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TRIPLE BAND-NOTCHED PLANAR UWB ANTENNA USING PARASITIC STRIPS

M. T. Islam[1, *], R. Azim[2], and A. T. Mobashsher[3]

[1]Institute of Space Science (ANGKASA), Universiti Kebangsaan Malaysia, UKM Bangi 43600, Malaysia

[2]Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia, UKM Bangi 43600, Malaysia

[3]Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, P. O. Box 80204, Jeddah 21589, Kingdom of Saudi Arabia

Abstract—A compact planar ultra-wideband (UWB) antenna with triple band notch characteristics is proposed in this paper. The antenna consist a rectangular radiating patch, a modified partial ground plane, and has an overall dimension of $30 \times 22\,\text{mm}^2$. Three resonant elements are placed above the ground plane to generate three notch frequency bands separately in the WiMAX, the lower WLAN and the upper WLAN frequency bands. The proposed antennas are successfully simulated, prototyped and measured. Effects of the key deign parameters on band notch characteristics are also investigated. The realized antenna achieved an operating bandwidth (VSWR ≤ 2) ranges from 2.9 to more than 11 GHz with triple notched bands of 3.26–3.71 (12.9%), 5.15–5.37 (8.5%), and 5.78–5.95 (2.9%) GHz. Measured flat transfer function and constant group delay within the operating band except notched bands make the proposed antenna suitable for being used in practical UWB applications.

1. INTRODUCTION

Ultra-wideband (UWB) technology has recently received much attention due to the characteristics such as low cost, low complexity, low spectral power density, high precision ranging and become the most potential candidate for short-range high speed wireless communication

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* Corresponding author: Mohammad Tariqul Islam (titareq@yahoo.com).

systems. As a key component of the UWB systems, the antennas with ultra-wide bandwidth have been widely investigated by both industry and academia since the Federal Communications Commission (FCC) released 3.1 to 10.6 GHz unlicensed band for radio communication. Several coplanar waveguide-fed and microstrip-fed planar antennas, which have the potential to meet UWB requirements, have been proposed [1–3]. However, over the designated UWB frequency band, there exist some narrow bands for other communication systems, such as WiMAX (3.3 to 3.7 GHz) and WLAN (5.15 to 5.825 GHz), which may cause electromagnetic interference with the UWB systems. Therefore, it is necessary for UWB antennas performing band notch characteristics in those narrow frequency bands to avert the potential interferences.

Several UWB antennas have been attempted to overcome interference problem using frequency band rejected characteristics design. Many techniques have already been proposed to design band-notched antennas, for example, an isolated slit inside a patch, two open-end slits at the top edge of a T-stub, two parasitic strips, embedded semi-circular annular parasitic strip; and a pair of T-shaped stubs inside an elliptical slot, inclusion of an additional small radiating patch, L-shaped quarter wavelength resonators coupled to the patch and a pair of ground stubs along the edge of ground plane [4–12]. However, each of these proposed designs can be notched only one frequency band.

Recently, some antennas address the dual or multi-rejected frequency band design [13–30]. For example, in [17], a band notch antenna with dual notched bands has been proposed for UWB applications. By placing two parasitic strips on the radiator, the proposed antenna successfully create dual notched band for lower and upper WLAN. Despite of being fairly compact dimensions, the antenna does not generate notched band for WiMAX. In [13], a UWB antenna with triple notched band has been proposed. By using meandered ground stubs, the proposed antenna achieved UWB characteristics with triple notched band for WiMAX, lower and upper WLAN. However, the antenna does not process a physically compact profile having dimensions of $39.3 \times 30\,\mathrm{mm}^2$. Some of the proposed band notch design for WLAN completely rejected the entire 5–6 GHz frequency band, though the desired notch-bands are 0.2 GHz (5.15–5.35 GHz) for lower WLAN band and 0.1 GHz (5.725–5.825 GHz) for upper WLAN band. Hence, any useful information contained in the frequency band of 5.35–5.725 GHz will also be lost resulting in the degradation of received information and thus shorter range of coverage and lower signal quality.

In the designing of triple or multi-band notch antenna, it is difficult to control bandwidth of the notch-bands in a limited space. Moreover, strong couplings between the band-notch characteristic designs for adjacent frequencies are the complication in achieving efficient triple band-notch UWB antenna. Therefore, an efficient frequency band notch technique for lower WLAN band and upper WLAN band along with the WiMAX band is still difficult to implement for allowing maximum available frequencies of the UWB applications [17].

In this paper, a novel planar antenna with triple notched bands is proposed. To realize the triple band notch characteristics for a compact monopole antenna, three resonating elements are etched out above the modified ground plane. By adjusting the sizes and the locations of the resonating elements, notched frequency bands can easily be achieved and controlled according to the practical requirements, and changing of parameters of the resonators (notch elements) affect only the notch bands, the VSWR in the rest of the UWB frequency band remains unchanged. These properties provide a great freedom to select the notch frequency band and bandwidth for the triple band notch antenna. With a compact dimension of $30 \times 22\,\mathrm{mm}^2$, the proposed antenna achieves a bandwidth ranging from 2.9 to more than 11 GHz with triple notched bands centered at 3.45 GHz, 5.25 GHz and 5.85 GHz. Moreover, the proposed antenna exhibit omni-directional radiation patterns and good time domain behaviors which make it very suitable for being used in practical UWB applications.

