A Multiple-notch UWB Printed Slot Antenna with CNSS Enhanced

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Abstract— This paper is focused on the design of a printed slot antenna with multiple-notch function for ultra-wideband applications, accompanied with enhanced gain for Compass Navigation Satellite Systems. The proposed antenna consists of a curved radiation patch with an arc gradient microstrip line configuration and a class octagonal-shaped wide slot on a rectangular ground plane, supporting a much wider impedance bandwidth. With a class C-shaped slot on the patch and a class L-shaped strip attached on the ground, the multiple-notch function could be achieved to cover all of the 5.2/5.8 GHz WLAN, 3.5 GHz WiMAX and 4 GHz C-bands. By introducing a third-order stepping strip at the upper part of the wide slot on the ground, an additional operating frequency at 2.492 GHz of CNSS band can also be realized. The simulation results show that the designed antenna is with a small size and relative bandwidth larger than 122% in the band of $3.10 \sim 12.99$ GHz. The radiation patterns and current distributions are also analyzed respectively for the performance improvement.

1. INTRODUCTION

Since the Federal Communications Commission (FCC) released the frequency range from 3.1 GHz to 10.6 GHz for ultra-wideband (UWB) communication systems, the research work for UWB applications has received universal attention. With the development of ultra wideband technology, the UWB antennas, as one of crucial components for UWB communication and radar systems, have been studied for many years. Hence, a lot of printed microstrip slot, monopole, and CPW-fed UWB antennas with different geometries were investigated to obtain a broad impedance bandwidth [1–3].

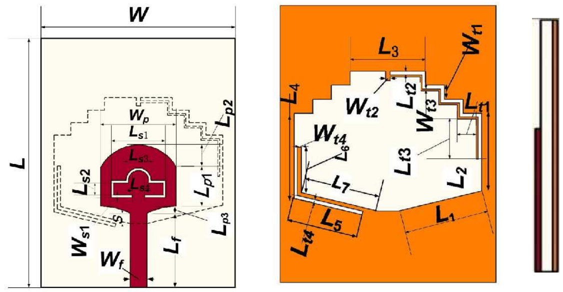
Some wireless communication systems work in the frequency range of UWB systems, such as the wireless local area network (WLAN) operating at $5.15 \sim 5.35$ GHz and $5.725 \sim 5.825$ GHz, the worldwide inter operability for microwave access (WiMAX) operating at 3.5 GHz and C-band of satellite communication operating at $3.7 \sim 4.2$ GHz. Consequently, the multiple band-notch performances are required for UWB antennas to reject these existing wireless frequency bands.

More and more prototypes of compact UWB antennas with band-notch function have been carried out recently. Generally, the existing techniques for band notched use can be classified into the following two categories: embedded diverse slots, including U-shaped slot [4], arc-shaped slot [5], pi-shaped slot [6], V-shaped slot [7], T-shaped slot [8] and complementary SRR- shaped slot [9] etc.; loading various parasitic elements on the antennas, including strip near patch [10], strip near ground [11], Split ring resonators (SRRs) [12] and stepped impedance resonators (SIRs) near feed-line [13] etc.. However, only a few papers have been reported to study the integration of the UWB bands with other wireless system bands. In Ref. [14], by adding three narrow symmetrical L-shaped strips to the ground of a printed slot UWB antenna, extra Bluetooth, GSM and GPS bands were created, but no band-notch characteristics. In Ref. [15], three narrow a symmetrical U-shaped stubs were attached on the ground of a printed slot UWB antenna to support extra Bluetooth band and two notched band.

Here, a multiple-notch UWB printed slot antenna with CNSS enhanced is proposed. The multiple notched bands centered at 3.5 GHz WiMAX, 4 GHz C-bands and 5.2/5.8 GHz WLAN are produced with a class C-shaped slot embedded on the patch and a class L-shaped strip attached on the ground. The extra band with CNSS enhanced is centered at 2.492 GHz by applying a third-order stepping strip.

