. 4 limns the antenna prototype, juxtaposition of simulated and measured results, comparison of proposed antennas with existing work followed by conclusion.

2 Antenna Configurations

2.1 Design of Octagonal Shaped Monopole UWB Antenna

The schematic configuration of proposed UWB monopole antenna without band notched characteristics is illustrated in Fig. 1. Proposed monopole antenna is simulated, designed and optimized using Ansys High Frequency Structure Simulator (HFSS 13) software. Proposed antenna is realized on low cost FR4 glass epoxy substrate with dielectric constant (ϵ_r) 4.4, loss tangent ($\tan\delta$) 0.02, mass density 19,000 kg/m³ and thickness 1.6 mm. The initial design of proposed UWB monopole antenna consists of octagonal shaped radiating patch with radius ' R_p ' which has been calculated by using Eqs. (1) and (2) [3]. The octagonal patch of designed antenna is being fed by a 50 Ω microstrip transmission line. The dimensions of microstrip transmission line are indicated by ' L_{fed} ' (length) and ' W_{fed} ' (width) in Fig. 1. Further, to improve the impedance matching and VSWR bandwidth over the entire range of UWB passband (3.1–10.6 GHz), a finite/partial ground plane with

Fig. 1 Geometry of proposed UWB monopole antenna without band notched characteristics



length ‘ L_{gnd} ’ and width ‘ W_{gnd} ’ has been introduced in the structure of proposed UWB monopole antenna.

In this manuscript, it has been discussed that VSWR bandwidth solely depends on the length of ground plane ‘ L_{gnd} ’, and by optimizing this parameter the VSWR bandwidth of proposed UWB monopole antenna can be controlled. The variations in the VSWR bandwidth occurred because of optimization of ground plane length, and it has been discussed in detail in this section. The proposed structure has been designed at 3.8 GHz resonant frequency, and design parameters are delineated in Table 1.

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \tag{1}$$

$$R_p = \frac{F}{\left\{ 1 + \frac{2h}{\pi F \epsilon_r} \left[\ln \left(\frac{\pi F}{2h} \right) + 1.7726 \right] \right\}^{\frac{1}{2}}} \tag{2}$$

The length of partial ground plane ‘ L_{gnd} ’ has been optimized from 7.2 to 4.2 mm with a reducing step size of 1.0 mm to obtain the optimal impedance matching ($\text{VSWR} \leq 2$) for the entire range of UWB. The comparison of VSWR versus frequency plot for the different values of ground length has been depicted in Fig. 2. It can be contemplated from Fig. 2 that for $L_{\text{gnd}}=7.2$ mm, the VSWR is ≤ 2 at the frequency range of 6.5–7.6 GHz and 9.3–12.0 GHz and corresponding VSWR bandwidth is 1.1 GHz and 2.7 GHz. Similarly, for $L_{\text{gnd}}=6.2$ mm, proposed monopole antenna exhibits VSWR bandwidth of 8.5 GHz with a frequency of 3.5–12.0 GHz. Further, if we take the value of $L_{\text{gnd}}=4.2$ mm; the proposed antenna adorns the value of $\text{VSWR} \leq 2$ at frequency range 2.63–6.9 GHz and 8.10–11.10 GHz with corresponding VSWR bandwidth of 4.27 GHz and 3.0 GHz. From, aforesaid discussion, it is crystal clear that the ground length values $L_{\text{gnd}}=7.2$ mm, 6.2 mm and 4.2 mm do not exhibit $\text{VSWR} \leq 2$ for the entire UWB band (3.1–10.6 GHz) due to impedance mismatch. But if we consider the value $L_{\text{gnd}}=5.2$ mm, the proposed monopole antenna exhibits an optimum impedance matching ($\text{VSWR} \leq 2$) in the frequency range of 2.94–12.0 GHz and also yields an ultra-wideband (UWB) impedance bandwidth of 9.06 GHz. So, it is obvious that at $L_{\text{gnd}}=5.2$ mm, the proposed UWB monopole antenna depicts optimal impedance matching by reporting the value of VSWR almost less than 1.5 for the desired range of UWB frequency band. The different results have been attained by varying the ground length and also have been juxtaposed with each other and delineated in Table 2 for more lucidity. In this section, UWB monopole antenna with wide VSWR bandwidth of 9.06 GHz (2.94–12.0 GHz) has been proposed. Further, a Complementary Split Ring Resonator (CSRR) and C-shaped slot have been introduced in the geometry of proposed antenna structure to acquire notched band at upper WLAN and Wi-MAX

Table 1 Parametric dimensions of proposed UWB monopole antenna

Parameters	Description	Values (mm)
R_p	Radius of octagonal patch	10.0
L_{sub}	Length of substrate	30.0
W_{sub}	Width of substrate	30.0
L_{fed}	Length of transmission line	5.72
W_{fed}	Width of transmission line	3.00
L_{gnd}	Length of partial ground plane	5.20
W_{gnd}	Width of partial ground plane	30.0

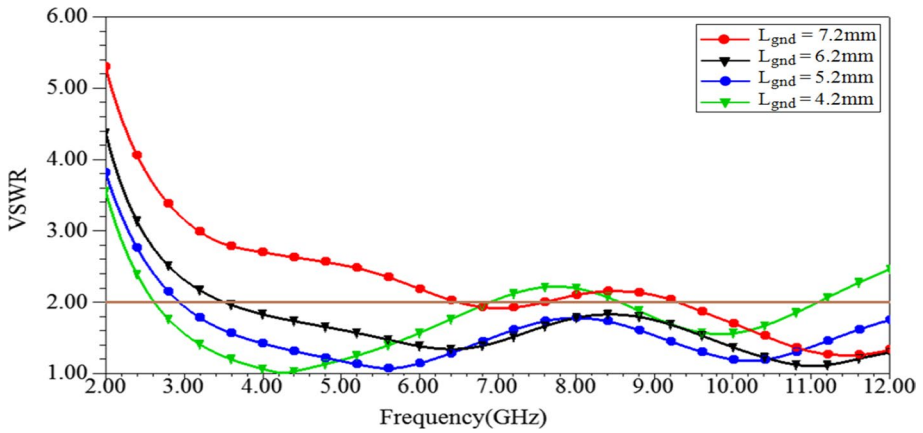


Fig. 2 VSWR plot of proposed UWB monopole antenna for different ground length variations

Table 2 Variation of ground length ‘L_{gnd}’ on the performance of proposed UWB antenna

Variation of ‘L _{gnd} ’ (mm)	Frequency range (GHz)	VSWR bandwidth (GHz)	Bandwidth (%)	Covers UWB frequency range (3.1–10.6 GHz)
7.2	6.5–7.6	1.1	15.60	No
	9.3–12.0	2.7	25.35	No
6.2	3.5–12.0	8.5	109.67	No
5.2	2.94–12.0	9.06	121.28	Yes
4.2	2.63–6.9	4.27	89.61	No
	8.1–11.1	3.0	31.25	No

respectively. The effects of CSRR and C-shaped slot on the performance of antenna for achieving desired notch band has been briefly discussed in the next section.