2. ANTENNA DESIGN

The microstrip line fed proposed triple band notch planar antenna consists of rectangular radiating patch and a partial rectangular ground plane as shown in Fig. 1. The patch with a dimension of $W_P \times L_P$ is printed on the top side PCB substrate while the partial ground plane having a side length Lg is printed on the bottom side. The width of the microstrip feed line, w_f is fixed at 3 mm to achieve $50\,\Omega$ Characteristics impedance from 2.9 more than 11 GHz. The proposed antenna has a compact size of $W \times L$ and is printed on 1.6 mm thick FR4 dielectric substrate with dielectric constant 4.6 and loss tangent 0.02.

To improve the bandwidth of the antenna, the partial ground plane is modified by cutting triangular shape slots at its top edge. The resultant antenna is shown in Fig. 1(d). The return losses in Fig. 2 shows that the triangular slots of dimension $2 \times 1 \times \sqrt{5}\,\mathrm{mm}^3$ has small effect on the lower edge frequency while it increase the upper edge frequency of the operating band and the antenna can provide an impedance bandwidth of 9.48 GHz operating from 2.96 to

12.44 GHz. To enhance the bandwidth further, the top edge of the partial ground plane are reshaped to form a sawtooth shape top edge, as shown in Fig. 1(e). The optimized dimension of the triangular shape slot is $4 \times \sqrt{5} \times \sqrt{5}\,\mathrm{mm}^3$. The return loss curve presented in Fig. 2 shows that the antenna with modified ground plane can be operated from 2.92 GHz to 15.70 GHz providing an impedance bandwidth of 12.78 GHz. The insertion of slots in the top edge of the ground plane increases the gap between the radiating patch and the ground plane and as a result the impedance bandwidth increases further due to extra electromagnetic coupling in between radiating element and the ground plane. Compared to the antenna with rectangular partial ground plane, the antenna with modified sawtooth shape ground plane can increase the bandwidth by 43.6% (3.89 GHz) as shown in Fig. 2.

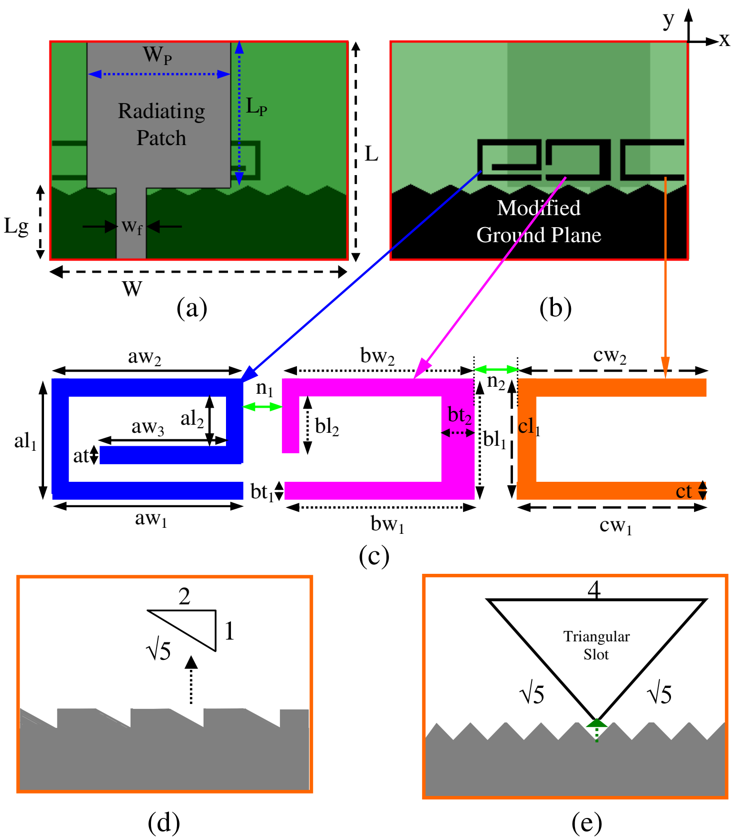


Figure 1. Geometry of the proposed antenna. (a) Top view. (b) Bottom view. (c) Band notch structure. (d)–(e) Modification of ground plane.

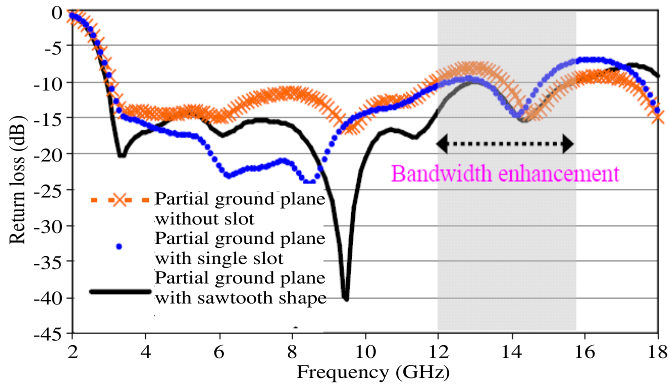


Figure 2. Return loss curves for different ground planes.

