Ultra-Wideband Planar Antenna with Notched Bands at 3.5/5.5 GHz

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Abstract **─** In this paper, a microstrip planar antenna with notch bands at 3.5/5.5 GHz is proposed for ultra-wideband communication. An e-shape parasitic slit and an inverted C-shape slit are imprinted beneath the radiating patch to generate notch bands to suppress the interference from WiMAX and WLAN respectively. The experimental results confirmed that the fabricated prototype with a very small size has achieved an UWB operating band for VSWR ≤ 2 with two notched bands covering frequencies of 3.32 - 3.76 GHz and 5.2 - 5.92 GHz. The presented design achieved a good gain except at notched bands and exhibits stable omnidirectional radiation patterns. In this design, filter elements are embedded only on one side of the substrate without cutting any slot/s in the radiating element/ground plane and no modification of the patch or the ground plane is required which gives the proposed design an advantages over many designs reported for the same applications.

Index Terms **─** Dual notch band, parasitic slit, UWB, WiMAX, WLAN.

I. INTRODUCTION

The requirement for short distance wireless communication technologies has increased rapidly. ultra-wideband (UWB) has gained lot of attention as one of the most prodigious solutions for high speed wireless communications, imaging systems and high accuracy radars. Despite of high data rate, UWB system consumes low power compared to the other narrow band systems, resulting in not causing undesired interference to the existing communication systems. However, strong signals from IEEE 802.16 WiMAX (operating at 3.3 – 3.8 GHz) and IEEE 802.11a WLAN (covering 5.15 – 5.825 GHz band) narrow bands may degrade the UWB system's performance due to electromagnetic interference (EMI). In order to suppress these strong interfering signals, antennas that have filtering properties at their allocated frequencies are very important to UWB systems. At the same time, UWB antennas should possesses wide operating bandwidth, stable radiation patterns for omnidirectional communications and minimum distortion of the received waveform.

A good number of antennas have already been presented with band notched characteristics [1-17]. Despite UWB performance, some of the reported designs fail to achieve desired notched band/s and some designs use complex structures to generate notch band/s. For example, in [1], a band rejected UWB antenna is presented. The band notch performance at WiMAX and ITU band was realized by using two spiral resonators beside the feedline while a pair of complementary split ring resonators was etched on the ground plane to produce third stop band covering 4.92 - 6.1 GHz WLAN band. By properly choosing the position and size of the resonators, the reported design with an area of 36×60 mm^2 exhibits UWB characteristics with multiple stop bands. An UWB circular patch antenna with dual band filtering performances is reported in [2]. By introducing slots in the ground and etching two arc-shaped strips near the radiator, the designed antenna with a dimension of 35×39 mm^2 achieved dual notch bands to filter out WiMAX and WLAN bands. A 36×34 mm^2 size UWB microstrip patch antenna with multiple stop bands is reported in [3]. By inserting two hook-shaped slots in the ground plane, a stop band at 3.3 - 3.9 GHz was achieved while dual stop bands centered at 5.2 GHz and 5.8 GHz were realized by inserting a Ω-shaped slot in the radiator and a semi-octagonal-shaped resonator in the ground plane. In [4], a dual notch band monopole antenna was reported for UWB application. A rejected band centered at 3.5 GHz was realized by imprinting a U-shaped slot in the feedline while another notched band at 5.5 GHz was attained by cutting two L-shape slots in the ground plane. In [5], an UWB monopole antenna with dual notched band was reported. The 3.8 GHz notch band was attained by inserting a U-shaped slot in the ground structure while 5.8 GHz notch band was realized by etching an E-shaped

