A COMPACT PROXIMITY–FED QUAD BAND–NOTCHED ULTRA–WIDEBAND PATCH ANTENNA

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ABSTRACT

A compact proximity feed printed ultra-wide band (UWB) patch antenna with four notched bands characteristics is proposed and investigated in this article. The proposed antenna introduces UWB performance in the frequency range of 3.1 GHz to 11.7 GHz with almost omnidirectional radiation pattern. Narrow rectangular slits and T–shaped slots are etching in the ground plane to provide four notched bands at frequencies of 3.5, 3.9, 5.25 and 5.9 GHz to avoid the interference with the existing wireless networks which occupy bands at these frequencies. The antenna is designed, simulated and fabricated. The measured data of the fabricated antenna demonstrate good agreement with the simulated results.

Keywords: Four Notched Bands, Microstrip Patch Antenna, Proximity Feed, UWB Antenna.

1. INTRODUCTION

The ultra–wide band (UWB) antennas have gained high interest in the recent years since 2002 when the unlicensed use of the commercial UWB communications devices is permitted [1–3]. However communications with these antennas need to avoid interference with the existing standard wireless networks such as WiMAX (3.3–3.6 GHz), C band satellite communication (3.7–4.2 GHz), lower WLAN (5.15–5.35 GHz), higher WLAN (5.725–5.825 GHz) and LMI C band (5.725–6.025 GHz). To avoid such interference, frequency band-notches are preferably applied directly to the UWB antennas instead of implementation of additional band stop filters. Most of researches in the literature are focused to design UWB antennas with a single [4–5], dual [6–7] or triple [8–10] frequency band–notches. In this paper, a compact planar patch antenna with UWB frequency range of 3.1 to 11.7 GHz with four rejected band–notches corresponding to the previously mentioned applications is presented. The proposed antenna in this work is adopted with a proximity-fed line technique. The desired four notched bands are achieved by etching different shaped slots in the ground plane of the antenna.
The analysis and design of the proposed antenna are carried out using the commercial software CST microwave studio (MWS) simulator. Also the antenna is fabricated and its performance parameters are measured using HP8719 vector network analyzer. The simulated results and the measured data are presented.

2. ANTENNA DESIGN (PARAMETRIC STUDIES)

The antenna is etched on FR4 substrate of a relative permittivity $\varepsilon_r = 4.5$, loss tangent $\tan \delta = 0.01$, a thickness $h = 1.5$ mm. The total dimension of the substrate and the ground plane is $l_g \times w_g = 20 \times 20$ mm$^2$. The Geometry of the proposed UWB antenna is shown in Fig. 1. The antenna is fed by a proximity 50 $\Omega$ microstrip line of dimensions $l_f \times w_f = 12 \times 2$ mm$^2$ printed on one surface of the substrate. To achieve UWB range a modified shape looks like a cedar tree is etched in the ground plane on the other side of the substrate as shown in the figure.

To provide a band-notch in the antenna performance a slot or slots can be etched in the ground plane with total length corresponding to a half guided wavelength at the notched frequency. The length of a slot can be considered approximately by $[11–12]$: 

$$l_{slot} \approx \frac{c_o}{4f_{notch}} \sqrt{\frac{\varepsilon_r + 1}{2}}$$  \hspace{1cm} (1)

where $l_{slot}$ is the length of the slot, $f_{notch}$ is the centre frequency of the notched band, $\varepsilon_r$ is the relative permittivity of the antenna substrate, and $c_o$ is the velocity of light. Firstly to achieve the proposed band notch at frequency (5.15–5.35 GHz) a two symmetric T-shaped slots of dimensions $l_s = 6$ mm, $w_r = 2.5$ mm, $t = 0.7$ mm, $g = 0.9$ mm and $t_s = 0.8$ mm with total length equal to $2 \times l_{slot}$ where $l_{slot}$ as it is shown in fig. 1, 