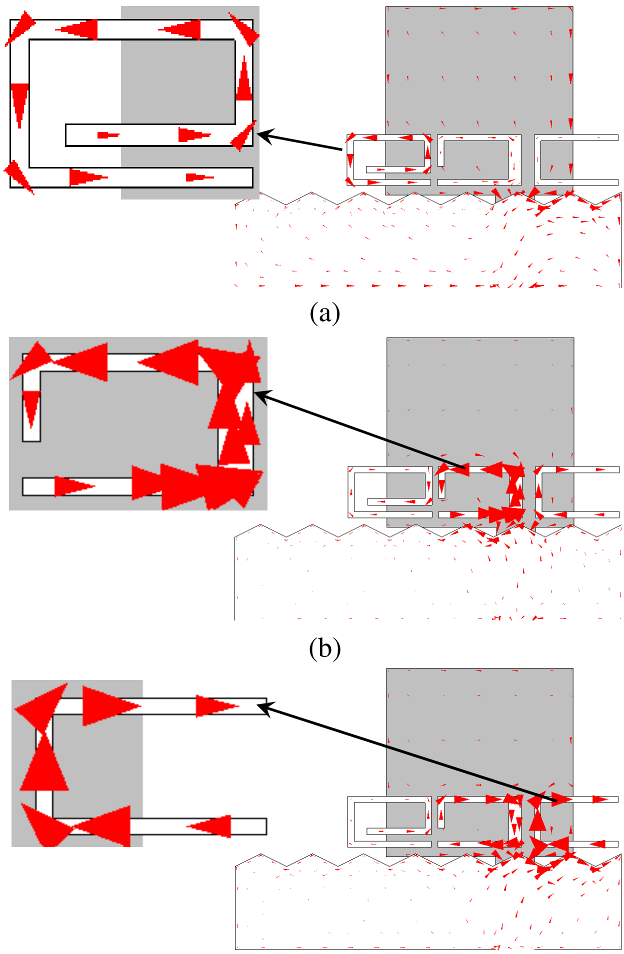
Table 1. Triple band notch UWB antenna dimensions.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
W	30	aw_3	5	bt_1	0.5
L	22	al_1	3	bt_2	1
W_P	14.5	al_2	2	cw_1	6.5
L_P	14.75	at	0.5	cw_2	6.5
Lg	7.5	bw_1	6.5	cl_1	4
w_f	3	bw_2	6.5	ct	0.5
aw_1	6.5	bl_1	4	n_1	0.5
aw_2	6.5	bl_2	2.5	n_2	1

To achieve triple band notch characteristics, three resonant elements are placed above the ground plane to generate three notches separately in the WiMAX, the lower WLAN and the upper WLAN bands. To create a band notch in the WiMAX frequency band, an **e**-shaped resonant element is symmetrically etched out at a distance of 0.5 mm from the top edge of the ground plane as shown in Fig. 1(b). To generate two more notch bands for lower and upper WLAN bands, one open circuit stub and one **c**-shaped resonant element are symmetrically placed at the same distance from the top edge of the modified ground plane as shown in Fig. 1(b). The band notch characteristics of the proposed antenna can be controlled by properly adjusting the parameters of these resonant elements placed at the backend of the patch as shown in Fig. 1(c). Detailed dimension of the triple band notch antenna are listed in Table 1.

To create notch bands, three different resonant have been used. The effective lengths of the resonant elements are approximately quarter wave length for the frequency around 3.45 5.25 and 5.85 GHz. At the vicinity of these frequencies the radiation is blocked and the notched bands are created.

This phenomenon also can clearly be explained by examining the current distributions. As shown in Fig. 3, at notch frequencies, the current flows are more dominant around the notch structures. The



(a)

(b)

(c)

Figure 3. Simulated current distributions at different frequencies. (a) 3.45 GHz. (b) 5.25 GHz. (c) 5.85 GHz.

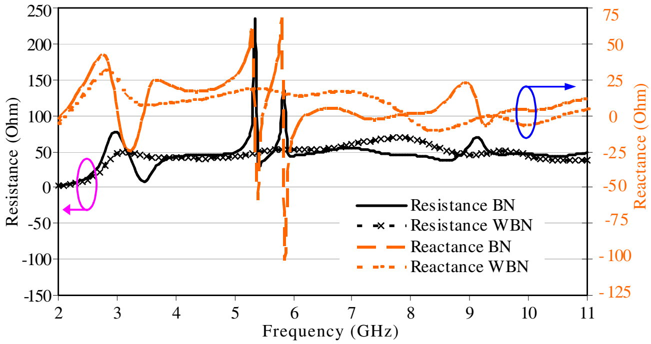


Figure 4. Simulated input impedances of the antennas with (BN) and without band notch (WBN).