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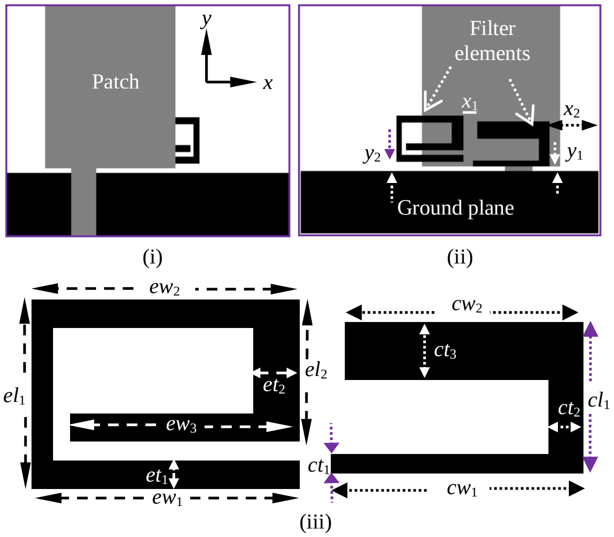
slot in the rectangular patch. A layout of an UWB antenna with notch band performance was proposed in [6]. To achieve band notch function for WiMAX, an arc H-shaped slot was inserted on the circular patch while to create a notched band for WLAN, two narrow slots were etched on the ground plane and the antenna occupies an area of 35.5×30 mm^2. In [7], a small planar antenna with band rejected performances has been presented. To produce a notch band at 3.25 - 3.85 GHz, a butterfly shaped backplane structure is inserted on the ground plane side while by imprinting a U-shaped slot in the radiator, a second notch band at 4.9 - 6.2 GHz is generated. An UWB antenna with multiple stop bands was reported in [8]. To achieved notch bands centered at 3.6 GHz, 7.5 GHz and 8.3 GHz three C-shaped slots have been inserted on the radiating patch while the notch bands for lower and upper WLAN are generated by etching C-shaped slots on the partial ground plane. In the design reported in [10], one capacitive loaded loop resonator has been attached to the radiator with an aim to reject the frequency band used by WLAN while one I-shape strip and one flip L-shape strip are added respectively to the lower and upper rectangular slots of the ground plane to filter out the frequency bands used by WiMAX and ITU band. In [16], a semicircular antenna with dual stop band performances is reported. To produce WLAN notch band of 5.2 - 5.9 GHz, a thin rectangular slot is etched in the radiating patch while by using two C-shaped circular slots in the defected ground structure, another notch band at 7.8 - 9.0 GHz is generated for C-band satellite communication. An UWB antenna with multiple stop band characteristics is reported in [17]. By inserting four modified bow-shaped slots in the radiator and a pair of rectangular-shaped slots in the ground plane, the designed antenna generates three notch bands covering frequencies of 3.3 - 4.2 GHz, 5.15 - 5.95 GHz and 7 - 8 GHz. All the above mentioned antennas exhibit wide operating band with required band notch characteristics. However to achieve dual/multiple notch bands, each of the above mentioned antennas uses slots, resonators and slits and they were etched simultaneously in both the ground plane and radiating patch which can create fabrication difficulties. Moreover, misplacement of the filter elements may also cause engineering problem resulting in the realization of undesired notched bands.

In this paper, a microstrip-line fed rectangular antenna that achieves compact planar profile is proposed for UWB communication. By etching two parasitic slits below the radiating element, the designed compact antenna realized UWB performance with two notched band at 3.5 GHz and 5.5 GHz. Unlike the antennas presented in [1-17], where the slit/s and slot/s were embedded on the radiating element as well as in the ground planes, the novelty of the proposed design is that it uses parasitic slits (filter element) on one side of the substrate without modifying or altering the shape, size of the patch and the ground plane.

II. ANTENNA DESIGN

The footprint of the proposed design is presented in Fig. 1. The microstrip line fed rectangular radiating patch of size 14.5×13.5 mm^2 is etched on the front side of a 1.6-mm thick FR4 dielectric material and the ground plane with side length 5.5 mm is imprinted on the rear side. The radiating patch is 0.5 mm away from the conducting partial ground plane. To achieve 50 Ω characteristic impedance, the feed line width and length are chosen as 2.75 mm and 6mm respectively. It is found that the radiating patch coupled strongly to the ground plane and designed antenna of overall volumetric size 29×20.5×1.6 mm^3 is able to achieve sufficient operating band to cover FCC defined ultra-wide frequency band as depicted in Fig. 4.



