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RESEARCH PAPER

Design of dual band-notched lamp-shaped antenna with UWB characteristics

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To restrict electromagnetic interference at WiMAX (3.3–3.7 GHz) and wireless local area network (WLAN) (5.15–5.825 GHz) bands operating within ultra wide bandwidth (UWB) band, a novel design of lamp-shaped UWB microstrip antenna with dual band-notched characteristics is presented. The proposed antenna is composed of a lamp-shaped radiating patch with two rectangular ground planes on both the sides of the radiator with the gap of 0.57 mm. To improve impedance mismatch at middle frequencies, two triangular strips one at each of the ground plane are added; whereas a rectangular slot is etched in the radiating patch to remove impedance mismatch at higher frequencies of the UWB band. Furthermore, an L-shaped slot in the radiator and two L-shaped slots in the ground plane are used to restrict electromagnetic interference (EMI) at WiMAX and WLAN bands, respectively, without affecting the electrical performance of the UWB antenna. Effects of the key parameters on the frequency range of the notched bands are also investigated. The proposed design shows a measured impedance bandwidth of 12.5 GHz (2.7–14.4 GHz), with the two band-notched bands of 3.0–3.9 and 4.9–5.8 GHz. The antenna is suitable to be integrated within the portable UWB devices without EMI interference at WiMAX and WLAN bands.

Keywords: Band-notched, CPW-fed, UWB monopole antenna, Dual-notch, WiMAX, WLAN

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I. INTRODUCTION

The ultra-wide bandwidth (UWB) technology has attracted great attention in the wireless world due to their advantages, including high-speed data rate, low-power consumption, high capacity, low-cost, and low complexity. Due to extremely large bandwidth, UWB promises to modernize high data rate transmission at power level below noise floor, efficient usage of the spectrum, easy connection and data exchange among a large number of multimedia devices such as PCs, high definition TVs, digital cameras, vehicular radar systems, imaging systems, surveillance systems, medical systems, etc. UWB systems necessitate UWB antennas with the appealing features, such as high bandwidth, simple structure, and omni-directional radiation pattern. Many UWB antenna designs have been developed recently [1–3], among those designs, planar monopole antennas are promising for UWB wireless communication applications. However, there still exist several narrow bands for other communication systems over the designated frequency band, such as: IEEE 802.16 WiMAX system operating at 3.3–3.7 GHz and the wireless local area network (WLAN) for IEEE 802.11a operating at 5.15–5.35 and 5.725–5.825 GHz, which may cause severe electromagnetic interference to the UWB system. Therefore, it is desirable to design UWB antennas with band-notched performance in those frequency bands to avoid potential interference. Many researches have been carried out to design an UWB antenna with band-notched characteristics to minimize the interference between UWB and narrow band system without mounting an additional bandstop filter [4, 5]. Different methods to get band-notched structure embrace cutting slot of different shapes in radiator and ground plane [6–8].

A number of antenna configurations have been suggested for WLAN and WiMAX bands rejection in recent years [9–17]. A UWB operation with a notched frequency band can be obtained by inserting an Archimedean spiral-shaped slot into a microstrip open-circuit circular stub of microstrip–slotline transition [9]. Two split-ring resonator slots are etched on the radiators to achieve band-notched characteristics [10]. In [12], the notched characteristics are as achieved by etching one quasi-complementary split-ring resonator in the feed line. An arc-shaped parasitic strip is printed inside a circular slot to achieve band-notched characteristics [11]. In [13], a switched band-notched UWB is proposed using S-shaped slots and switch. The compact folded stepped impedance resonator is located beside the feed line to achieve the band rejection characteristics [14]. A $\lambda/3$ rectangular metal strip with the antenna element and $\lambda/4$ open slots are used to obtain notched characteristics [15]. In [16], the open-loop resonators and etching C-shaped slot on radiating patch and L-shaped stub on the ground plane [17] are used to achieve band-notched characteristics. From the review of the above papers, it is evident that there are

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Table 1. Dimensions and fractional bandwidth comparison of recently reported antennas with band-notched characteristics.

Reference	Size (mm × mm)	Bandwidth (GHz)
[9]	50 × 50	2.4–11.4
[10]	48 × 48	2.5–12
[12]	46.5 × 38.5	2–12.5
[11]	38 × 39	3.1–10.6
[13]	35 × 30	2.4–11
[14]	33 × 25	3.04–10.61
[15]	27 × 30	3.0–11.6
[16]	24 × 28	3–14
[17]	20 × 27	2.8–11.52
Proposed antenna	15 × 28	2.7–14.4

many techniques to achieve band-notched characteristics. Table 1 illustrates the comparison of the size and obtained fractional bandwidth of the recently published ultra-wideband antennas with band-notched characteristics. It is clearly seen from the comparison that the proposed antenna shows a compact size with comparable fractional bandwidth.

