# Monopole UWB Antenna with Dual Band Frequency Notch

Lokesh Ranjan[1], Dileep Kumar Upadhyay[1], Babu Lal Shahu[2]

*Abstract* – **In this paper, a monopole UWB antenna with a dual band notch is presented. The UWB antenna is designed using four circular patches of different radii with a very wide impedance bandwidth from 2.9 GHz to beyond 11.0 GHz. The dual band notch is created by etching two U shape slots in the radiating patch. This UWB antenna is capable of suppressing the interferences from the WLAN (5.3 to 5.7 GHz) and WiMAX (3.2 to 3.7 GHz). The antenna is fabricated on the RT/Duroid 5880 substrate with a relative permittivity of 2.2 and a thickness of 1.57 mm. The total size of the antenna is 32 x 30 x 1.57 mm$^3$. The prototype of the proposed antenna is fabricated and measured. The simulated and measured results show a good agreement between various parameters like return loss and radiation patterns.**

*Keywords* – **Frequency notch, Monopole antenna, Ultra wideband (UWB).**

## I. INTRODUCTION

Since the Federal Communication Commission (FCC) unlicensed the use of the frequency band from 3.1 to 10.6 GHz in 2002 for UWB applications, the UWB technology is advancing very fast due to its high data rate [1]. As a result of this rapid development of wireless communication, the radio spectrum is very congested. The congestion is a bigger problem due to the strong narrow band interference which lies between the UWB bandwidth. The narrow band interferences include the IEEE 802.16 WiMAX system having the frequency range from 3.3 to 3.6 GHz. The other strong narrow band interference is offered by IEEE 802.11 WLAN (Wireless Local Area Network) operating from 5.15 to 5.825 GHz [2-4]. For the significant use of UWB technology, it is necessary to protect the UWB system from these two strong narrow band interferences. The UWB system can be protected from the two strong narrow band interferences discussed above by simply using the filters. But, these additional filters increase the size, cost and the complexity of the UWB system. Due to these reasons, the UWB system with filters loses all its advantages as the UWB system is popular for its reduced size, cost and complexity [5-6]. In short, by using filters to suppress the narrow band interferences, all the advantages of UWB technology will be lost.

*Article history: Received July 29, 2015; Accepted April 21, 2017*

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It is desirable to design slots in the UWB antenna which will create band notches to suppress the narrow band interferences. Various studies and research have been conducted to understand the size and shape of the slots and their effects. The slots for the desired notches may be of different shapes like U-shape, L-shape, H-shape, rectangular shape [7-8]. The length of the slot plays a very important role in determining the notch frequency [9]. An easy and convenient way to achieve the band notch is to cut slots in the radiating structure or in the ground plane. These slots change the surface current distribution. The desired frequency band slots are cut at that point of the radiating patch or the ground plane where the surface current density is maximum [10].

In this paper, a UWB antenna with a dual band notch is proposed. The return loss ($S_{11}$) of less than -10 dB from 2.9 GHz to 11.0 GHz with a dual band notch from 3.2 to 3.7 GHz and from 5.3 to 5.7 GHz is achieved. The simulation is performed using the Finite Element Method (FEM) based on the Ansoft High Frequency Structure Simulator (HFSS). The proposed antenna is developed and measured to validate the simulation results.