3 Parametric Study and Design of Antenna with Band Rejection Characteristics

3.1 Realization of Negative Permittivity of CSRR

To explore the performance of CSRR, it has been printed on FR4 substrate, further it is being inserted into the waveguide setup as depicted in Fig. 3. In this setup, the perfect magnetic field (PMC) is assigned to the top and bottom side of waveguide, while front and back sides of waveguide are attributed as perfect electric field (PEC) and the other two sides are used for excitation signal (port 1 and port 2). CSRR structure is excited with the help of incident electromagnetic waves and its scattering parameters such as reflection coefficient (S_{11}) and transmission coefficient (S_{21}) reported in Fig. 4. S-Parameters exhibits the stop band characteristics of the CSRR at the frequency 6.7 GHz, where S_{11} almost approaches to zero (< -3 dB) and S_{21} is -9 dB (approaches

Fig. 3 Waveguide setup of CSRR for retrieving S-parameters

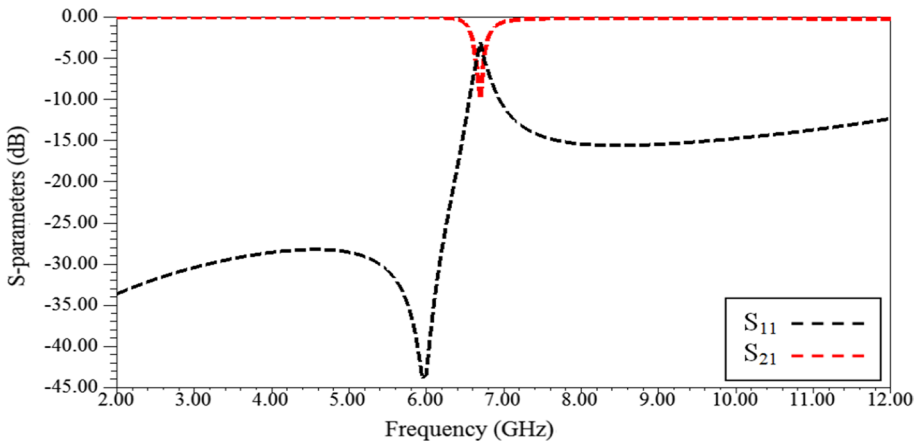
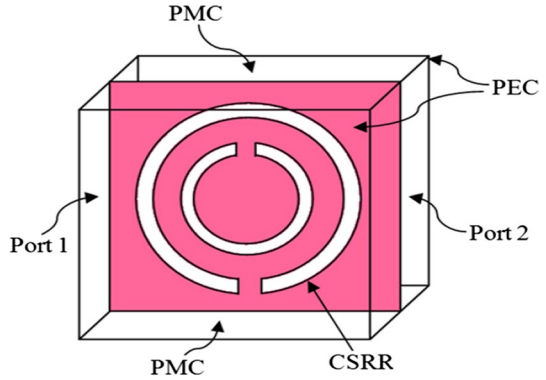


Fig. 4 Scattering parameters of unit cell of CSRR structure

to -10 dB). By using the aforementioned S-parameters, the values of refractive index (n) and wave impedance (z) is being calculated from Eqs. (3) and (4) [32], whereas, the negative permittivity (ϵ) of the CSRR unit cell is observed at 6.7 GHz has been computed using Eq. (5) [33] and demarcated in Fig. 5.

$$n = \frac{1}{kd} \text{Cos}^{-1} \left[\frac{1}{2S_{21}} (1 - S_{11}^2 + S_{21}^2) \right] \tag{3}$$

$$Z = \frac{\sqrt{(1 + S_{11})^2 - S_{21}^2}}{\sqrt{(1 - S_{11})^2 - S_{21}^2}} \tag{4}$$

$$\epsilon = \frac{n}{Z} \tag{5}$$

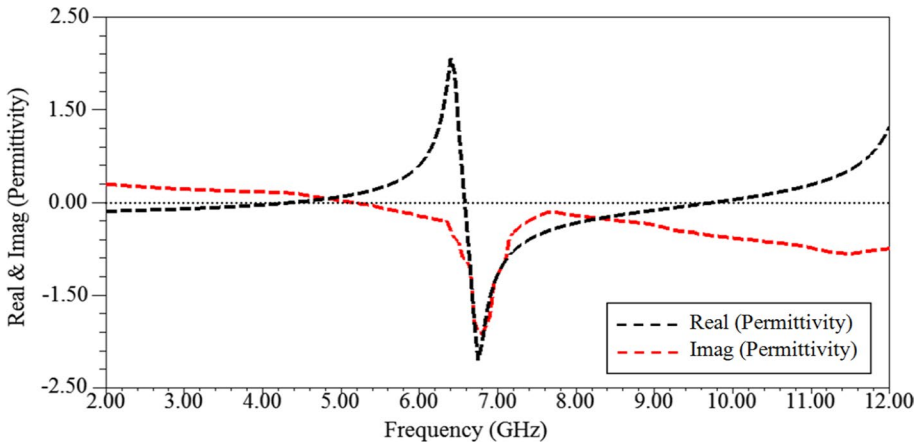


Fig. 5 Extracted negative permittivity of CSRR structure

3.1.1 UWB Antenna with WLAN Band Rejection

In this section, Complementary Split Ring Resonator (CSRR) has been introduced in the geometry of proposed UWB monopole antenna to obtain upper WLAN rejection characteristics centered at 5.8 GHz. CSRR is merely the dual counterpart of conventional Split Ring Resonator (SRR), this is reason that a time varying electric field exhibits strong component in the axial direction which resulted to an effective ϵ medium. By adjusting or optimizing the geometric configuration of CSRR, the notch band frequency can effortlessly be tuned to the desired value. Proposed antenna with CSRR (incorporated on patch) is illustrated in Fig. 6a, whereas, the zoomed version of CSRR with parametric dimensions is depicted in Fig. 6b. The dimensions of CSRR and the frequency of notched band have been calculated and adjusted by using Eqs. (6) and (7) [30]. The dimensions of proposed CSRR are also delineated in Table 3.