(i) (ii)

(iii)

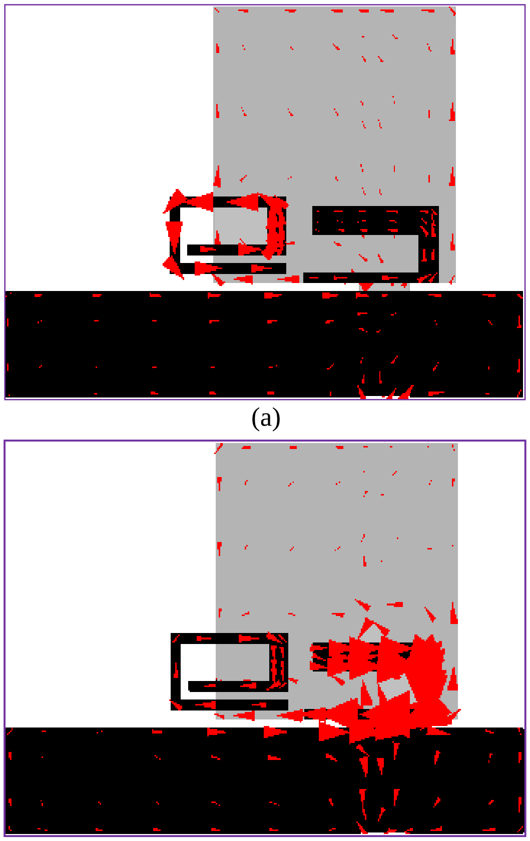
Fig. 1. Geometry of proposed antenna: (i) front view, (ii) rear view, and (iii) parasitic slits (filter element).

To generate a notch band at 3.5 GHz, an e-shape parasitic slit is etched systematically at a distance y_2 from the top edge of the ground plane. To produce second notch band at around 5.5 GHz, an inverted C-shape slit is embedded below the patch along with the e-shaped slit and it is at y_1 away from the ground plane. The distance between these two slits is x_1. The total length of each slit is about half of the guided wavelength (λg), which is given by [11]:

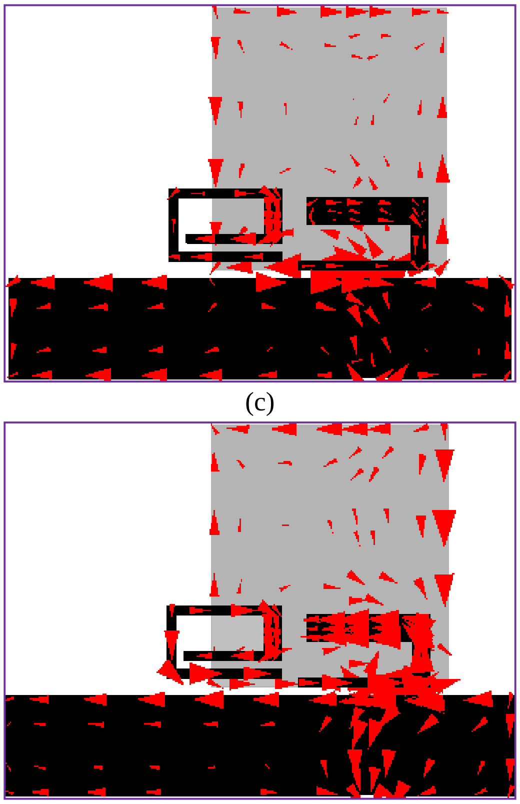
$$\lambda_g = \frac{\lambda}{\sqrt{\frac{\varepsilon_r + 1}{2}}}, \qquad (1)$$

where ε_r is the dielectric constant of the substrate and λ is the wavelength of the respective notch band, i.e., centre frequency of the corresponding notch band. The detail dimensions of the different parameters of the parasitic slits are depicted in Fig. 1 (iii).