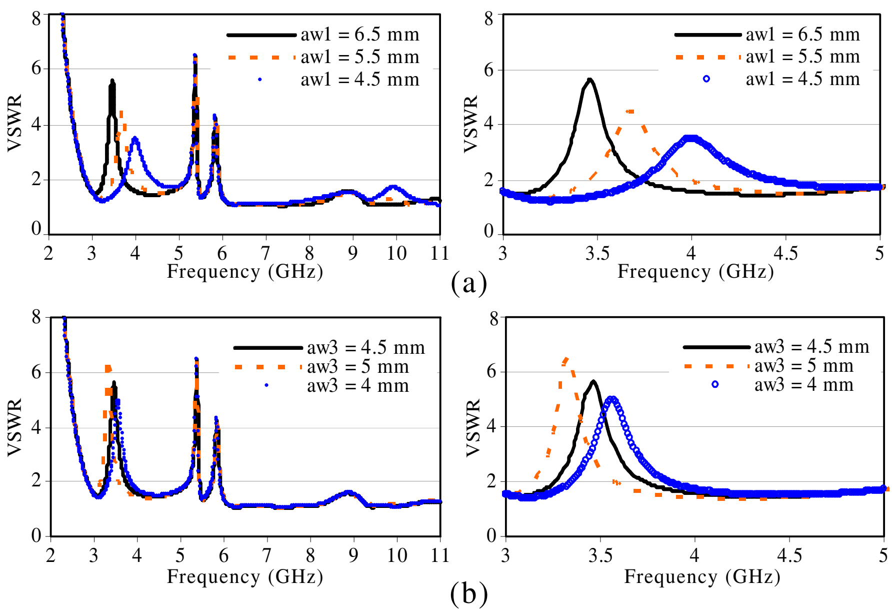
directions of the current in the similar arms of the resonant elements are opposite and they cancel each other. As a result the antenna does not radiate at that frequency and a frequency notch is created around the frequency of 3.45 GHz, 5.25 GHz and 5.85 GHz. Therefore, from the current distributions, it can be concluded that the parasitic resonant elements causes the frequency notched functions as explained in detail in [13, 17]. In [13], it was shown that at notched frequency, the current flows are dominant around the pair of Γ-shaped filter structures, and they are oppositely directed between and exterior edges. Therefore the resultant radiation fields are cancelled, and high attenuation near notch frequency band is produced. Similar operating principle also applied in [17] to create notch frequency bands.

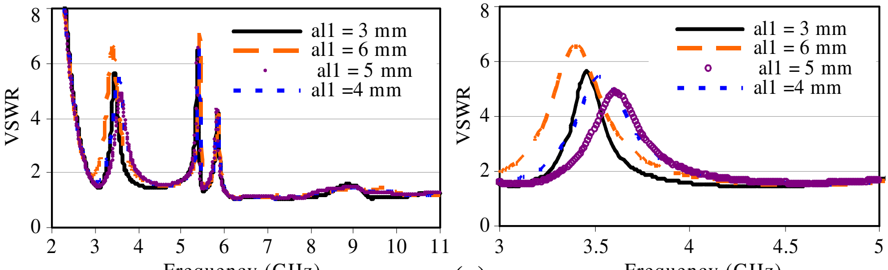
Figure 4 provides an illustration for the input impedance characteristics of the proposed triple band notch antenna along with the antenna without band notch. As discovered, compared to antenna without band notch, the resistance of the band notch antenna is far away from 50 Ω lead to the mismatch at around 3.45, 5.25 and 5.85 GHz. In addition, at the centre frequency of the notch bands, the zero reactance results in the syntonic of the antenna at those frequencies. These results can readily account for the triple band-notched characteristics. Moreover, outside those notched bands the proposed antenna is well matched and similar to that of antenna without band notch characteristics.

3. EFFECT OF NOTCHED PARAMETERS ON ANTENNA PERFORMANCES

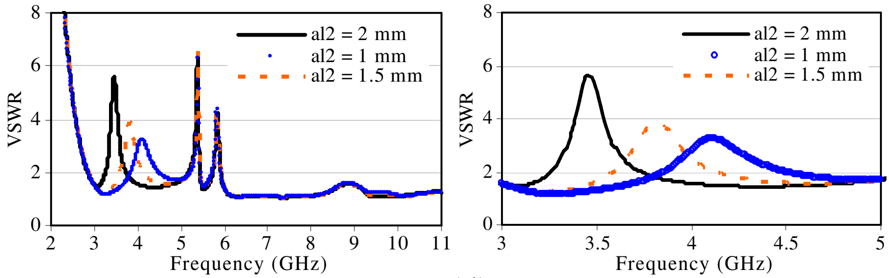
A parametric study of the triple band-notched UWB antenna has been conducted by computer simulation to explore how the dimensions of the different resonant elements affect the performances of band notches. Therefore, we need to investigate the individual resonant effects based on length, width, and position. Basically, the length and width of the each resonator acts as the inductance, and the distance between the adjacent arms acts as the capacitance. The couplings between the resonators and the main radiator act as the filter to create a notch band at certain frequency as explained in detail in [18, 19].

Figure 5 exhibits the effect of different parameters of **e**-shaped resonant element on band notch characteristics as well on VSWR of the antenna. Its parameters aw_1, aw_3, al_1 and al_2 significantly affect the notch band for WiMAX. It can be observed from Fig. 5(a) as the value of aw_1 increases, the notch frequency band for WiMAX shifts towards lower frequency band and the bandwidth of the notch frequency band is decreases. The optimized value of aw_1 is taken as to be 6.5 mm to create a notch frequency band ranges from 3.26–3.75 GHz. Fig. 5(b) shows that effect of aw_3 on notch frequency band for WiMAX. It can be revealed that the centre frequency of the notch band moves towards lower edge frequency as the value of aw_3 increases from 4 to 5 mm. Bandwidth of the notch band also decreases with the increasing value of aw_3. As is seen in Fig. 5(c), increase in al_1 from 3 to 5 mm with other parameters constant, the centre frequency of the first notch band for WiMAX moves to a higher frequency. At the same time the bandwidth of the first notch also changes with changing al_1. Fig. 5(d) depicts the effect of al_2 on band notch performance. It is observed that the centre





(c)



(d)

Figure 5. Simulated VSWRs for different values of (a) aw_1, (b) aw_3, (c) al_1, (d) al_2.

frequency of first notch band shifts down from 4.13 to 3.45 GHz as al_2 increases from 1 to 2 mm and the bandwidth of notch band increases from 0.49 GHz to 0.64 GHz. Therefore, from above analysis it can be concluded that, the first notched band for WiMAX is controlled by the **e**-shaped resonator where as it has no effect on the other notch bands. It can also be concluded that the centre frequency as well as the bandwidth of the first notch band can be adjusted by properly selecting the values of aw_1, aw_3, al_1 and al_2.

