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A NOVEL ULTRA-WIDE BAND ANTENNA WITH REDUCED RADAR CROSS SECTION

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Abstract—A novel printed dual circular ring monopole antenna with low radar cross section (RCS) for ultra-wide band (UWB) application is proposed. The proposed antenna is designed to realize RCS reduction. The two circular rings are connected by several metallic via holes to improve the radiation characteristics of the proposed antenna. Its UWB-related characteristics are simulated and experimentally verified. The RCS performance of the proposed antenna under different loads is studied and compared with that of a commonly used circular-disc monopole antenna. The results show that the proposed antenna has good radiation performances and lower RCS than the reference antenna. The proposed antenna serves as a good candidate in the design of UWB antenna with the requirement of RCS control.

1. INTRODUCTION

More and more attention has been paid to antenna scattering since it is the main contribution to the total radar cross section (RCS) of low-observable platforms. Antenna is a special scatter whose scattering is related with its feed port, which embarrasses the design of antenna with low RCS and good radiation characteristic simultaneously [1, 2]. The antenna unit with low RCS is pivotal to the antenna array on low-observable platforms, which makes the design of antennas with low RCS pressing.

In recent years, with the continuous development of ultra-wide band (UWB) wireless communication technologies, the design and manufacture of low cost microwave components are among the most critical problems in communication systems. An UWB antenna should

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provide a gain and impedance bandwidth from 3.1 GHz to 10.6 GHz [3–10]. It has been widely used for many military applications such as UWB radars, military high data rate wireless communications, etc. But with the development of target identification technology, UWB antennas with low RCS become crucial to the survivability of the antenna platforms [11–15]. However, few publications on the RCS reduction of UWB antennas have been published.

The printed circular disc antenna is commonly used as a UWB monopole antenna for its good radiation performance [16]. But its RCS is very large especially in the threatening and perpendicular direction of the antenna surface, for the proportion of circular radiator's area in total area is very large [17]. To reduce the antenna RCS, we can use circular ring radiator instead of the circular one. But the circular ring antenna does not perform as good radiation characteristic as the circular one. In this paper, the authors connect the top and bottom circular ring patches by several metallic via holes to obtain an antenna with low RCS, good radiation performance, and wide impedance band width [18, 19].

2. THEORETICAL ANALYSIS

It is well known that antenna is a special scatter, and its scattering is related with the feed termination impedance. The scattering of antenna is structural mode scattering when its feed port is connected with matched load. If not, part of the received energy would be reradiated, which contributes to antenna mode scattering. The total RCS (σ) of an antenna can be divided into the following two categories: RCS of structural mode (σ_s) and antenna mode (σ_a). Their relationship is given by $\sigma = |\sqrt{\sigma_s} + \sqrt{\sigma_a} e^{j\phi}|^2$, where ϕ is the phase difference between these two modes [20].

A model was proposed to analyze the scattering of antenna in [21]. With the scattering field in two cases, the scattering of antenna with arbitrary load can be obtained conveniently. The problem of phase difference between the two components is solved. The following equation is the antenna scattering field under any load,

$$\vec{E}^s(Z_l) = \frac{(1-\Gamma_a)\vec{E}^s(\infty) + (1+\Gamma_a)\vec{E}^s(0)}{2} + \frac{\Gamma_l}{1-\Gamma_l\Gamma_a}\frac{1-\Gamma_a^2}{2}[\vec{E}^s(\infty) - \vec{E}^s(0)] \quad (1)$$

The first part of the above equation is the structural mode scattering field, and the second one is the antenna mode scattering field. Γ_l is the reflection coefficient of load, and Γ_a is the reflection coefficient of antenna. $\vec{E}^s(\infty)$ and $\vec{E}^s(0)$ are the scattering field of the antenna terminated with open-circuit and short-circuit, respectively. In this model, the total antenna RCS can be obtained easily by the open- and short-circuit RCS.