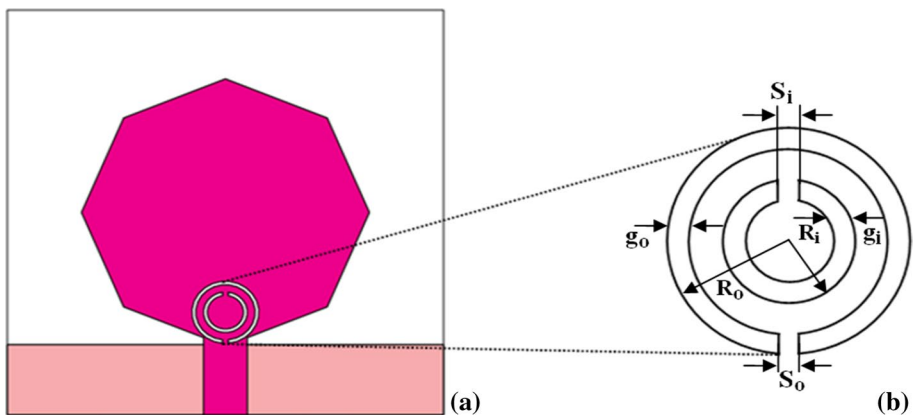


Fig. 6 Proposed UWB antenna: **a** with CSRR and **b** zoomed version of CSRR with parametric dimensions

Table 3 Parametric dimensions of CSRR

Parameters	Description	Values (mm)
S_o	Split gap width of outer ring	0.4
g_o	Thickness of outer ring	0.25
R_o	Radius of outer ring	2.3
S_i	Split gap width of inner ring	0.4
g_i	Thickness of inner ring	0.25
R_i	Radius of inner ring	1.5

$$\lambda_g = \lambda_0 / \sqrt{\epsilon_{reff}} \tag{6}$$

$$f_r \approx \frac{c}{\sqrt{\epsilon_{reff}} \lambda_g} \approx \frac{c}{\sqrt{\epsilon_{reff}} \cdot 2 \cdot \text{slot_length}} \tag{7}$$

where λ_0 is free space wavelength, $\epsilon_{reff} = (\epsilon_r + 1)/2$ is the effective dielectric constant and c is the speed of light in vacuum.

After inserting the CSRR in the geometry of proposed UWB monopole antenna, its parameters have been optimized to obtain WLAN band rejection characteristics. Initially, the outer ring of CSRR is incorporated in the proposed geometry and its parametric study has been carried out to achieve rejection in UWB frequency band. In the proposed design, the width of split gap (S_o) has been varied from 1.0 to 0.4 mm with reducing step size 0.2 mm. It also has been observed that antenna exhibits peak VSWR of 3.73 at 6.5 GHz rejection frequency at gap width 1.0 mm. Similarly, at gap width 0.8 mm, the rejection band is being shifted towards lower side with a peak VSWR of 4.1 at 6.4 GHz rejection frequency. Further, if gap width is considered as 0.6 mm, the rejection band again shifted towards the lower side with peak VSWR of 3.95 at 6.2 GHz frequency. At the final iteration, gap width is taken as 0.4 mm and noted that the band is again shifted towards the lower side with a peak VSWR of 3.93 at 6.1 GHz rejection frequency. The VSWR plot of proposed antenna with variation in ‘ S_o ’ parameter has been reported in Fig. 7. It can be anticipated from Fig. 7 that by decreasing the gap width (S_o) of outer ring of CSRR, the notch frequency is being shifted towards lower side and complete rejection becomes stronger towards this side. At the gap width 0.4 mm, the peak frequency of rejection band is 6.1 GHz. To shift the 6.1 GHz frequency band towards the upper WLAN frequency rejection band, the inner ring of CSRR has been introduced along with the outer ring as limned in Fig. 6a. From aforementioned discussion, it can be perceived that by decreasing the gap width of CSRR ring and increasing the length of ring, decrease in rejection band frequency has been noticed which also justifies the Eq. (4).

The split gap width (S_o) of outer ring of CSRR is being fixed to 0.4 mm and gap width (S_i) of inner ring is being varied from 1.0 to 0.4 mm to control and adjust the rejection band. Optimization of inner ring split gap has been illustrated in Fig. 8; here the length of inner ring has been varied with respect to split gap (S_i) with a step size of 0.2 mm. By varying the split gap, it has been perceived that undesired signal will almost get suppressed when rejection band is being shifted towards lower side at split gap width 0.4 mm, and also exhibits notch frequency of 5.8 GHz. So, it can be revealed that by adjusting the split gap width size 0.4 mm of inner and outer ring of CSRR, the proposed UWB antenna rejects the upper WLAN frequency band centered at 5.8 GHz.

