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A CPW-FED DUAL BAND-NOTCHED UWB ANTENNA WITH A PAIR OF BENDED DUAL-L-SHAPE PARASITIC BRANCHES

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Abstract—In this paper, a novel coplanar waveguide (CPW) fed dual band-notched ultra-wideband (UWB) antenna with circular slotted ground is proposed. In order to achieve two notched bands at 3.3–3.7 GHz for worldwide interoperability for microwave access (WiMAX) and 5.15–5.825 GHz for wireless local area network (WLAN) respectively, a pair of bended dual- L-shape branches are attached to the slotted ground. By optimizing the lengths and positions of the branches, the desired notch-bands of WLAN and WiMAX can be achieved. The prototype of the proposed antenna was fabricated and tested. The simulated and measured results show good agreement over the ultra-wideband. Besides these mechanical features, such as compact in size, easy in fabrication, the proposed antenna also shows good characteristics in its radiation patterns and time-domain behaviors. So it is a nice candidate for modern UWB communication systems.

1. INTRODUCTION

Since the Federal Communications Commission (FCC) released the unlicensed frequency band of 3.1–10.6 GHz for commercial UWB applications [1], ultra-wideband (UWB) systems have drawn lots of interests for their high data rates, great capacity, low complexity and low operating power level [2]. The UWB systems are usually used in home networking systems as a convenient way for personal wireless communications. As one of the most essential parts of the

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UWB systems, UWB antennas have drawn attention of researchers. But when UWB systems bring us conveniences, they also carry us problems at the same time. One problem is the interference between the UWB systems and other communication systems such as local area network (WLAN, 5.15–5.825 GHz), worldwide interoperability for microwave access (WiMAX, 3.3–3.7 GHz) IEEE802.11a in the United States (5.15–5.35 GHz, 5.725–5.825 GHz) and HIPERLAN/2 in Europe (5.15–5.35 GHz, 5.47–5.725 GHz) [3]. So UWB antennas with band-notched characteristics at these existing bands are needed.

Among recent researches, many UWB antennas with band-notched characteristics have been proposed and studied. The conventional and effective way to achieve the notch-band is inserting a slit on the patch [4–10]. While there are also many other ways to create band-notched characteristics on a UWB antenna, such as using parasitic structures [11–18], embedding a slit in the feeding strip [19], or adding split ring resonator (SRR) coupled to the feed-line [20, 21]. These slots or slits are in different shapes, such as L-shape [5, 12, 20], T-shape [7, 16, 17], C-shape [8, 9, 11, 13, 15, 18, 19] and etc., but the common point they all share is to introduce a perturbation into the UWB antennas. All these shapes are near $\lambda/2$ or $\lambda/4$ resonant lengths corresponding their notched frequencies, so in band-notched antennas designing procedures, appropriate slotcoupling and resonant length are very important.

In this study, a new UWB monopole antenna with notched band at 3.3–3.7 GHz (WLAN) and 5.15–5.825 GHz (WiMAX) is developed. The original UWB antenna is mainly composed of a hexagon radiation patch and a circular slotted ground plane. In order to obtain band-notched characteristics at 3.3–3.7 GHz and 5.1–5.8 GHz, a pair of bended dual-L-shape branches are added to the slotted ground symmetrically. Also, one branch consists of two strips which different in length, but this two strips share a common circle center. The different strip controls different notch-band, the longer strip for the lower notch-band and the shorter one for the upper notch-band. Some key parameters which affect the characteristics of the notch bands are specially studied. Finally, the proposed antenna is designed, fabricated and tested. The simulated and measured results are also compared and discussed which shows the theoretical analysis and the practice are match well. The proposed antenna has stable radiation pattern and nice omni-directional performances across the whole operating band, which validates our design concept and theoretical analysis.

This paper mainly consists of three parts. First, the configuration of the proposed antenna is given and the equivalent circuit of the antenna is proposed and discussed. Secondly, the antenna evolution and its key parameters are analyzed. What's more, both the measured and simulated results are given in this part. Finally, the paper is summarized.