3. ANTENNA STRUCTURE

A commonly used printed circular disc monopole antenna was proposed in [16]. A similar antenna is presented in this paper as a reference antenna, which is shown in Fig. 1. As shown in Fig. 2, the proposed antenna consists of two circular ring patches, a ground plane, a microstrip line, and a square dielectric substrate of thickness 1.6 mm, relative permittivity 2.65 and loss tangent 0.02. One of the circular ring radiators fed by a 50 ohm microstrip line of width 3.2 mm is printed on the top surface of the substrate, while the other one is printed on the bottom surface of the substrate together with the ground plane. Several metallic via holes are constructed on the substrate to connect the two circular ring radiators on the top and bottom surfaces. These metallic via holes of radius 0.3 mm are uniformly distributed on the inner and outer edges of the circular ring radiators. In order to demonstrate the superiority of the proposed antenna's radiator in RCS reduction, the ground plane and dielectric substrate of the proposed antenna are designed the same as those of the reference antenna.

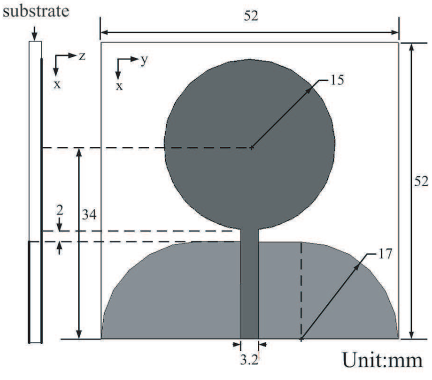


Figure 1. Geometry of the reference antenna.

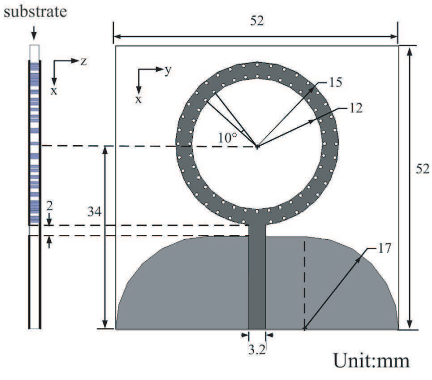


Figure 2. Geometry of the proposed antenna.

4. EXPERIMENTAL RESULTS

The two antennas are fabricated as shown in Fig. 3. In this paper, all the simulations are done based on HFSS software (high frequency structure simulator based on Finite Element Method). Measured and simulated return loss curves of the two antennas are shown in Fig. 4 and Fig. 5 respectively. The proposed antenna's measured operating band width of −10-dB is 1.99–10.8 GHz which covers the frequency range of UWB. The gain curves of the reference and proposed antenna are shown in Fig. 6. The gain curve of the proposed antenna keeps consistent with that of the reference antenna, and the difference between them is less than 0.5 dBi. In the frequency range 3–11 GHz, gain variation of the proposed antenna is less than about 3.5 dBi.

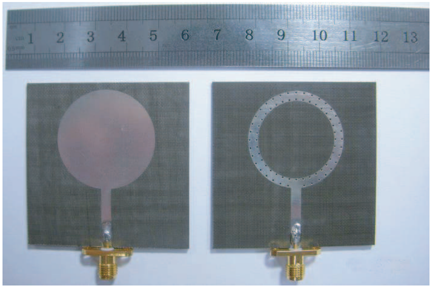


Figure 3. Pictures of the reference and proposed antennas.

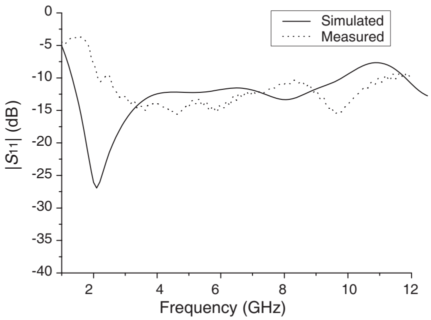


Figure 4. Simulated and measured return loss curves of the reference antenna.

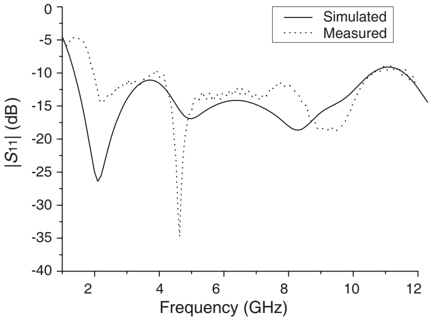


Figure 5. Simulated and measured return loss curves of the proposed antenna.

