The design of ultra-wide band circular monopole antenna with Quad-Band Notch characteristics

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ABSTRACT

A novel microstrip fed Ultra-wide band (UWB) with quad notch characteristics is presented in this paper to avoid the interference of narrow bands. The proposed antenna is having the size of 55x56x1.6 mm³ placed on FR4 epoxy substrate. Based on the methodologies, the first notch is created to attenuate the WiMAX (World Interoperability for Microwave Access) range 2.94-3.7GHz by using T slot. The two rectangular slots are used to reject the INSAT (Indian National Satellite) band of the range 4.5-4.8GHz and of WLAN (Wireless LAN) band of the range 5.1-5.9GHz. These three notch band characteristics are attained by etching the notches on the radiation patch and the fourth notch is created by etching U shaped slot in the feed which attenuates the ITU (International Telecommunication Union) band of the range 7.4-8.7GHz. All simulations are performed using HFSS software. The simulated antenna yields a good impedance bandwidth of 2-11GHz with Return loss (S11) ≤ -10dB, VSWR< 2 and exhibits good radiation properties except at the notch band range. The peak gain of more than 2.2dBi and an efficiency of above 90% is obtained from 2-11GHz excluding at the notched narrow bands. The obtained results depict that the antenna is very well suitable for real-time UWB applications.

Keywords— UWB antenna, Quad notches, narrow band ranges, Interference, HFSS Software

1. INTRODUCTION

In recent years, UWB has attained the concentration of many researchers due to the advantages of simple structure, convenient feeding structure, wide bandwidth and its cost effectiveness [1-2]. UWB has many uniquely attractive features such as high data rate, coexistence with existence narrow band systems and low power consumption etc. The federal communication commission (FCC) has prescribed 3.1 to 10.6 GHz range of commercial ultra-wide band communication systems [3]. UWB systems include the narrow frequency bands of 2.94-3.7 GHz (WiMAX band), 5.1-5.9 GHz (WLAN-band), 4.5-4.8 GHz (INSAT band), 7.4-8.7 GHz (ITU band) etc [4], which may generate interference with UWB systems. The interference levels caused by the nearby systems can be suppressed by using RF filtering, using lumped elements, using CPW resonators, using meander lines (MLs), embedding a slit in the feed line, cutting different kinds of slots in the radiation patch and ground plane etc [5]. The UWB antenna with band stop characteristics is a straight forward and effective solution to restrain the interference of signals for UWB communication [6]. Several printed monopole UWB antennas (PMA) have various geometries, but the foremost common shapes of PMAs employed by researches for UWB applications are rectangular, circular, square, triangular, elliptical and hexagonal etc [7-10].

In this paper, we propose a simple circular UWB antenna design [11] with quad band notched characteristics [12-14]. A T-shaped slot on the circular radiation patch notched WiMAX range i.e., (2.8-3.8GHz) frequency range. The two rectangular-shaped slots on the circular radiation patch notched the WLAN (5.13-5.9GHz) and INSAT (4.4-5.0GHz) respectively. A U shaped slot is cut in the feed of the circular patch to generate the fourth notch band in ITU band (7.38-8.9GHz). The equivalent design model, return loss (S11), VSWR, surface current distributions, peak gain, radiation efficiency and antenna radiation patterns at different frequencies are discussed in this paper.
2. ANTENNA DESIGN

2.1. Antenna Geometry

A simple UWB antenna and antenna with notch band characteristics are represented in Fig 1(a). The proposed antenna was printed on FR4 substrate with a thickness of 1.6mm and relative permittivity ($\varepsilon_r$) of 4.4, dielectric loss tangent (tan$\delta$) of 0.019. The volume occupied by the designed microstrip patch antenna is 55x56x1.6 mm$^3$. The upper radiating part comprises of a circular patch of radius of 12mm and the resonant frequency 10.6 GHz. The microstrip matching should be 50$\Omega$ to be matched perfectly. Here the quad notches which are shown in Fig. 1(b) are introduced to avoid interference between UWB and other wireless services. The quad slots (T-slot, two Rectangular-slots and U-slot) were adjusted by varying their length. By optimising the ground structure and the radiation patch with the notch band characteristics, good results are obtained.

![Figure 1(a). Geometry of the UWB antenna](image)

**Figure 1(a).** Geometry of the UWB antenna (i) conventional UWB circular patch antenna (ii) proposed UWB antenna.

![Figure 1(b).](image)

**Figure 1 (b).** (a) T-shaped slot, (b) Upper Rectangular-shaped slot, (c) Lower Rectangular-shaped slot, (d) U-shaped slot

HFSS software is used to simulate the antenna and following are the dimensions presented in the table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (in mm)</th>
<th>Parameter</th>
<th>Value (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>55</td>
<td>$L_1$</td>
<td>3.5</td>
</tr>
<tr>
<td>W</td>
<td>36</td>
<td>$L_2$</td>
<td>2.5</td>
</tr>
<tr>
<td>$L_f$</td>
<td>20.59</td>
<td>$W_1$</td>
<td>7</td>
</tr>
<tr>
<td>$W_f$</td>
<td>3</td>
<td>$W_2$</td>
<td>0.3</td>
</tr>
<tr>
<td>$L_\sigma$</td>
<td>20</td>
<td>$W_3$</td>
<td>8.1</td>
</tr>
<tr>
<td>R</td>
<td>12</td>
<td>$L_\lambda$</td>
<td>5.4</td>
</tr>
<tr>
<td>S</td>
<td>0.3</td>
<td>$W_4$</td>
<td>1.3</td>
</tr>
</tbody>
</table>