In this paper, a coplanar waveguide (CPW)-fed lamp-shaped UWB microstrip antenna with dual band-notched characteristics is designed which successfully rejects the electromagnetic interference at WiMAX (3.3–3.7) and WLAN (5.15–5.825) bands. The proposed antenna possesses a lamp-shaped radiator patch with two rectangular ground planes on both the sides of the radiating patch. Two triangular strips one at each of the ground plane are added and a rectangular slot in the radiating patch is etched to improve impedance mismatch at middle and higher frequencies of the UWB band, respectively. Furthermore, an L-shaped slot in the radiator and two L-shaped slots in the ground plane are used to restrict electromagnetic interference (EMI) at WiMAX and WLAN bands, respectively, without affecting the electrical performance of the UWB antenna. Detailed design of the antenna is discussed in the following sections:

II. ANTENNA DESIGN AND PARAMETRIC STUDY

A) Ultra wide band antenna

Figure 1 shows the geometry with detailed design parameters of the proposed UWB microstrip antenna. The UWB antenna is fabricated on a 1.6-mm-thick FR4 substrate with dielectric constant $\epsilon_r = 4.4$ and loss tangent tan $\delta = 0.02$. The overall size of the antenna is $15 \times 28 \times 1.6$ mm^3, and each of the embedded ground planes is separated from the feed line with a gap of 0.57 mm, respectively. The antenna consists of a simple lamp-shaped radiating patch with rectangular slot of $L_{p2} \times W_{p2}$ at the top and two rectangular ground planes embedded with two triangular-shaped structures to enhance the impedance bandwidth. The width of 8.9 mm long feed line is kept constant at 3 mm for providing the 50 Ω characteristics impedance. The length L_{p1} of the radiator, length L_{g3} of the triangular-shaped structure and gap between the feed line and ground planes are used for the parametric study and the optimized values of all parameters are listed in Table 2.

Figure 2 shows the variation of length (L_{p1}) of the lamp-shaped radiating patch from 5.5 to 9.5 mm. As the value of

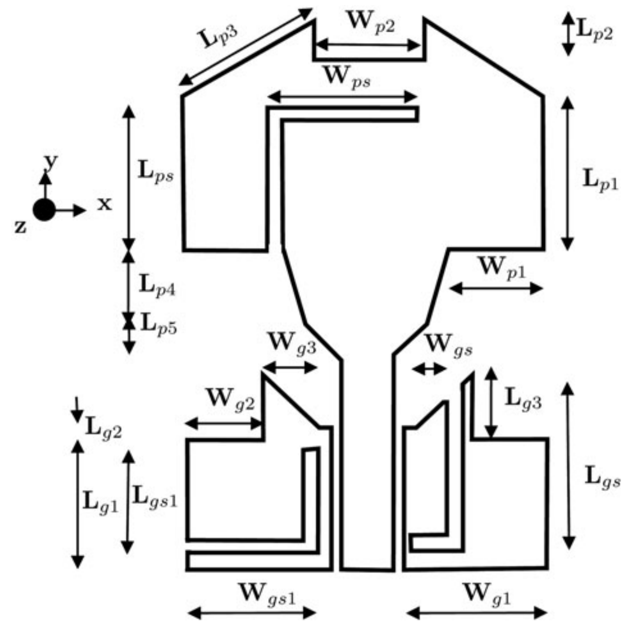

Fig. 1. Geometry of the proposed dual band-notched antenna with UWB characteristics.

L_{p1} increases from 5.5 to 7.5 mm, the bandwidth of antenna increases greatly with an improvement in impedance mismatch furthermore, the bandwidth starts decreasing with a high-impedance mismatch. Therefore, the value 7.5 mm is chosen as an optimum value for L_{p1}. Figure 3 shows the variation of length L_{g3} of the triangular-shaped structure attached to the ground plane on the voltage standing wave ratio (VSWR) of the antenna. As the values of L_{g3} change from 0.9 to 2.9 mm, the impedance bandwidth of the antenna increases greatly with an improvement in impedance mismatch at all the frequency bands and decreases furthermore. Therefore, $L_{g3} = 2.9$ mm is chosen as an optimum value.

