

# Design and investigation of printed monopole antenna with three band-notched structures for UWB applications

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**Abstract** In this paper, a printed microstrip-fed monopole antenna for ultra-wideband range applications with multi band-notched functionality is designed and simulated. The antenna has a simple structure and miniaturized size so can be easily compatible with printed circuit board based systems. The design is used to filter the interferences due to coexisting narrow bands such as 3.3–3.7 GHz for WiMax, downlink 3.7–4.2 GHz for C-band, 5–6 GHz for WLAN as well as uplink 7.9–8.4 GHz and downlink 7.25–7.75 GHz frequency bands for X-band used for various wireless communications. The antenna is designed by using two different band-notching techniques such as embedding slots of various shapes in a radiation patch and putting parasitic stubs close to the radiator within antenna itself. The first band-notched structure a pair of L-shaped slot embedded on radiation patch notched WiMax and C-band. The second band-notched structure a C-shaped slot on radiation patch filter out WLAN band while third structure a pair of arc-shaped parasitic stub sited around the radiator suppressed X-band. The designed antenna is realized on FR4 substrate with relative permittivity ( $\epsilon_r$ ) 4.4 and the thickness of 1.6 mm. The parametric analysis of each band-notched structure is mention along with the surface current distributions are illuminated in detailed to examine the effects of these structures.

## 1 Introduction

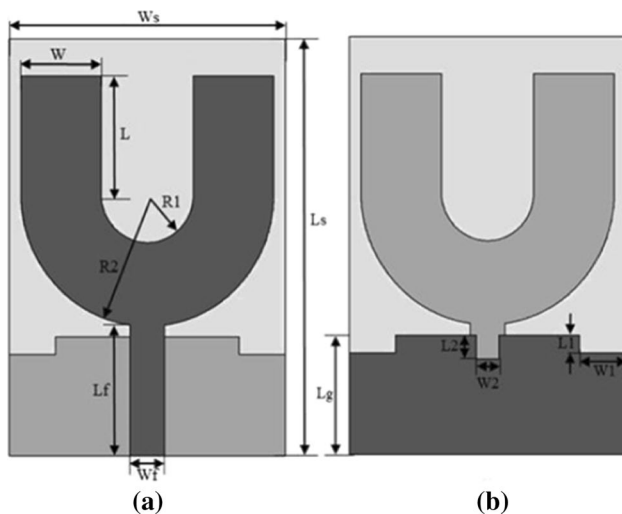
In 2002, the Federal Communication Commission's (FCC) allocation of 3.1–10.6 GHz for commercial applications of ultra-wideband (UWB) systems has created interest in antennas with a wide bandwidth (Federal Communications Commission 2002). Present day research focuses on designing antennas which cover all the desired frequencies within a single antenna with good radiation properties along with reduce dimension. The FCC entitled band for UWB systems but there exist some narrow frequency bands used by other licensed wireless systems such as WiMax, C-band, WLAN and X-band for various communication applications which cause interference. To avoid this interference, earlier extra band-notched filters along with antenna were added to the UWB system. However, these filters increase the size, weight and complexity of the system. A simpler way to filter out these interferences, UWB antenna with band-notched characteristics within itself is to be designed. There are different band-notching techniques such as embedding slots of various shapes in a radiation patch or feed line (Luo et al. 2013; Nguyen et al. 2011, 2012; Liu et al. 2012; Li et al. 2009), putting parasitic stubs in aperture area of antenna (Chiu and Li 2009; Cai and Feng 2008; Zhang et al. 2010), using band-stop transmission lines (Yang et al. 2012; Panda and Kshetrimayum 2011). Printed monopole antennas are widely used due to their advantages of low cost, light weight and ease of fabricating and integrating with printed circuit board technology devices.

A printed wideband monopole antenna with three band-notched structures to filter the interferences is presented in this paper. It is systemize as follows. Section II describes the basic geometry of UWB antenna with its evolution from circular shape to U-shaped radiating antenna element.