2. ANTENNA CONFIGURATION AND ANALYSIS

2.1. Configuration of the Proposed Antenna

The configuration of the proposed antenna with its geometrical parameters are depicted in Figure 1. The antenna is printed on a 1.2-mm-thick substrate of FR4 whose dielectric constant is 4.4 and loss tangent is 0.02. The overall dimensions of the antenna are $40 \times 30\,\text{mm}^2$. The antenna consists of a hexagon monopole radiator, a circular slotted ground plane and a pair of parasitic branches. They are all printed on the same side of the substrate and the other side of the substrate is empty.

In Figure 1, we can see the monopole radiator is connected to a $50\,\Omega$ coplanar wave guide (CPW) feed-line. In order to achieve ultra-wideband (UWB) performance, a pair of right angle cuts with depth of h_1 and width of w_4 are cut on the ground plane symmetrically. In Figure 1, the two bended dual-L-shape parasitic branches which are added to the ground are for dual band-notched performance, with their dimensions are zoomed in and depicted in detail especially.

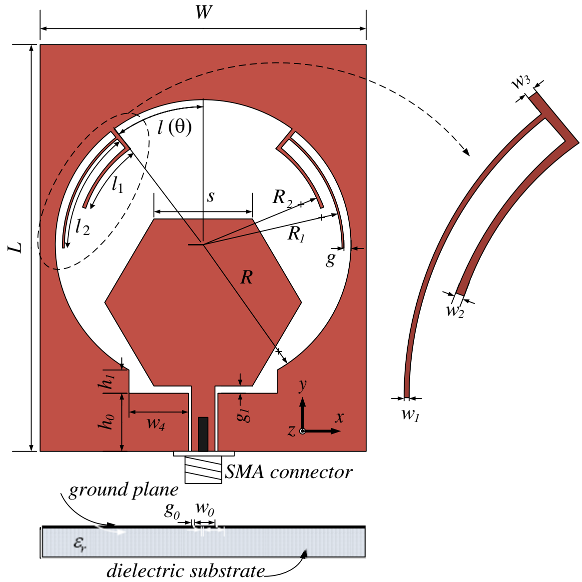


Figure 1. Configuration of the proposed antenna.

Table 1. Optimal geometrical dimensions of the proposed antenna.

Parameters	L	W	w_0	w_1	w_2	w_3	w_4	h_0	h_1	g_0
Value (mm)	40	30	2.6	0.18	0.29	0.35	4.32	6	1.35	0.38
Parameters	g_1	R	R_1	R_2	$l(\theta)$		l_1	l_2	g	
Value (mm)	0.7	14	12.95	12	6.3 (25.6°)		6.9	12.2	0.87	

All values of these parameters are given in Table 1, and several of these design parameters will be studied in following discussions. The numerical analysis and geometry refinement of the proposed antenna are performed by using ANSYS HFSS 13.0.

The length of the bended single-L-shape branches L_i $(i = 1, 2)$ can be calculated according to the following formulas:

$$L_i \approx \frac{c}{4f_i\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{2}$$

where c is the speed of light in free space, ε_r is the dielectric constant of the substrate, ε_{eff} is the efficiency dielectric constant and f_i $(i = 1, 2)$ is the center frequency of notched bands. For the frequency at 5.5 GHz, the theoretically calculated value $L_1 \approx 8.3$ mm, and the practical length of the bended single-L-shape branch is $l_1 + R - R_2 - w_2 = 6.9 + 14 - 12 - 0.29 = 8.61$ mm; For the frequency at 3.5 GHz, the theoretically calculated value $L_2 \approx 13.1$ mm, the practical length of the bended single-L-shape branch is $l_2 + R - R_1 - w_1 = 12.2 + 14 - 12.95 - 0.18 = 13.07$ mm. The comparison of the theoretically calculated and simulated results reveals that our design theory is matching with the practice. The inaccuracies between the theory and the practice are mainly coming from the properties of dielectric, which are changing over the operating band, and the errors of calculating the efficiency dielectric constant.

