# Design of Compact Monopole UWB Antenna with Dual Notched-Band Characteristics using Pair of Elliptical Split-Ring Slots

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**Abstract.** In this paper, a novel design of compact microstripline-fed ultra-wideband (UWB) antenna with dual notched-band characteristics is presented. By etching a pair of elliptical split- ring slots on the radiating patch the dual notched-band characteristics are realized. The separate band-rejected characteristics are achieved at 3.5 and 5.75 GHz which covers a WiMAX (3.3-3.7 GHz) and WLAN (5.725-5.825 GHz) operating ranges respectively by adjusting the length of the elliptical split-ring slots. The proposed UWB antenna has the size of 26 × 32 $mm^2$ which is printed on a low cost FR4 dielectric substrate having a relative permittivity (Ů) of 4.4 and a loss tangent (tan ŭ) of 0.02 with a substrate thickness of 1.6 mm. The total length of the elliptical split-ring slots which affects the performance of the dual band notched characteristics and corresponding VSWR plots are investigated in this paper. The simulated result of the proposed antenna is presented and shows a good agreement with measured one. Moreover, the proposed antenna exhibits omnidirectional radiation characteristics with stable gain across the UWB range expect at 3.5 and 5.75 GHz which meets a real requirement for UWB applications.

Keywords: Elliptical split-ring slot, dual notched-band, ultra-wideband application, WiMAX, WLAN

## 1. Introduction

The Federal Communications Commission (FCC), United States, has released a first report and order [1] on ultra-wideband radio spectrum to operate in the range of 3.1-10.6 GHz frequency band for various commercial and scientific services. Since then, the UWB technology becomes one of the greater attractive applications in modern wireless communication systems, due to its favorable advantages such as providing a high-speed data transmissions, short range indoor communications, short narrow pulses, wide operating bandwidth, less power consumption and relatively inexpensive [2]. Planar monopole antennas have received more attention and have been settled as a successful candidate for UWB systems because of their outstanding benefits such as ease of fabrication and integration, broad impedance bandwidth, acceptable omnidirectional radiation characteristics and its compactness.

In recent years, numerous monopole antenna configurations like circular, rectangular, crescent-type, elliptical, semi-circle, square, triangular and annular ring have been proposed by antenna designers with considering radiation properties for current and future UWB applications [3-10]. However, within the FCC allocated UWB operating frequency range, it may suffer from a significant obstruction with an existing narrow operating bands such as World Interoperability for Microwave Access (WiMAX) communication service from 3.3-3.7 GHz, IEEE 802.11a such as Wireless Local Area Network (WLAN) which covers from 5.15 GHz-5.825 GHz and HIPERLAN/2 in Europe country covering from 5.47-5.725 GHz. Therefore, the band-rejection performance is mandatory for preventing the potential interference in those WiMAX and WLAN narrow frequency bands. One or more feasible ways to resolve this complication is to develop UWB antennas with the band-notched feature. For achieving the single, dual, triple and multi notched-band characteristics several techniques have already been studied such as embedding slots like T-shaped, C-shaped, Ý-shaped, U-shaped, L-shaped, elliptical slots [11-17], and designing a simple slits in planar radiating patch edges and in the ground plane [18-20], adding a parasitic strips [21-23] to radiating patches, and creating a split-ring resonators [24-28]. The use of metamaterial based filter such as composite right/left-handed (CRLH) [29] has also been used to create a notch in the UWB band.

In this paper, a novel compact UWB monopole antenna with dual notched-band function at WiMAX (3.3-3.7 GHz) and WLAN (5.725-5.825 GHz) frequency bands is studied. The proposed antenna is consists of a concave arch shaped radiating patch and truncated bottom ground plane. To achieve a proper impedance matching and large impedance bandwidth with VSWR Ò2, a rectangular notch is created at mid top of the ground plane. Further, to obtain dual notched-band characteristics, a pair of elliptical split-ring slots is loaded onto the radiating patch. With a slight change of total length of the elliptical split-ring slots, it is easy to adjust the center frequencies of the notched bands at particular frequency ranges. A prototype of the proposed dual notched-band antenna has been constructed and tested successfully. The performance results of the simulated and measured parameters such as voltage standing wave ratio (VSWR), radiation characteristics and gain are discussed in this paper.