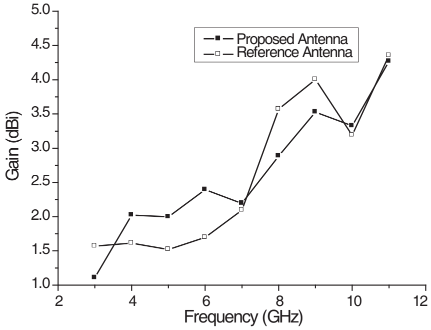
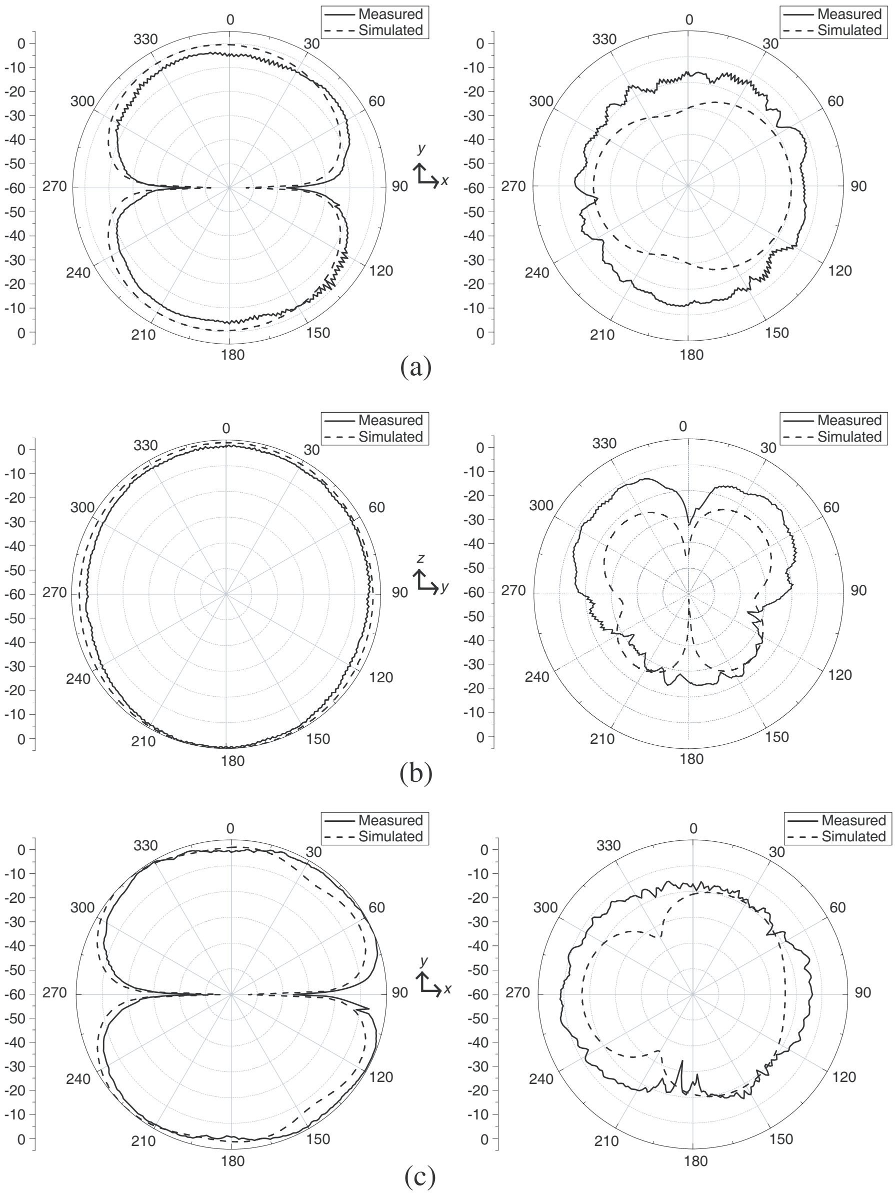


Figure 6. Gain curves of the reference antenna and proposed antenna.