The influence of the gap between two ground planes and single radiator patch is depicted in Fig. 4. Since in the present design, the radiator is surrounded by a metal ground plane for reducing the antenna area, the small gap between the radiator and the ground plane is a major factor to cause over-strong capacitive coupling. Thus a small change in the gap between ground planes will adversely affect the impedance matching of the structure. As the gap between ground plane and feed line increases from 0.37 to 0.57 mm, the impedance bandwidth remains almost constant but as it affects the tuning of feed line and ground planes, the impedance mismatch at middle and higher frequency bands starts improving. This mismatch increases with furthermore

Table 2. Design parameters (mm) of the proposed dual band-notched antenna with UWB characteristics.

L_{p1}	L_{p2}	L_{p3}	L_{p4}	L_{p5}
7.5	1.75	7.32	3	1.125
L_{ps}	L_f	L_{g1}	L_{g2}	L_{g3}
7.5	8.875	6.1	0.3	2.9
L_{gs}	L_{gs1}	W_{p1}	W_{p2}	W_{ps}
7	5.101	3.78	5	5.37
W_{g1}	W_{g2}	W_{g3}	W_{gs}	W_{gs1}
5.43	2.5	1.574	1.65	4.8

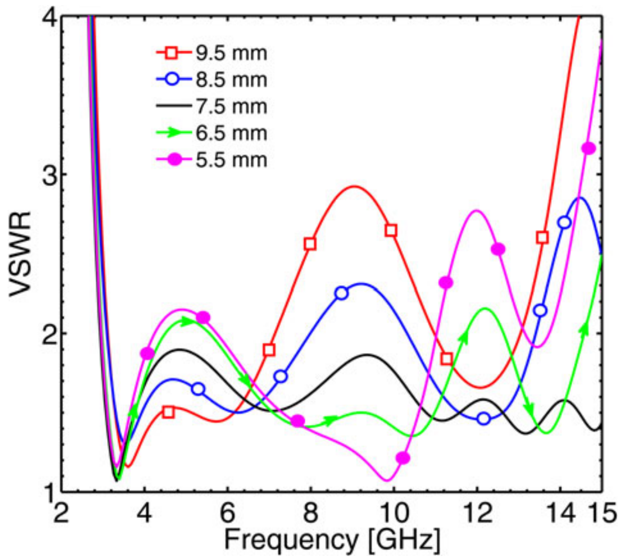

Fig. 2. Simulated VSWR against frequency for the proposed UWB microstrip antenna with various L_{p1}; other parameters are the same as listed in Table 2.

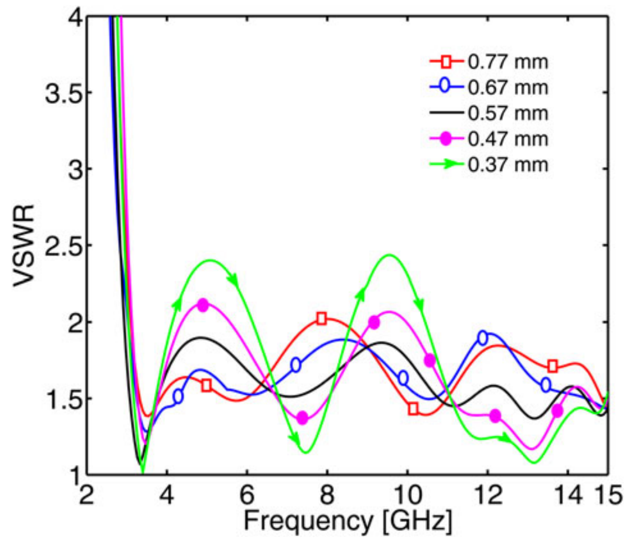

Fig. 4. Influence of the gap between two ground planes and feeding line patch on antenna performance.

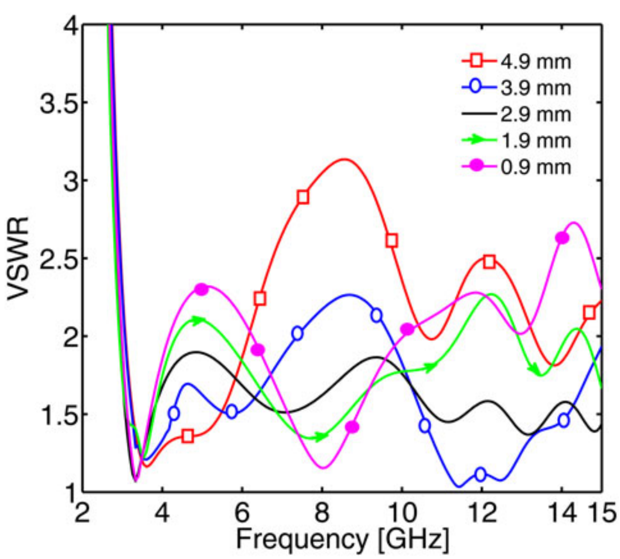

Fig. 3. Simulated VSWR against frequency for the proposed UWB microstrip antenna with various L_{g3}; other parameters are the same as listed in Table 2.

change. Therefore, the gap between feed line and ground planes is chosen 0.57 mm as an optimum value.

