A Compact Ultra-Wideband Antenna with Improved Triple Band-Notched Characteristics

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Abstract **─** In order to prevent interference problem due to existing nearby communication systems within the ultra-wideband (UWB) operating frequency, a compact CPW fed triple-band-notched antenna using modified co-directional complementary split ring resonators (CSRRs) is proposed and investigated. The proposed antenna is realized by etching three modified co-directional CSRRs with different centers in the radiating patch. The measurement result shows that the proposed antenna can guarantee a wide bandwidth from 2 GHz to 16 GHz (VSWR $<$ 2) with triple unwanted band-notches successfully. The proposed antenna occupies a compact area of 25 × 27.9 mm^2 only. The antenna demonstrates omni-directional radiation patterns across almost the whole operating bandwidth, which is useful for UWB (3.1 GHz - 10.6 GHz) applications.

Index Terms **-** Complementary split ring resonators (CSRRs), triple notched bands, and ultra-wideband antenna.

I. INTRODUCTION

Since the Federal Communications Commission (FCC)'s allocation of the frequency band 3.1 GHz - 10.6 GHz for commercial use, ultra-wideband (UWB) antennas have attracted much attention in recent years. Since the UWB approval, the technology has become one of the most promising technologies for future high data-rate wireless communication, high-accuracy radars, and imaging systems. It has the advantage of high-speed transmission, low power consumption, and simple hardware configuration compared with conventional wireless communication systems [1].

However, given the challenges encountered in the UWB antenna design, such as the system interferences, it necessitates the rejection of interference with some narrow bands for UWB applications in other communication systems, for example, the existing WLAN covering the 5.15 GHz - 5.35 GHz and 5.725 GHz - 5.825 GHz, and the C-band (3.7 GHz - 4.2 GHz) satellite communication systems [2]. To solve this problem, the existing techniques in extensive use can be classified into the following two categories: one method focuses on loading diverse parasitic elements on the antennas, such as strip near patch, stepped impedance resonators (SIRs) near the feed line, and ring-shaped patch near the ground. The other effective method is embedding various slots, such as arc-shaped slot, U-shaped slot, square-shaped slot, pi-shaped slot, H-shaped slot, and fractal slot [3]. However, these methods unavoidably exhibit some inherent defects in practical applications. Moreover, these methods usually occupy large area in designing antenna.

In this paper, we present a compact printed antenna with round slot, which has an UWB operating bandwidth with a tuneable triple-notched frequency at 3.9 GHz, 5.2 GHz and 5.9 GHz. Band-notched operations are achieved by embedding co-directional modified CSRR slots on the radiated patch. Both triple-band-notched characteristics and compact size can be achieved. The antenna has promising features, including good impedance matching performance over the whole operating frequency band, stable radiation patterns, and flexible frequency notched function.

II. ANTENNA DESIGN

The optimized co-directional CSRR antenna is depicted in Fig. 1. This antenna is printed on a 0.508 mm thick substrate RT5880 (dielectric constant ε_r = 2.2 and loss tangent tanδ = 0.0009) with dimension of

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25 × 27.9 mm^2. The size of the inner-square (R_1, R_2, R_3) should be adjusted to determine the triple-band-notched frequency of the antenna. If other parameters are fixed, the triple-band notched frequency will increase with the decrease of R_1, R_2, and R_3. After that, the distance (C_1, C_2, and C_3) among these co-directional CSRRs should be also optimized. The radiation patch is excited using a 50 Ω CPW-feed [4-5]. The design of R_i and C_i (I = 1, 2, 3) can be easily fulfilled by commercial 3-D full-wave electromagnetic software HFSS [6]. The photography of the proposed prototype antenna is shown in Fig. 2. In order to investigate the causes of the band-notched, the surface current density of the antenna at different notched bands is presented [7]. The comparison of the surface current density between the convention structure and the proposed structure are shown in Figs. 3 and 4, respectively.

Figure 4 shows the surface current distributions at three center notched bands. The dimensions of the three co-directional complementary SRRs are corresponding to three 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 in Fig. 4 (a), which almost has no relation to the other band-notches [8]. Similarly, the middle complementary SRR operates as a second separator for the center of the middle notched band near 5.2 GHz in Fig. 4 (b). From Fig. 4 (c), the upper notched band near 5.9 GHz is ensured by the inner complementary SRR [9]. Additionally, as a certain current crowded on the ground plane near the CPW feed line would affect the antenna performance. Considering the simulation, one can find the dimensions of the ground plane, especially that has a significant effect on the triple band-notches performance, as well as the impedance bandwidth [10].