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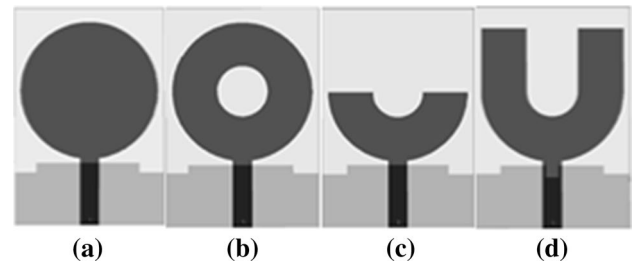
**Fig. 1** Geometry of printed monopole antenna for UWB. **a** Top view, **b** bottom view

Section III describes the three band-notched structures, which are realized on printed monopole antenna operating in UWB range.

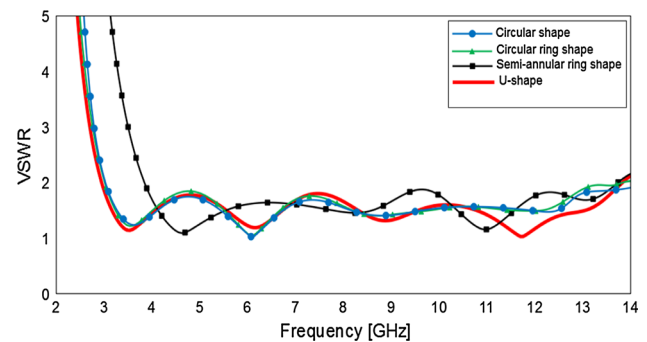
## 2 Basic antenna design

The antenna design consists of a printed U-shape radiating patch with a modified ground plane, illustrated in Fig. 1. The patch and the ground plane are realized on the top and bottom surfaces of a FR4 substrate with the relative permittivity ( $\epsilon_r$ ) 4.4 and the thickness of 1.6 mm. The U-shape radiating patch which is the modified shape of circular patch is fed by a microstrip feeding line. A basic antenna design consists of circular shape radiating patch of radius  $R_2$  and to achieve the better impedance match over UWB range the rectangular  $W_1 \times L_1$  corner slots are etched on ground plane. The U-shape radiating patch monopole antenna design is based on the fact that the current is mainly concentrated around the periphery of the circular patch of antenna; therefore, central portion of the circular patch of radius  $R_1$  is removed and the patch is modified to U-shaped radiating patch by placing a rectangular strip on both sides at the top of semi annular ring shape antenna. The evolution of monopole antenna is shown in Fig. 2. The simulated results shown in Fig. 3 clearly indicate that antenna is operating in UWB range along with enhanced bandwidth. And the variation of circular shape to U-shape radiating patch has negligible effect on impedance bandwidth.

Parametric analyses of printed monopole UWB antenna have been conducted by changing one parameter



**Fig. 2** Evolution of U-shape radiating patch UWB antenna. **a** Circular shape patch, **b** circular ring shape patch, **c** semi-annular ring shape patch, **d** U-shape patch



**Fig. 3** Simulation VSWR result of evolution of U-shape radiating patch UWB antenna

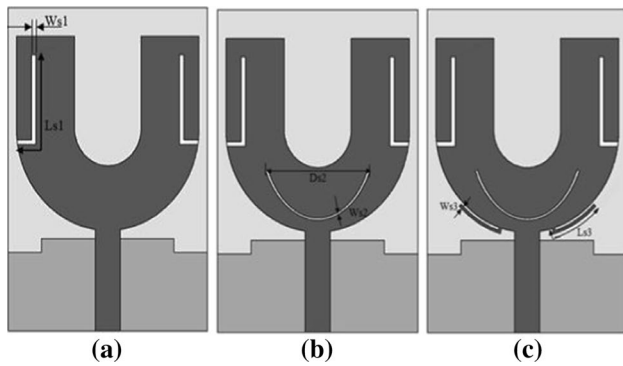
at a time while keeping the others constant. With proper selection of the parameters of the ground plane and radiation patch, a greatly enhanced impedance bandwidth can be achieved. The designated parameter values are listed in Table 1.