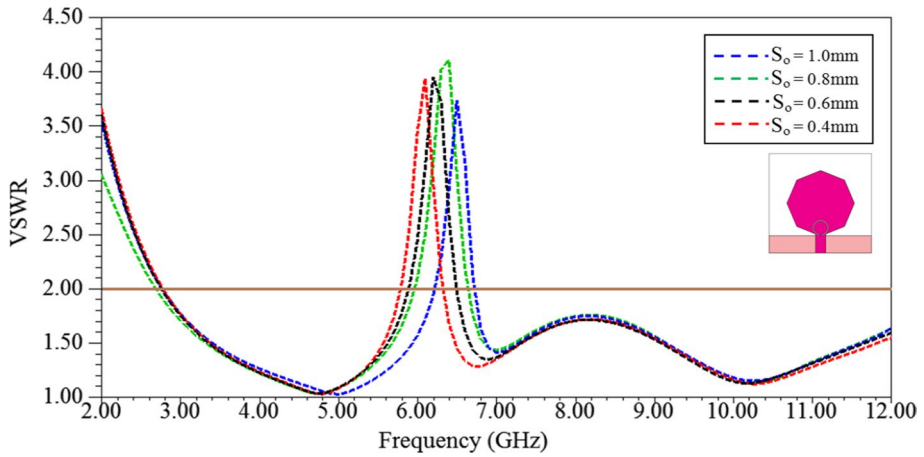


Fig. 7 VSWR plot for optimization of CSRR outer ring parameter S_o

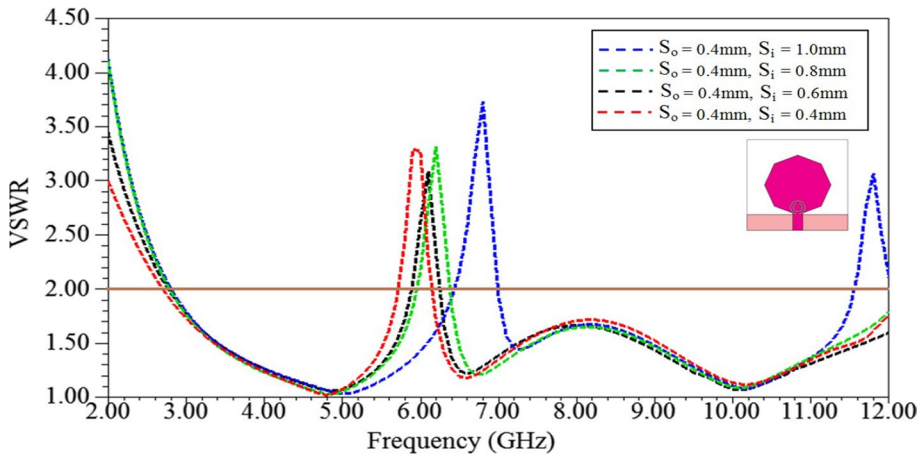


Fig. 8 VSWR plot for optimization of CSRR inner ring parameter S_i

3.2 UWB Antenna with Wi-MAX Band Rejection

C-shaped slot has been etched from the geometry of proposed octagonal antenna to acquire the band rejection characteristics in Wi-Max band, and limned in Fig. 9a. The zoomed version of C-shaped slot along with dimensional parameters is delineated in Fig. 9b for more lucidity. The dimensions of incised slot are also being optimized to obtain the desired band notch characteristics. Performance of antenna after employing the C-shaped slot has been discussed thoroughly in this section. The optimized parameters of slot are tabulated in Table 4 for better understanding.

Parametric variations of proposed antenna for Wi-MAX band rejection characteristics has been illustrated in Fig. 10, where, G_1 parameter is being varied from 6.0 to 4.5 mm with reducing step size 0.5 mm for obtaining Wi-MAX band rejection. It has been

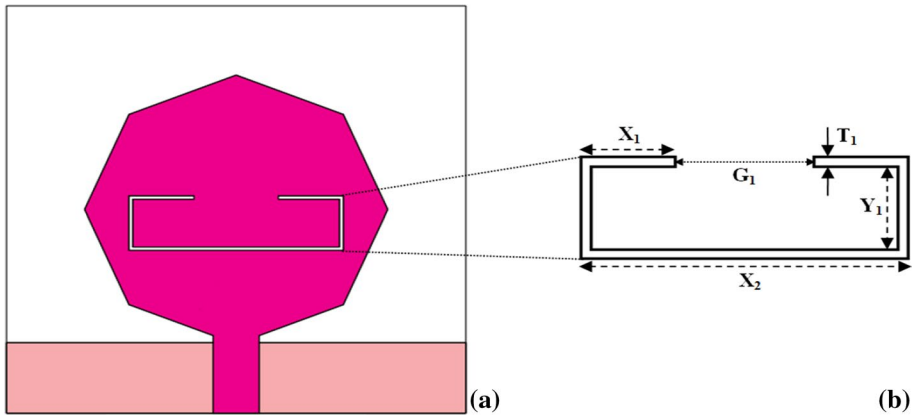


Fig. 9 Proposed UWB antenna: **a** with C-shaped slot and **b** zoomed version of C-shaped slot with parametric dimensions

Table 4 Parametric dimensions of C-shaped slot

Parameters	Description	Values (mm)
X_1	Length of smaller horizontal side	4.25
X_2	Length of larger horizontal side	14.0
Y_1	Length of vertical side	3.5
G_1	Gap between smaller sides	5.5
T_1	Thickness of slot	0.25

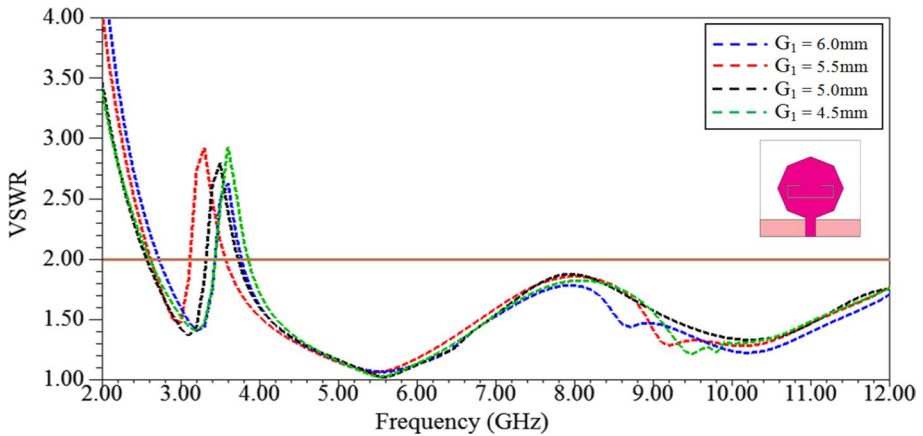


Fig. 10 VSWR plot for optimization of C-shaped parameter G_1

observed from Fig. 10 that the rejection band exhibits frequency 3.6 GHz with corresponding VSWR 2.62 and also becomes weaker at $G_1=0.6$ mm. When G_1 is taken as 5.5 mm and 4.5 mm the rejection band depicts the frequency 3.3 GHz and 3.6 GHz respectively, with corresponding VSWR 2.92. It also has been noticed that at $G_1=5.5$ mm and 4.5 mm,