2.2. Equivalent Circuit

Figure 2 illustrates the equivalent circuit of the proposed antenna around the notch band. To realize this circuit, let us start from the feed port of the proposed antenna. Since the branches are a quarter-wavelength long at their own resonant frequencies, two LC shorted ways, (L_1, C_1) with resonant frequency at 3.5 GHz and (L_2, C_2) with resonant frequency at 5.5 GHz, emerge when one looks into the circuit

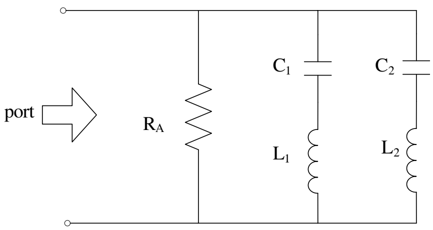


Figure 2. Equivalent circuit of the proposed band-notched UWB antenna around the notch band.

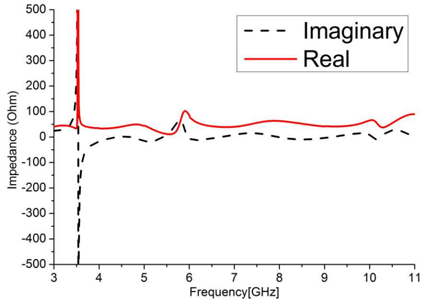


Figure 3. The simulated impedance curve of the proposed antenna.

from the feed port. According to the formulas

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right) \tag{3}$$

$$\omega_0 = 2\pi f_0 = \frac{1}{\sqrt{LC}} \tag{4}$$

When the circuit is operating at its resonant frequency, we have,

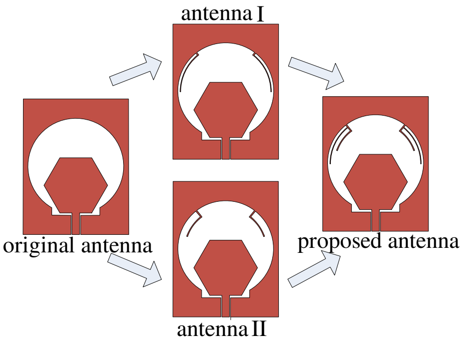
$$Z = R + j\left(\omega_0 L - \frac{1}{\omega_0 C}\right) = R + j0, \quad \text{as} \quad \omega_0 L = \frac{1}{\omega_0 C} \tag{5}$$

The imaginary part of its impedance becomes zero, just like the Equation (5) shows. For an circuit that consists of ideal L and C, the circuit impedance will become zero, i.e., $R = 0$, when it works at its own resonant frequency. As the Figure 2 shows, the radiation resistance R_A will be shorted at 3.5 GHz or 5.5 GHz, when one looks into the equivalent circuit of the proposed antenna from the feed port. This means the impedance of the proposed antenna is mismatched at the 3.5 GHz and 5.5 GHz, so the band-notched characteristics of the proposed antenna is achieved. Figure 3 shows the simulated impedance curve of the proposed antenna over the operating band. It can be see that the mismatched impedance areas consist of two part, one is near 3.5 GHz and another is near 5.5 GHz, which are corresponding to the notch-band positions.

3. ANTENNA EVOLUTION, DISCUSSIONS AND RESULTS

3.1. Antenna Evolution

The evolution procedure of the proposed antenna is given in Figure 4(a) in which the models of original antenna, antenna I and antenna II are



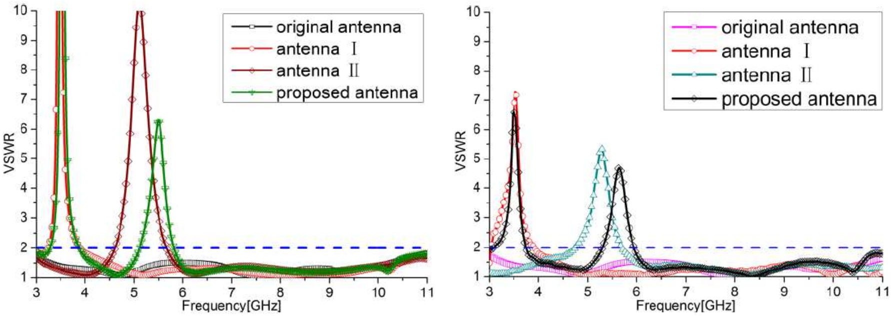
(a)