## II. ANTENNA CONFIGURATION AND DESIGN

The proposed antenna structure is designed using the RT/Duroid 5880 substrate of relative permittivity of 2.2, height of 1.57 mm and a loss tangent of 0.0009. The design of the primitive antenna is shown in Fig.1. The total dimension of the antenna is 32 × 30 × 1.57 mm$^3$. The proposed antenna is designed using four circular patches of radii $R_1$, $R_2$, $R_3$ and $R_4$. The circle with radius $R_3$ is subtracted from the circle of radius $R_4$ and the circle with radius $R_1$ is subtracted from the circle of radius $R_2$ and hence, both resulted patches are merged. Two rectangles of the length $W_2$ and $W_3$ are subtracted as shown in Fig. 1(a). The centers of the circles $R_1$, $R_2$, $R_3$ and $R_4$ are $C_1$, $C_2$, $C_3$ and $C_4$ respectively as shown in Fig. 1(a). As per the given dimensions of the geometry, the positions of the centers of the circles can easily be determined. All the centers of the circles lie in a vertical straight line as shown in Fig. 1(a). In the horizontal direction, the position of centers $C_1$, $C_2$, $C_3$ and $C_4$ is $\frac{W}{2}$ from the left/right of the geometry. In the vertical direction, the positions of the centers $C_1$ and $C_2$, are $L_1 + R_4 - d_2$ and $L_1 + R_4 - (d_1 + d_2)$, respectively, whereas the position of the centers $C_4$ and $C_3$ are $L_1 + R_4$ and $L_1 + R_4 + d_3$, respectively, from the bottom of the geometry. The designed antenna is fed using a microstrip line. The ground plane as shown in Fig. 1(b) is a rectangle of the dimension W x $L_2$. The ground plane then tapered at the center of the feed line. Tapering the ground plane helps to enhance the impedance bandwidth of the proposed antenna. The antenna parameters and ground parameters are optimized to improve the impedance matching and wide band response. The dimensions of the various parameters are tabulated in Table 1. All the dimensions are given in mm.

The dual notch band characteristic is obtained by etching two U shaped slots of the length $L_6$ and $L_3$ and height $L_4$ and $L_5$ as shown in Fig. 2. The width of both the slots is S = 0.1 mm. The length and height of the slots are optimized to get the desired notches. The outer slot provides protection from the WiMAX and C band interference. The inner etched slot prevents the interference from the WLAN frequencies. The various dimensional parameters of the slots are tabulated in Table 2. Various dimensions of the antenna are obtained manually through the simulation software HFSS. While optimizing one dimension, the other dimensions are kept constant so that the close effect of variation of one dimension can be observed to get the desired optimized results.