The vector-current distribution at notch bands and pass bands frequencies are illustrated in Fig. 2 with an aim to understand the creation of notch bands. In the plot, the currents are strongly distributed as it approaches the areas marked red and concentration becomes denser. It can be seen in Fig. 2 (a) that at lower notch center frequency of 3.5 GHz, most of the surface current concentrated near the e-shaped slit while the currents in the rest part of the antenna is very weak. Figure 2 (b) displayed that at 5.5 GHz the surface currents at inverted C-shaped slit is stronger than the other part of the antenna. Therefore, the antenna impedance altered at these frequencies due to the insertion of parasitic slits. It is also revealed from Fig. 2 (a) and 2 (b) that, the currents in the symmetrical sides of the filter elements are reverse to each other resulting in weak radiation from the antenna at these frequencies. These current distributions implies that at the notch frequencies strong resonances are created and hence notch bands are produced at around 3.5 GHz and 5.5 GHz. Other than WiMAX and WLAN band, the currents in the parasitic slits are almost similar to that of the other parts of the antenna as displayed in Fig. 2 (c) and Fig. 2 (d). As a result, the parasitic slits (filter elements) act as a part of the radiating element and radiate effectively.


(a)

(b)


(c)

(d)

Fig. 2. Vector-current distribution at: (a) 3.5, (b) 5.5, (c) 6.2, and (d) 8.5 GHz.

The input impedance characteristic of the designed antenna, the antenna without filter structures (slits) and with single parasitic slit is displayed in Fig. 3. It is revealed from graph that for the antenna without notch bands, the input impedance is very much close to 50 Ω line and exhibits good impedance matching resulting in a UWB operating band.

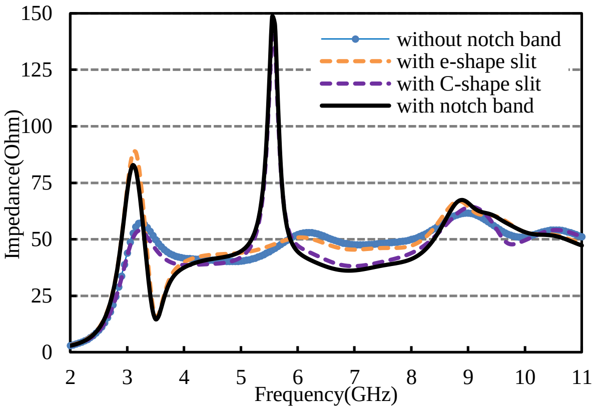


Fig. 3. Input impedances for without, with single and with double filter structure.

On the other hand, some parts of the impedance lines (at around 3.5 GHz and 5.5 GHz) of the antenna with notch bands are away from the 50 Ω characteristic impedance line and offers higher impedances resulting in poor matching. Due to this poor matching dual notch bands are created at around 3.5 GHz and 5.5 GHz. For embedment of single parasitic slit, high impedance is observed at the respective frequency band and hence single notch band at WiMAX and WLAN frequency spectrum are produced. Other than notched frequency band/s, the impedances are almost similar to that of antenna without notched bands.

III. SENSITIVITY ANALYSIS

As the notched bands are created by the parasitic slits, their size and location have a great impact on the notched band characteristics. A sensitivity test has been performed to examine the effects of different design parameters as well as to observe the performance of the proposed band notch design. All the simulations are done by using IE3D simulator from Zeland. Different VSWR curves are displayed in Fig. 4 by etching one slit (filter element) at a time while keeping the other slit absent. From Fig. 4 it can be seen that each slit stops a targeted frequency band. It is confirmed from Fig. 4 that e-shape slit reject 3.5 GHz WiMAX band while inverted C-shape slit notch WLAN band and insertion of both the e-shape and C-shape slits together can generate dual notch bands at 3.5 and 5.5 GHz. It is also revealed from the plot that the two slits can perform independently without any strong interference between them.

