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A Compact Dual Band-Notched Ultrawideband Antenna with $\lambda/4$ Stub and Open Slots

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Abstract—A novel compact UWB antenna with 3.5/5.5 GHz dual notch-band characteristics is presented. The proposed antenna has a simple structure and compact size of $30 \times 35\,\mathrm{mm}^2$. Firstly, a compact modified rotated monopole antenna that covers UWB band is achieved. Then by inserting a $\lambda/4$ stub and etching two symmetrical $\lambda/4$ L-shape slots on the UWB antenna achieved before, a dual band-notched ultra-wideband antenna is obtained. The prototypes of UWB antenna with and without notched bands were fabricated and measured. Good performance of dual notched bands, stable gain and omnidirectional radiation patterns make the proposed antenna promising for UWB application.

1. INTRODUCTION

In recent years, ultra-wideband (UWB) communication systems draw great attention in the wireless world because of their many advantages. Since the Federal Communication Commission (FCC) allowed 3.1–10.6 GHz unlicensed band for UWB communication, UWB communication becomes a hot topic in the wireless communication area [1]. As an important part of UWB communication systems, UWB antennas have attracted significant research power these years. Challenges in designing UWB antenna include wide impedance matching, radiation stability, low profile, compact size, and low cost [2]. Recently, many efforts have been made for achieving antennas that can cover UWB band, including printed circular disc monopole [3], self-complementary antenna [4], etc.

However, UWB bandwidth may cause interference with existing narrowband wireless systems, including Worldwide Interoperability for Microwave Access (WiMAX) service (3.4–3.7 GHz) and Wireless Local Area Network (WLAN) services (5.15–5.825 GHz), which has to be avoided. A proper solution is integrating notching structures in the antenna [5]. In the open literatures, numerous methods have been applied to UWB antennas to achieve single or multi band-notched function [6–12]. To achieve single band-notched antenna, a simple method is to embed $\lambda/2$ slots with different shapes, such as U-shaped [7], C-shaped [8], and $\lambda/4$ open-ended slots [12] on the patch or the ground plane. In addition, inserting a $\lambda/4$ stub in a proper location has also been widely used [2]. For the multi-notch-band antennas, the solutions is similar to that for single band-notch antenna, including inserting dual $\lambda/4$ stubs [10], embedding dual C-shaped slots on the patch of the antenna [11] and utilizing a couple of half-wavelength parasitic elements in an open rectangular slot [12].

In this paper, a novel compact UWB antenna with dual notch-band characteristics was proposed. Firstly, a modified UWB rotated cross monopole antenna was presented. The obtained UWB antenna can cover 2.92–11.72 GHz. The cut part which has little effect on the reflection coefficient of the monopole antenna makes the UWB antenna compact. Then a $\lambda/4$ stub is inserted in the UWB antenna proposed previously, and a single band-notched antenna that covers 5.15–5.825 GHz can be achieved. Finally, by inserting a $\lambda/4$ L-shaped slot on each edge of the monopole patch, a dual notch-band

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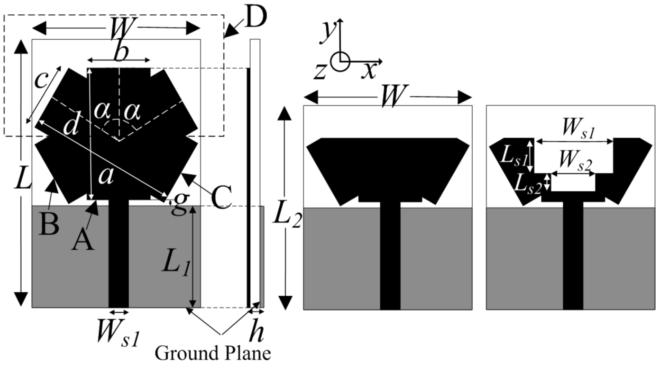
characteristic was achieved. The final proposed antenna here can reject the frequency bands of 3.4–3.7 GHz and 5.15–5.825 GHz without using an additional band-stop filter. The prototypes of UWB antenna with and without notched bands are fabricated and measured. The design process is described in detail in following sections.