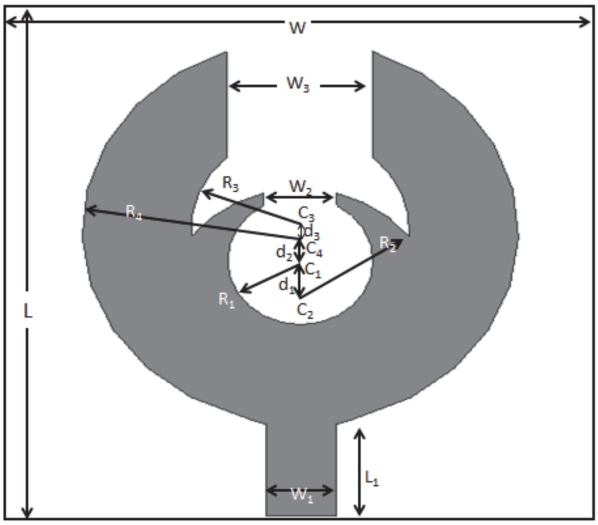



Fig. 1(a). Geometry of proposed primitive antenna

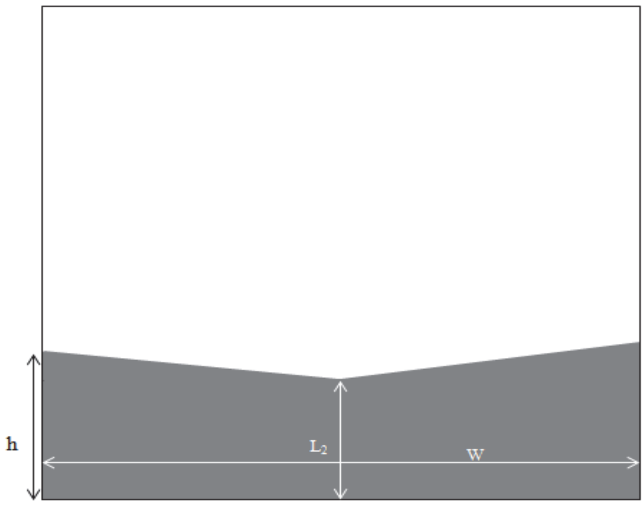



Fig. 1(b). Geometry of ground plane of primitive antenna

TABLE 1
GEOMETRICAL DIMENSIONS OF PRIMITIVE ANTENNA PARAMETERS

| Parameter | L | $L_1$ | $L_2$ | h | W |
|---|---|---|---|---|---|
| Dimension (mm) | 30 | 5.8 | 5.5 | 7.5 | 32 |
| Parameter | $W_1$ | $W_2$ | $W_3$ | $R_1$ | $R_2$ |
| Dimension (mm) | 3.8 | 4 | 8 | 4 | 7.5 |
| Parameter | $R_3$ | $R_4$ | $d_1$ | $d_2$ | $d_3$ |
| Dimension (mm) | 6 | 12 | 3 | 1.8 | 0.2 |

The total length of the slot is a very important parameter to get the notch at the desired frequencies. The total length of the slots is nearly half the wavelength of the desired unwanted frequency. The basic equation used in finding the length of the slot is given by equation [9]

$$f_{notch} = \frac{c}{2L \cdot \sqrt{\varepsilon_{reff}}}, \quad (1)$$

where, $f_{notch}$ is the desired unwanted frequency, $c$ is the speed of light in the vacuum, $L$ is length of the slot and $\varepsilon_{reff}$ is the effective dielectric constant of the substrate

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2}. \quad (2)$$

The wavelength in a medium can approximately be given by

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}}, \quad (3)$$

where $\lambda_g$ and $\lambda_0$ are the wavelength in medium and in free space respectively.

The design expression of a simple circular microstrip antenna of the radius, $r_0$ for calculating the resonant frequency is given as [11]

$$f_r = \frac{1.841 \cdot v_0}{2\pi \cdot r_{eff} \cdot \sqrt{\varepsilon_{reff}}}. \quad (4)$$

where, $v_0$ is the velocity of light. If $h$ and $\varepsilon_r$ are the height and the relative permittivity of the dielectric then the effective radius $r_{eff}$ can be calculated by

$$r_{eff} = r_0 \cdot \left[1 + \frac{2h}{\pi \cdot r_0 \cdot \varepsilon_{reff}} \cdot \left\{\ln\left(\frac{r_0}{2h}\right) + (1.41 \cdot \varepsilon_r + 1.77) + \right.\right.$$
$$\left.\left. + \frac{h}{r_0} \cdot (0.268 \cdot \varepsilon_{eff} + 1.65)\right\}\right]^{1/2} \quad (5)$$

TABLE 2
GEOMETRICAL DIMENSIONS OF SLOTS

| Parameter | $X_1$ | $X_2$ | $Y_1$ | $Y_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ | S |
|---|---|---|---|---|---|---|---|---|---|
| Dimension (mm) | 9 | 9.9 | 9.7 | 11 | 12 | 13.8 | 4.9 | 9.9 | 0.1 |