Figure 6 illustrates the effect of bw_1, bl_1, bl_2 and bt_1 on band notch characteristics as well as on the antenna performance. Theoretically, the notch frequency band for lower WLAN is determined by the widths and lengths of the open circuit stub that placed in between **e**- and **c**-shaped resonant elements. From Fig. 6(a) it is observed that the as the value of bw_1 increases, the centre frequency of the second notch band for lower WLAN shifts towards lower frequency band. The bandwidth of the notch band also decreases with the increase of bw_1. The parameters bl_1 and bl_2 also affect the second notch frequency band significantly.

It is observed from Figs. 6(b) and 6(c) that the notch band moves to lower frequency band as the values of bl_1 and bl_2 increases. The bandwidth of notch band is also deceases with increasing bl_1 and bl_2.

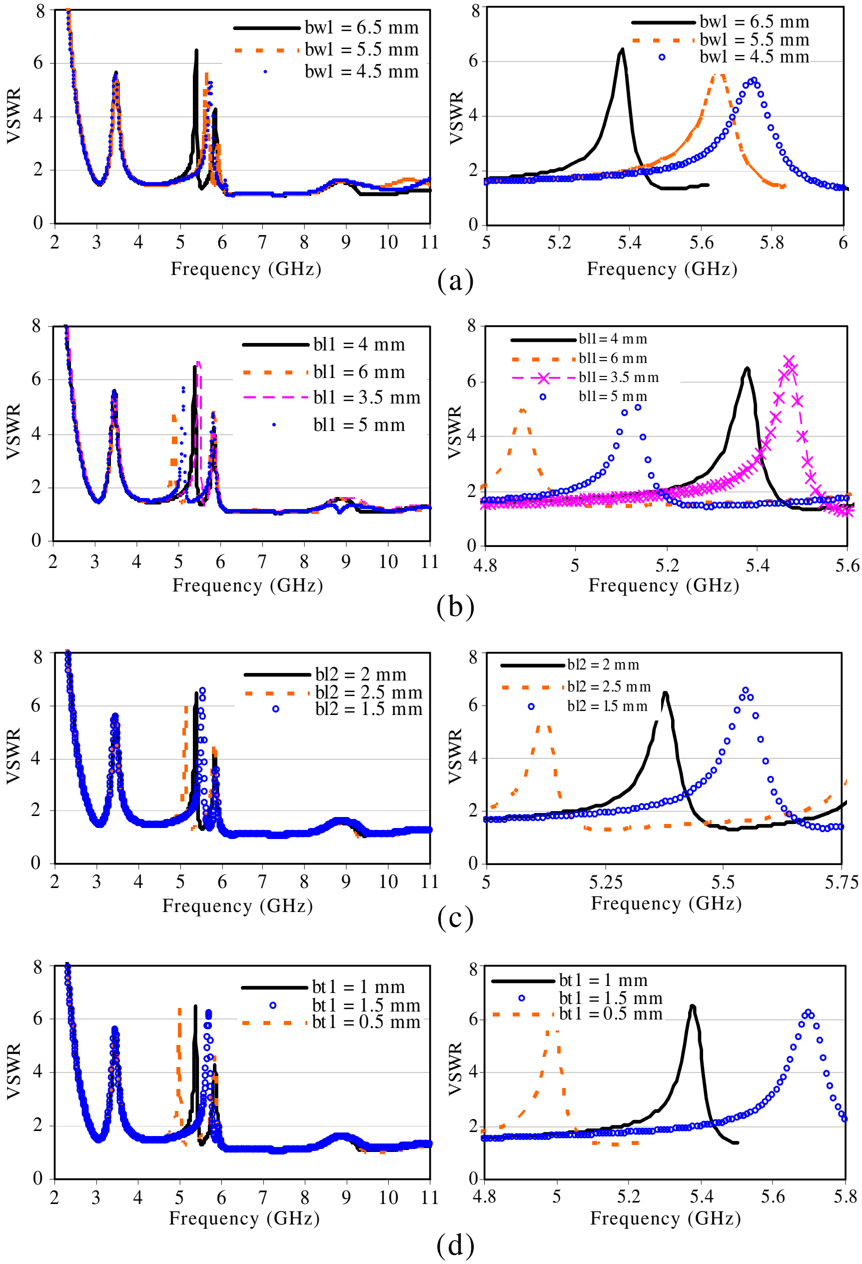


Figure 6. Simulated VSWRs for different values of (a) bw_1, (b) bl_1, (c) bl_2, (d) bt_1.