B) Band-notch WiMAX band

The band-notch at 3.35 GHz occurs due to the narrow (0.27 mm wide) L-shaped slits in the radiating patch. This slot will disturb the impedance matching between the feed line and radiating patch as the field across the slits will be out of phase. As a result, the VSWR in this band is increased and notched band is created. This can also be established by studying the current distribution as shown in Fig. 7(a). In this figure, it is clearly illustrated that the current maxima occurs at the end edge of this slit. At resonant frequency, the length of the current path would be half of the guided wavelength. Therefore,

$$L_{n1} = W_{ps} + L_{ps}. \quad (1)$$

In the proposed antenna design, this L-shaped slit acts as a quarter-guided wavelength resonator, and thus a center-rejected frequency f_n may be empirically approximated by [11]

$$f_n = \frac{c}{4L_{n1}\sqrt{\frac{\epsilon_r + 1}{2}}}, \quad (2)$$

where L_{n1} is the total length of the L-shaped slit, ϵ_r is the relative dielectric constant, and c is the speed of the light. Given a desired resonance frequency, one can then use numerical simulations to adjust the dimensions of the L-slot to obtain the final design. The total length of the L-slot is 12.87 mm corresponding to the center frequency of the band-notch at 3.35 GHz. The effectiveness of the design method is further validated by predicting the notch frequency for the data presented in Fig. 5. In Table 3, the notched resonant frequency as a function of L_{ps} is compared with the full-wave simulated data.

From Fig 5, it can be seen that the resonant frequencies calculated from the design method are agreeing well with the simulated data. From the above result, it is concluded that the notch frequency is controllable by changing the overall length of the L-slot.

C) Band-notch at WLAN band

Further, to reject the interference of the WLAN band (from 5.1 to 5.8 GHz), L-shaped slots (0.45 mm wide) are etched on the right-hand side of the ground plane as a quarter-guided wavelength resonator to generate band-notched. As discussed above, this slot in the right-hand side of the ground plane will disturb the impedance matching between the feed line and radiating patch as the field across the slits will be out of phase. As a result, the VSWR in this band is increased and notched band is created. This can also be established by studying the current distribution as shown in Fig. 7(b). In this

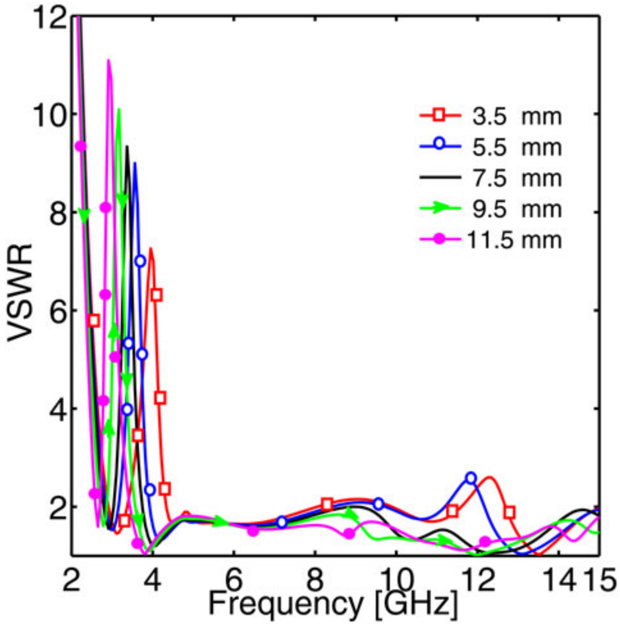

Fig. 5. Simulated VSWR against frequency for the proposed band-notched UWB microstrip antenna with length L_{ps} of L-slot in the radiating patch.

