Compact Printed Band-Notched UWB Antenna With 90 Degree Rotation Angle CSRR

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Abstract **—** A novel band-notched ultra-wideband monopole antenna is presented. The proposed antenna consists of a swallow shape radiating patch, two novel 90 degree rotation angle complementary splitring resonator (CSRR) structures for generating band-notched function instead of changing the patchor feeding shapes, and a trapezoidal ground plane that provides a wide usable bandwidth of more than 143 % (2 GHz – 11.2 GHz). With two novel 90 degree rotation angle complementary SRR structures, band-stop frequency performance is realized, and some key characteristics such as band-notched frequency and bandwidth can be controlled easily. The designed antenna has a small size of 25 × 27.9 mm^2，showing the band-rejection performance in the frequency band of 3.9 GHz / 5.9GHz. The antenna demonstrates omni-directional and stable radiation patterns across all the relevant bands. Moreover, a prototype of the proposed antenna is fabricated, and the measured results are shown to be in good agreement with the simulated results.

Index Terms **—** Complementary split ring resonator (CSRR), multiband, notch bands, and ultra-wideband (UWB).

I. INTRODUCTION

Wideband antennas with band-notched characteristics will play an important role in future wideband communication systems. In 2002 the FCC designated the area of the frequency spectrum, which can be occupied by unlicensed ultra-wideband (UWB) communication systems. Unfortunately, this overlaps various narrow band communication systems such as C-band (3.7 GHz – 4.2 GHz) satellite communication systems and WLAN. The front-end receiver for an UWB system incorporates a high gain LNA, which could be saturated by interference from a narrow band system in the vicinity [1]. One of the more attractive solutions to this problem is to integrate a band notch filter performance into a wideband omni-directional antenna [2].

In this paper, we present a compact printed antenna with novel 90 degree rotation angle complementary split ring resonator (CSRR) structures, which has an UWB operating bandwidth with a tunable dual-notched frequency at 3.9 GHz and 5.9GHz is presented. Band-notched operation is achieved by novel 90 degree rotation angle CSRR slots on swallow shape radiated patch [3]. The CSRR has been implemented in designing left-hand material, the 90 degree rotation angle CSRR is promising for UWB antennas to ensure multiple notched bands [4]. Both dual-band-notched characteristics and compact size are achieved in our design. The antenna has promising features, including good impedance matching performance over the whole operating frequency band, stable radiation patterns, and flexible frequency notched function [5].

II. ANTENNA DESIGN

Compared with microstrip, coplanar waveguides (CPW) have several advantages, including low loss, high integration, low dispersion, weak coupling, and compact size.

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Moreover, it enjoys low complexity since the CPW-fed is coplanar with the ground. In addition, it can be integrated with other components straight forwardly. Therefore, it is considered as a milestone in the development of the monolithic microwave integrated circuit. These characteristics enable the CPW to be used in the application of high frequency microwave integrated circuits. Especially, when applied in the antenna feeding, it broadens the bandwidth of the antenna obviously. Therefore, the CPW-fed is widely used in the printed antenna. Antenna feeding based on CPW, in fact, is a kind of electromagnetic coupling. The electromagnetic coupling can be easily controlled by the distance between CPW-fed and the radiating patch since they are in the same layer. If the radiating patch has gradient shape, wide bandwidth can be achieved.

To fabricate swallow-shaped antenna mentioned in this paper, a half ellipse is cut from a rectangle radiating patch firstly and then moved into the bottom side of the radiating patch. This new shape with a gradient structure has the same area as the rectangle one. In addition, the ground of the antenna has a chamber-like shape so that ground also has a gradient structure. Since both the radiating patch and the ground have a gradient structure, the antenna can ensure a smooth transition from one mode to another. In this case, the antenna will have a good impedance matching within a broad bandwidth.

The performance of this antenna depends on the distance between the ground and the CPW-fed as well as the shape of the ground. As illustrated in Fig. 1, the distance between the CPW-fed and the ground (S_1) will influence the voltage standing wave ratio (VSWR), resulting in the drift of band-notched at the high frequency.