Fig. 11 Proposed UWB antenna with Wi-MAX and WLAN band notch characteristics

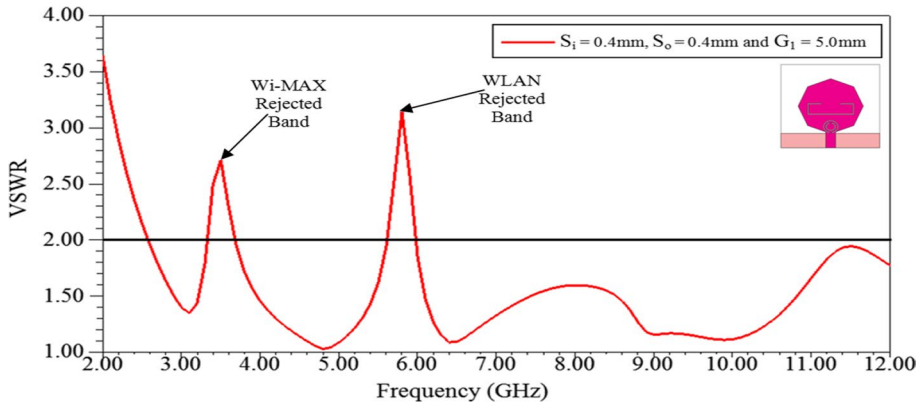
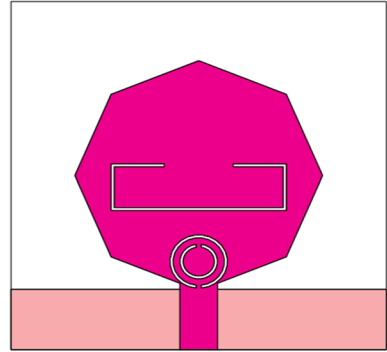


Fig. 12 VSWR plot of proposed UWB antenna with Wi-MAX and WLAN band notch characteristics

the rejection band is being shifted towards left and right side but does not exhibit the desired rejection frequency of Wi-MAX band. Whereas, at $G_1 = 5.0$ mm; the rejection band exhibits the frequency 3.5 GHz with maximum VSWR 2.71. So, it can be concluded that at $G_1 = 5.0$ mm, the rejection band becomes stronger and Wi-Max band rejection characteristics has been achieved.

3.3 UWB Antenna with Wi-MAX and WLAN Band Rejection

In this section, dual rejection bands have been achieved by applying CSRR and C-shaped slot at the same time in the geometry of proposed UWB antenna. The structure of antenna comprises of CSRR and C-shaped slot has been demonstrated in Fig. 11. The optimized parameters of CSRR and C-shaped slot are restricted to the desired values as explained in previous sections. VSWR plot of proposed antenna with combined geometry has been delineated in Fig. 12. It has been perceived from Fig. 12; that proposed antenna exhibits dual band rejection characteristics at Wi-MAX band with 3.5 GHz center frequency and upper WLAN band with 5.8 GHz center frequency.

Surface current distribution of proposed UWB monopole antenna has been simulated and reported in Fig. 13; for the further investigation of dual band notch characteristics. Figure 13a indicates the current distribution at 5.8 GHz notch frequency, whereas;

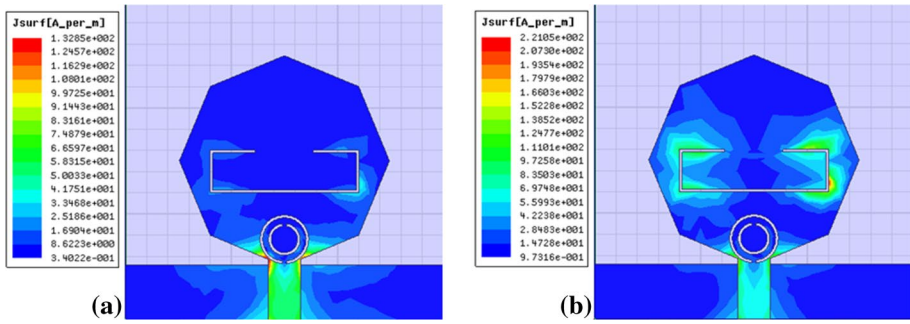


Fig. 13 Surface current distribution of proposed UWB antenna at **a** 5.8 GHz and **b** 3.5 GHz rejected frequency band

Fig. 13b demonstrates the current distribution at 3.5 GHz notch frequency. It can be adorned from the Fig. 13 that the current is more concentrated at the desired notch frequency bands, and the energy will not radiate much in the air as it is being stored around the band notched elements. Even the flow of current is more prevailing around the CSRR rings, especially at notch centre frequency 5.8 GHz, as shown in Fig. 13a. Similarly, the flow of current is more prominent around the C-shaped slot at notch centre frequency 3.5 GHz, limned in Fig. 13b. It can be anticipated from the aforesaid discussion that each rejected band can be controlled individually as low mutual coupling has been perceived at notch frequency elements.

The simulated three dimensional gain of proposed UWB monopole antenna with and without dual band notch characteristics is illustrated in Fig. 14. It can be revealed from the Fig. 14 that the values of gain are less than 0 dB at notched bands of proposed UWB monopole antenna with band notch characteristics, and the maximal gain values reported are -3.71 dB at 3.5 GHz and -4.25 dB at 5.8 GHz. The value of gain below 0 dB i.e.; negative at notched bands, itself prove that the proposed antenna will not radiate at 3.5 GHz and 5.8 GHz frequency bands. Therefore, it can be concluded from the 3D gain plots that antenna will reject the dual band from the entire range of UWB passband.

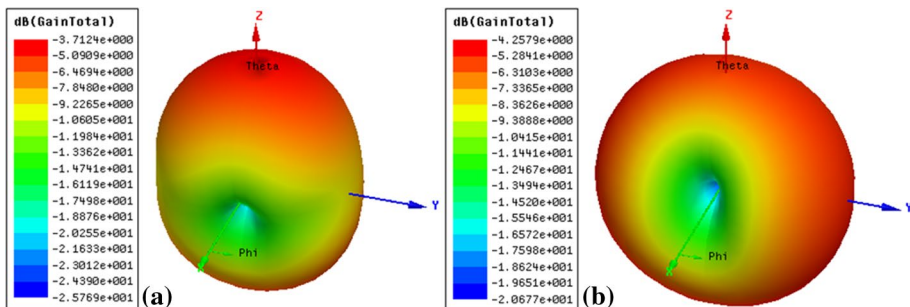


Fig. 14 3D gain plots of proposed antenna at notch frequency band **a** 3.5 GHz and **b** 5.8 GHz