## 3 Triple band-notched UWB antenna

One of the ways to remove the potential interference between the UWB system and other existing communication systems is to add filters. However, the use of an additional filter will result in increasing the complexity, weight and size of UWB systems. Therefore, antenna designs with notched functions within itself to overcome the electromagnetic interference have been proposed. One common and simple way is to etch slots on the radiation patch or ground plane. By investigating the surface current distribution at central frequency of notched band insertion of slot is done. Similar to the embedding slot technique another commonly used technique is a parasitic strip or stub in the aperture area of the antenna and leads to a sudden change in the impedance in the notched

**Table 1** Designated parameter values of antenna [mm]

R2	R1	Wf	Lf	Ws	Ls	Lg
11	4	3	11	24	35	10.5
W	L	W1	L1	W2	L2	
7	10	4	1.5	2	2	

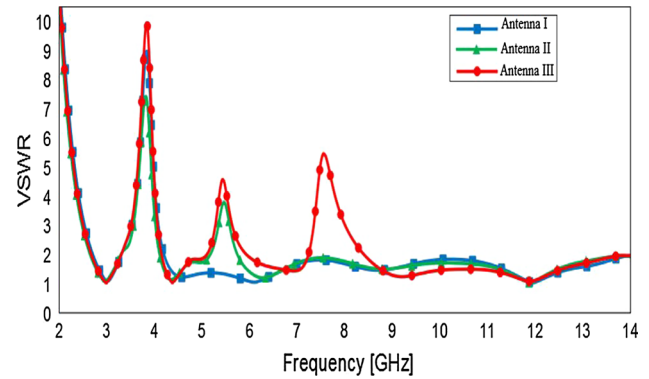


**Fig. 4** Geometry of antennas with band-notched structures. **a** Antenna I, **b** antenna II, **c** antenna III

band. A transmission line with a bandstop characteristic to feed the UWB antenna can be considered as an integration design of the printed UWB antenna and the filter, which have a little influence to the antenna radiation, is also an efficient band-notching technique. Using one notched-band technique will face difficulties to have sharp and narrow stop band and also to control each band independently. Therefore, multi notched-band techniques have been together used to realize notching. In this paper, we have used two band-notching techniques to filter the undesirable bands.

### 3.1 First band-notched structure

First notched band is achieved by embedding a symmetrical pair of L-shape slots on radiating patch to filter the WiMax band and as well as C-band simultaneously. A pair of L-shape slots is symmetrically positioned on the radiation patch by investigating the surface current distribution at central frequency 3.75 GHz covering both bands 3.3–3.7 GHz WiMax and downlink 3.7–4.2 GHz C-band respectively. By properly placing the L-shape slots, two undesirable frequency bands have been filter by only one band-notched structure. The antenna design is as shown in Fig. 4a and simulated result shown in Fig. 5 shows that antenna is operating in UWB range except the frequency band which is filtered.



**Fig. 5** Simulation VSWR results of evolution of antenna with multi band-notched functionality

**Table 2** Optimised designed parameters of band-notched structures [mm]

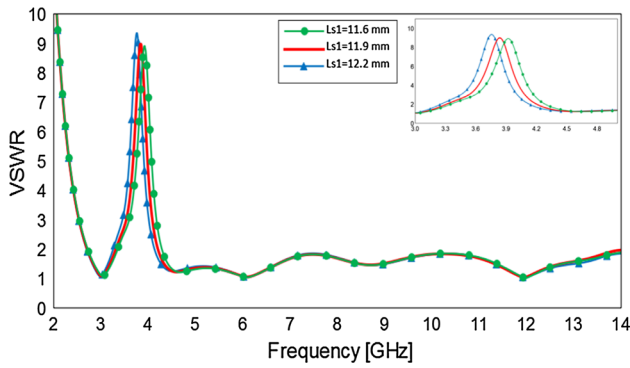
Ls1	Ws1	Ds2	Ws2	Ls3	Ws3
11.9	2.2	10.74	0.30	5.88	0.32

### 3.2 Second band-notched structure

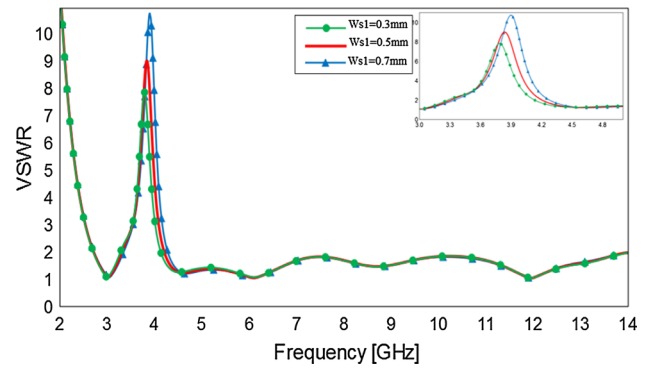
To produce a notched band around 5.5 GHz, the surface current distribution at 5.5 GHz is analyzed and the second band-notched structure a C-shape slot is etched on radiating patch. The antenna design is shown in Fig. 4b and simulated result shown in Fig. 5 shows that antenna operating in UWB range along with two band-notching.