As shown in Fig. 2, the width of the ground (W_1) has a relatively small effect on the band-notched at the low frequency. However, its impact on the high frequency is very obvious. As shown in Fig. 3, the VSWR of the proposed antenna have little change with the height of the ground layer (H).

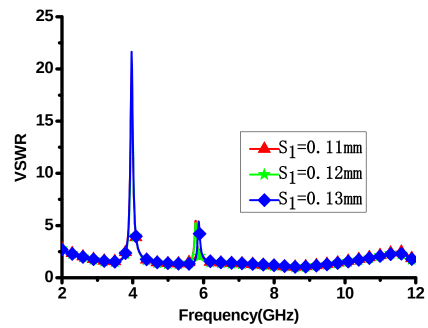


Fig. 1. S-parameters of different width of gap (S_1).

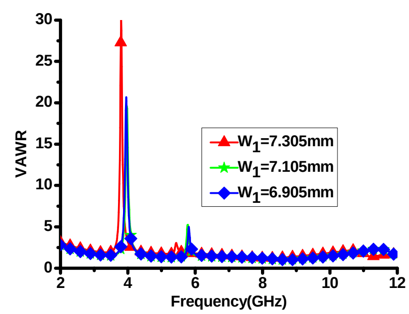


Fig. 2. S-parameters of different width of ground (W_1).

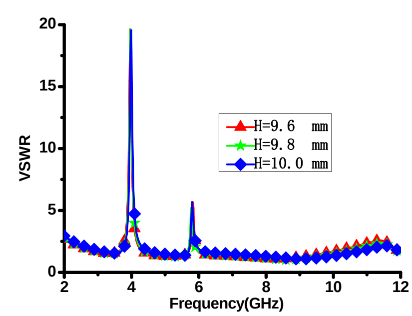


Fig. 3. S-parameters of different height of ground (H).

According to earlier research, the band-notched can realized by the complementary splitring resonator (CSRR) structures in the radiating patch. If the length of the CSRR is roughly the same as the half wavelength of the corresponding central band-notched frequency, the currency is restricted around the CSRR, resulting antenna cannot radiate. This is due to band-notched. In order to achieve two notched bands, two complementary split ring resonators, which are perpendicular to each other, are introduced into the radiating patch in the antenna. This can be expressed by,

$$L = \frac{C}{2 f_{notch}\sqrt{\varepsilon_r}} \tag{1}$$

C represents the light speed, f central frequency of the band-notched, ε_r effectively dielectric constant.

The size of inner-square (R_1, R_2) should be adjusted to determine the dual-band-notched frequency of the antenna. If other parameters are fixed, the dual-band-notched frequency will increase with the decrease of R_1 and R_2. Moreover, if R_1 and R_2 are fixed, the resonance frequency could be also enhanced by increasing slit width of squares (g). For the convenience of optimization, the width of squares (d_1, d_2) and distance between squares are set to be the same as (g). After that, the distance (C_1,C_2) between these two CSRRs should be also optimized. These optimization works were managed by using commercial 3-D electromagnetic software HFSS.

The geometry of the proposed novel 90 degree rotation angle CSRR slot UWB antenna with band-notched function is depicted in Fig. 4. The antenna is located on the *xz* - plane and the normal direction is parallel to the *y*-axis [6, 7]. The radiating ring is fed via the 50 Ω coplanar waveguide (CPW) feed-line of width 2.55 mm, as illustrated in Fig. 5. The proposed antenna was fabricated on a dielectric substrate RT5880 with a relative permittivity (ε_r) of 2.2 and thickness of 0.508 mm. A novel 90 degree rotation angle complementary SRR slot are used and fabricated on the swallow shape radiation patch. To achieve good impedance matching for the ultra-wideband operation, the swallow radiator is feed by coplanar waveguide (CPW) transmission line with trapezoidal ground-plane, which is terminated with a sub miniature A (SMA) connector for the measurement purpose [8-15]. Since the antenna and the feeding are fabricated on the same side of the plane, only one layer of the substrate with single-sided metallization is used, and the manufacturing of antenna is very easy and extremely low cost. Good performance of multiple band-notched characteristic is simply accomplished by embedding 90 degree rotation angle complementary split ring resonators to the swallow shape radiation patch. The novel 90 degree rotation angle complementary SRR can show distinct double band gaps due to the weaker mutual coupling between the inner and outer rings even the two band gaps are adjacent. Thus, 90 degree rotation angle complementary SRR is selected to obtain adjacent dual notched-bands for C-band (3.7 GHz – 4.2 GHz) satellite communication systems and upper WLAN [16-21]. Figure 5 shows the photograph of the dual band-notched UWB antenna. It is noted that the inner and outer openings are just 90 degrees.