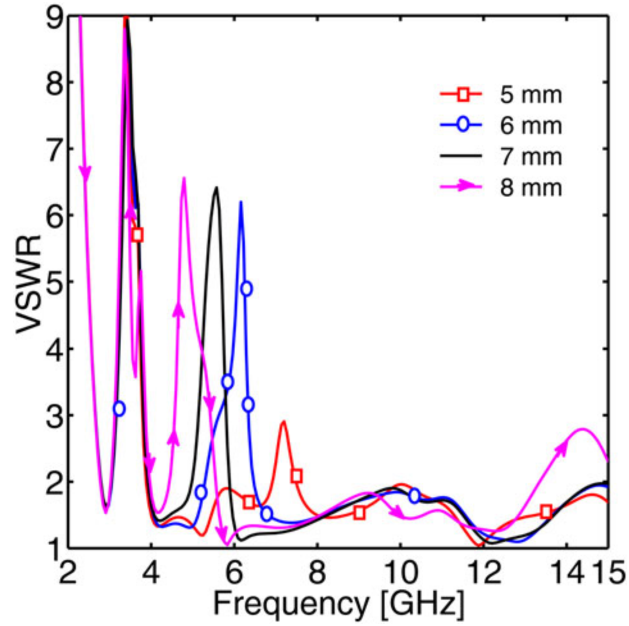

Fig. 6. Simulated VSWR against frequency for the proposed band-notched UWB microstrip antenna with length L_{gs} of L-slot in the ground plane.

figure, it is clearly illustrated that the current maxima occurs at the end edge of this slit; whereas the L-slit (0.2 mm wide) in the left-hand side ground is used to restrict the bandwidth of the band notch from 4.9 to 5.8 GHz only. At resonant frequency, the length of the current path would be half of the guided wavelength. Therefore,

$$L_{n2} = W_{gs} + L_{gs}. \quad (3)$$

In the proposed antenna design, this L-shaped slit acts as a quarter-guided wavelength resonator and thus a center-rejected frequency f_n may be calculated by (2). Fig. 6 shows, the simulated VSWR characteristics for the length L_{gs} of the L-shaped slot etched in the right-hand side of the ground plane from 5 to 8 mm. It is observed that the change in slot length causes the change in current path, in turn, additional stop band occurs at WLAN band. Furthermore, it is evident from Fig. 6 that the center frequency of the band-notch shifts toward lower frequency. Therefore, the length of L-shaped slit filter is chosen 7 mm as an optimum value for the band-notch rejection at 5.51 GHz. The effectiveness of the design method is further validated by predicting the notch frequency for the data presented in Fig. 6. In Table 4, the notched resonant frequency as a function of L_{gs} is compared with the full-wave simulated data.

Table 3. Comparison of notched resonant frequency as a function of L_{ps} with the full-wave simulated data.

L_{ps} (mm)	L_{n1} (mm)	Resonant frequency (GHz)	
		Full-wave simulation	Design equation
3.5	8.87	5.05	5.14
5.5	10.87	4.06	4.19
7.5	12.87	3.4	3.54
9.5	14.87	2.9	3.06
11.5	16.87	2.64	2.7

From Fig. 6, it can be seen that the resonant frequencies calculated from the design method are agreeing well with the simulated data. From the above result, it is concluded that the notch frequency is controllable by changing the overall length of the L-slot.

D) Current density

The simulated current densities at various frequencies are plotted in Fig. 7 to understand the ultra-wideband and band-notched behavior of the antenna. It is seen from Fig. 7(a) that the current is mainly distributed on the lower part of the radiator and the ground planes for the UWB antenna, and it is also concentrated around the L-shaped slit in the lamp-shaped radiator for the band-notched antenna, as the total current is dissipated within the slit. The electric field across the L-shaped slit is out of phase, thus no radiation will take place. This clearly indicates that the L-shaped slit in the radiator effectively provides the electrical current path for producing the 3.43 GHz rejection frequency band. Figure 7(b) shows that the surface currents are mainly distributed over the ground plane and the lower part of the radiator for the UWB antenna, and it is also concentrated around the L-shaped slits in the ground plane for the band-notched antenna. It clearly indicates that the L-shaped cuts in the ground plane dissipate the total current within the slits. Again the electric field across the slits are out of phase, thus no

Table 4. Comparison of notched resonant frequency as a function of L_{gs} with the full-wave simulated data.