### 3.3 Third band-notched structure

Further, the third band around 7.5 GHz is notched by parasitic stub placed around the lower edge of radiating patch. The pair of arc-shaped parasitic stub is inserted around the periphery of radiator that forms a resonant structure and leads to an abrupt change in the impedance in the notched band. The total length of pair of stubs is approximately equal to half of the wavelength. The antenna design is shown in Fig. 4c and simulated result shown in Fig. 5



**Fig. 6** Simulation VSWR result of parametric of L-slot length



**Fig. 7** Simulation VSWR result of parametric analysis of L-slot width

shows that antenna with wideband with three notched-bands (Table 2).

### 4 Results and discussions

In the design, the notched function is determined by the lengths of the slots. Theoretically, the relationship between the band-notched frequency and length of slot is given approximately by the expression:

$$f_{notch} = \frac{c}{2L_{slot}\sqrt{\epsilon_{eff}}}$$

$$\epsilon_{eff} = \frac{(\epsilon_r + 1)}{2}$$

where,  $f_{notch}$  is the resonant frequency,  $L_{slot}$  is the total length of the slot,  $\epsilon_r$  is dielectric constant of the substrate, and  $c$  is the speed of the light. Initially, length of the slot is calculated theoretically and taken as initial values for designing the slot. The parametric analysis of each structure is done to obtain the desired notched-band. The designed values stated in Table 2 and theoretically calculated values

using above mention expressions of the structures used to band-notched are approximately the same.

The parametric analysis of each band-notched structure is carried out separately. The simulated VSWR result of L-shaped slot length is as shown in Fig. 6 and numerically stated in Table 3, clearly indicates that increase in the length of slot decreases the resonant frequency of notched band. While Table 4 and Fig. 7 shows the increase in a width of slot increases the notched bandwidth (see Figs. 7, 8, 9).

The length of the C-shape slot is varying by changing the angle inscribed by slot and the change in angle is represented in terms of  $Ds_2$ . The increase in length of the slot has less effect on bandwidth but resonant frequency shifts to lower edge frequency as illustrated in Table 5 and Fig. 8. From the Table 6 and Fig. 9, it is clear that increase in the width  $Ws_2$  leads to increase in the bandwidth while resonance frequency is approximately same.

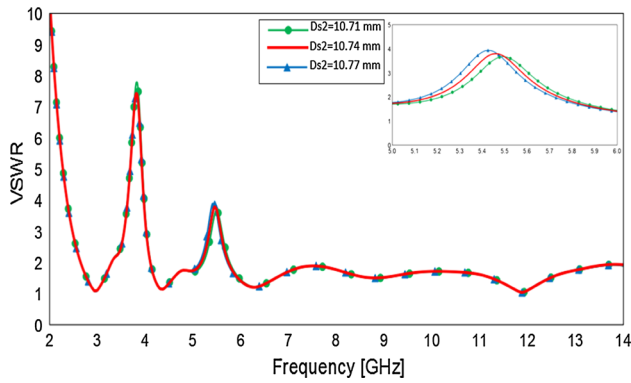
The parametric analysis of parasitic stub is carried out separately as shown in Figs. 10 and 11. It is observed that as length increases the notched band shifts to lower edge frequency. As width goes on increasing bandwidth

**Table 3** Parametric analysis of  $Ls_1$

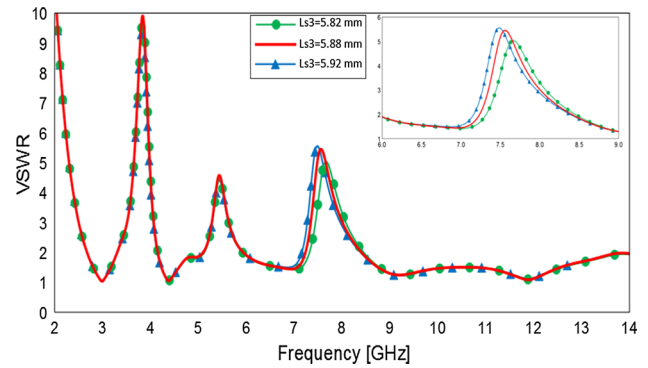
$Ls_1$ (mm)	Notched frequency range (GHz)	Resonant frequency (GHz)	BW (GHz)
11.6	3.42–4.31	3.92	0.89
11.9	3.34–4.20	3.85	0.85
12.2	3.29–4.12	3.75	0.84