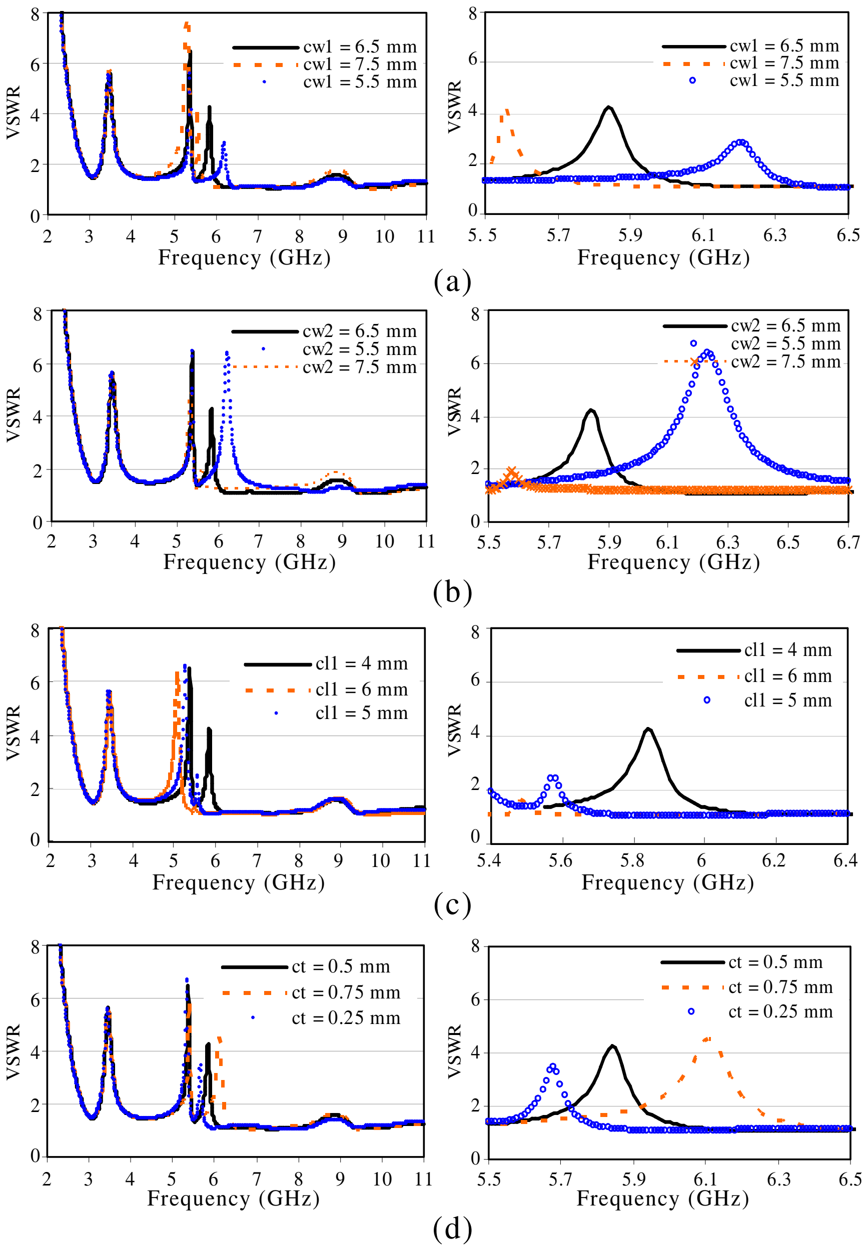


Figure 7. Simulated VSWRs for different values of (a) cw_1, (b) cw_2, (c) cl_1, (d) ct.

The thickness of bt_1 has a great effect on band notch performance especially the notch band lower WLAN. It is seen in Fig. 6(d) that as the value of bt_1 changes from 0.5 to 1.5 mm, the centre frequency of the second notch band shifts from 4.99 to 5.7 GHz (0.71 GHz) and the bandwidth of notch band increased by 0.21 GHz.

So, from the parametric studies presented in Fig. 6, it can be concluded that, the second notched band for lower WLAN is significantly dependent on the parameters of open circuit stub whereas these parameters have no effect on the first notch band and little effect on third band notch. It can also be concluded that the centre frequency as well as the bandwidth of the first notch band can be adjusted by properly selecting the values of bw_1, bl_1, bl_2 and bt_1.

The effects of different parameters of **c**-shaped on band notch characteristics as well as antenna performance are depicted in Fig. 7. As is seen in Fig. 7(a) the centre frequency of third notch for upper WALN shifts towards lower frequency band gradually as the value of cw_1 is increases. The bandwidth of this notch also varies with the variation of cw_1. It is observed from Fig. 7(b) that the bandwidth of third notch band is critically dependent on cw_2. As the value of cw_2 increases from 5.5 to 7.5 mm, the central frequency of the notch band for upper WALN gradually moves to lower frequency band and bandwidth of this band becomes zero, i.e., there is no notch band. Hence, by optimizing the value of cw_2, a proper notch band at around 5.85 GHz can easily be achieved. The length, cl_1 of the **c**-shaped resonator also strongly affects the third notch band as shown in Fig. 7(c). The bandwidth of third notch band gradually decreases with increasing cl_1 and stop to create this notch band for at $cl_1 = 6$ mm. The centre frequency of this band is also sensitive and moves towards lower frequencies with increasing cl_1. Fig. 7(d) shows the variation of VSWR with the values of ct. When the values of ct varies from 0.25 mm to 0.75 mm, the center frequency of third notch band shifts from 5.68 GHz to 6.12 GHz (0.44 GHz) and the notch bandwidth increases from 0.09 GHz to 0.3 GHz (0.21 GHz).