2. UWB ANTENNA DESIGN AND RESULTS

Figure 1 shows the design evolution process for the compact UWB antenna. The rotated cross monopole antenna is used as the reference antenna (referred to as antenna 1). It is constituted of a rotated cross-shaped planar monopole fed by a 50 Ω-microstrip line and a ground plane. The rotated cross monopole patch consists of three parts: the vertical rectangular patch (A) and two rotated rectangular patches (B and C), which has a rotated angle of α. By rotating the two rectangular patches (area B and C), the impedance bandwidth of the proposed cross monopole antenna can be significantly enhanced. The vertical rectangular patch (A) acts as a radiator as well as feed for the cross patch antenna. To simplify the design, parts B and C have the same dimensions of $a \times c$. The size of patch A is $b \times d$, and the whole antenna is fed by a 50 Ω-microstrip line with width of W_f. The antenna is fabricated on a FR4 substrate with a thickness of 1.6 mm and relative permittivity of 4.4, and has a dimension of $W \times L$. The dimension of ground plane for antenna 1 is $W \times L_1$. The feed gap width between the ground plane and the feed point is g.

Figure 2(a) shows the simulated VSWR of antenna 1. In order to get further size reduction, the part that has almost no current on (area D) was cut, and then a step slot is etched on the patch. The upper part of the step slot has a dimension of $W_{s1} \times L_{s1}$ while the lower part has a dimension of $W_{s2} \times L_{s2}$ as shown in Figure 1(c). The final modified UWB antenna (referred to as antenna 3) is obtained. The geometric dimensions of the proposed UWB antenna are as follows: $W = 30\,\text{mm}$, $L = 50\,\text{mm}$, $L_1 = 15\,\text{mm}$, $L_2 = 35\,\text{mm}$, $a = 27\,\text{mm}$, $b = 9\,\text{mm}$, $c = 13\,\text{mm}$, $d = 28\,\text{mm}$, $g = 0.5\,\text{mm}$, $\alpha = 38^\circ$, $W_{s1} = 12\,\text{mm}$, $W_{s2} = 6\,\text{mm}$, $L_{s1} = 8\,\text{mm}$, $L_{s2} = 5\,\text{mm}$. Figure 2 shows the simulated VSWR of antenna 1, antenna 2 and antenna 3. The SMA connector was included in the simulated model to improve the simulation precision. To further investigate on the antenna, the prototype of the UWB antenna is fabricated and measured. The measured VSWR and a photo of the prototype are also given in Figure 2(a). From the results, it can be seen that the operation band of antenna 3 can reach 2.92–11.72 GHz, which meets the UWB application band. The operation band of antenna 3 shifts to higher frequency since the antenna has a smaller size than antenna 1.

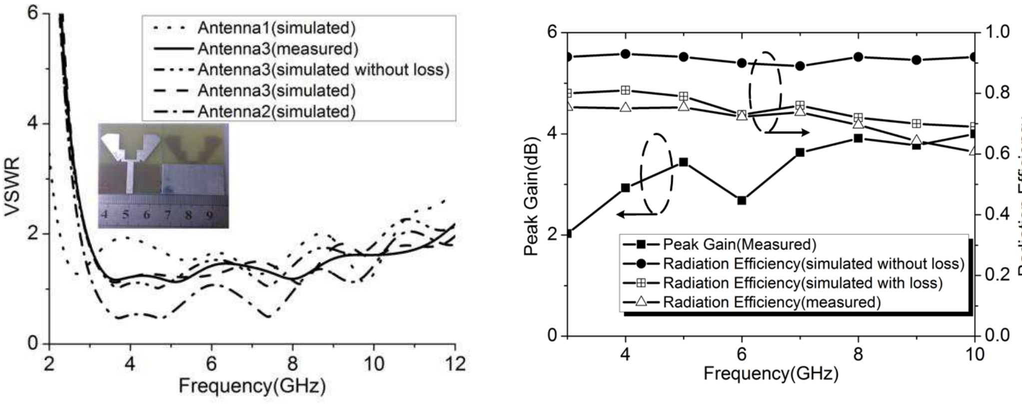
For an UWB antenna associated with a low-Q which may be caused either by wideband high radiation resistance or by wideband loss, the gain and radiation efficiency are important. The radiation pattern and efficiency of antenna 3 are measured, and the results are shown in Figure 2(b). From the



antenna1 antenna2 antenna3

(a) (b) (c)