III. RESULTS AND DISCUSSION

The co-directional CSRRs can show distinct triple-band gaps due to the weaker mutual coupling between the inner and outer rings even when the triple band gaps are adjacent [11]. Thus, co-directional CSRRs is selected to obtain adjacent triple notched bands for C-band (3.7 GHz - 4.2 GHz) satellite communication systems and WLAN (5.15 GHz - 5.35 GHz and 5.725 GHz - 5.825 GHz) [12]. It is noted that the inner opening and outer opening are just co-directional [13]. Figure 5 shows the measured and simulated VSWRs versus frequency. The antenna could provide sufficiently wide impedance bandwidth covering 2 GHz - 16 GHz or more with the triple notched bands. Measured triple notched bands are 3.68 GHz - 4.25 GHz, 5.05 GHz - 5.60 GHz and 5.75 GHz - 6.22 GHz, respectively, covering C-band satellite communication systems and WLAN [14]. The measurements results show that the second notched band is a little offset compared with the simulation results, which is mainly due to the error induced by fabrication and assembly [15]. Therefore, by loading co-directional CSRRs with different centers, the co-directional CSRRs can provide good triple band-notch performance [16]. Owning to its triple band-notch structure, the co-directional complementary SRR can reduce the design space to achieve triple notched bands in comparison with the complementary edge-coupled SRR [17].

The radiation characteristics of the frequencies across the band have also been studied. Figure 6 shows the measured far-field radiation patterns of the *YZ* and *XY* plane at 3.5 GHz, 5 GHz, and 7.5 GHz. The three frequencies are chosen to be the frequency under lower notch band, the frequency between lower notch band and higher notch band, and the frequency beyond the higher notch band. Figure 6 shows the measured radiation patterns including the co- and cross-polarization in the H-plane (*XY* plane) and E-plane (*YZ* plane). The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. The pattern plots are expressed by Electric field co-polar and cross-polar components instead of the conventional method due to the measurement condition we have. However, this is also a good way to describe the radiation property of the antenna. The co-polar and cross-polar components may be smaller than ideal point source, which results in peaks lower than 0dB. Clearly, the *XY* plane patterns are close to omni-directional and the *YZ* plane patterns are monopole-like. All the obtained radiation patterns accord with those of the conventional printed UWB monopole antennas.

Figure 7 shows the measured radiation efficiency of the antenna. Due to the limitations of measurement facility, the radiation patterns above 12 GHz were not measured. The proposed antenna features efficiency between 50 % and 65% over the whole UWB frequency and lower than 10 % in the notch band. The features of the 55 % average radiation efficiency are good enough to satisfy an acceptable variation for practical power transmission [18].

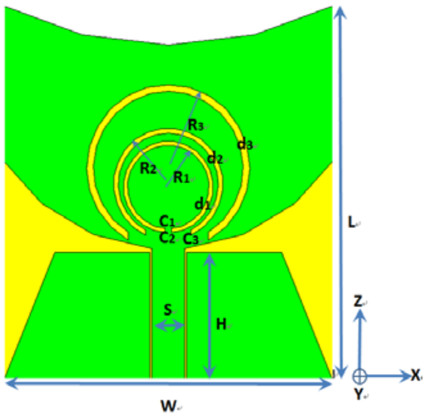


Fig. 1. Geometry of the antenna with dimensions R_1 = 3.35 mm, R_2 = 4.09 mm, R_3 = 6.1 mm, d_1 = 0.3 mm, d_2 = 0.34 mm, d_3 = 0.5 mm, C_1 = 0.5 mm, C_2 = 3.35 mm, C_3 = 6mm, S = 2.5 mm, H = 9.8 mm, W = 25 mm, and L = 27.9 mm.

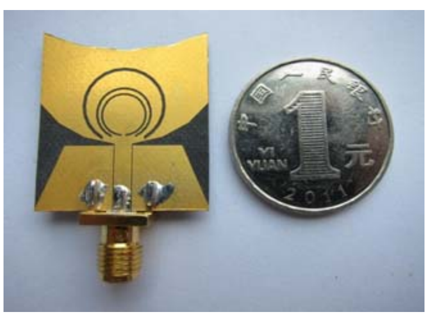


Fig. 2. Photograph of the proposed antenna.