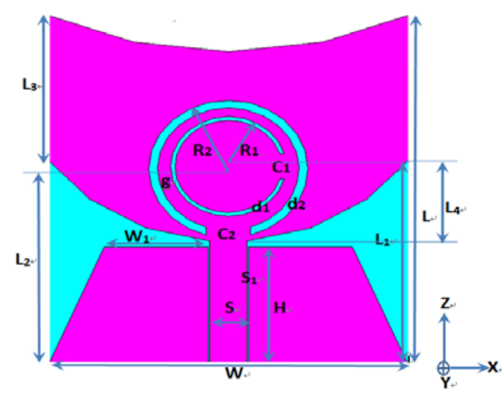
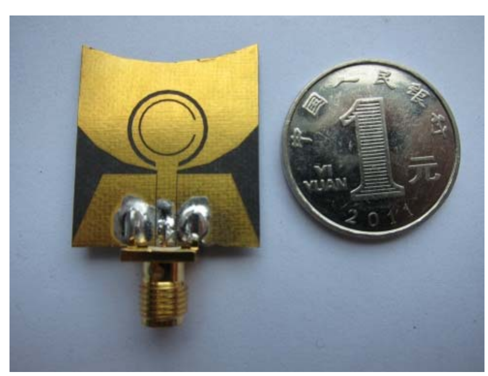
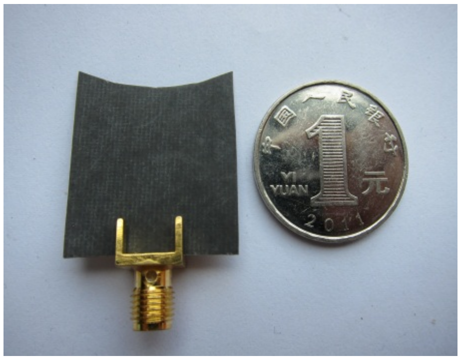


Fig. 4. Geometry of the antenna, with dimensions R_1 = 3.65 mm, R_2 = 4.85 mm, C_1 = 2 mm, C_2 = 3 mm, d_1 = 0.3 mm, d_2 = 0.6 mm, S = 2.55 mm, S_1 = 0.12 mm, H = 9.8 mm, W = 25 mm, W_1 = 7.105 mm, L = 27.9 mm, L_1 = 16.5 mm, L_2 = 16 mm, L_3 = 11.34 mm, and L_4 = 6.61 mm.



(a)



(b)

Fig. 5. Photograph of the proposed antenna; (a) top view and (b) bottom view.

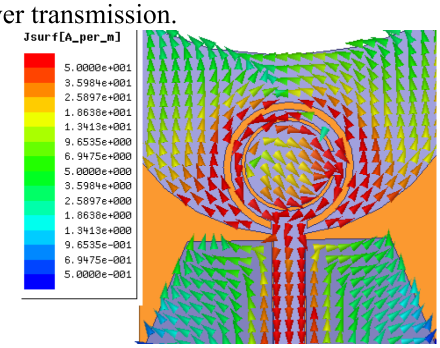
Figure 6 shows the current distributions at dual center notched bands. The dimensions of two 90 degree rotation angle complementary SRRs are corresponding to the dual notched bands. When the antenna is working at the center of lower notched band near 3.9 GHz, the outer complementary SRR behaves as a separator as shown in Fig. 6 (a), which almost has no relation to the other band-notched. Similarly, from Fig. 6 (b), the upper notched band near 5.9 GHz is ensured by the inner complementary SRR.