**Table 4** Parametric analysis of  $Ws_1$

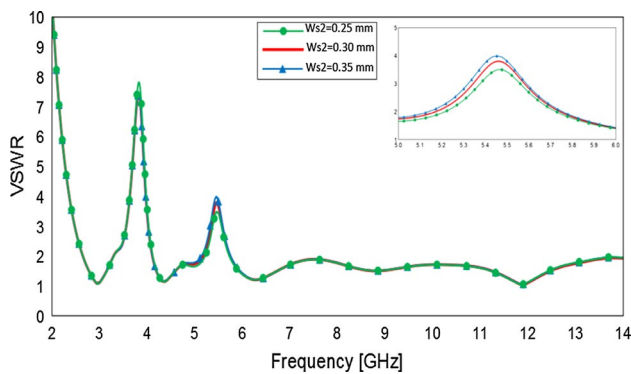
$Ws_1$ (mm)	Notched frequency range (GHz)	Resonant frequency (GHz)	BW (GHz)
0.30	3.36–4.14	3.84	0.78
0.50	3.35–4.20	3.86	0.85
0.70	3.33–4.26	3.86	0.93



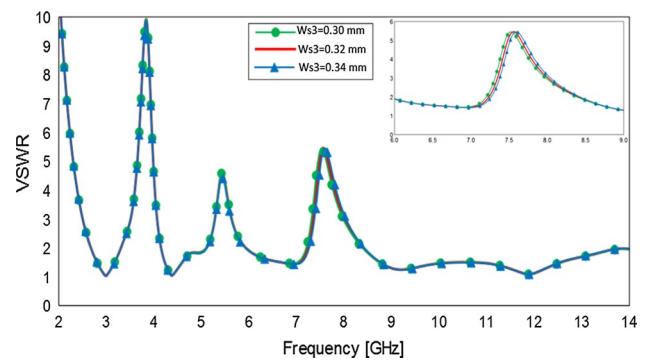
**Fig. 8** Simulation VSWR result of parametric analysis of C-shape length



**Fig. 10** Simulation VSWR result of parametric analysis of arc-shape stub length



**Fig. 9** Simulation VSWR result of parametric analysis of C-shape width



**Fig. 11** Simulation VSWR result of parametric analysis of arc-shape stub width

decreases due to coupling gap between the radiating patch and stub decreases. Due to decrease in gap between stub and radiator leads to increase in mutual coupling between them. From the Tables 7 and 8, it is observed that the center frequency of the notch band is the consequence of arc length variation while the bandwidth of the notch band is the consequence of variation of arc width.

The parametric analysis of band-notched structures satisfies the expression of relation between band-notched frequency and total length of slot mention above.

To understand the antenna operation along with the band-notched property, the surface current distributions of the proposed antenna at center of notched frequencies before and after adding the band-notched structures have been simulated as shown in Fig. 12. The embedding of L-shape slot on

**Table 5** Parametric analysis of Ds2

Ds2 (mm)	Notched frequency range (GHz)	Resonant frequency (GHz)	BW (GHz)
10.71	5.22–5.77	5.50	0.55
10.74	5.17–5.73	5.45	0.56
10.77	5.13–5.71	5.40	0.57