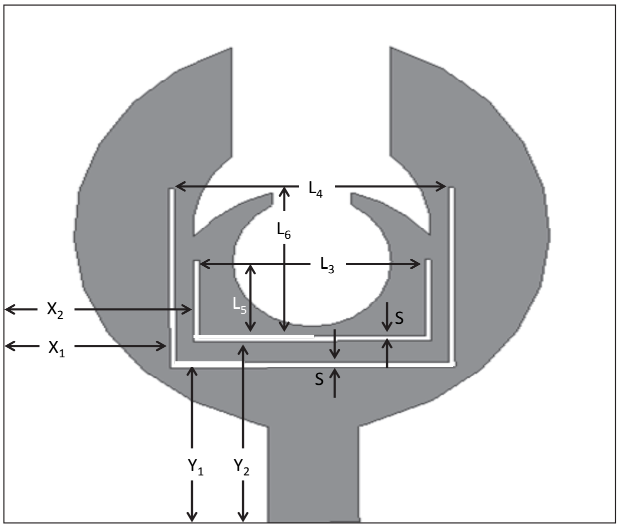



Fig. 2. Geometry of proposed antenna with slots

## III. RESULTS AND DISCUSSION

The simulated return loss ($S_{11}$) vs. frequency of the primitive antenna and the antenna with a dual notch is shown in Fig. 3. The return loss of the primitive antenna below -10dB is from 3.2 GHz to more than 11.0 GHz. The return loss of the antenna with a dual notch is below –10 dB from 2.9 GHz to 11.0 GHz with two notch bands from 3.2 GHz to 3.7 GHz and from 5.3 GHz to 5.7 GHz. The plot of the return loss vs. frequency for various values of h, the height of the ground plane is shown in Fig. 4. Fig. 4 shows that the desired optimized result is for *h* =7.5 mm. If the height of the ground plane is varied from 7.5 mm, then a steep variation in the return loss is observed. So, the height of the ground plane is a very important parameter and its optimization required many iterations. The plot of the return loss vs. frequency with the variation of distance between the two slots d, i.e. ($Y_2$-$Y_1$) is shown in Fig. 5. A slight variation in the distance between the two slots showed noticeable variations in the return loss.

Analysis of the UWB in the time domain is an important feature because it is based on a short pulse transmission. The group delay response indicates the degree of distortion in the transmitted signal. The group delay is a measure of any non-linearity present in the phase response of the device. The Group delay should be constant over the entire band for UWB application except at the notched band frequencies, where it may have some higher values as compared to the rest of the band of the UWB. The simulated and measured group delay vs. frequency plot of the proposed antenna is shown in Fig. 6. Fig. 6 shows that the maximum group delay values are 3.5 ns and 1.3 ns at first notch frequency (3.1 GHz to 3.8 GHz) and second notch frequency (5.0 GHz to 5.8 GHz) respectively. Fig. 6 also shows that for the rest of the UWB frequency band the group delay is less than 1.0 ns, which indicates the linear phase response in the far-field region and distortion free pulse transmission. The group delay performance is measured by a Vector Network Analyzer (VNA). Two ports of the VNA are connected by two identical antennas placed face to face at a distance of 30 cm, where they serve as transmitter and receiver.

The real part of the impedance vs. frequency plot of the proposed antenna is shown in Fig. 7. Fig. 7 shows that the antenna impedance varies between 23 Ω and 75 Ω except for two notched band frequencies (3.2-3.7 GHz and 5.3-5.7 GHz). The antenna offers a minimum impedance of 5Ω and 10Ω at the first notched frequency and second notched frequency respectively.

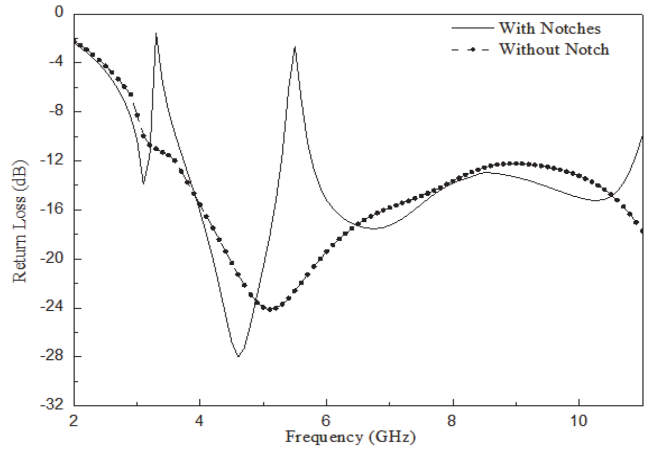



Fig. 3. Simulated return loss (dB) vs. frequency of the proposed antenna

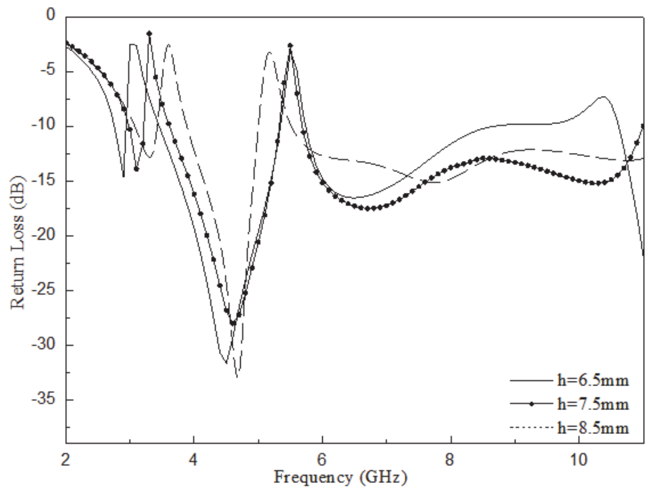



Fig. 4. Plot of return loss (dB) vs. frequency for the different height of ground plane