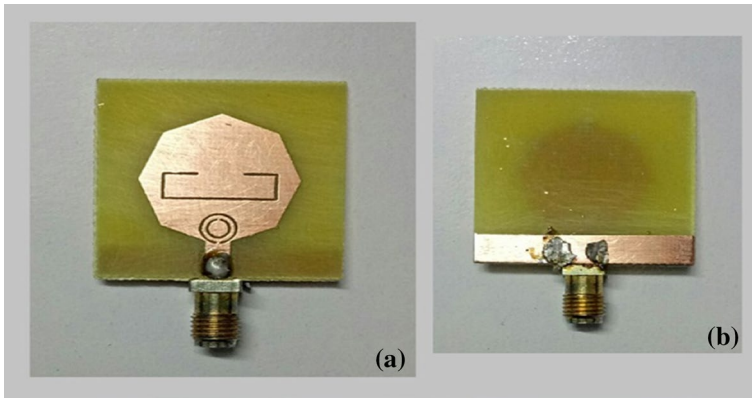


Fig. 15 Fabricated prototype of proposed UWB monopole antenna **a** front view and **b** back view

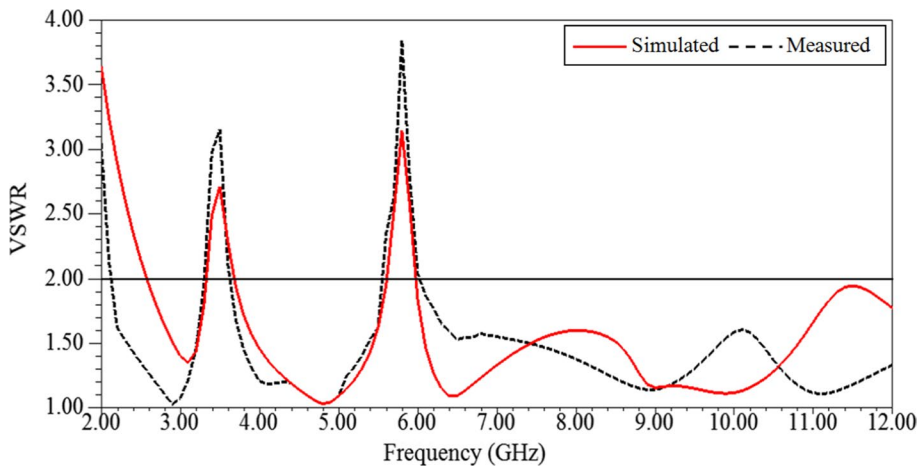


Fig. 16 Measured and simulated VSWR of proposed UWB antenna

4 Experimental Results

To reveal the discussed designed strategy in Sects. 2 and 3, the prototype of proposed UWB antenna has been fabricated and shown in Fig. 15. The comparison of simulated and measured VSWR characteristics reveals good agreement with each other as delineated in Fig. 16 even the slight variations between simulated and measured results have been noticed which may occur because of mismatch of impedance between microstrip feed line, solder bumps, environmental conditions, vagueness in electrical properties of substrate and reflection from SMA connector. By vigilantly designing the prototype of antenna and experimental process, more accurate results can be obtained. The fabricated UWB antenna has a frequency band of 2.12–12.0 GHz with dual rejection bands at the peak frequency 3.5 GHz and 5.8 GHz with corresponding VSWR 3.15 and 3.84 respectively.

Simulated gain of antenna without notch filter and measured gain with notch filter have been illustrated in Fig. 17. It has been observed that the antenna without notch filter

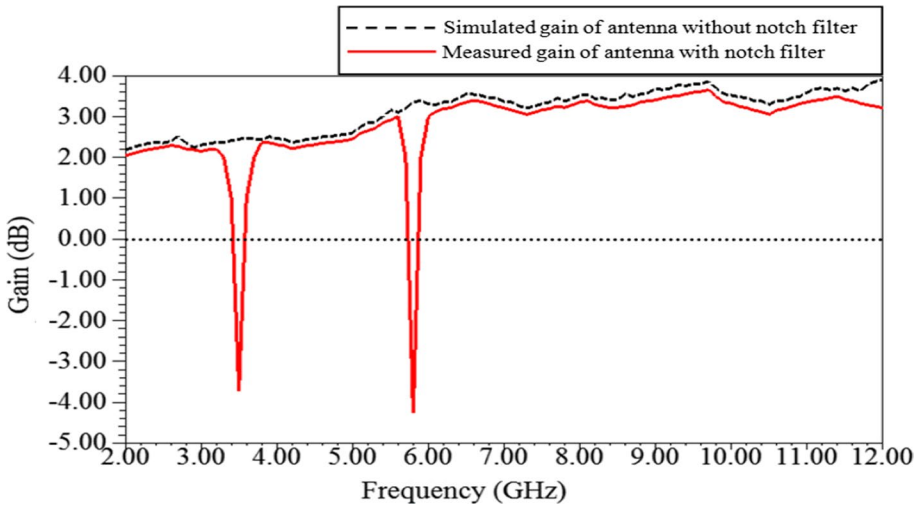


Fig. 17 Measured gain with notch filter and simulated gain without notch filter of proposed UWB antenna

exhibits the positive gain throughout the frequency range of 2.94–12.0 GHz, which varies from 2.21 to 3.98 dB. Whereas; negative gain of -3.91 dB and -4.37 dB has been noticed at notch frequency bands and also the gain is matched throughout the remaining UWB passband of proposed antenna with notch filters. At these two notch bands, the gain of antenna falls down below 0 dB, which clearly indicates that antenna does not radiates at these frequency bands.