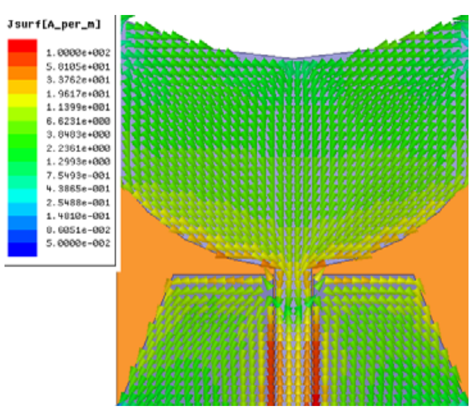
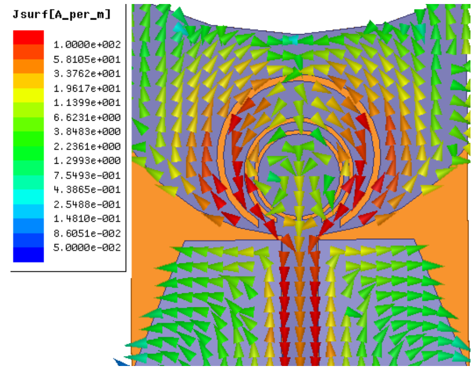
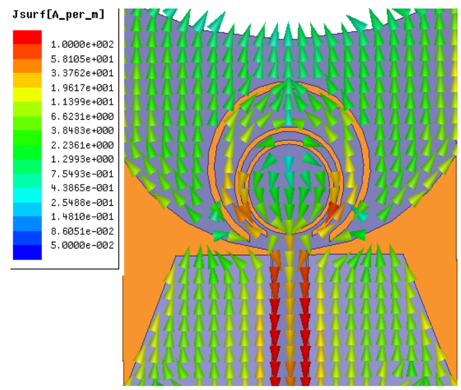


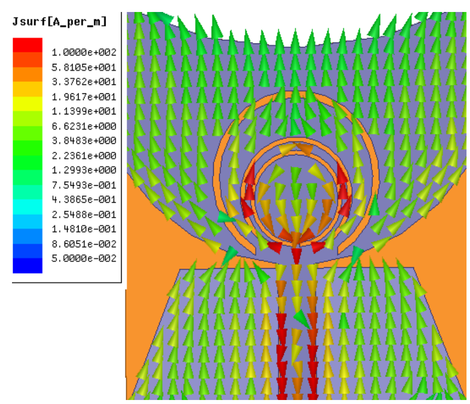
Fig. 3. Surface current distribution at 6 GHz without co-directional CSRR.



(a)



(b)



(c)

Fig. 4. Surface current distribution with co-directional CSRR at (a) 3.9 GHz, (b) 5.2 GHz, and (c) 5.9 GHz.

The gain patterns 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 [19]. These techniques aim at limiting the alterations of the measurement coaxial cable on omni-directional radiation antennas. Figure 8 reveals its measured peak gain and simulated realized gain versus frequency. As can be seen from Fig. 8, the simulation and measured results fit each other well. It shows 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 that the proposed antenna gain decreases significantly to about -9.5 dBi, -7 dBi, and -5 dBi in the notched band. This confirms that the proposed antenna provides a high level of rejection to signal frequencies within the notched band [20]. Therefore, the results of the work are useful for short-range wireless communication systems.

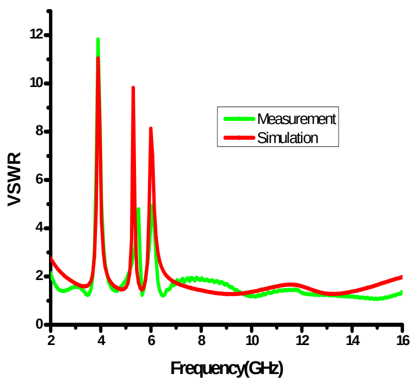
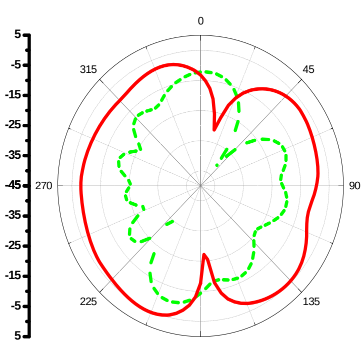
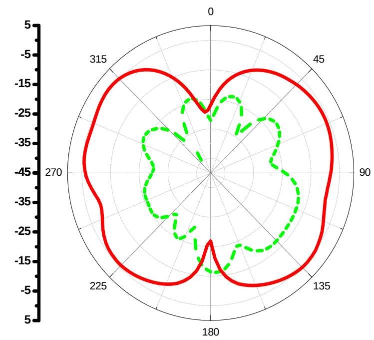