**Table 6** Parametric analysis of Ws2

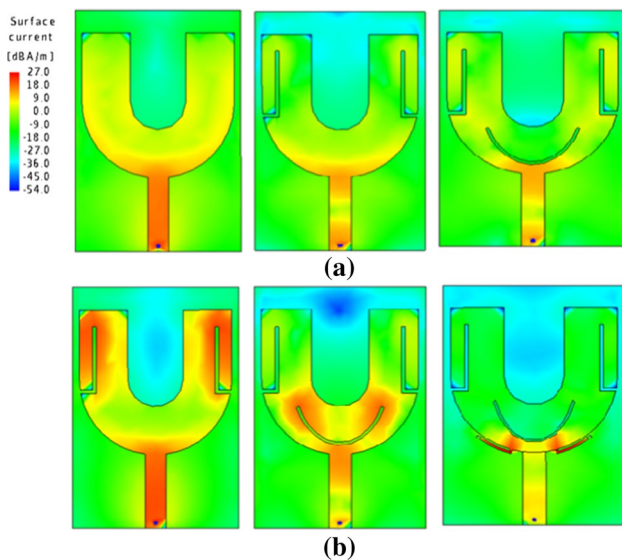
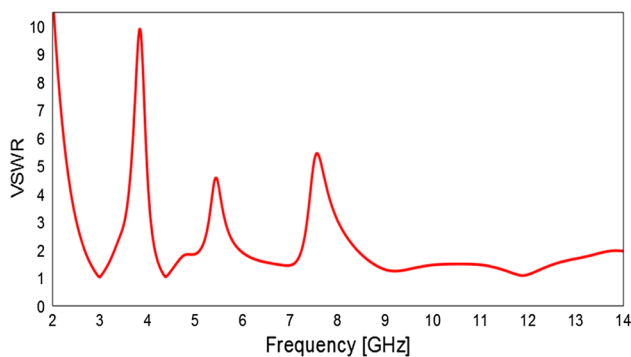
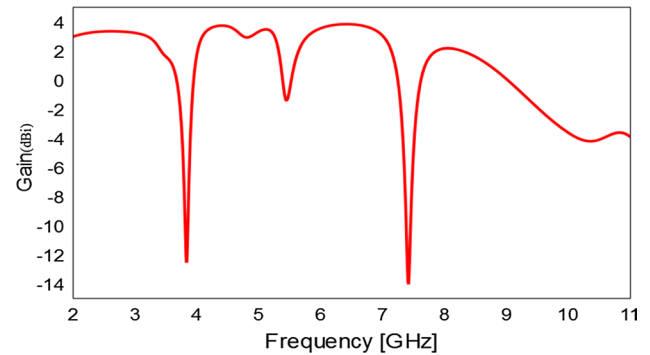
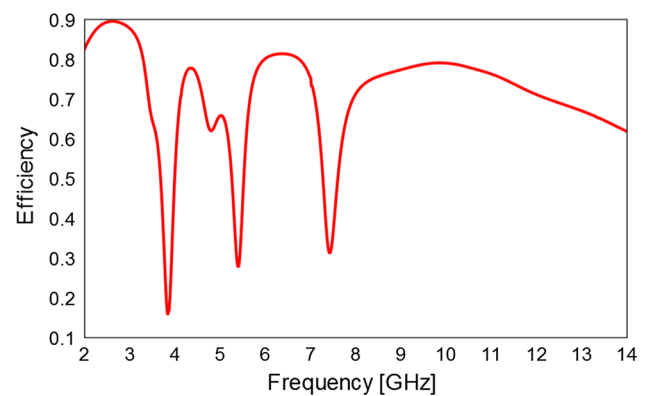
Ws2 (mm)	Notched frequency range (GHz)	Resonant frequency (GHz)	BW (GHz)
0.25	5.21–5.72	5.46	0.50
0.30	5.17–5.74	5.46	0.56
0.35	5.14–5.75	5.45	0.61

**Table 7** Parametric analysis of Ls3

Ls3 (mm)	Notched frequency range (GHz)	Resonant frequency (GHz)	BW (GHz)
5.82	7.33–8.45	7.66	1.11
5.88	7.24–8.38	7.57	1.14
5.92	7.16–8.37	7.49	1.21