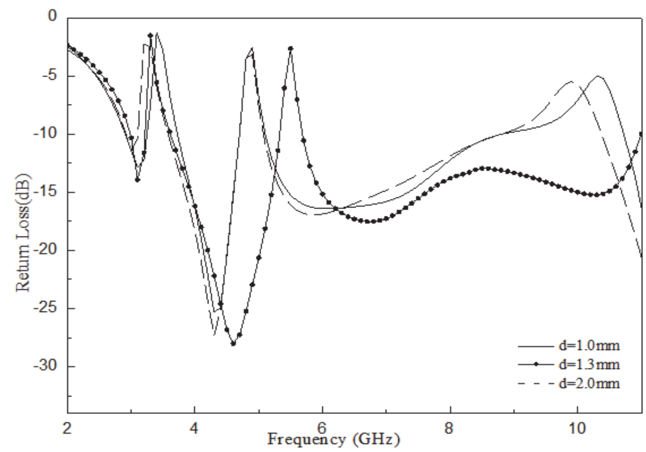



Fig. 5. Plot of return loss (dB) vs. frequency for the different distance between the two slots

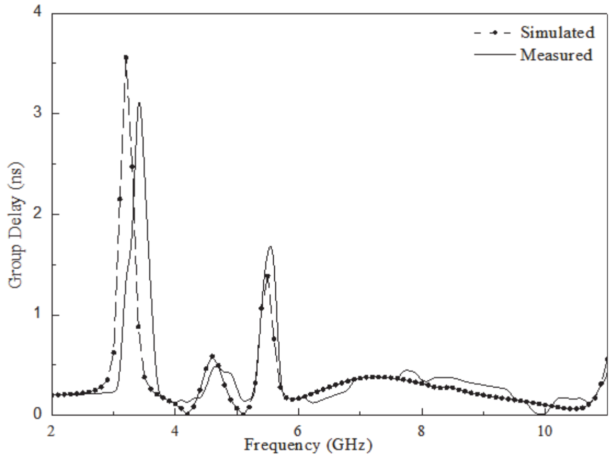



Fig. 6. Group delay vs. frequency response

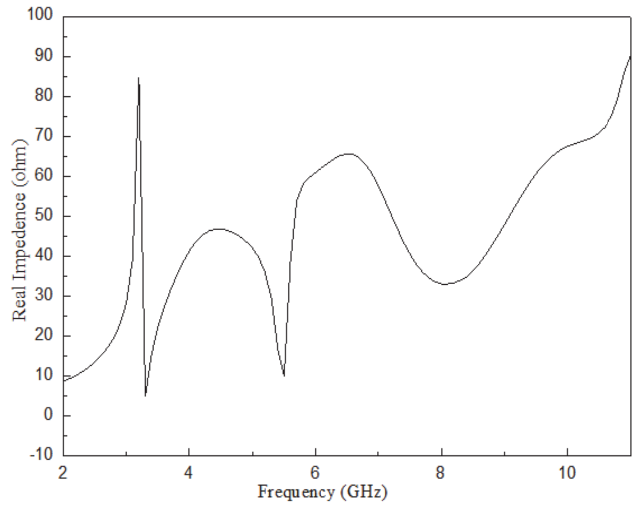



Fig. 7. Real impedance vs. frequency response

The photograph of the fabricated prototype of the proposed antenna is shown in Fig. 8. The simulated and measured return loss vs. the frequency response is compared in Fig. 9. The measured result of the return loss vs. frequency shows a good agreement with the simulated results.