## 2. Antenna design

The configuration of the proposed dual notched-band UWB antenna is illustrated in Figure 1. The antenna design is sketched and fabricated on a low-cost FR-4 substrate having a relative permittivity ($\varepsilon_r$) of 4.4, loss tangent (*tan δ*) of 0.02 and a substrate thickness of 1.6 mm. The proposed antenna is composed of a concave arch-shaped radiating patch with a pair of elliptical split-ring slots and a partial finite-size ground plane on a bottom side of the substrate.

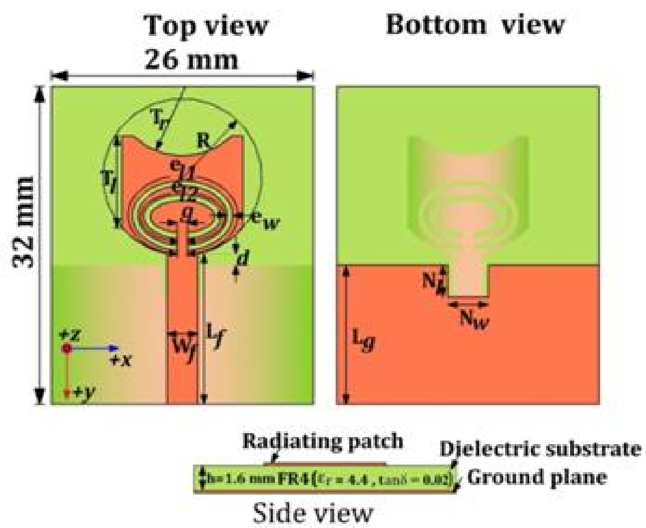



Fig.1. Configuration of the proposed dual notched-band UWB antenna

The concave arch-shaped radiating element is a modified geometry of a conventional circular shape with radius $R$ of 7.9 mm. Further, the side edges of the circular radiating patch are truncated which will form a proposed antenna structure. A rectangular notch with a size of $N_l \times N_w = 3.2\ mm \times 4\ mm$ is designed on the mid top of the ground plane that provides a mechanism to enhance the impedance bandwidth with VSWR Ò2 over the UWB range. Moreover, to achieve an optimum impedance matching between a radiating patch and microstrip line the distance $d=1.15\ mm$ is maintained. The entire antenna structure is printed within a small size of $26 \times 32\ mm^2$ substrate which represents a compact size. A simple $50\Omega$ microstrip line feed with a length $L_f$ of $15.15\ mm$ and $W_f$ of $3.06\ mm$ is selected to excite the radiating patch.

A pair of elliptical split-ring slots is designed to achieve separate notched-bands at 3.5 GHz and 5.8 GHz for WiMAX (3.3-3.7 GHz) and WLAN (5.725-5.825 GHz) systems. The key parameter to predict the center frequencies of the notched bands is mainly depends on the corresponding total length of the slots. In this design, the lengths of the elliptical split-ring slots $e_{l1}$ and $e_{l2}$ can be approximately determined by one wavelength of the rejected frequencies at 3.5 GHz and 5.75 GHz respectively. The wavelengths for the desired notched frequencies at 3.5 and 5.75 GHz are approximately calculated by the empirical formula given in Eq. (1),

$$\lambda_g = \frac{\lambda_0}{\left(\frac{\varepsilon_r + 1}{2}\right)} \qquad (1)$$

where, $\lambda_g$ and $\lambda_0$ are the wavelengths in the medium and free space respectively in cm. $c$ is the velocity of light and $\varepsilon_r$ is the relative dielectric constant. To optimize the central frequencies of the notched bands the values of œl1ô and œl2ô are varied through conducting the parametric study with the aid of electromagnetics Ansys High Frequency Structure Simulator (HFSS) [30] tool. The final optimized design parameters of the proposed antenna are depicted as follows: $R= 7.5\ mm$, $T_r=9.2\ mm$, $e_{l1}=25.91\ mm$, $e_{l2}= 18.36\ mm$, $e_w=0.5\ mm$, $g=1\ mm$, $L_f=15.15\ mm$, $W_f = 3.06\ mm$, $L_g= 14\ mm$, $N_l=3.2\ mm$ and $Nw= 4\ mm$. The photograph of the proposed antenna is given in Figure 2.