$$l_{slot} = \frac{t}{2} + l_r + t_r + \frac{\sqrt{l_s}}{2} = 8.4 \text{ mm}$$

which approximately corresponds to notched frequency 5.25 GHz according to equation (1) are etched in the lower part of the ground plane. Secondly to provide a notched band at 5.725–6.025 GHz, two other symmetric narrow rectangular slits of dimensions $l_{s1} \times w_{s1} = 7.4 \times 0.25$ mm$^2$ with total length equal to $2 \times l_{slot}$ where $l_{slot} = 7.65$ mm which approximately corresponds to a notched frequency at 5.9 GHz are etched in the ground plane at both sides of the modified cedar tree–shaped slot. Also to achieve another band notch at frequency band of 3.7–4.2 GHz, two other symmetric narrow rectangular slits of dimensions $l_{s2} \times w_{s2} = 11.4 \times 0.25$ mm$^2$ with total length equal to $2 \times l_{slot}$ where $l_{slot} = 11.65$ mm which approximately corresponds to a notched frequency at 3.9 GHz are etched in the ground plane and at distance $d = 0.5$ mm from the 5.9 GHz slots. Lastly to provide the fourth–proposed notched band of 3.3–3.6 GHz, two narrow rectangular symmetric slits of dimensions $l_{s3} \times w_{s3} = 13 \times 0.25$ mm$^2$ with total length equal to $2 \times l_{slot}$ where $l_{slot} = 13.25$ mm which approximately corresponds to the notched frequency of 3.5 GHz are etched in the ground plane at a distance $c = 0.25$ mm from the 3.9 GHz slots. Dimensions of each part of the antenna are illustrated in detail in Table 1. The antenna is fabricated and photographs of the top and bottom views of the antenna are shown in Fig. 2.
Figure 1: The Geometry of the proposed UWB antenna, (a) bottom–view of the antenna, (b) top–view of the antenna

Table 1: Dimensions of the elements of the proposed UWB antenna

<table>
<thead>
<tr>
<th>Dim.</th>
<th>Value (mm)</th>
<th>Dim.</th>
<th>Value (mm)</th>
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<tbody>
<tr>
<td>l_g</td>
<td>20</td>
<td>l_f</td>
<td>12</td>
</tr>
<tr>
<td>w_g</td>
<td>20</td>
<td>w_f</td>
<td>2</td>
</tr>
<tr>
<td>l_s1</td>
<td>7.4</td>
<td>l_s2</td>
<td>11.4</td>
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<tr>
<td>l_s3</td>
<td>13</td>
<td>w_s1</td>
<td>0.25</td>
</tr>
<tr>
<td>w_s2</td>
<td>0.25</td>
<td>w_s3</td>
<td>0.25</td>
</tr>
<tr>
<td>l_t</td>
<td>6</td>
<td>w_t</td>
<td>2.5</td>
</tr>
<tr>
<td>t_s</td>
<td>0.8</td>
<td>g</td>
<td>0.9</td>
</tr>
<tr>
<td>t</td>
<td>0.7</td>
<td>a</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>1.75</td>
<td>c</td>
<td>0.25</td>
</tr>
<tr>
<td>d</td>
<td>0.5</td>
<td>e</td>
<td>3.5</td>
</tr>
<tr>
<td>Substrate's height (h)</td>
<td>Value (mm)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
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Figure 2: Photographs of the fabricated proposed antenna, (a) top–view, (b) bottom–view.

3. IMPLEMENTATION AND RESULTS

The proposed antenna is designed and simulated using the CST MWS simulator software. Also the antenna is fabricated and tested using the vector network analyzer HP8719. Fig. 3 illustrates the simulated results and measured data of the $S_{11}$ parameter as a function of frequency for the proposed quad band–notched UWB antenna. The simulation results show a bandwidth from 3.1 GHz
to 11.7 GHz (8.6 GHz Bandwidth) whereas the measured bandwidth of the antenna is from 2.7 GHz to 10.3 GHz (7.6 GHz Bandwidth).

Ultimately, the prototype antenna without any slots and with only the modified cedar tree–shaped slot covers the entire UWB band of 4 – 13 GHz. Fig. 4(a) – (d) shows the gradual processes for etching the cedar tree–shaped slot in the ground plane which are carried out with the help of the CST MWS simulator to get the UWB range for the proposed antenna. Fig. 4(e) present the $S_{11}$ as a function of frequency for the designs shown in fig. 4(a) – (d) passes through these processes. From the figure it is observed that, fig. 4(d) shows acceptable UWB range.

**Figure 3:** Simulated and measured $S_{11}$ parameter versus frequency of the proposed quad band-notched UWB antenna

**Figure 4:** (a) – (d) Gradual processes for the modified cedar tree to get UWB range, (e) Simulated $S_{11}$ versus frequency of the designs in figures 4(a) – (d)
To achieve a notched band at frequency 5.25 GHz two T–shaped slots are etched in the ground plane and each is at a distance \( e \) from the substrate’s edge. Fig. 5 shows the effect of etching the T–shaped slots with different values of \( e \) on the \( S_{11} \) parameter. The figure illustrates that the optimum value is \( e = 3.5 \) mm to provide a band notch at frequency 5.25 GHz. To achieve another band notch at frequency 5.9 GHz two narrow rectangular slits of dimensions \( l_{s1} \times w_{s1} = 7.4 \times 0.25 \text{ mm}^2 \) are etched in the ground plane at a distance \( b = 1.75 \) mm from the right and left edge of the substrate. Fig. 6 illustrates the effect of etching these slits on the \( S_{11} \) of the proposed antenna with different values of the distance \( b \). The two slits with a distance \( b = 1.75 \) mm provide a band notch at frequency 5.9 GHz.