L_{gs} (mm)	L_{n2} (mm)	Resonant frequency (GHz)	
		Full-wave simulation	Design equation
5	6.65	7.1	6.9
6	7.65	6.1	5.9
7	8.65	5.52	5.3
8	9.65	4.7	4.7

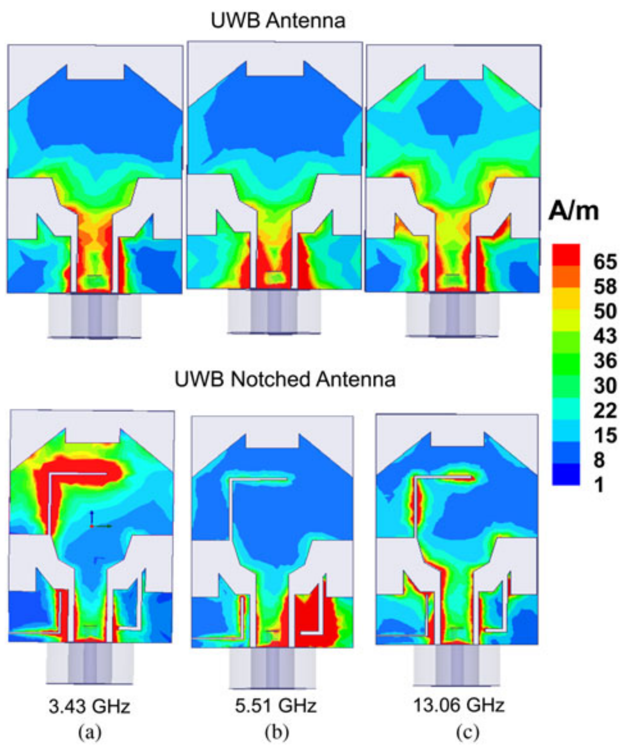

Fig. 7. Surface current densities for the proposed antennas.

radiation will take place at the frequencies around 5.5 GHz. At the other passband frequency of 13 GHz, the surface current is uniformly distributed over the radiator and ground planes (see Fig. 7(c)). From the above Figs 7(a)–(c), it is evident that the L-shaped slits in radiator and ground planes affects the performance of UWB antenna at notch frequencies only otherwise they offer no effect on the antenna as expected.

III. RESULTS AND DISCUSSION

After optimization, the proposed antenna was fabricated with the MITS-Eleven Laboratory PCB machine. Figure 8 shows the simulated and measured VSWR of the proposed antennas. The measurement was performed with an Agilent N5230A vector network analyzer. Measured data show good agreement with the simulated one. It is found that the proposed antenna shows two-designed band notches at 3.0–3.9 and 4.9–5.8 GHz, while maintaining broadband performance from 2.7 to 14.4 GHz with VSWR less than 2, covering the entire UWB frequency band.

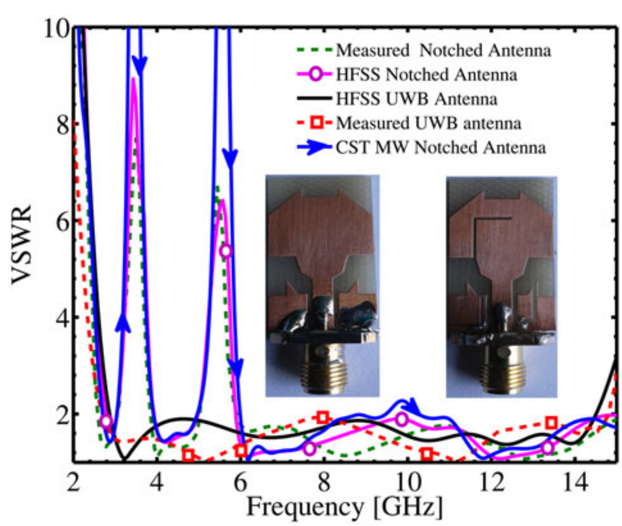

Fig. 8. Measured and simulated VSWR for the proposed CPW-fed UWB microstrip antenna with band-notched characteristics and UWB antenna.