To explore the sensitivity of various design parameters of the parasitic slits on filtering performance, a parametric study is done. Since the parasitic slits are only the filter element in generating dual stop band, their width, length and thickness are chosen to do the sensitivity analysis. The effects of different design parameters such as ew_3, el_2, cl_1 and ct_2 on antenna performances are depicted in Fig. 5. Figures 5 (a) and 5 (b) respectively show the VSWR curves for different values of ew_3 and el_2 while the rest of the antenna dimension are remain fixed. As the width ew_3 varies from 3.5 to 5.5 mm, the WiMAX center frequency changes from 3.99 GHz to 3.52 GHz and the bandwidth of the this stop band is reduces with the increment of ew_3. However the second stop band for WLAN does not vary with the variation of ew_3. The simulated VSWR in Fig. 5 (b) shows that the resonance frequency of the WiMAX band as well as the bandwidth is strongly dependent on el_2 while it does not affect second stop band for WLAN. When the values of el_2 increases, the WiMAX center frequency goes to the lower frequency spectrum and its bandwidth is decreased with el_2. From these results, it may be commented that WiMAX center frequency as well as the bandwidth can be controlled by the ew_3 and el_2.

The simulated VSWR's with number of values of cl_1 is displayed in Fig. 5 (c). As the value of cl_1 varied from 3 mm to 5 mm, the WLAN center frequency is varied from 6.02 to 5.2 GHz and the operating band of this notch band is decreases. Figure 5 (d) indicates the VSWR characteristics for different ct_2. For ct_2 = 0.5, 1 and 1.5 mm with other dimensions remain fixed, the center frequency of the second notch band changes from 5.12 GHz to 6.08 GHz. It can be observed from the figure that ct_2 has significant effects on shifting the center frequency and operating band of the second notch band for WLAN.

The effects of all the parameters of the filter structures and their final values are summarized in the Table 1 from where it can be concluded that the bandwidth (BW) and center frequency (f_c) of the rejected band for WiMAX is completely controlled by the parameters of the e-shape slit, whereas the 5.5 GHz WLAN band can solely be generated and adjusted by the inverted C-shape slit, i.e., each notch band is not affected by the creation of others which give us an engineering advantages in the designing of band notch UWB antenna.