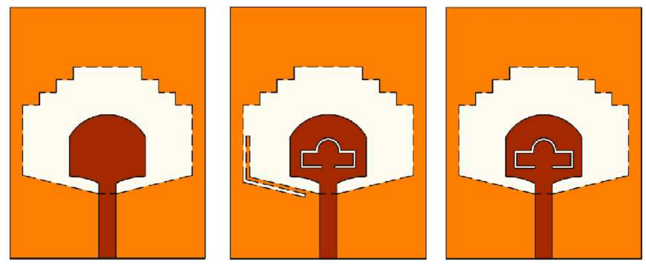
2. ANTENNA DESIGN

As shown in Fig. 1, an UWB printed slot antenna (named as Antenna I) consists of a curved radiation patch with an arc gradient microstrip line configuration and a class octagonal-shaped wide slot (with beveled bottom edges and stepped top edges) on a rectangular ground plane. The proposed antenna is designed to be printed on a FR4 substrate with an area size of $29 \times 23\,\mathrm{mm}^2$ and thickness of 1 mm, relative permittivity of 4.4, and loss tangent of 0.02. The class C-shaped slot on the radiation patch and the class L-shaped stub on the ground act as a quarter-wave resonant structure at the required notch center frequency respectively, perturbing the resonant response. A third-order stepping strip is introduced at the upper part of the wide slot on the ground to create



(a) (b) (c)

Figure 1: Configuration of the proposed antenna, Antenna I. (a) Top view. (b) Bottom view. (c) Side view.



(a) (b) (c)

Figure 2: Configurations of the proposed UWB antennas. (a) Antenna II: base antenna. (b) Antenna III: with a class C-shaped slot. (c) Antenna IV: with a class C-shaped antenna and a class L-shaped stub.

an extra frequency. The optimal dimensions of the designed antenna are as follows: $W = 23.1\,\text{mm}$, $L = 29.7\,\text{mm}$, $W_f = 2\,\text{mm}$, $L_f = 8.9\,\text{mm}$, $S = 1.2\,\text{mm}$, $W_p = 9\,\text{mm}$, $L_{p1} = 4.7\,\text{mm}$, $L_{p2} = 2.7\,\text{mm}$, $L_{p3} = 0.8\,\text{mm}$, $W_{s1} = 0.3\,\text{mm}$, $L_{s1} = 6.5\,\text{mm}$, $L_{s2} = 2\,\text{mm}$, $L_{s3} = 2.4\,\text{mm}$, $L_{s4} = 1.5\,\text{mm}$, $L_1 = 9.3\,\text{mm}$, $L_2 = 8.2\,\text{mm}$, $L_3 = 8.1\,\text{mm}$, $L_4 = 9\,\text{mm}$, $L_5 = 7.5\,\text{mm}$, $L_6 = 4.8\,\text{mm}$, $L_7 = 8.5\,\text{mm}$, $W_{t1} = 1.5\,\text{mm}$, $L_{t1} = 2\,\text{mm}$, $W_{t2} = 0.5\,\text{mm}$, $L_{t2} = 0.4\,\text{mm}$, $W_{t3} = 0.2\,\text{mm}$, $L_{t3} = 4.4\,\text{mm}$, $W_{t4} = 0.4\,\text{mm}$, $L_{t4} = 0.5\,\text{mm}$.

A base UWB antenna, named as Antenna II, is depicted in Fig. 2(a), consisting of a curved radiation patch with a microstrip transmission line and a class octagonal-shaped wide slot on a rectangular ground plane. For a better impendence matching over the whole of UWB band, the patch is fed through an arc gradient 50-Ω microstrip line. To create multiband-notch function within the UWB, a class L-shaped stub of quarter-wavelength and a class C-shaped slot of half-wavelength can be considered to be introduced on the proposed antenna. For the frequency rejection of 5.2/5.8 GHz WLAN bands, a class C-shaped slot with a length L slot of 21.58 mm and a width of 0.3 mm is applied on the patch, referred to Antenna III as shown in Fig. 2(b). Similarly, for the frequency rejection of 3.5 GHz WiMAX and 4 GHz C-bands, a class L-shaped stub with a length L stub of 12.3 mm and a width of 0.4 mm is applied on the bottom of the slot ground, referred to Antenna IV as shown in Fig. 2(c). An additional resonance can be produced for the proposed UWB antenna by attaching a resonant strip of appropriate length to the ground. Exactly to have the 2.492 GHz CNSS band, a narrow third-order stepping strip of18.45 mm length and 0.2 mm width is attached to the top of the slot ground for Antenna I.