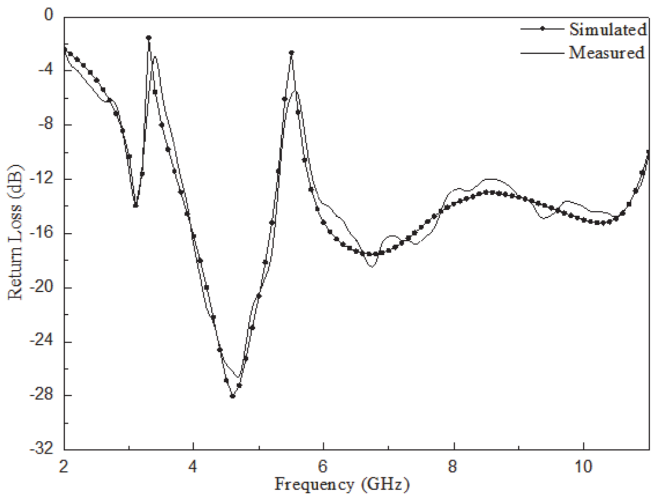
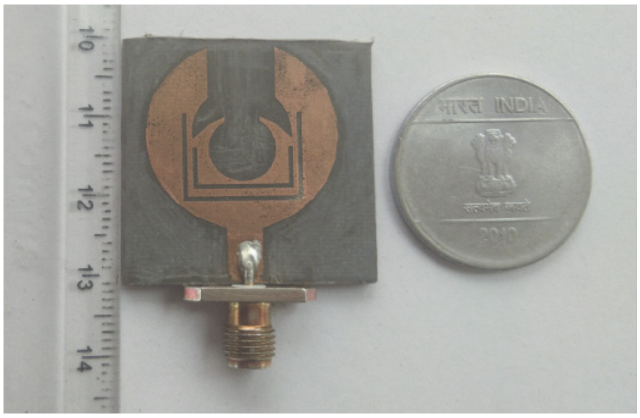
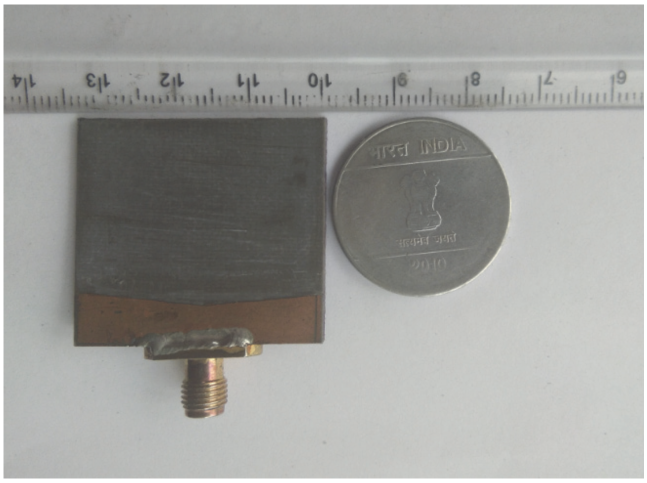