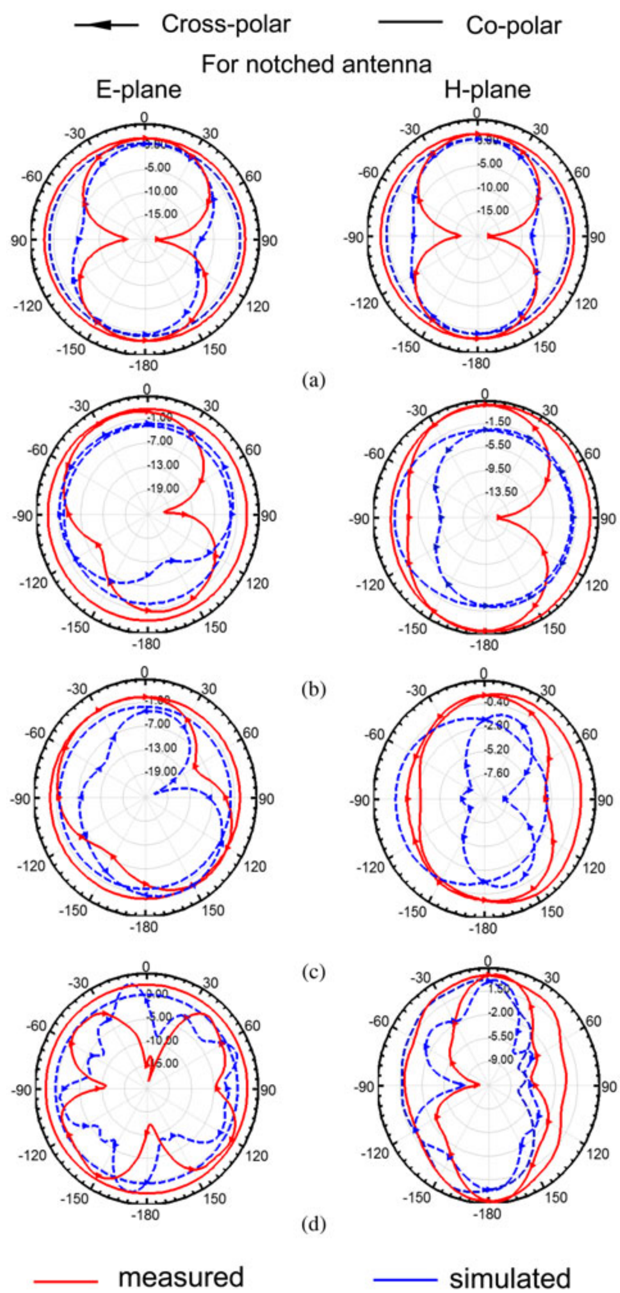

Fig. 9. Radiation pattern for various resonance frequencies for the proposed lamp-shaped UWB antenna with dual band-notched characteristics with – measured – simulated at (a) 2.78 GHz, (b) 3.43 GHz, (c) 5.51 GHz, and (d) 12.4 GHz.

The measured and simulated radiation patterns of UWB antenna with dual band-notched characteristics, in the *E*-(*xz*-) and the *H*-(*xy*-) planes at (a) 2.78, (b) 3.43, (c) 5.51, and (d) 12.4 GHz, are shown in Figs 9(a)–(d), respectively. It is found that the antenna has nearly good omni-directional radiation

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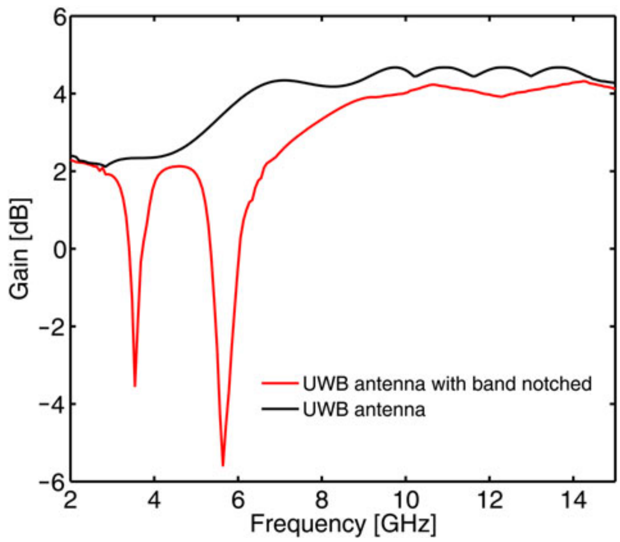

Fig. 10. Gain for various resonance frequencies for the proposed UWB antenna and UWB antenna with dual-notched characteristics.

patterns at all frequencies in the *E*- (*xz*-) plane and the *H*- (*xy*-) plane. However, at the band-notched frequencies (3.43 and 5.51), the antenna displays unstable radiation patterns with degradation in gain as shown in Fig. 10 which illustrates the measured gain of UWB antenna and UWB antenna with dual band-notched characteristics. It is observed from Fig. 10 that the gain of the antenna drops down (~6.5 dB) at both the band-notches and remains constant for the rest of the band. Thus, the design shows the ultra-wideband performance with band-notched operation at WiMAX and WLAN bands.