Each of the rejected or extra resonances takes place when the length of the strip, stub or the slot is equal to $\lambda_g/4$ or $\lambda_g/2$, in which λ_g is the guided wavelength at the desired frequency. Thus, the length L_G of each strip or stub located on the slot ground and the length L_P of each slot introduced on the patch can be obtained approximately from the following formula

$$L_G = \frac{c}{4f\sqrt{(\varepsilon_r + 1)/2}},\, L_P = \frac{c}{2f\sqrt{(\varepsilon_r + 1)/2}} \tag{1}$$

where ε_r, c, and f are the relative dielectric constant of the substrate, the light velocity in free space, and the desired center frequency, respectively.

3. RESULTS AND DISCUSSION

The simulate reflection coefficients of Antennas I, II, III and IV are given in Fig. 3. It can be seen that Antenna I covers the whole UWB band ($3.1 \sim 10.6\,\text{GHz}$), with multiple notch-bands and an extra band. By comparing all the antennas, it is obvious that the base antenna without slots, strips and stubs provides an impedance bandwidth covering $3.1 \sim 10.6\,\text{GHz}$. While the class C-shaped slot on the patch creates a notch band in $5.2 \sim 5.8\,\text{GHz}$, and the class L-shaped stub on the ground creates a notch band in $3.5 \sim 4\,\text{GHz}$. In addition, an extra band at 2.492 GHz is introduced to the initial UWB through the attachment of the third-order stepping strip to the ground. The simulated results confirm that the introduced slots and stubs or strips operate independently and have little effect on each other.

The simulated current distributions for the proposed antenna at the notched frequencies of

3.5 GHz, 4 GHz, 5.2 GHz and 5.8 GHz as well as the extra resonance frequency of 2.492 GHz are presented in Figs. 4(a)–(e), respectively. It can be observed that the current distributions at 3.5 GHz and 4 GHz concentrate mainly on the edges of the class L-shaped stub, and also the current distributions at 5.2 GHz and 5.8 GHz concentrate on the edges of the class C-shaped slot. In addition, the current distribution at 2.492 GHz is primarily decided by the third-order stepping strip structure. It can also be seen that, at some desired frequency, only the corresponding structure is active while the others are inactive, confirming the independence of the frequency bands. The directions of the current vectors in the stepping strip for extra band are the same as that in the radiation patch, while the directions of the current vectors in the class C-shaped slot and the class L-shaped stub are opposite to that in the radiation patch, resulting in shorting out the radiation patch at the relevant notch frequency.

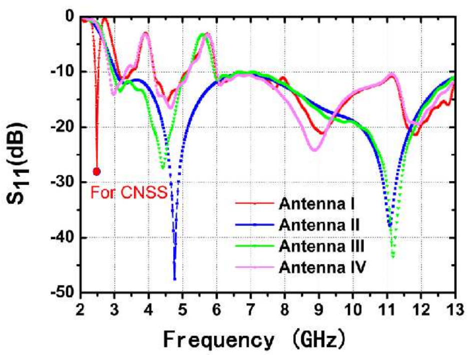


Figure 3: Simulated reflection coefficients of Antenna I, Antenna II, Antenna III and Antenna IV.