## 3. Results and discussion

All the simulations are carried out using ANSYS HFSS, Parametric study of some of the key parameter is carried out for better understanding of the dual notched-band characteristics. Measured VSWR and radiation characteristics of the proposed antenna are obtained by using Agilent's PNA (N5230A) Vector Network Analyzer (VNA). Figure 3 showed a measured and simulated VSWR of the proposed antenna with slots and the simulated VSWR result of the actual UWB antenna without slots. From the figure, it is noted that the measured result is in good acceptance with the simulated one. The impedance bandwidth of the proposed antenna is observed from 2.96 to more than 18 GHz for VSWR Ò2 which covers the entire UWB frequency band with dual notched bands of 3.2-3.88 GHz and 5.41-5.96 GHz.

To understand the better radiation mechanism of the proposed antenna, the simulated surface current dispersions at 3.5 and 5.75 GHz are illustrated in Figure 4. It can be observed from the Figure 4(a) that, the surface current density at 3.5 GHz is mainly accumulated around the edges of the bigger size elliptical split-ring slot. Whereas the surface currents density at 5.75 GHz is mostly allocated along the edges of the lower size elliptical split-ring slot as shown in Figure 4(b). Also, from this figures it is well known that the proposed antenna shows a dual notched-band feature within the UWB band.

(a) (b)

Fig.2. Photograph of the manufactured proposed antenna: (a) Top view (b) Bottom view

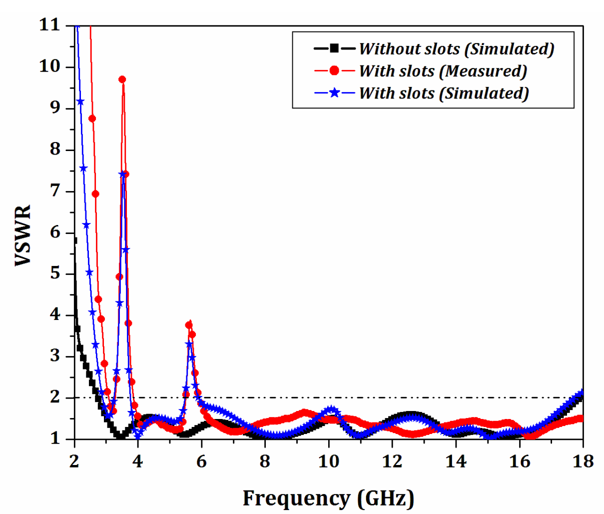
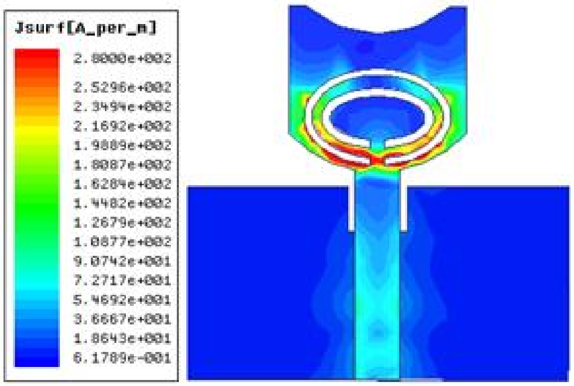
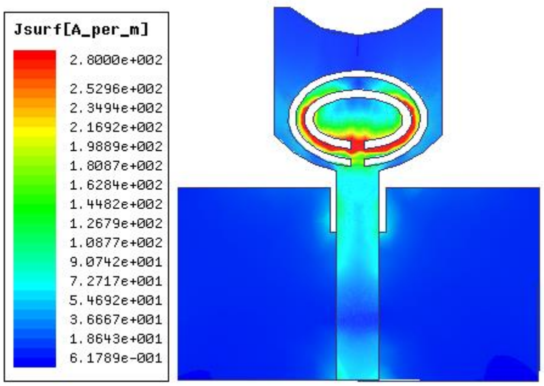