From the parametric studies presented in Fig. 7, it can be concluded that the final notch band for upper WLAN is greatly dependent on the different parameters of **c**-shaped resonator and sizes of these parameters have a serious impact on the position and bandwidth of this notch band.

4. RESULT AND DISCUSSION

The performance of the proposed antenna has been analyzed and optimized using full-wave electromagnetic simulator IE3D which is based on method of moments. The antenna is subsequently fabricated with optimal parameters tabulated in Table 1 and is shown in Fig. 8. The antenna performance is measured in an anechoic chamber using far field antenna measurement system and Agilent E8362C vector network analyzer. The group delay characteristics between a pair of the proposed antennas are also investigated. Since UWB technology employed in short range communication systems, in the measurements the transmitting and receiving antennas are placed at distance 50 cm apart in face to face orientation.

The measured and simulated VSWR of the proposed triple band notch antenna is shown in Fig. 9. It can be observed that the simulated result agrees very well with the measured one. Besides, the designed antenna has wideband performance of 2.9 to more than 11 GHz for VSWR $\leq$ 2, covering the entire UWB frequency band with triple notched bands. In three desired notched bands, the measured VSWR is substantially higher than 2. The measured bandwidths (VSWR $\leq$ 2) of the proposed antenna at three notched bands are listed in Table 2.

The realized gain of the proposed triple band notch antenna is shown in Fig. 10. The average peak gain of antenna is around 3.62 dBi over the UWB operating band, except in the notched bands. At three notched bands, significant reductions in gain can be observed.

The measured radiation patterns of the triple band notch antenna at frequencies of 3, 6 and 8 GHz in two principle planes, yz-(E) and

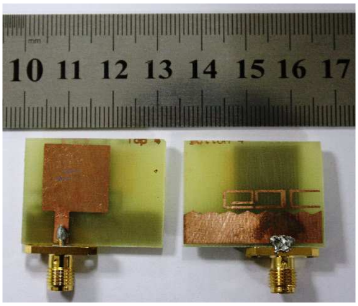


Figure 8. Prototype of the proposed antenna.

Table 2. Measured notched bands with VSWR $\leq$ 2.

	WiMAX	Lower WLAN	Upper WLAN
Required	3.3–3.7 GHz	5.15–5.35 GHz	5.725–5.825 GHz
Measured	3.26–3.71 GHz	5.15–5.37 GHz	5.78–5.95 GHz
Notch bandwidth	0.45 GHz (12.9%)	0.22 GHz (8.5%)	0.17 GHz (2.9%)

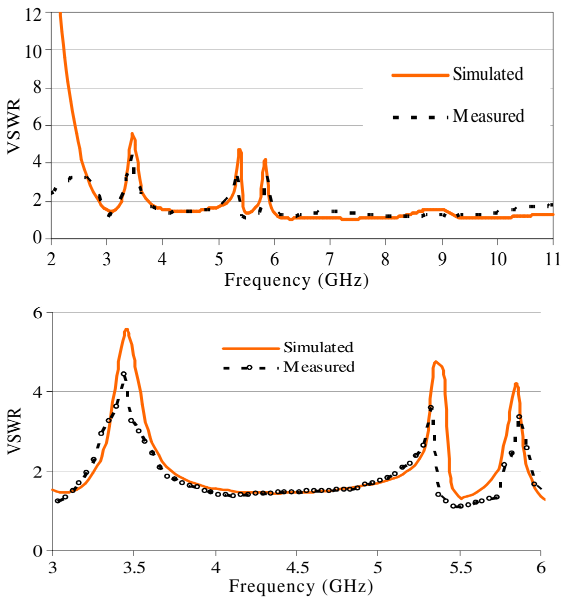


Figure 9. Simulated and measured VSWR of the proposed antenna.

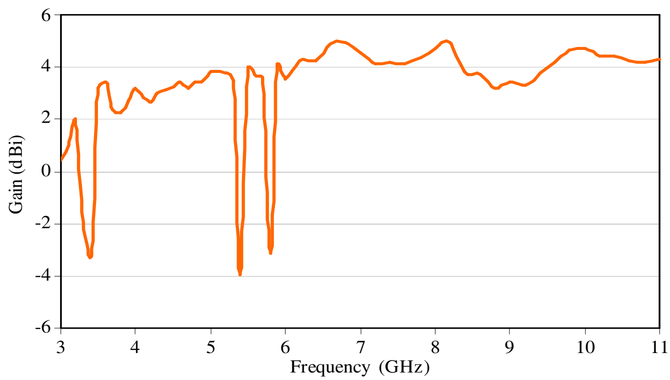


Figure 10. Gain of the proposed antenna with notched bands.

xz-(H) planes are shown in Fig. 11. At lower frequencies the antenna exhibits approximately omni-directional radiation patterns in yz-plane. In xz-plane there are two nulls in x-direction. This is similar to that of a typical monopole antenna. The cross-polarization level of xz-plane increases marginally with increasing frequency and the patterns become slightly directional. Although some nulls are observed at higher frequencies due to higher order harmonics, the antenna exhibits stable radiation patterns throughout the operating band. The ripples in the radiation patterns may be due to the reflections into the field between the antenna under test and reference antenna. The power loss in the RF cable that used in the measurement is also responsible for these ripples.