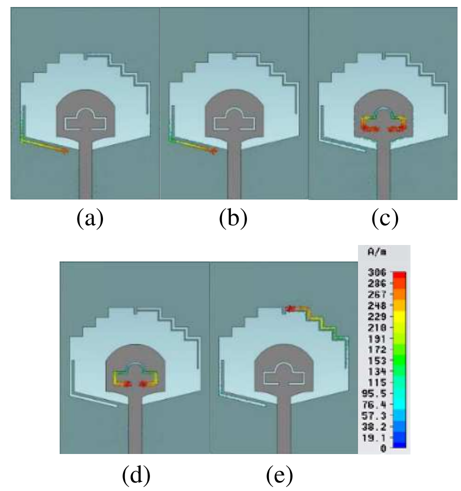


Figure 4: Simulated current distributions of Antenna I at frequencies of (a) 3.5 G, (b) 4 G, (c) 5.2 G, (d) 5.8 G, and (e) 2.492 G.

Figs. 5(a)–(c) show the simulated reflection coefficients vs different structure lengths for the proposed antenna with L-shaped stub in the notched band of 3.5 GHz $\sim$ 4 GHz), class C-shaped slot in the notched bands of 5.2 GHz $\sim$ 5.8 GHz) and third-order stepping strip in the extra band of 2.492 GHz respectively. It can be seen that an increase in some structure length results in a drop in the extra resonance frequency of CNSS, and vice versa. This confirms the validity of Eq. (1) and proves that the introduction of such slots, stubs and strips to the initial UWB slot antenna can lead to tunable notched bands and extra resonance bands.

According to the simulated E-plane and H-plane radiation patterns of the proposed antenna at three pass band frequencies of 2.492 GHz, 4.5 GHz and 9 GHz as presented in Fig. 6, the radiation features are all nearly omnidirectional for these three frequencies. For a prototype of the proposed antenna as shown in Fig. 7(a), the measured reflection coefficient is presented in Fig. 7(b) along

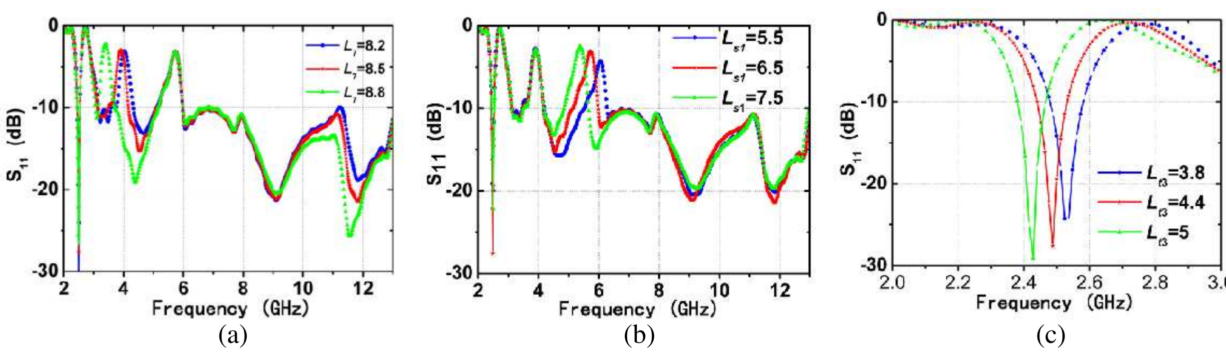


Figure 5: Simulated reflection coefficients vs different lengths for Antenna I with (a) class L-shaped stub, (b) class of C-shaped slot, and (c) third-order stepping strip. All dimensions are millimeters.