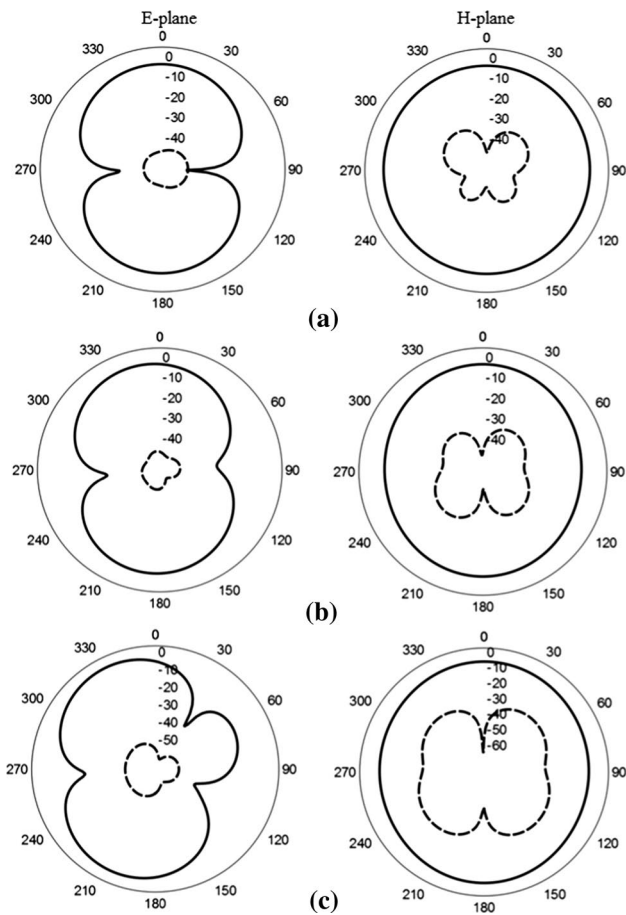
**Table 8** Parametric analysis of Ws3

Ws3 (mm)	Frequency range (GHz)	Resonant frequency (GHz)	BW (GHz)
0.30	7.22–8.37	7.53	1.15
0.32	7.24–8.39	7.56	1.15
0.34	7.27–8.42	7.59	1.15

**Fig. 12** Simulated surface current distributions on antenna. **a** At center of notched frequencies before inserting band-notched structures. **b** At center of notched frequencies after inserting band-notched structures**Fig. 13** Simulation result of VSWR of printed UWB monopole antenna with triple band-notched functionality**Fig. 14** Simulation gain versus frequency result of design antenna**Fig. 15** Simulation efficiency versus frequency result of design antenna

radiating patch depends on the surface current distribution and length of the slot is about half of the wavelength. The surface current distribution frequencies correspond to the centers of the three notched bands. The stronger current distribution concentrated near the edge of slots at the center frequency of the corresponding notched band and there is very weak current flow in the rest of the monopole. The C-shape slot acts as a half wavelength slot while parasitic stub acts as a quarter wavelength resonator to notched WLAN band simultaneously.

The simulation results reveal that the designed UWB antenna offers a very wide bandwidth with band-notching at 3.31–3.7, 3.7–4.2, 5.1–5.95, and 7.24–8.39 GHz. Figure 13 illustrates the simulated VSWR against frequency of the antenna. As observed, the measured impedance bandwidth of the proposed antenna for  $S_{11} < -10$  dB is from



**Fig. 16** Simulated radiation patterns of the antenna at pass bands 3.2 GHz, 4.75 GHz and 6.5 GHz. **a** H-plane, **b** E-plane

2.7 to 13.6 GHz, covering the entire UWB frequency band with enhanced bandwidth. Fairly good simulation results have been achieved minimizing the effects due to existing narrow bands interference. Figure 14 simulated result of gain versus frequency shows that for UWB range the maximum gain 3.84 dBi is achieved while at notched bands  $-12.6$  dBi for WiMax,  $-1.41$  dBi for WLAN and  $-14$  dBi for X-band. Figure 15 displays the simulated result of efficiency of the antenna with three drops of the efficiency can be observed. These results confirm the suppression of radiation in the notched frequency bands except the UWB range. The antenna efficiency is approximately 75 % for entire UWB range. Figure 16 shows nearly good omnidirectional patterns in the H-plane and the patterns in the E-plane are close to bidirectional. The design antenna is reliable as parameters such as measured VSWR, gain, efficiency and radiation pattern properties validate their reliability (Figs. 12, 13, 14, 15, 16).

## 5 Conclusion

In order to overcome the electromagnetic interferences a compact printed monopole antenna with tri-band notched operating in wideband (2.7–13.6 GHz) with bandwidth ratio of 5:1 is designed and simulated. The proposed antenna has wide bandwidth enough to cover UWB services along with the band-stop characteristic for coexisting bands (3.31–3.7, 3.7–4.2, 5.1–5.95, and 7.24–8.39 GHz) in UWB range. This is achieved by using more than one band-notching technique. The parametric analysis of each band-notched structure length and width were analysed to get the optimized dimension of the structure to get a good level of band rejection. Surface current distributions have been studied and discussed to illustrate the effect of these structures in getting the notched bands. The simulated results show that the designed antenna is applicable for various UWB services.

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