Fig. 3. Measured and simulated VSWR plot of the proposed UWB antenna




(a)




(b)

Fig. 4. Surface current distributions on the proposed antenna observed at (a) 3.5 GHz and (b) 5.75 GHz

Indeed, the notched bands at 3.5 GHz and 5.75 GHz are implemented by inserting a pair of elliptical split-ring slots in the radiating patch. The notched bands can be affected by varying the total lengths of the corresponding slots and slot location of the proposed antenna. Parametric analysis is conducted for further investigation to understand the effect of notched-bands. Figure 5 shows the simulated VSWR plots of the proposed antenna with different values of total lengths of the elliptical split-ring slot $e_{l1}$ by keeping $e_{l2}$ value as constant. It can be observed that with the increase of el1 values, the center frequencies of the corresponding notched-band shifts towards the lower frequency. Similarly, the effect of simulated VSWR plots for different values of el2 is shown in Figure 6. It is observed that with the increase of the total length of the elliptical split-ring slot values $e_{l2}$ by keeping the $e_{l1}$ value constant, the center frequencies of the corresponding notched-band frequency decreases. Besides, it is evident from the results that the lengths of the corresponding slots and by adjusting the one parameter keeping the other parameters constant, only the relevant notched band changes without disturbing the other notched-band. When the total lengths of the slots are approximately equal to a half wavelength, the optimal notched-band characteristics can be achieved. The proposed antenna design the optimal values of the elliptical split-ring slots $e_{l1}$ and *el2* are chosen as 25.91 mm and 18.36 mm which approximately determines the center frequencies of the desired notched-bands of WiMAX (3.3-3.7 GHz) and WLAN (5.725-5.825 GHz).

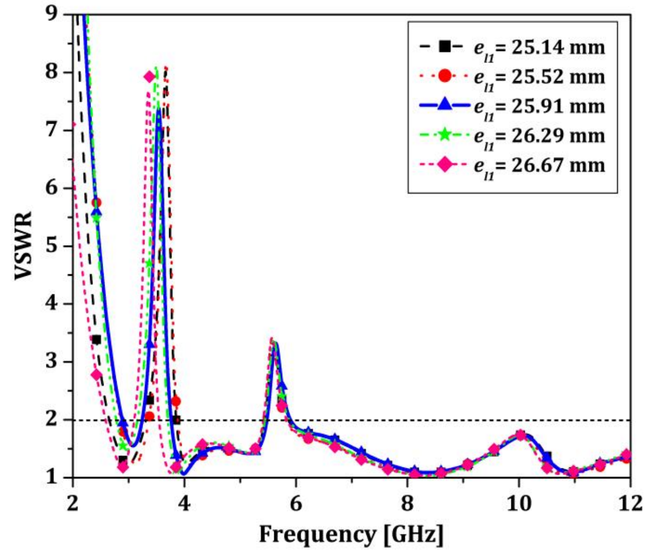



Fig. 5. Simulated VSWR plots for different values of $e_{l1}$ by keeping $e_{l2}$ constant