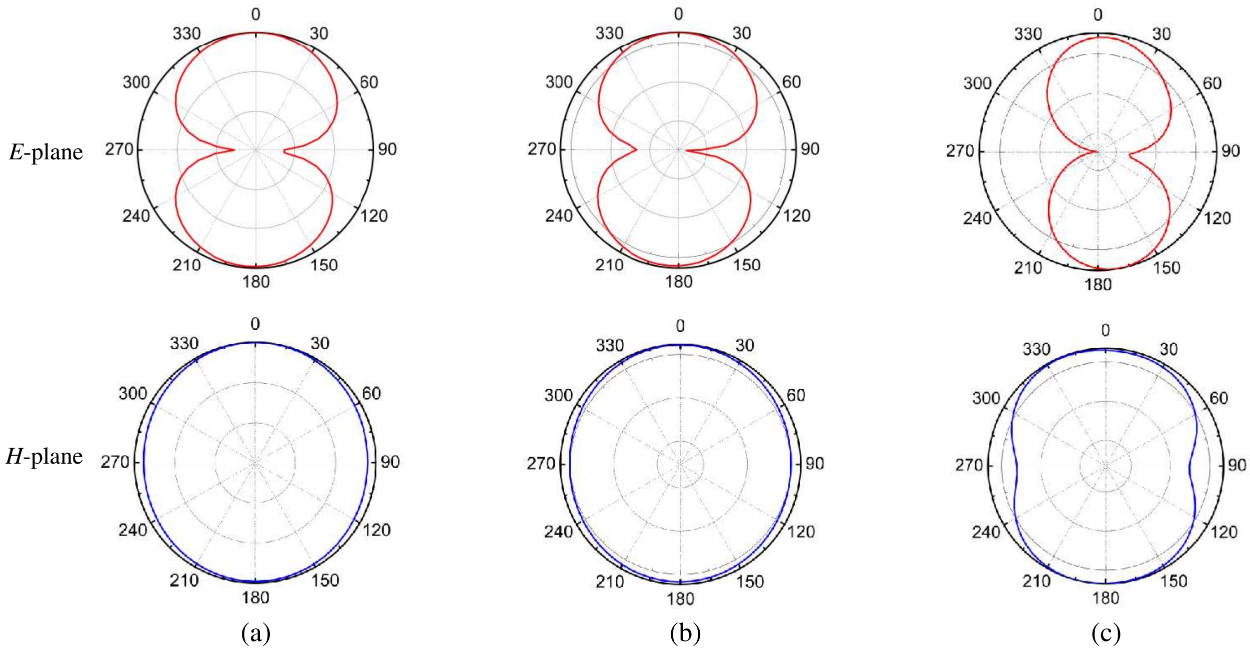


Figure 6: Simulated E-plane and H-plane radiation patterns of the proposed antenna at 2.492 G, (b) 4.5 G, and (c) 9 G.

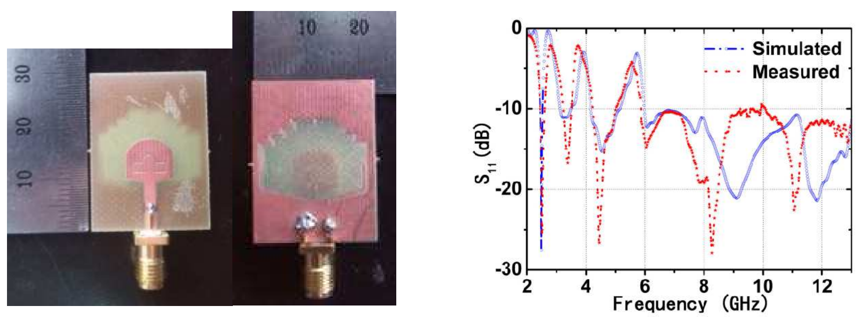


Figure 7: Prototype of the proposed antenna and the contrast of simulation and measurement.

with the simulated one. Most of the measurement agrees well with the simulation, specifically for lower frequency band.

4. CONCLUSION

In this letter, a printed slot antenna with multiple-notch function for UWB applications and also enhanced gain for CNSS is proposed. The multiple-notch performance is implemented by introducing a class C-shaped slot and a class L-shaped stub to the proposed antenna, and also an additional resonant frequency of CNSS is excited by attaching a third-order stepping strip. The designed antenna with optimized dimensions can operate in the frequency range from 3.10 GHz to 12.99 GHz, with multiple rejection bands around 3.15 $\sim$ 4.16 GHz and 5.15 $\sim$ 5.98 GHz. The simulation and measurement show that the proposed antenna could be a good candidate for UWB applications.

ACKNOWLEDGMENT

This work is supported by Fujian Provincial Key Sci-Tech Project (2013HZ0002-1) of China. We thank the staff members of Microwave Library for helpful supports.

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