Fig. 9. Comparative return loss vs. frequency for simulated and measured results



(a) Front view



(b) Back view

Fig. 8. Prototype of fabricated antenna

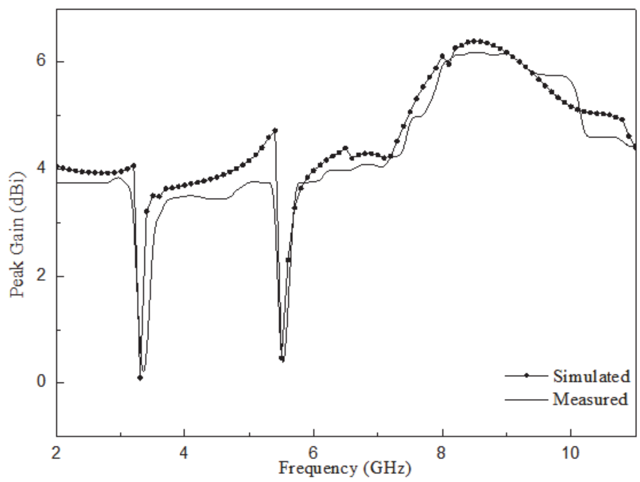
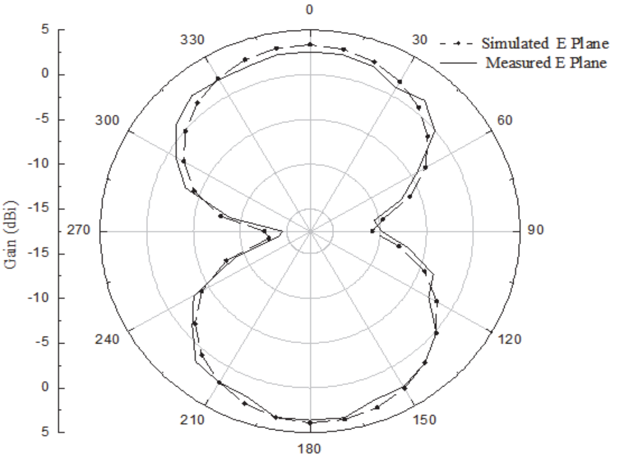
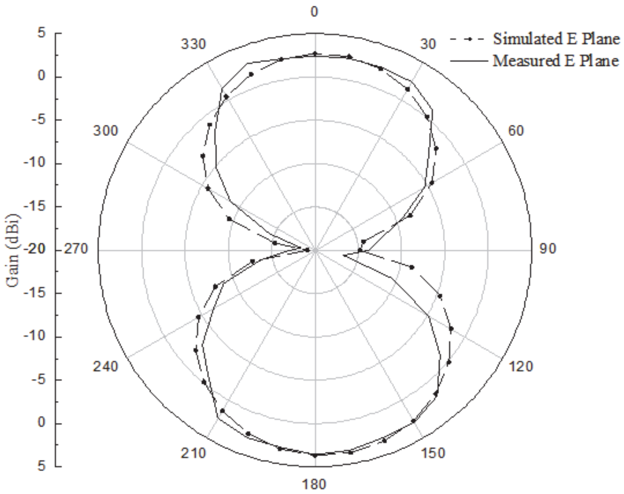


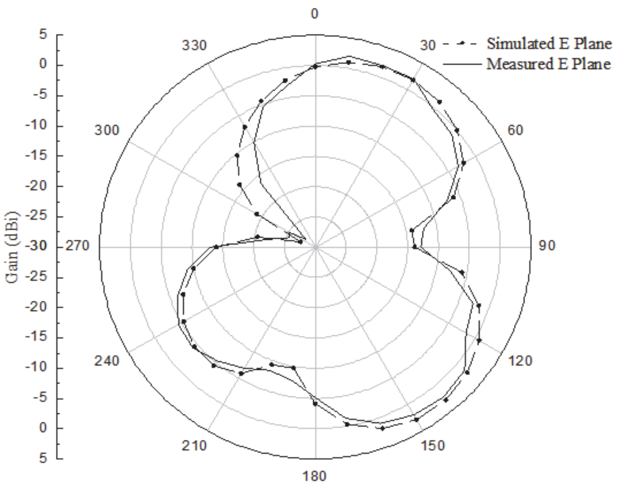

Fig. 10. Comparative simulated and measured peak gain vs. frequency plot




(a)

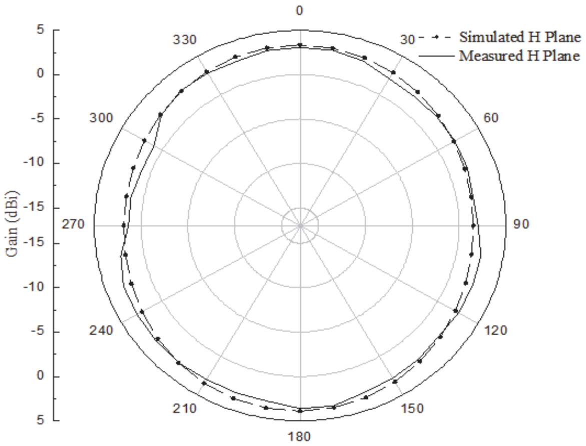



(b)