Antenna radiation pattern measurements of the proposed antenna have been performed in an anechoic chamber at 3.0, 6.0, and 9.0 GHz in the principal cuts, E- and H-planes, which correspond to x-y and y-z planes, respectively. Both co- and cross-polar components were



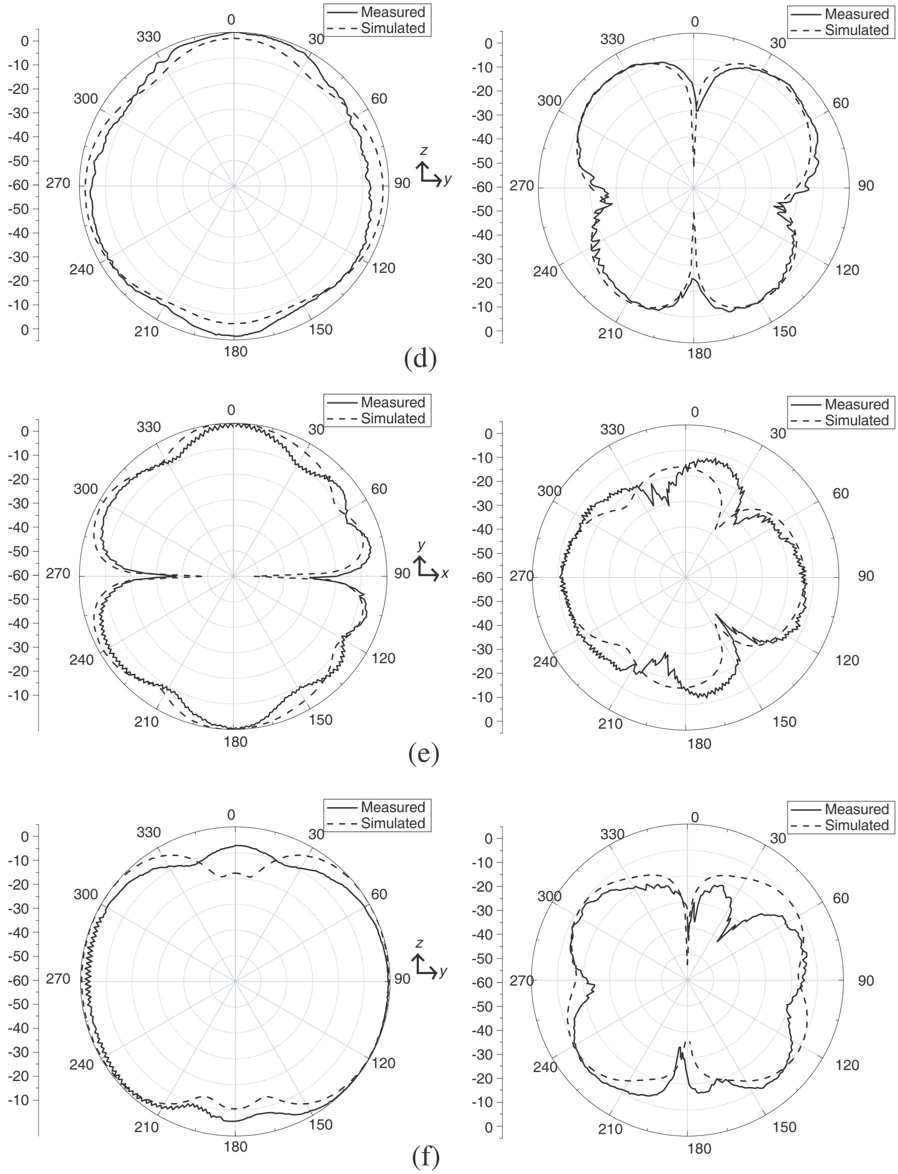


Figure 7. Co- and cross-polar radiation pattern at (a) 3.0 GHz in E-plane, (b) 3.0 GHz in H-plane, (c) 6.0 GHz in E-plane, (d) 6.0 GHz in H-plane, (e) 9.0 GHz in E-plane, (f) 9.0 GHz in H-plane.

measured and simulated. At each frequency, the radiation pattern in the E- and H-planes is normalized with respect to the maximum in their crossing points. As seen in Figs. 7(a)–(f), the agreement between simulations and measurements is very good. The antenna may be seen as a planar monopole, whose maximum radiation is normal to x-axis. The antenna exhibits a stable omnidirectional radiation behavior across the UWB band. The results show that it serves as a good candidate for UWB applications.