Simulated efficiency of proposed UWB antenna with and without notch filters is depicted in Fig. 18. It can be contemplated from Fig. 18 that proposed antenna exhibits good radiation efficiency ($\geq 85.54\%$) in both the cases for entire UWB frequency band

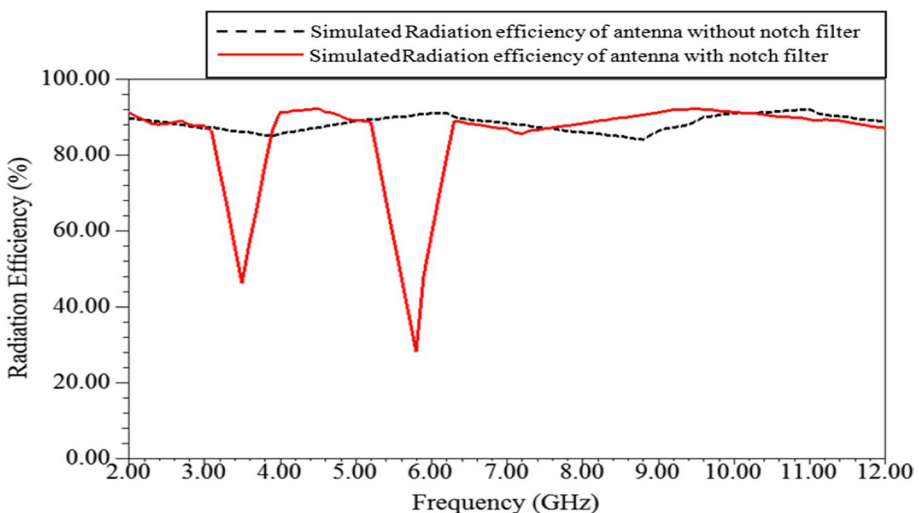


Fig. 18 Simulated radiation efficiency with and without notch filter of proposed UWB antenna

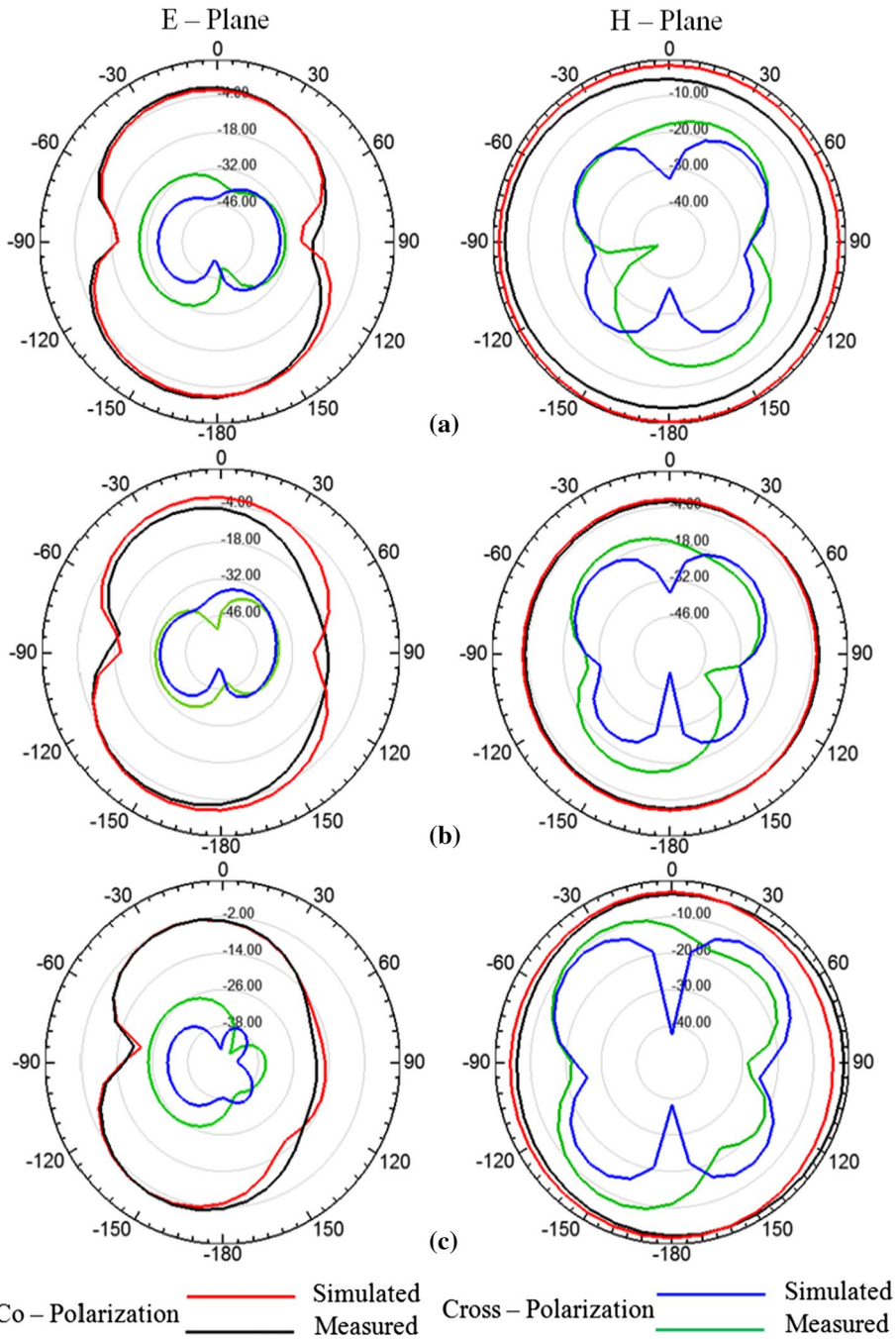


Fig. 19 Simulated and measured radiation pattern (dB) at: a 4.4 GHz, b 6.4 GHz and c 9.4 GHz frequencies

Table 5 Comparison of proposed band notch antenna with various existing antennas

Reference	Size of antenna (mm ²)	VSWR bandwidth range (GHz)	First rejected frequency band (GHz)	Second rejected frequency band (GHz)	Peak gain of first rejected band (dB)	Peak gain of second rejected band (dB)
[34]	53 × 39.8	3.1–10.6	Wi-MAX	WLAN	< -10	< -10
[35]	34 × 34	3.1–10.6	-	WLAN	-	-4.15
[36]	78 × 44.6	2.63–10.86	Wi-MAX	WLAN	-0.56	-1.68
[37]	40 × 30	3.1–10.6	Wi-MAX	WLAN	-	-
[38]	40 × 30	2.68–17.50	-	WLAN	-	-3.2
[39]	22 × 24	3.08–11.2	-	WLAN	-	0.9
[40]	27 × 21	2.3–11.2	-	WLAN	-	-5.7
[41]	60 × 60	2.8–9.0	-	WLAN	-	-
[42]	50 × 40	3.1–10.6	Wi-MAX	WLAN	-	-2.9
[43]	40 × 43	3.0–11.0	-	WLAN	-	-5.9/-3.8
Proposed antenna	30 × 30	2.45–12.0	Wi-MAX	Upper WLAN	-3.71	-4.25

except in two notch bands. Moreover, the simulated radiation efficiency of antenna with dual notch bands reveals only radiation efficiency 46% and 28% at 3.5 GHz and 5.8 GHz respectively.