(b)

Figure 4. The evolution of the proposed antenna: (a) steps of design the proposed antenna, (b) the photograph contains the prototypes of each antenna.

given, while Figure 4(b) gives the prototypes of these antennas. At the same time, Figure 4(a) shows how the proposed antenna is designed from a original UWB antenna. The fundamental of starting the design procedure that a original UWB antenna with good impedance matching over the operating band is needed. The design is started from antenna I and antenna II, which are designed with single band-notched characteristics at 3.3–3.7 GHz or 5.15–5.825 GHz respectively. At this step of design, two pair of bended single-L-shape branches with different in length are respectively added to the circularly cut ground, the longer one for antenna I and the shorter one for antenna II. Although our concept to do this design is coming from the basic theory of $\lambda/4$ resonator, the achievement of band-notch characteristics at the right band also needs much tuning work. If we want to achieve dual band-notched characteristics, the combination of antenna I and antenna II is easily coming to our mind. Again lots of tuning work is always needed to achieve the right notch-band.

The simulated and measured VSWRs of original antenna, antenna I, antenna II and the proposed antenna are presented in Figure 5(a) simulated and (b) measured, which is convenient for comparison between them. As Figure 5 reveals, antenna I with the longer branch generates the lower notch-band, while antenna II with shorter branch generates the upper notch-band. By uniting them together, we get the dual band-notched UWB antenna as proposed in this paper. From Figure 5, we can see the simulated and measured results of these antennas match well and each antenna can generate its own notch-band as predicted.



(a) (b)

Figure 5. The VSWRs of original antenna, antenna I, antenna II and the proposed antenna. (a) Simulated, (b) measured.

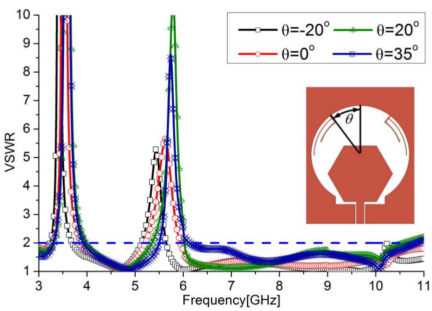


Figure 6. The simulated VSWRs of the proposed antenna vary with the branch-rotation.

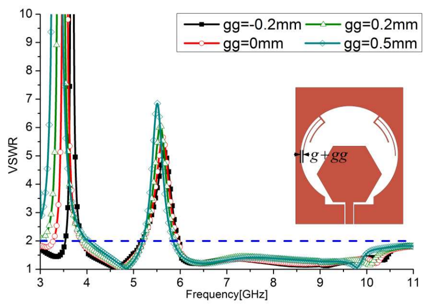


Figure 7. The simulated VSWRs of the proposed antenna vary with the distance of branches and ground.

3.2. The Free Design of the Proposed Antenna

As the ground plane is cut by a circle, the attached branches can rotate around the center of the circle in the xoy plane. So the symmetrical branches with angle θ to the y axis is studied, Figure 6 shows the simulated VSWRs vary with the θ. It can be see that the proposed antenna is always can achieve dual band-notched characteristics with θ ranging from -20° to 35°. What's more, the proposed design also leaves a lot of free space on the distance between the branches and the ground plane, which reveals in Figure 7. With the gg's value changing form -0.2 mm to 0.5 mm, the proposed design always has dual band-notched characteristics. All the factors that mentioned above are evidences of the antenna we have presented in this paper is not only a special designed antenna, while it is a kind of design that with a large of freedom.