Figure 1. Geometries of the proposed antennas, (a) top view and side view of antenna 1, (b) top view of antenna 2, (c) top view of antenna 3.



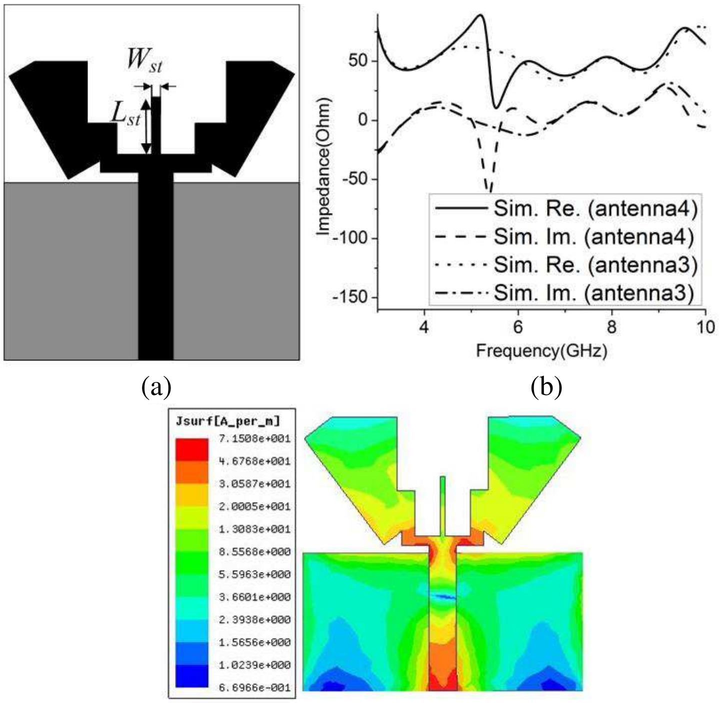
(a) (b)

Figure 2. (a) The simulated and measured VSWRs, (b) simulated and measured gain and efficiency.

results it can be seen that in the operation band the peak gain of the UWB antenna is more than 2 dB. The radiation efficiency is about 70% in the whole band. The radiation efficiency decreases with the frequency increasing, and at the high band, the efficiency is lower than 65%. The low radiation efficiency is mainly caused by the loss of material. However, we should note that the antenna's UWB character is not caused by the loss of material. To prove this, the antenna with no-loss material is simulated. The result is also shown in Figure 2. In this case, the impedance match can remain good, and the efficiency is improved significantly to over 90%.

3. SINGLE BAND-NOTCHED UWB ANTENNA DESIGN AND RESULTS

To reduce the interferences from the IEEE802.11a and HIPERLAN/2 WLAN systems, the band-notched function is desirable in the UWB system [2]. In order to meet this requirement, an open stub with size



(a) (b)

(c)

Figure 3. (a) Geometry of the proposed antenna 4, (b) the simulated VSWRs of antenna 4 with different L_{st}, (c) the current distribution of the antenna 4 at 3.5 GHz.

of $W_{st} \times L_{st}$ is inserted to the antenna. Figure 3(a) shows the geometry and dimensions of the UWB antenna with band notch property operating in the 5.15–5.825 GHz band (referred to as antenna 4). The length of the stub at the center frequency of the notched band can be calculated by

$$L = \frac{c}{4f\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

Here, c is the speed of the light and ε_r the dielectric constant. For achieving the notch-band at 5.5 GHz, here $f = 5.5$ GHz. According to (1), the calculated length of the stub is 8.1 mm, while the final optimized value of L_{st} is 7.5 mm, which is consistent with the calculated value.