III. RESULTS AND DISCUSSION

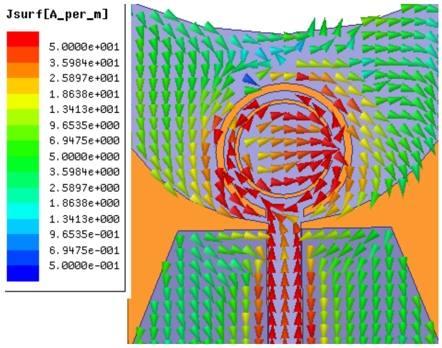
The VSWR performance of the fabricated prototype was measured with an Agilent 85052C vector network analyzer. Figure 7 shows the simulated and measured VSWRs for the proposed antenna. By introducing the novel 90 degree rotation angle complementary SRR, band-notched function is obtained. The designed antenna has an impedance bandwidth of 2 GHz – 11.2 GHz for VSWR less than 2, except the frequency-notched-band of 3.68 GHz – 4.20 GHz and 5.72 GHz – 6.12 GHz, respectively. Obviously, this measured frequency range covers commercial UWB band (3.1 GHz – 10.6 GHz) and rejects the frequency band of C-band satellite communication systems and IEEE802.11a to overcome the electromagnetic interference (EMI) problems among UWB [22-25]. As shown in Fig. 7, it is also observed the measured notched-band width is slightly wider than the simulated result. This may have been caused by the use of an SMA connector and fabrication error.

The measured far-field radiation patterns of the proposed antenna in the H-plane (*xy*-plane) and E-plane (*yz*-plane) at frequencies 4.75 GHz and 7.5 GHz are plotted in Fig. 8, respectively. Like the behavior of conventional wide slot antennas, the proposed antenna has relatively omni-directional *xy*-plane radiation patterns with non circularity of about 5–8 dB over the operating frequency band [26-28]. The radiation patterns in the *yz*-plane (E-plane) are monopole alike. All the obtained radiation patterns accord with those of the conventional printed UWB monopole antennas. The proposed antenna has proved to be capable of providing favorable spatial-independent band-notched characteristics.

The gain patterns (total realized gain) of the antenna are measured in an anechoic chamber. A fiber-optic link connected to the antenna under test has been used in order to measure the radiation pattern of our proposed compact antenna. This technique aims at limiting alterations of measurement coaxial cable on omni-directional radiation antennas. Figure 9 reveals that the antenna gain ranges from 1.9 dBi to 7 dBi within the 2 GHz – 12 GHz frequency band. Of course, this is except for the notched band decreases significantly to about -8 dBi and -1.5 dBi. This confirms that the proposed antenna provides a high level of rejection to signal frequencies within the notched band. Figure 10 shows the measured radiation efficiency of the antenna. The proposed antenna features an efficiency between 50 % and 70 % over the whole UWB frequency and lower than 5 % in the notch band. The features of about 60 % average radiation efficiency is good enough to satisfy an acceptable variation for practical power transmission.



(a)



(b)

Fig. 6. The current distribution at (a) 3.9 GHz and (b) 5.9 GHz.

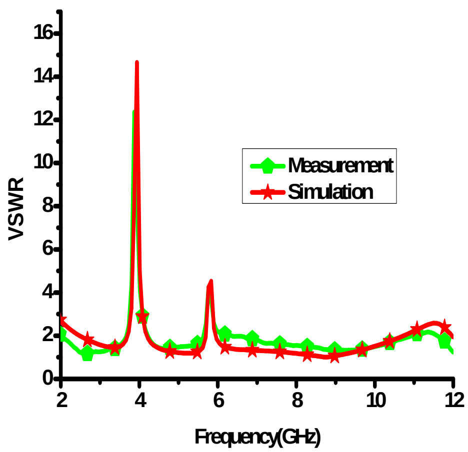
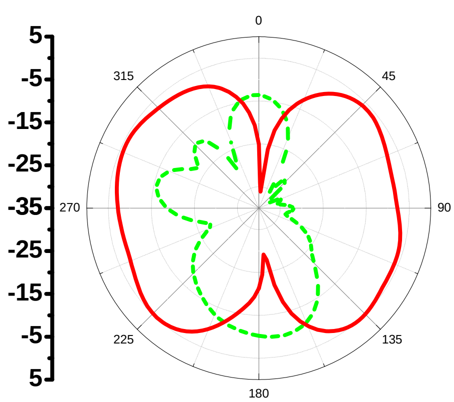
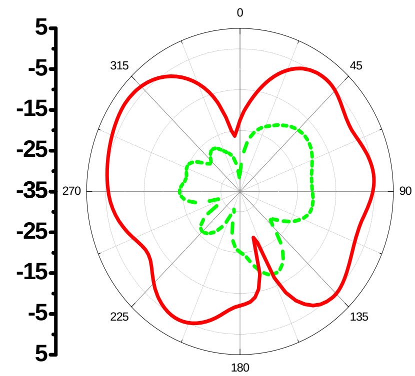