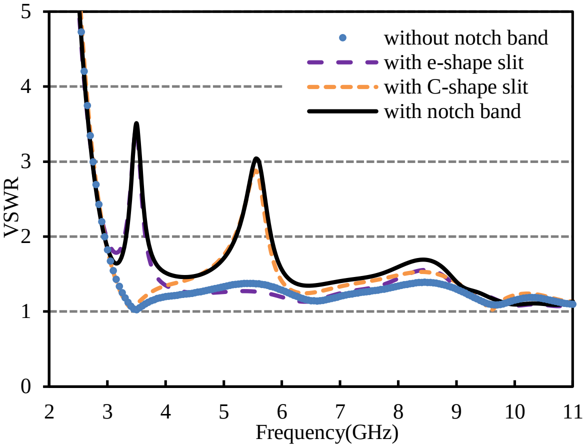
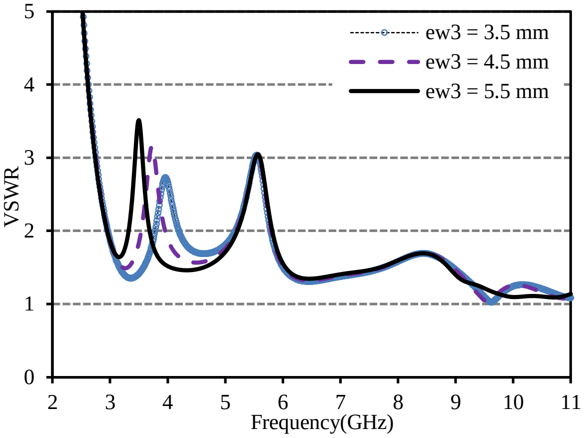
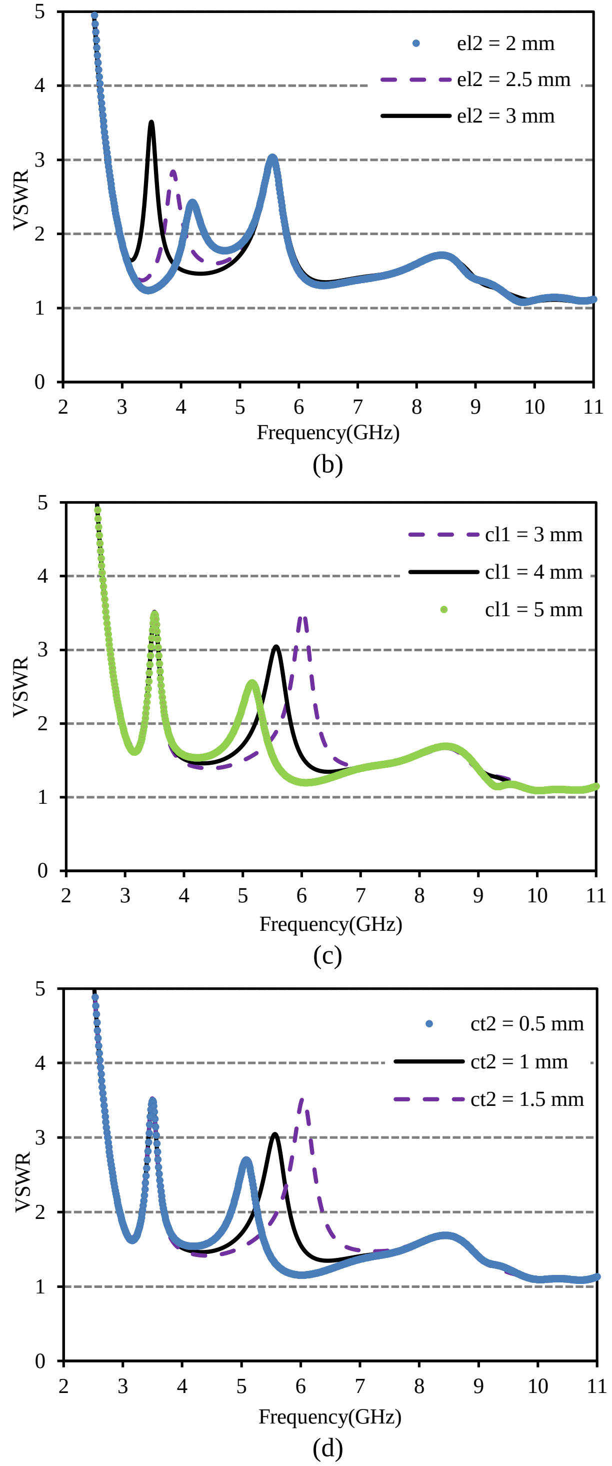


Fig. 4. VSWR curves for without and with parasitic slit/s.



(a)



(b)

(c)

(d)

Fig. 5. Effects of: (a) ew_3, (b) el_2, (c) cl_1, and (d) ct_2 on antenna performance.

Table 1: Effects of different parameters on notch bands

Parameter	WiMAX Band		WLAN Band		Final Value (mm)
	BW	f_c	BW	f_c	
el_1▲	▲	Shifted to higher band	—	—	4
el_2▲	▼	Shifted to lower band	—	—	3
ew_1▲	—	Shifted to lower band	—	—	6.5
ew_2▲	▲	Shifted to lower band	—	—	6.5
ew_3▲	▼	Shifted to lower band	—	—	5.5
et_1▲	▼	Shifted to higher band	—	—	0.5
et_2▲	▲	Shifted to higher band	—	—	1
cl_1▲	—	—	▼	Shifted to lower band	4
cw_1▲	—	—	▼	Shifted to lower band	7.5
cw_2▲	—	—	▼	Shifted to lower band	7
ct_1▲	—	—	▼	Shifted to lower band	0.5
ct_2▲	—	—	▲	Shifted to higher band	1
ct_3▲	—	—	▲	Shifted to higher band	1.5
y_1▲	—	—	▼	Shifted to lower band	0.5
y_2▲	▲	Shifted to lower band	—	—	1
x_1▲	—	Shifted to lower band	—	—	1.5
x_2▲	▲	Shifted to lower band	▼	Shifted to higher band	4.75