IV. TIME-DOMAIN CHARACTERISTICS

To investigate the performance of UWB antenna in transmitter and receiver UWB systems, two identical antennas are

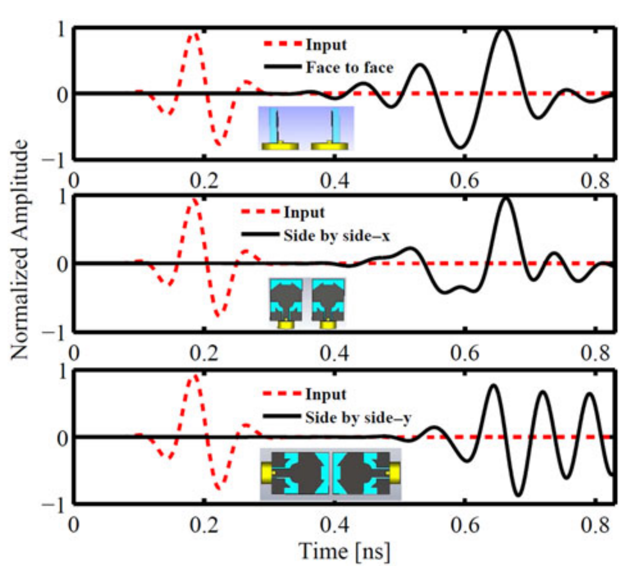

Fig. 11. Input and received pulses in different orientations of the proposed antenna.

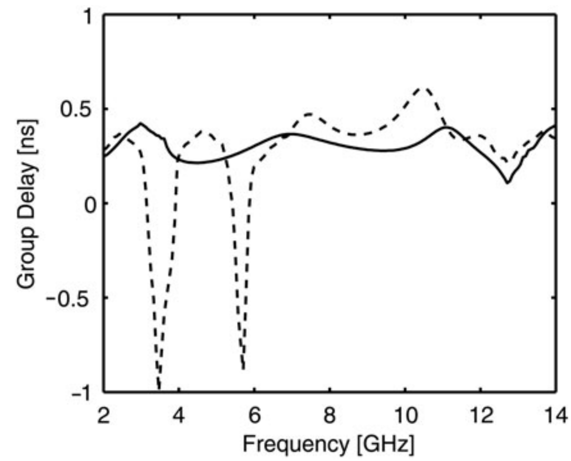

Fig. 12. Group delays for the proposed compact UWB microstrip antenna – and UWB microstrip antenna with dual band-notched characteristics.

placed at some distance from each other in three different orientations (face-to-face, side-by-side-*x*, and side-by-side-*y*) in the far-field region as shown in Fig. 11 using CST MWS [18]. A well-defined parameter named fidelity is proposed to access the quality of received signal waveform regarding the input signals in (4):

$$F = \max\left|\frac{\int_{-\infty}^{\infty} s_t(t)s_r(t+\tau)dt}{\sqrt{\left(\int_{-\infty}^{\infty} s_t(t)^2 dt\right)\left(\int_{-\infty}^{\infty} s_r(t)^2 dt\right)}}\right|, \qquad (4)$$

where $s_t(t)$ and $s_r(t)$ are the input and received signals. The fidelity (F) is the maximum correlation coefficient of the two signals by varying the time delay [19]. The fidelity factor in three different orientations (face-to-face, side-by-side-*x*, and side-by-side-*y*) comes out to be 66.82, 72.55, 71.26 %, respectively. In Fig. 11, the time-domain transmitted and received pulses for three different orientations confirm the fidelity factor results.

Group delay is another parameter in time-domain analysis used to measure the pulse distortion. Generally, it is desirable to have a linear phase response, i.e. constant group delay. Figure 12 describes the simulated group delay of the UWB antenna and the UWB antenna with band-notched characteristics. The variation of the group delay of the UWB antenna is less than 1 ns, while group delay of the UWB antenna with notch characteristics exceed 1 ns at the notch band, which distorts the minimal phase linearity. However, the group delay variations are small in rest of the frequency band of the UWB antenna with notch characteristics. The group delay characteristics discussed above demonstrate that the proposed antennas exhibit phase linearity at desired UWB frequencies. It is found from aforesaid studies that the antenna has good pulse handling capability in the UWB frequency band.

V. CONCLUSION

A compact CPW-fed UWB-printed monopole antenna with dual band-notched characteristics is proposed, fabricated, and discussed. The two designed band notches were realized by etching quarter-wavelength L-shaped slot in radiating patch and two quarter-wavelength L-shaped slots in both the ground planes. To get the desired band rejection, the effects of the overall length of the slots were analyzed. Surface current distributions were used to show the effect of these L-shaped slots in getting the notched bands. The fabricated antenna showed good agreement between the measured and simulated results with a wide bandwidth from 2.7 to 14.40 GHz and two intended notched bands in a small size.

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