For the UWB antenna with single notched band, the inserted stub can be equivalent to a series resonant circuit connected in parallel with the antenna. When the length of the stub equals quarter wavelength, the series resonant circuit will be syntonic, which causes shorted input. Consequently, the antenna cannot radiate at this frequency. In order to approve this, the simulated impedance curves of Antennas 3 and 4 are plotted in Figure 3(b) to further explain the operating principle of the band-rejected element. As can be seen, at about 5.5 GHz, after adding the stub, the imaginary component curve of the band-notched antenna exhibits a series resonance characteristic, and the real component is low (about 10 Ohm).

4. DUAL BAND-NOTCHED UWB ANTENNA DESIGN AND RESULTS

In addition to WLAN systems, WiMAX from 3.4–3.7 GHz also operates in the UWB band. To minimize the potential interferences between UWB system and WiMAX system, the antenna with dual notched bands becomes necessary. Here a $\lambda/4$ open slot is etched on antenna 4 to achieve a dual band-notch antenna. In order to determine the proper location of the open slot, Figure 3(d) gives the current distribution at 3.5 GHz. As can be seen, the current mainly distribute on the edge of the patch of

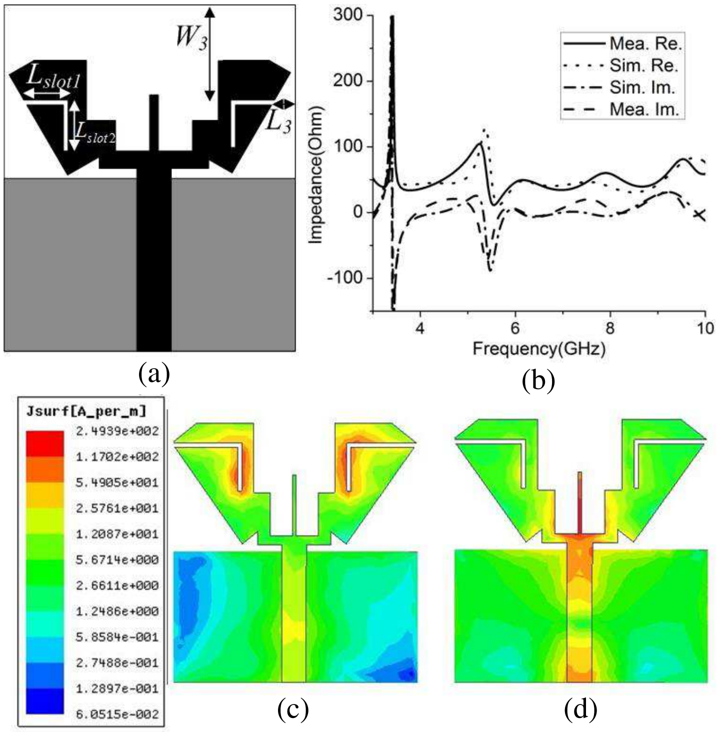


Figure 4. (a) Geometry of the proposed antenna 5, (b) the simulated VSWRs of antenna 4 with different L_{slot2}, (c) the current distribution of the antenna 5 at 3.5 GHz, (d) the current distribution of the antenna 5 at 5.5 GHz.

antenna 4. So by etching a L-shaped slot on each edge of antenna 4, the required dual band-notched filtering properties both in 3.3–3.6 GHz and 5.15–5.825 GHz can be achieved. Figure 4(a) gives the geometry and dimensions of the UWB antenna with dual band-notch property (referred to as antenna 5). The L-shaped slots are placed away from the edges of W_3 and L_3. The horizontal slot has a length of L_{slot1} while the vertical slot has a length of L_{slot2}. All the slots all have a width of W_{slot}. As described previously, the length of the L-shaped slots $L = L_{\text{slot1}} + L_{\text{slot2}}$. According to (1), the calculated value of L is 13 mm, about quarter wavelength at the notch band. Here we set L_{slot1} as 8 mm and optimize L_{slot2}. The final optimized value of L_{slot2} is 4.8 mm, which agrees with the calculated value (5 mm) well. In order to analyze the principle of the notched structure, the simulated impedance curves of antenna 5 are plotted in Figure 4(b). From the results it can be seen that the open slots can be equivalent to a parallel RLC resonant circuit connected with the antenna in series. When the length of the slots is equal to $\lambda_g/4$, the antenna will operate at the notched frequency. The resonant circuit will be resonant, which results in the input to be opened.