Fig. 7. Comparison of the simulated and measured VSWR of the proposed antenna.

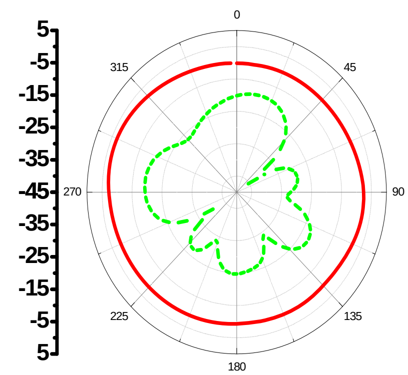


f = 4.75GHz

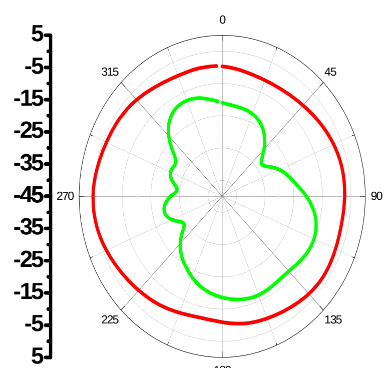


f = 7.5GHz

(a)



f = 4.75 GHz



f = 7.5 GHz

(b)

Co-polar: Cross-polar:

Fig. 8. Measured radiation patterns at (a) *yz* -plane and (b) *xy*-plane.

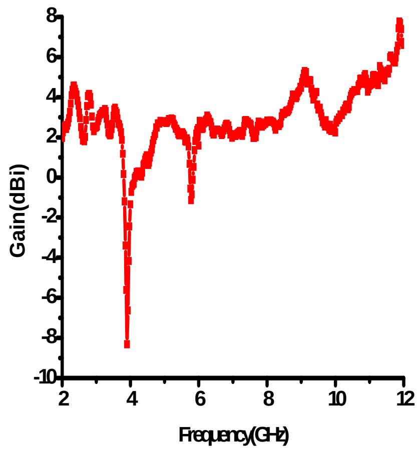


Fig. 9. Measured gain of the proposed antenna.

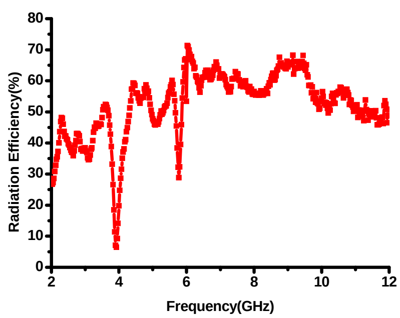


Fig.10. Measured radiation efficiency of the proposed antenna.

IV. CONCLUSION

A very compact CPW-fed UWB printed monopole antenna with dual band-notched characteristics was proposed, fabricated, and discussed. The two designed notched bands were realized by etching 90 degree rotation angle complementary SRRs slots in the radiating patch. The effects of the width and position of the slot in the radiating patch were analyzed to find the optimized configuration of the slot to get a good level of band rejection even at high frequencies. Surface current distributions were used to show the effect of these slots in getting the notched bands. The fabricated antenna showed good agreement between measured and simulated results within a wide bandwidth from 2 GHz to 11.2 GHz and two intended notched bands in asmall size.

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