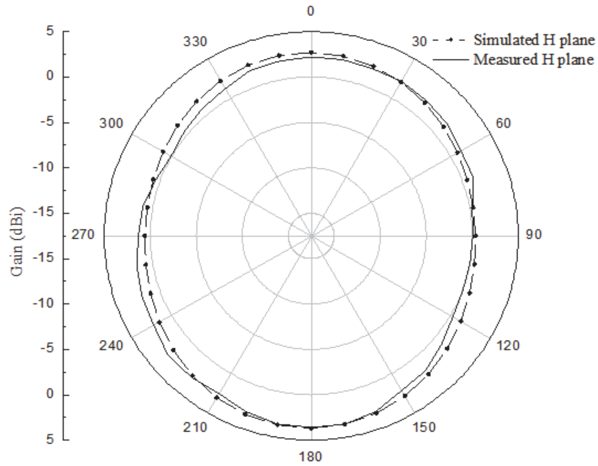



(c)

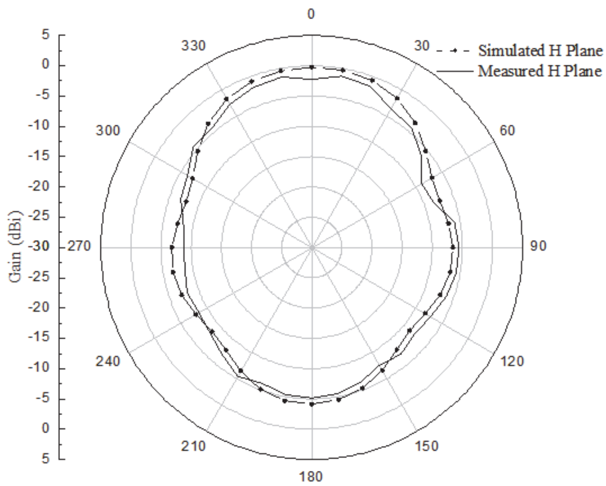
Fig. 11. Comparative simulated and measured E plane (dBi) radiation patterns at (a) 2.7 GHz (b) 4.2 GHz (c) 8.0 GHz




(a)




(b)




(c)

Fig. 12. Comparative simulated and measured H plane (dBi) radiation patterns at (a) 2.7 GHz (b) 4.2 GHz (c) 8.0 GHz

The comparative simulated and measured peak gain (dBi) vs. the frequency plot of the proposed antenna with two U shaped slots is shown in Fig. 10. Fig. 10 shows that the simulated peak gain of the antenna decreases sharply in the first notched frequency band (3.1 GHz to 3.8 GHz) and the second notched frequency band (5.0 GHz to 5.8 GHz). These sharp decreases in peak gain of the antenna at two notched frequencies show that the proposed antenna can protect the UWB system from the strong narrowband interferences arising within the notched band frequencies.

The simulated and the measured radiation patterns for the E plane are compared in Fig. 11 at frequencies 2.7 GHz, 4.2 GHz and 8 GHz, respectively. Very good agreement is observed between the simulated and the measured E plane radiation patterns which are a figure of eight shapes with slight variations. The simulated and the measured radiation patterns for the H plane are compared in Fig. 12 at similar frequencies. Almost omnidirectional and similar patterns are observed. The radiation pattern at high frequency (8 GHz) deteriorates as the equivalent radiating area changes with respect to frequency over UWB frequency range [12].

## IV. Conclusion

A monopole UWB antenna with a dual band notched frequency is designed and fabricated on the substrate RT/Duroid 5880. The antenna fulfills the FCC regulation for the UWB antenna with an operating frequency from 2.9 GHz to 11.0 GHz, which gives a total impedance bandwidth of 8.1 GHz. The dual notch created is successful at avoiding strong interference from WiMAX and WLAN which co-exist with the UWB system. The various measured results are compared with the simulated results and very good agreement is found between them.

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