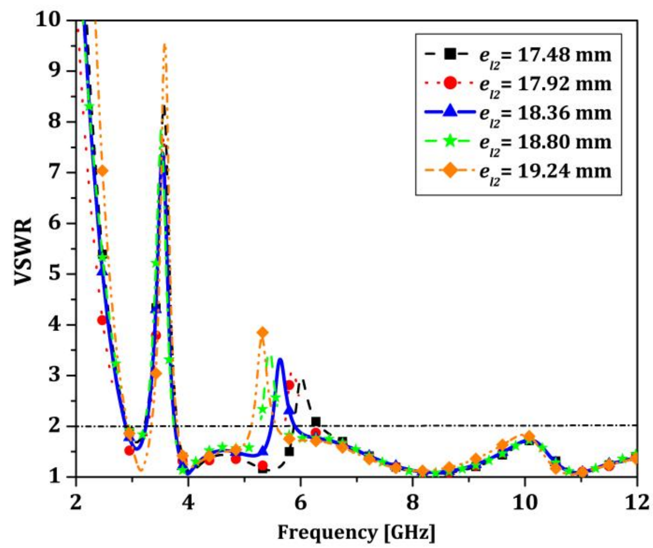



Fig. 6. Simulated VSWR plots for various values of $e_{l2}$ by keeping $e_{l1}$ constant

Figure 7 represents far-field normalized radiation patterns in both E and H-plane of the proposed dual notched-band antenna measured at 3, 4 and 8.35 GHz respectively. From these figures, it is observed that the proposed antenna reveals a bidirectional radiation pattern in the E-plane (Y-Z plane) and an omnidirectional radiation pattern in the H-plane (X-Z plane). The simulated peak gain plot of the proposed UWB antenna with and without slots is as shown in Figure 8. It can notice from this figure, that, the two sudden sharp cutback of the antenna gain can be observed in the rejected frequency bands, this is due to loading a pair of slots onto a radiating patch. The peak gains found are from 3.5 to 5.5 dBi for the UWB operating bands and -3.61 dBi and -4.09 dBi for the rejected bands at 3.5 GHz and 5.75 GHz respectively. This result confers that the proposed UWB antenna has an excellent dual notched-band characteristics at WiMAX (3.2-3.7GHz) and WLAN (5.725-5.825 GHz).

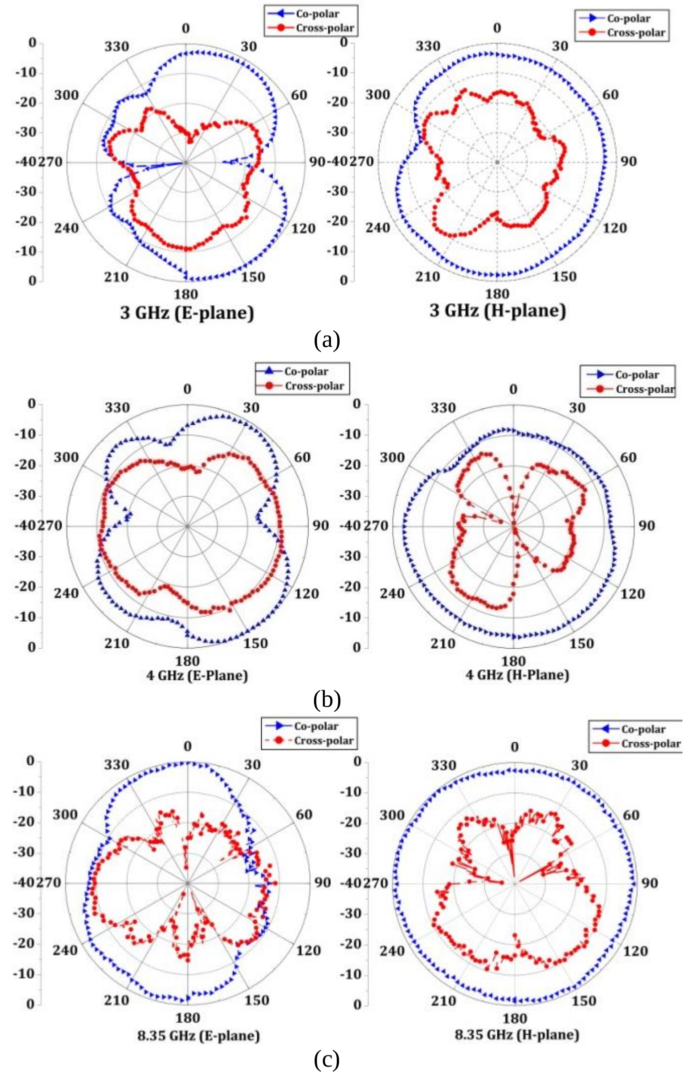



Fig. 7. Normalized radiation patterns in E and H-plane of the proposed antenna measured at (a) 3.0 GHz, (b) 4.0 GHz, and (c) 8.35 GHz.