** '▲' indicates increment '▼' indicates decrement and '—' unaffected.

IV. MEASURED RESULTS AND DISCUSSIONS

With the final design parameters displayed in Table 1, a pair of the proposed antenna was prototyped for experimental validation and is displayed in inset of Fig. 6. The VSWR characteristic was measured using E8362C PNA series VNA from Agilent. It can be revealed from the plot in Fig. 6 that the prototype of the proposed design exhibited a good impedance matching ranging from 3 to 10.72 GHz for VSWR ≤ 2. Two sharp notch bands centered at 3.5 GHz and 5.5 GHz have also been observed in the achieved UWB operating bands. The disagreement between experimental result and predicted one especially at upper edge frequency is due to inaccuracies in fabrication, effect of feeding cable and higher loss tangent of inexpensive FR4 dielectric material. In spite of being compact in size than the antennas presented in [1-4, 6, 8, 11-13], the proposed design reveals UWB performances with two stop bands that may help to suppress the interference caused by WiMAX and WLAN.

The realized peak gain of the prototyped antenna is displayed in Fig. 7. It can be revealed from the figure that the proposed antenna achieved a good peak gain except at WiMAX and WLAN notched bands. At notched bands the gain decreases drastically, which indicate the effects of filter elements.

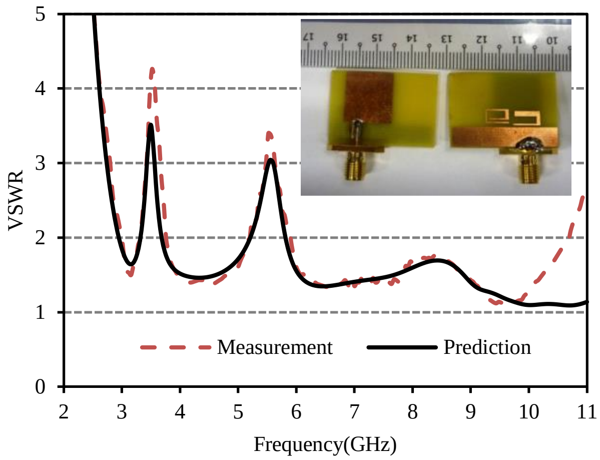


Fig. 6. Measured and predicted VSWR of the proposed antenna.

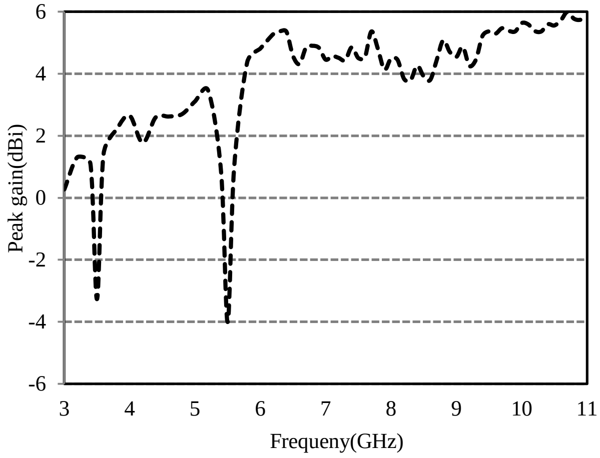


Fig. 7. Measured peak gain of the proposed antenna.

Figure 8 displayed the measured patterns of the radiation characteristics for *H*-plane (*xz*-plane) and *E*-plane (*yz*-plane). An omnidirectional radiation pattern has been exhibited by both *H*- & *E*-field plane of the designed antenna. As the frequency increases, nulls have been observed especially in the *E*-plane patterns which may be due to higher order harmonic and asymmetric radiating patch. Despite the nulls at higher frequencies, it can be commented that the realized antenna displays symmetric radiation characteristics all over the UWB spectrum.

The group delay that indicates the time delay of a signal is measured using a pair of identical prototypes at a distance 50 cm apart and is depicted in Fig. 9. Other than notched frequency bands, a fairly flat group delays with a variation of less than a nanosecond is observed. This property indicates that the proposed design could transmit the signal with minimum dispersion, which is a primary requisite for UWB applications.