The simulated and measured radiation pattern of designed UWB antenna in E and H-plane (principle planes) at 4.4, 6.4 and 9.4 GHz has been reported in Fig. 19. Radiation pattern at the pass band frequencies shows that antenna displays nearly dipole like radiation pattern in E-plane at lower frequencies, whereas, small variation has been noted at higher frequencies which may happen only because of cross-polarization. The radiation pattern at higher frequencies is almost distorted because of variation in the area of radiation, whereas, in the case of H-plane, the pattern is flawlessly omni-directional at all the pass band frequencies.

Furthermore; the comparison of proposed UWB antenna with existing antennas has been delineated in Table 5. It can be adorned from Table 5 that proposed antenna is compact in size in juxtaposition to references [34–38, 41–43] except references [39] and [40]. Though the size of antenna designed in [34] and [35] is compact, but these antennas only exhibit single band notch frequency. It has also been observed that proposed antenna reports wider VSWR bandwidth in comparison to all the references displayed in Table 5, except Ref. [38]; whereas, it reports the rejection of WLAN frequency band only. So, we can say that proposed antenna is better in comparison to the antennas delineated in Table 5, as it rejects dual frequency bands Wi-MAX and WLAN. Similarly, if we observe the Ref. [34] it also rejects dual frequency bands, but designed antenna is heavy in comparison to proposed antenna. Based on aforementioned discussion, it can be anticipated that proposed UWB antenna is novel, compact in size and useful for UWB applications with band notched characteristics at Wi-MAX and WLAN frequency band.

5 Conclusion

Proposed octagonal shaped monopole antenna exhibits dual band notch characteristics at Wi-MAX and WLAN frequency bands in UWB pass band. The partial ground plane has been employed in the geometry of proposed antenna to improve the VSWR bandwidth over the entire range of UWB (3.1–10.6 GHz). The octagonal radiating patch with 50Ω transmission line and partial ground plane exhibits the VSWR bandwidth of 9.06 GHz (121.28%) with a frequency range of 2.94–12.0 GHz. After employing the C-shaped slot and CSRR, the proposed antenna depicts dual band rejection characteristics at Wi-MAX (3.5 GHz) and upper WLAN (5.8 GHz). The dimensions of the incised notch filters such as (C-shaped slot and CSRR) have been varied to achieve the optimal band notch characteristics centered at frequencies 3.5 and 5.8 GHz. Designed antenna is compact and also skilled to suppress the interference of Wi-MAX and upper WLAN from the UWB passband. The results of simulated and fabricated antenna are juxtaposed and found in reasonable agreement with each other.

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Dr. Narinder Sharma is B.E. (Electronics), M.Tech. (ECE) and Ph.D. (ECE) from Uttarakhand Technical University, Dehradun, India. He has total 23 Years of experience. 6 years' experience in the industry and 17 years' experience in teaching. He has been associated with Department of Electronics and Communication Engineering of Amritsar College of Engineering and Technology, Amritsar since 2004. Presently, he has been heading the Department of Electronics and Communication Engineering and Department of Electrical Engineering. He has more than 8 years' experience in the administration and 10 years' experience in research. He is reviewer of the various esteemed journals like IET Microwaves, Antennas and Propagation, International Journal of Electrical and Computer Engineering (IJECE), Indian Journal of Radio and Space Physics (IJRSP) of NISCAIR, International Journal of RF and Microwave Computer Aided Engine (WILEY) and Artificial Intelligence Review (Springer). He is Editorial Board member of "i-manager's Journal on Communication Engineering and Systems". He has successfully guided more than 26 students for M.Tech. Thesis

and 01 student is pursuing Ph.D. under him. He is appointed as Board of Studies member and External Examiner by I.K.G. Punjab Technical University for the evaluation of Ph.D. aspirants. He has established the Antenna Designing Lab. in ACET with help of grant Rs. 8,000,000 received from DST under FIST program. He was Session Chair and Co-Chair for various reputed international conferences including 3rd IEEE International Conference on MOOCs, Innovation and Technology in Education (MITE-2015). He has delivered the expert talk in IKGPTU sponsored FDP and also attended various Workshops, FDP's and Conferences. More than 63 research papers in peer reviewed International Journals and 24 papers in reputed International/National conferences goes into his credit.



Sumeet Singh Bhatia was born at Sri Karanpur, Rajasthan in 1990. He received Bachelor of Technology degree in Electronics and Communication Engineering from Amritsar college of Engineering and Technology, Amritsar, Punjab, India in 2012. He completed his Master of Technology degree in Electronics and Communication Engineering from Yadavindra College of Engineering, Guru Kashi Campus, Punjab University, Talwandi Sabo, Bathinda, Punjab, India in 2015. He is reviewer of the various esteemed journals like International Journal of Electronics, Electronics Letter (Taylor and Francis), Progress In Electromagnetic Research (PIER) and International Journal of Sensors, Wireless Communications and Control (Bentham Science Publishers). More than 13 research papers in various International Journals and referred conferences goes into his credit. His research interest lies in the areas of microstrip, fractal and Ultra-wideband antennas.



Dr. Vipul Sharma is working as Associate Professor in the Department of Electronics and Communication Engineering of Gurukul Kangri University, Haridwar. He has successfully guided the various M.Tech. and Ph.D. students. He is a member of IEEE society of U.P. Section and member of various reviewed boards. He has published his research papers in the reputed peer reviewed journals.



Dr. Jagtar Singh Sivia was born in 1976 at Bathinda, Punjab, India. He received Bachelor of Engineering Degree in Electrical and Electronics Communication Engineering from Punjab Technical University Jalandhar, Punjab, India in 1999 and M.Tech. Degree in Electronics Communication Engineering from Punjab Technical University, Jalandhar, Punjab, India in 2005. He received Ph.D. Degree in the area of antenna systems from Sant Longowal Institute of Engineering and Technology, Longowal, Sangrur, Punjab, India. He is Professor in Department of Punjabi University at Yadawindra college of Engineering Talwandi Sabo in Electronics Communication Engineering Section, Bathinda, and Punjab, India. He has published more than 40 papers in various international Journals and referred conferences. His main research interests are in Neural Networks, Antenna Systems Engineering, Electromagnetic Waves and Genetic Algorithms. He is a member of the Institution Engineers (India), Indian Society of Technical Education (India) and International Association of Engineers (IAENG).