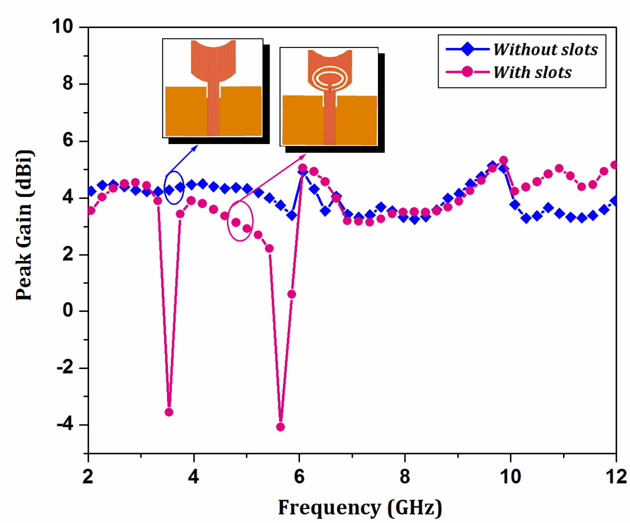



Fig. 8. Peak gain of the proposed antenna with/without elliptical split ring slots

In order to ensure the time-domain performance, the group delay characteristic of the proposed antenna is simul-

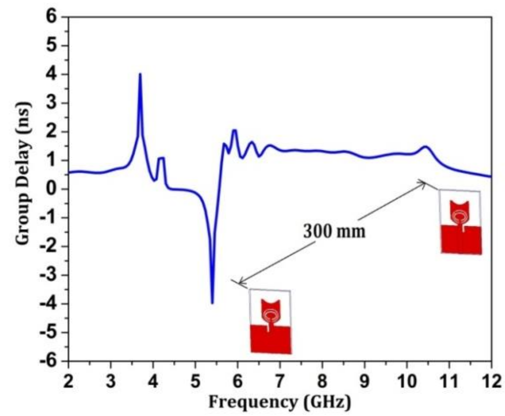



Fig. 9. Group delay variation in the time domain of the proposed antennas

ated between two identical prototype antenna models in the face-to-face orientation with keeping distance 300 mm between them. Figure 9 shows a group delay of response of the proposed antenna. A constant delay is less than 2 ns are observed throughout the UWB operating band except in the notched bands. This phenomenon represents the proposed antenna exhibits an excellent time-domain characteristics for linear transmission.

## 4. Conclusion

A novel compact concave arch-shaped UWB antenna with dual notched-band characteristics at 3.5 GHz and 5.75 GHz frequencies has been proposed and investigated. A dual notched-band function is achieved by incorporating a pair of elliptical split-ring slots onto the radiating patch. The proposed antenna has covered the frequency band from 2.8 GHz to more than 18 GHz for VSWR Ò2 with two narrow rejected frequency band services of WiMAX (3.2-3.7 GHz) and WLAN (5.75-5.90 GHz). The central frequencies of the notched bands can be adjusted by varying the total lengths of the elliptical split-ring slots. This antenna is compact in its size is printed on a low-cost FR-4 dielectric substrate material, and the overall antenna structure is placed in just 26 × 32 × 1.6 $mm^3$. Additionally, the proposed antenna presents a nearly omnidirectional radiation patterns in H-plane and stable gain at desired frequencies over the UWB band. Hence, the proposed antenna with dual notched-band nature is expected to be a promising candidate for FCC defined UWB applications.

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