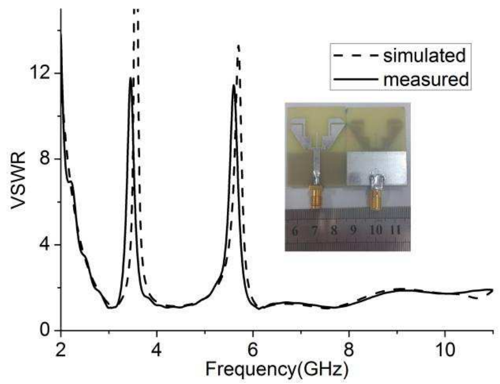
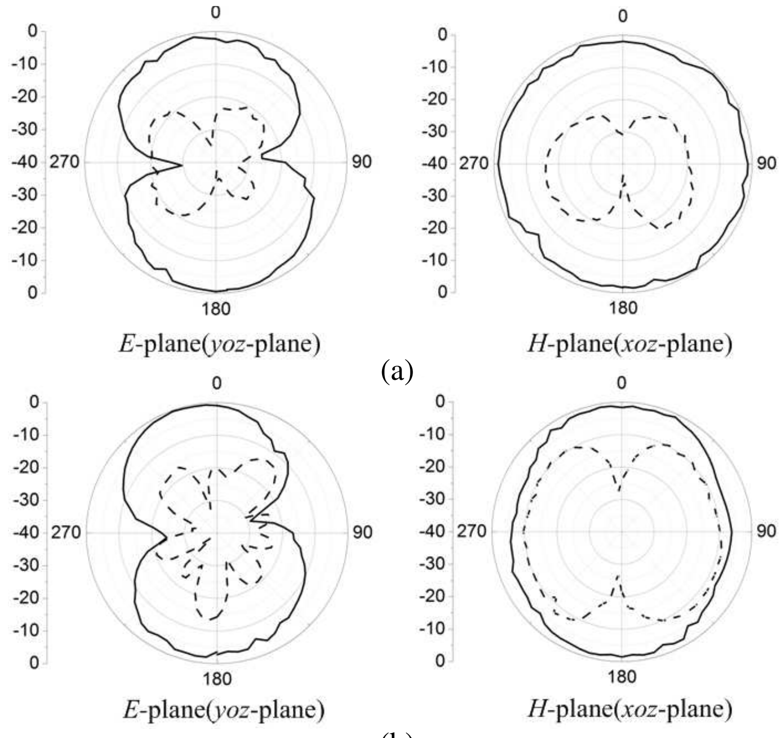
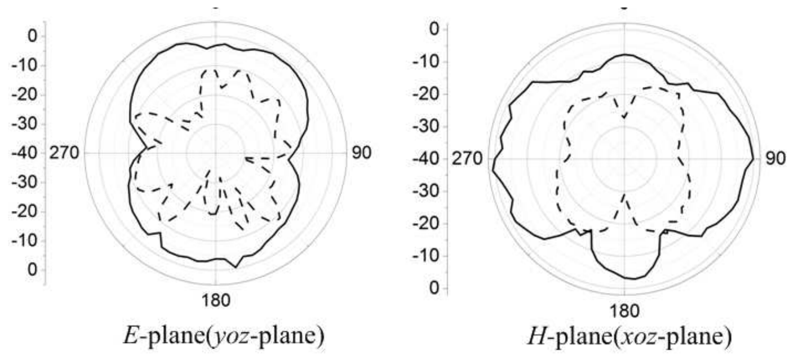


Figure 5. The prototype of the proposed antenna and the simulated and measured VSWR of the proposed antenna.