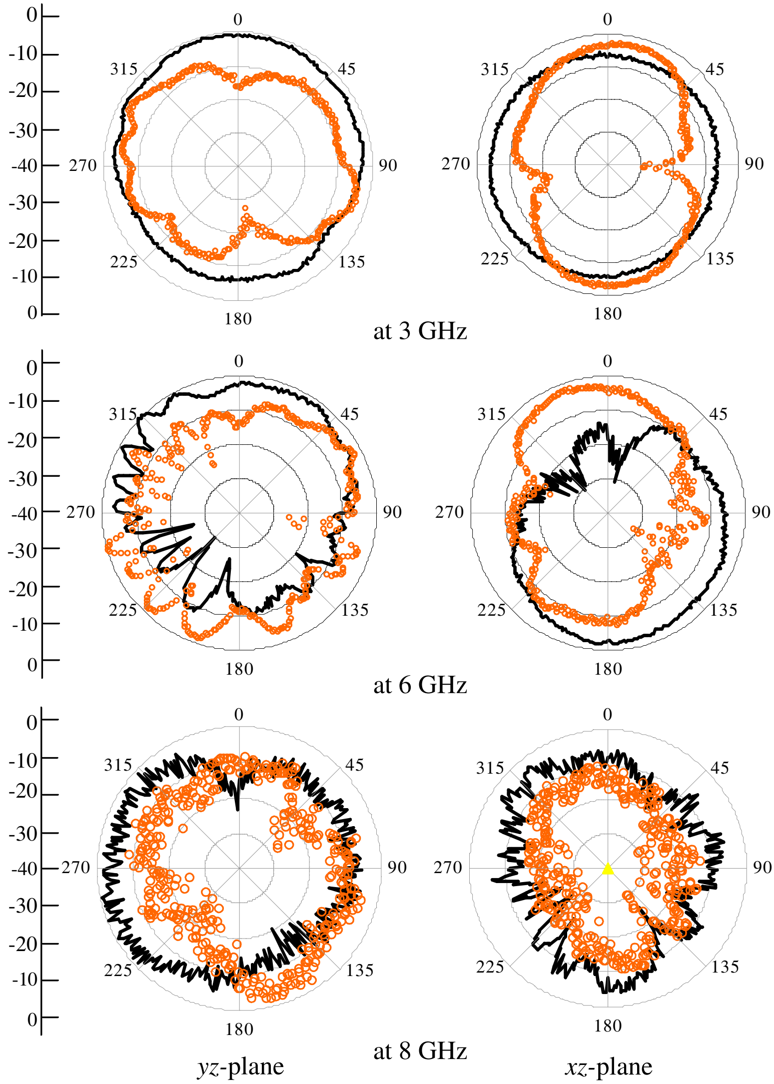


Figure 11. Measured radiation patterns at different frequencies [co-polarization: black line; cross-polarization: orange line].

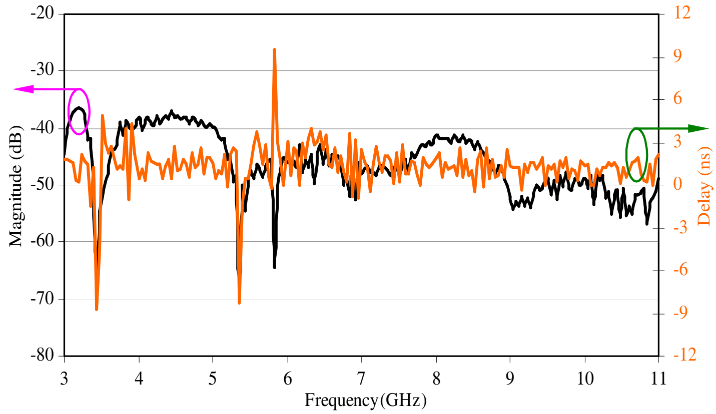


Figure 12. Magnitude of the measured transfer function and group delay.

To examine the antenna performance in time domain, the magnitude of the transfer function and group delay between pair of identical antennas are also measured and discussed. In the measurement, the antenna pair, aligned face to face with a distance 50 cm, is connected to the two ports of the vector network analyzer. In Fig. 12, it is seen that the triple band-notch antenna pair exhibits approximately flat magnitude of transfer gain in UWB frequency band, except in the notched bands centered on 3.45, 5.25 and 5.85 GHz, where the magnitudes reduce significantly by 15–20 dB. It is also observed that the measured group delay variation is less than 1.5 ns throughout the operating band except in the notched bands. These results indicate that the antenna has good linear transmission performances and could be useful for multiband UWB or impulse UWB radio applications.

5. CONCLUSION

A compact planar antenna with triple band notch characteristics has been proposed for UWB applications. To achieve triple notch band characteristics, three resonating elements are used to generate three notches separately in the WiMAX, the lower WLAN and the upper WLAN frequency bands. It has been observed that changing of parameters of the band notch structure affects only the notched bands, the rest of the UWB frequency band remains unaltered which offers a great freedom to select the notch frequency band and bandwidth for the band notch antenna. The experimental results show that the proposed antenna with a very compact size achieves UWB characteristics with triple notch bands for WiMAX (3.26–3.71 GHz), lower WLAN (5.15–5.37 GHz) and upper WLAN (5.78 5.95 GHz). It has been revealed that the antenna has a flat magnitude of transfer function and constant group delay within the operating band except at notched bands which ensures the good linear transmission performances.

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