2.2. Antenna Evaluation and Working

The evaluation of the quad band notched antenna is depicted in Fig 2. The simple UWB antenna is working in the range of 2-11 GHz. Antenna-1 constitutes of single notch with T shape on the radiating patch which notches the range from (2.94-3.7 GHz) represented in fig-2(a). Antenna-2 constitutes of dual notches i.e., with T and rectangular shaped slots which attenuates the ranges (2.94-3.7GHz) and (4.5-4.8GHz) respectively depicted in fig-2(b). Antenna-3 comprises of triple notches on the radiating patch which notches the narrow band ranges i.e., (2.94-3.7GHz),(4.5-4.8GHz),(5.2-6.1GHz) respectively shown in fig-2(c). The proposed antenna with quad notches is designed by placing the U shaped slot in the feed. The proposed antenna is capable of notching 4 narrow band such as WiMAX(2.94-3.7GHz), INSAT(4.5-4.8 GHz), WLAN(5.2-6.1GHz) and ITU(7.4-8.7GHz) shown in fig.2(d). The simulated return loss parameters (S11) and VSWR are presented in fig 3 and fig4.
Figure 2. The evolution of antenna design (a) Ant-1 (b) Ant-2 (c) Ant-3 (d) Proposed-Ant

Figure 3. Simulated Return Loss Parameters of Antenna at five Stages
2.3 Effects of T-shaped slot, Rectangular and U-shaped slot:
The effects of T, two rectangular and U-shaped slots on the return loss, VSWR etc, of UWB antenna are presented in this section.
In this design, notched characteristics are obtained by the T-slot on the left edge of the UWB monopole, upper rectangular slot on the right edge of the monopole, another lower rectangular slot at the edge of the circular radiating patch and U-slot on the microstrip feed line. The notching slots can exhibit different notching characteristics based on different lengths. In this paper, the lengths of the slots at center frequencies are having lengths of \( \frac{\lambda}{4} \), \( \frac{\lambda}{4} \), \( \frac{\lambda}{2} \), \( \frac{\lambda}{4} \) respectively, where \( \lambda \) is the guided wavelength expressed in equation (1)

\[
\hat{\lambda} = \frac{c}{f_N \sqrt{(\varepsilon_r+1)/2}}
\]

where \( \varepsilon_r \) is the dielectric constant of FR4 substrate

The length of the slots can be determined by using the following two equations (2) & (3)

\[
L_{N1} = L_{N2} = L_{N4} = \frac{c}{4f_N \sqrt{(\varepsilon_r+1)/2}}
\]

\[
L_{N3} = \frac{c}{2f_N \sqrt{(\varepsilon_r+1)/2}}
\]

where \( f_N \) is the center frequency of the narrow band

\[
f_N = \frac{f_L + f_u}{2}
\]

where

- \( f_L \) is the lower frequency of narrow band
- \( f_u \) is the upper frequency of narrow band

\( L_{N1}, L_{N2}, L_{N3}, L_{N4} \) represents the lengths of the slots. By making use of equations (2) & (3), the desired notch lengths can be selected.

With \( \varepsilon_r \) of 4.4, the calculated total lengths are 13.748 mm at 3.32 GHz, 9.815 mm at 4.65 GHz, 8.078 mm at 5.65 GHz and 11.34 mm at 8.05 GHz. Whereas the total length with which the slots are designed are 13 mm at 3.7 GHz, 9.009 mm at 4.9 GHz, 8.109 mm at 5.5 GHz and 12.15 mm at 7.8 GHz.

From equations (2) & (3), it is clear that the length of the slot is inversely proportional to its notch frequency, \( f_N \). The notch center frequency increases as the length of the slot decreases and vice versa.

3. RESULTS AND DISCUSSION
The return loss of the proposed antenna is depicted in Fig.5. The proposed antenna offers good impedance matching from 2 to 11 GHz, with a return loss of \( \leq -10 \) dB except at the notched bands.
The following fig 6 represents the surface current distributions at 3.32GHz, 4.65GHz, 5.65GHz, 8.05GHz respectively, and at the resonant frequency of 10.4GHz. These figs i.e 6 (a-d) illustrates that the antenna does not radiate energy near the narrow band notching slots. Hence, the antenna effectively suppresses the frequency interference from the existing narrow band systems. Fig-6(e) i.e., at 10.4 GHz, depicts that the current is flowing along the feed, radiating circular patch and a very small amount of current around the slots. Therefore, the proposed antenna radiates more energy with a good return loss of less than -10dB.
The 2D radiation patterns of the proposed antenna at 2.2GHz, 4GHz, 5.1GHz, 10.3GHz respectively, are visualized in fig-7(a-d). The antenna achieves nearly the quasi-omni directional pattern on H-plane and bidirectional pattern on the E-plane.

![Figure 7. 2-D Radiation pattern (violet colour represents E-plane, Red colour represents H-plane)](image)

The radiation efficiency and peak gain of proposed antenna are shown in the fig 8(a) and (b). For the proposed antenna, the gain of more than 2.2dBi and efficiency of above 90% is obtained from 2 to 11 GHz excluding at the notching narrow bands. The obtained less peak gain and radiation efficiency at the notched bands confirms that the proposed antenna greatly suppresses the interference from the narrow band systems.
Figure 8. (a) Radiation efficiency (abs) (b) peakGain(dBi)

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