Third–notched–band at frequency 3.9 GHz is obtained by etching another two narrow rectangular slits of dimensions \( l_{s2} \times w_{s2} = 11.4 \times 0.25 \text{ mm}^2 \) and separated with a distance \( d \) from the previous slits in the ground plane as shown in fig. 1. Fig. 7 shows the effect of changing the distance \( d \) on the \( S_{11} \) of the proposed antenna. It is clear that the best value is \( d = 0.5 \) mm. Furthermore by etching two other narrow rectangular slits of dimensions \( l_{s3} \times w_{s3} = 13 \times 0.25 \text{ mm}^2 \) and at a distance \( c \) from the previous slits a fourth–band notched at frequency 3.5 GHz can be achieved. Fig. 8 shows the effect of varying the distance \( c \) of the two rectangular slits on the center frequency and the band of the fourth–band notched. The figure demonstrates that the optimum value is \( c = 0.25 \) mm.

**Figure 5:** Simulated \( S_{11} \) versus frequency for different values of \( e \) of T–shaped slots

**Figure 6:** Simulated \( S_{11} \) versus frequency for different values of \( b \) of narrow slits of dimensions \( l_{s1} \times w_{s1} = 7.4 \times 0.25 \text{ mm}^2 \)
Figure 7: Simulated $S_{11}$ versus frequency for different values of $d$ of narrow slits of dimensions $l_{s2} \times w_{s2} = 11.4 \times 0.25$ mm$^2$

Figure 8: Simulated $S_{11}$ versus frequency for different values of $c$ of narrow slits of dimensions $l_{s3} \times w_{s3} = 13 \times 0.25$ mm$^2$

For more clarification to the antenna design, the simulated surface current distributions of the proposed quad band–notched UWB antenna at frequencies of 3.5, 3.9, 5.25, and 5.9 GHz are shown in Fig. 9. It can be seen that the currents mainly concentrate over the corresponding T– and rectangular–shaped slots at frequencies 3.5, 3.9, 5.25 and 5.9 GHz which means that a large portion of electromagnetic energy has been stored around the etched slots. This response causes the antenna to be nonresponsive at the corresponding notch frequencies.

Fig. 10 shows the normalized far-field radiation patterns of $E_\phi$ and $E_\theta$ in the $yz$– ($E$–plane) and $xz$– ($H$–plane) planes of the proposed antenna at frequencies 4.5 GHz, 7 GHz and 9.5 GHz. The results demonstrate that the radiation patterns exhibit a nearly omnidirectional radiations in the $xz$–plane at these frequencies, whereas, in yz–plane the radiation patterns is bi-directional and look like the radiation from a dipole antenna. Fig. 11 illustrates the gain and the radiation efficiency of the proposed antenna versus frequency. The figure shows that the proposed antenna has high gain and
good radiation efficiency over the entire frequency band except at the four proposed frequency band-notches.

Figure 9: Surface current distributions of the proposed antenna at notched frequencies (a) 3.5 GHz, (b) 3.9 GHz, (c) 5.25 GHz, (d) 5.9 GHz
4. CONCLUSION

In this work an UWB antenna with four notched bands is designed. Matching between the UWB antenna and the 50 ohm microstrip line is done through a proximity feed technique. To obtain the required four band notches, slots etching in the ground plane are implemented. The effects of adding these slots on the performance of the antenna are demonstrated. The proposed antenna provides wideband performance in a frequency band from 3 to 11.7 GHz with notched bands at 3.5, 3.9, 5.25 and 5.9 GHz which correspond to WiMAX, C band satellite communication, lower WLAN, higher WLAN and LMI C band respectively. The proposed antenna shows omnidirectional radiation with good radiation efficiency over the frequency band except at the four notched bands. The proposed antenna is fabricated and the measured data of the S\textsubscript{11} showed a very good agreement with the simulated results. The performances of the antenna illustrate that it is good candidate for UWB applications.
REFERENCES