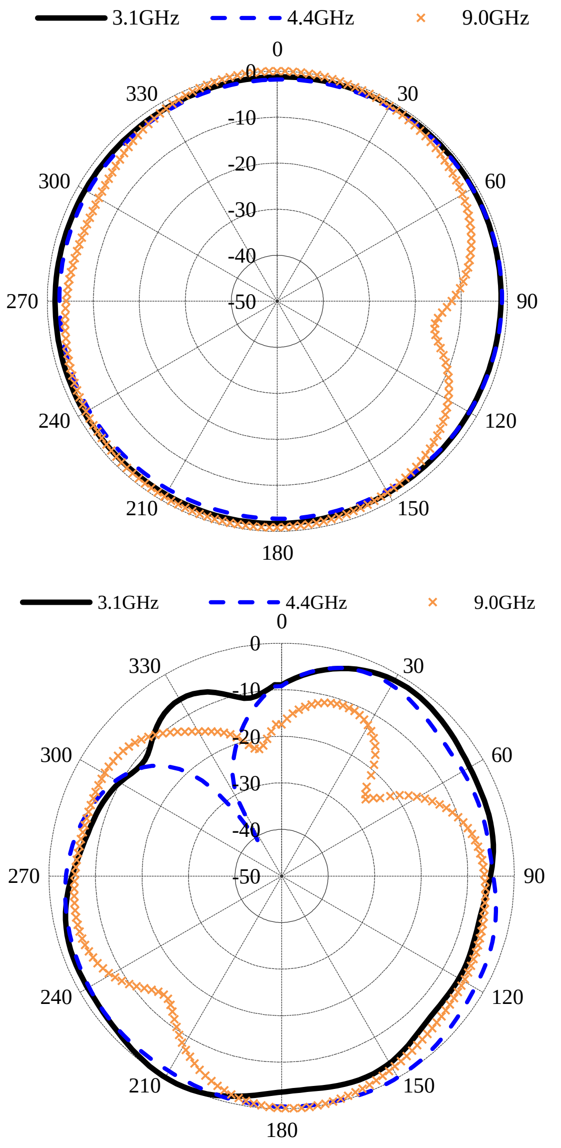


Fig. 8. Measured *H*-plane (top) and *E*-plane (bottom) patterns at different frequencies.

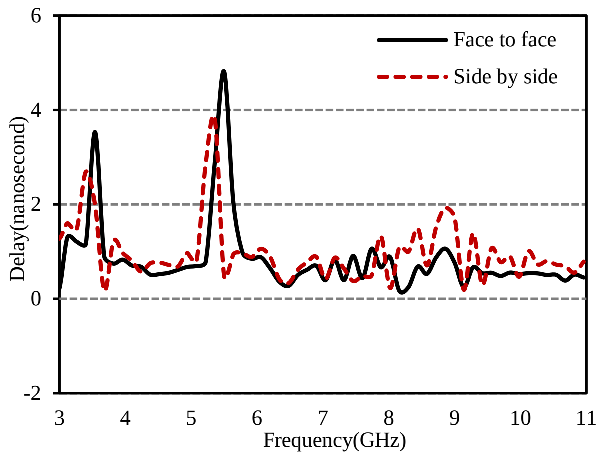


Fig. 9. Measured group delay of the proposed antenna.

V. CONCLUSION

A low profile planar antenna with two notch band is introduced for UWB application. To attain dual band notch performance, the designed antenna uses parasitic slits only on one side of the substrate without modifying or altering the patch or ground plane. It is found that by properly placing the slits, the prototype with optimized design parameters has been able to achieve UWB performance with two notch bands at 3.5 GHz and 5.5 GHz. These achieved notch bands will help to suppress the electromagnetic interference caused from WiMAX and WLAN respectively. Furthermore the fabricated prototype demonstrates stable radiation characteristics and achieved good gain except at notched bands.

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