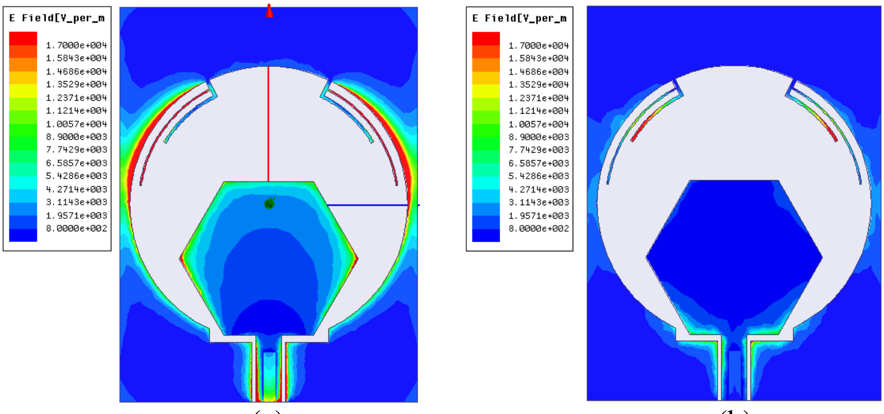


Figure 8. Surface current distributions of the proposed antenna at (a) 3.5 GHz and (b) 5.5 GHz.

3.3. Results and Discussions

The surface current distributions on the proposed antenna at the two notched frequencies are shown in Figures 8(a) and(b). It is observed that the energy is strongly coupled to the longer bended single-L-shape branches at 3.5 GHz while the energy is coupled to the shorter bended single-L-shape branches at 5.5 GHz, which introduce the notched bands into the proposed antenna.

According to the design concept and the dimensions given above, the prototype of the proposed antenna is fabricated and tested. The practical voltage standing wave ratio (VSWR) of the proposed antenna is measured with Agilent N5230A vector network analyzer and together with the simulated VSWR are all given in Figure 9. It can be seen that the proposed antenna has two notched bands at 3.3–3.7 GHz for WiMAX and 5.15–5.825 GHz for WLAN, respectively. According to our design concepts, the lower notch-band is controlled by l_2 and the upper one is controlled by l_1, which is proved again by the measured results in Figure 9. And the good agreement between the simulated and measured results is also a good validation for our design concepts.

The radiation patterns of the proposed antenna are simulated and measured. Figures 10(a) and (b) exhibit the simulated and measured far-field radiation patterns in x-z plane (E plane) and x-y plane (H-plane) for frequencies at 4.5 GHz, 6.5 GHz and 10 GHz, respectively. Figure 10 illustrates that the proposed antenna has nice bidirectional radiation patterns in the E-plane and omnidirectional radiation patterns in the H-plane at low frequencies, but some

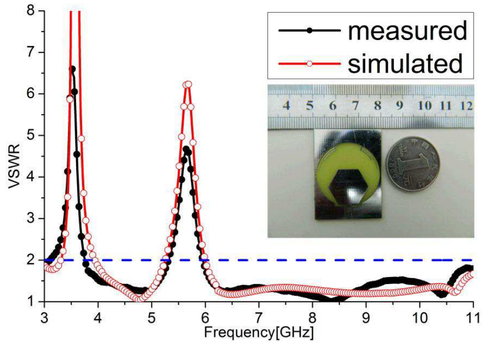


Figure 9. The measured and simulated VSWR of the proposed antenna.