(a)

(b)



(c)

Figure 6. Radiation pattern for various resonance frequency for the proposed compact UWB antenna with —— copolar and - - - - - cross-polar, (a) 3 GHz, (b) 6 GHz, and (c) 9 GHz.

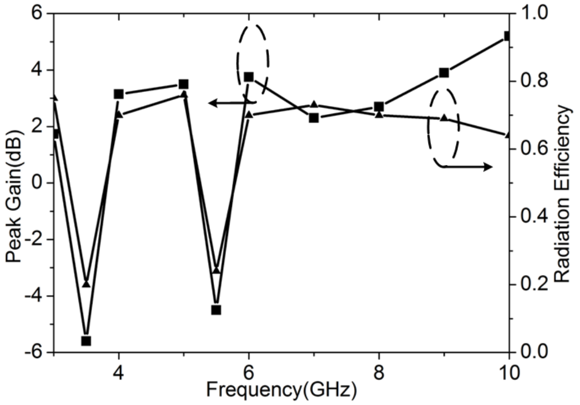


Figure 7. The measured gain and radiation efficiency of the proposed antenna.

The prototype of the proposed antenna 5 with optimal geometrical parameters is fabricated and measured. The antenna proposed is fabricated with $W_s = 0.5\,\text{mm}$, $L_{\text{slot1}} = 8\,\text{mm}$, $L_{\text{slot2}} = 4.8\,\text{mm}$, $W_{st} = 0.5\,\text{mm}$, $L_{st} = 7.5\,\text{mm}$. Figure 5 gives the simulated and measured VSWRs of the proposed antenna. It can be seen that the measured impedance bandwidth for VSWR < 2 is 2.8–11.09 GHz, except for 3.4–3.83 and 5.15–5.86 GHz. The center frequencies of the two notched bands are 3.52 and 5.54 GHz, and the maximum values of the VSWR are 10.5 and 10.2. Good consistency between the simulated and measured results is observed. The slight difference between the measured and simulated results is mainly caused by the fabrication tolerance.

The measured radiation patterns of antenna 3 at frequencies 3 GHz, 6 GHz and 9 GHz are illustrated in Figure 6. The radiation pattern is bidirectional in E-plane (*yoz*-plane) and omnidirectional in H-plane (*xoz*-plane) at 3 GHz and 6 GHz. It can be regarded as a monopole which features a doughnut-shaped pattern at the fundamental mode. As the frequency increases, the radiation pattern in H-plane (*xoz*-plane) is quasi-omnidirectional, and the cross-polarization component becomes larger at 6 GHz. At 9 GHz, as the higher-order modes exist, the pattern in the H-plane (*xoz*-plane) is similar to the shape of a four-leaved clover, and the cross-polarization component is large. Figure 7 gives the measured peak gains and the radiation efficiency of the antenna from 3 GHz–10 GHz. It can be seen that sharp gain drops of the antenna with notch bands occur both in 3.4–3.7 GHz and 5.15–5.825 GHz bands. As discussed in the last section, with the increase of frequency, the efficiency of the antenna is deceased for the dielectric loss and conductor loss. In addition, it can be observed that the measurement decreases sharply in the notched band.

5. CONCLUSION

In this paper, we propose a novel compact UWB antenna with 3.5/5.5 GHz dual notch-band characteristics. The antenna has a simple structure and compact size of $30 \times 35\,\mathrm{mm}^2$. The compact UWB antenna is achieved by modifying the rotated cross monopole antenna. Then a quarter-guide-wavelength stub is inserted in the UWB antenna for the 5.5 GHz band notching. Finally, by analyzing the current distribution, a $\lambda/4$ L-shaped slot is etched on the antenna for 3.5 GHz band notching. The design process is described in detail, and the prototype of the proposed antenna is manufactured and measured. Good agreement between the simulated and measured results is observed.

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