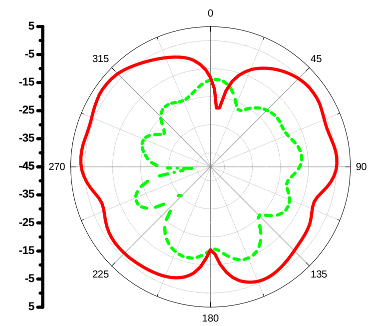
Fig. 5. Comparison of the simulated and measured VSWR of the proposed antenna.



F = 3.5 GHz

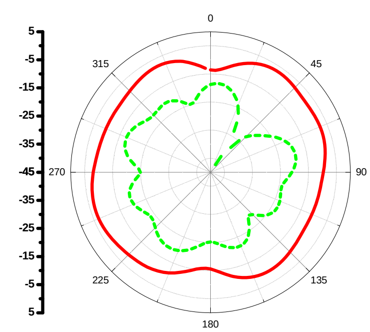


F = 5 GHz

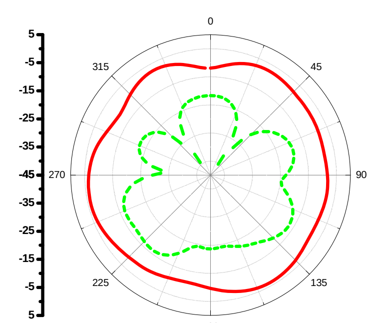


F = 7.5 GHz

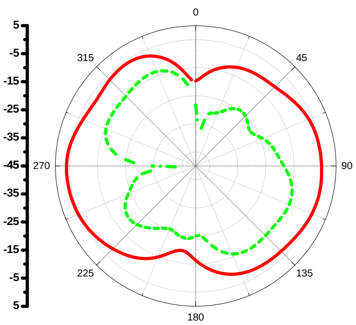
(a)



F = 3.5 GHz



F = 5 GHz



F = 7.5 GHz

(b)

Co-polar: Cross-polar:

Fig. 6. Measured radiation patterns at the (a) *YZ* plane and (b) *XY* plane.

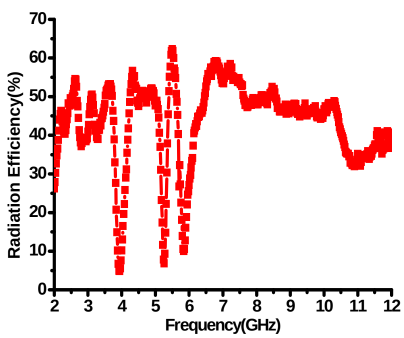


Fig. 7. Measured radiation efficiency of the proposed antenna.

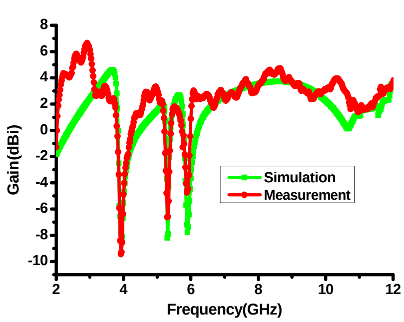


Fig. 8. Comparison of the simulated and measured gain of the proposed antenna.

IV. CONCLUSION

In this paper, a novel CPW-fed compact planar monopole UWB antenna with triple notched bands is proposed. By loading co-directional CSRRs with different centers, narrower and stronger band-notched properties as well as small design space size for the frequency band rejection function are achieved. Furthermore, broad bandwidth and good monopole-like radiation patterns are obtained with a rather compact antenna size. Also, the prototype has been constructed and measured to show a good agreement with the simulated results. Therefore, the results of the work are useful for short-range wireless communication systems.

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