RCS curves of the two antennas terminated with open- and short-circuit load are shown in Fig. 8 and Fig. 9. These values can be used to obtain structural mode RCS, antenna mode RCS, and total antenna RCS [21]. In this paper, all the RCS are monostatic RCS which are for vertical polarization, i.e., both the incident and received electric fields

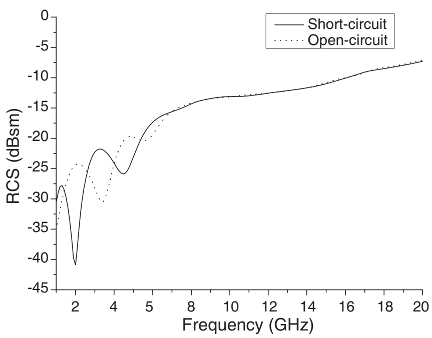


Figure 8. Simulated RCS values of the reference antenna with different kinds of loads.

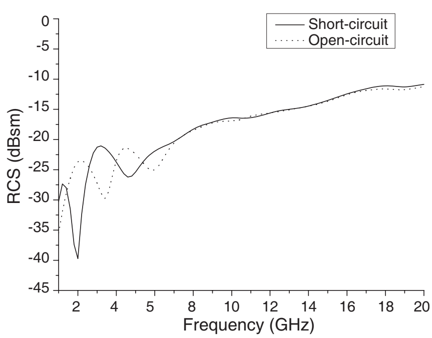


Figure 9. Simulated RCS values of the proposed antenna with different kinds of loads.

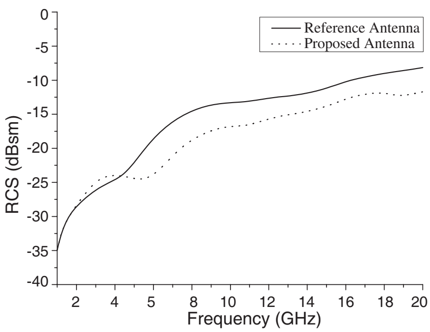


Figure 10. RCS comparison between the reference antenna and the proposed antenna.

are parallel to the x-axis. The incident wave direction is parallel to the z-axis.

When the antenna is terminated with different loads, the structural mode scattering will remain invariable, but the antenna mode scattering will change. Because of the ultra wide impedance band of the two UWB antennas, RCS curves of the two antennas terminated with 50 ohm load are calculated and compared to demonstrate the advantage of the proposed antenna in RCS reduction. The comparison results are shown in Fig. 10. In high frequency range, the RCS of the proposed antenna is largely reduced, which is due to the relatively small geometrical size of the dual circular ring radiators. In low frequency range, because the scale of the proposed antenna is similar to the incident wavelength, the antenna structural mode scattering should be regarded as the low frequency resonance scattering, which makes the changes in the structure of the antenna ineffective in antenna RCS reduction. However, compared with the reference antenna, the proposed antenna has advantages on antenna RCS reduction. The proposed antenna can be conveniently used as an UWB antenna where low RCS property is required.

5. CONCLUSION

A novel printed dual circular ring monopole antenna with low RCS is presented. The two circular rings are connected by several metallic via holes to improve its radiation characteristics. The bandwidth and radiation properties of the proposed antenna are analyzed and experimentally verified. Its scattering properties are studied and compared with those of the reference antenna. The results show that the proposed antenna has low RCS and good ultra-wide band characteristics. The proposed antenna can be used for the design of UWB antenna with the requirement of RCS control.

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