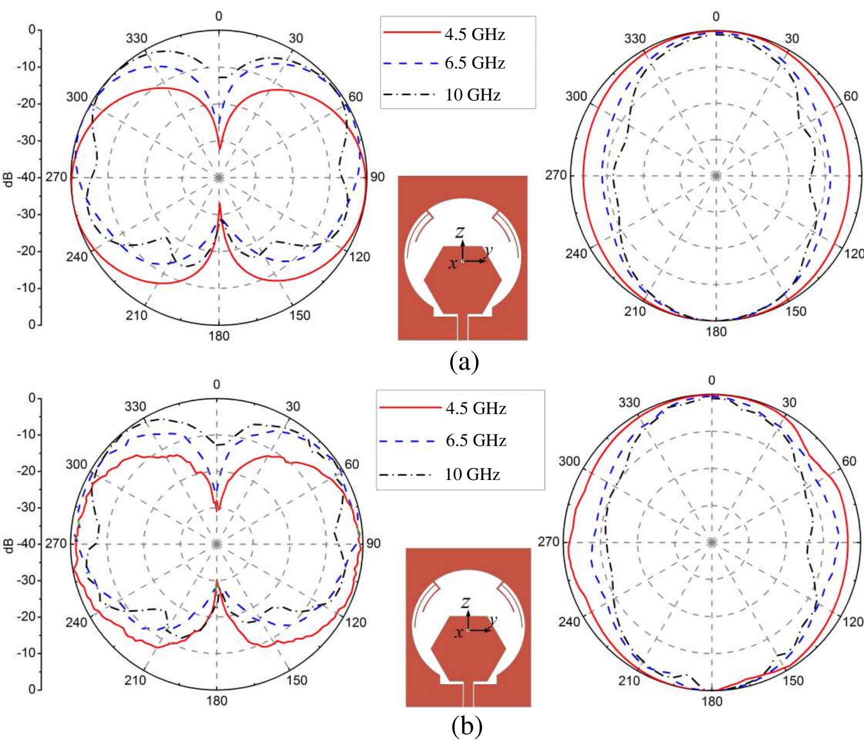


Figure 10. (a) is simulated and (b) is measured radiation pattern at 4.5 GHz, 6.5 GHz and 10 GHz.

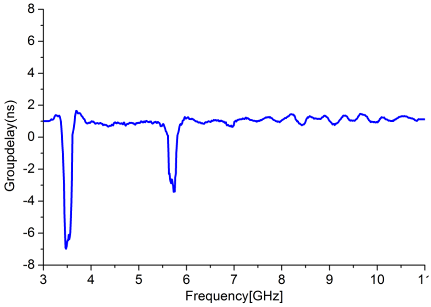


Figure 11. The measured group-delay.

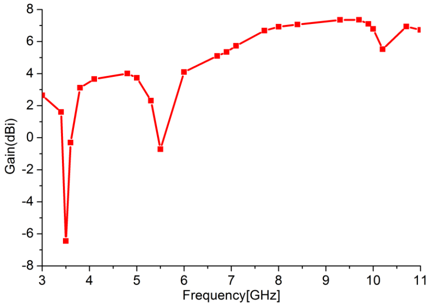


Figure 12. The measured peak gains.

distortions have occurred with frequency increasing, which may due to the high frequencies are more sensitive to the antenna structures.

The group delay of this design is measured by placing two identical face-to-face at the distance of 30 cm, and the corresponding results are presented in Figure 11. The group delay curve is nearly flat in the ultra-wideband except at the two notched bands that are distorted sharply. As indicated in Figure 11, the group delay is fluctuating within a range of 2 ns except the notched bands, showing that the proposed design is suitable for UWB operation.

The measured peak gains variation against frequency are shown in Figure 11. As it shows obviously, two sharp gains reduction are obtained at the 3.5 GHz (WiMAX) and 5.5 GHz (WLAN), respectively. For the frequencies outside the notched bands, the gains reach as high as 7.3 dBi and preserve some flatness.

4. CONCLUSION

In this study, a novel dual bandnotched UWB antenna with circularly slotted ground has been presented. By attaching a pair of bended dual-L-shape branches to the ground plane, the dual bandnotched characteristics are obtained. The configuration and prototype of the proposed antenna is illustrated and tested. At the same time, the design evolution, equivalent circuit and some critical parameters of the proposed antenna are studied and discussed. The simulated and measured VSWRs, radiation patterns, group delay and peak gains show good properties which indicates our design is a nice work. Moreover, the advantages of simple structure, single side print, and low profile make this antenna a good choice for UWB systems.

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