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# PRINTED UWB END-FIRE VIVALDI ANTENNA WITH LOW RCS

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**Abstract**—A novel Vivaldi antenna with low radar cross section (RCS) for ultra-wide band (UWB) applications is proposed in this paper. As a printed antenna with electrically large length, the Vivaldi antenna has large backscattering when the incident waves are in the grazing directions. By sleeking the edges of the proposed antenna, the reflected currents are reduced so that the peaks of the backscattering can be inhibited. Its radiation characteristics are simulated and verified. The RCS performance of the proposed antenna is studied and compared with that of a commonly used Vivaldi antenna. The result shows that the proposed antenna has lower RCS than the reference antenna in both the perpendicular and grazing directions while maintaining similar radiation characteristics. So the results illuminate that the proposed Vivaldi antenna is a good candidate in the design of printed UWB end-fire antennas requiring low RCS.

## 1. INTRODUCTION

In recent years, antenna scattering has drawn more and more attention since it is the main contribution to the total radar cross section (RCS) of low-observable platforms. Antenna is a special scatter because of the difficulty in balancing the characteristics of low RCS and good radiation performance simultaneously [1]. For ultra-wide band (UWB) antennas, it's a big challenge to realize RCS reduction owing to the frequency under consideration is so wide [2]. Furthermore, when the UWB antennas are terminated with different kinds of load, the RCS values is neither the greater nor the smaller one over the whole UWB frequency band, which is different from that of the narrowband antennas [3]. So, this brings a challenge for RCS reduction of the UWB antennas.

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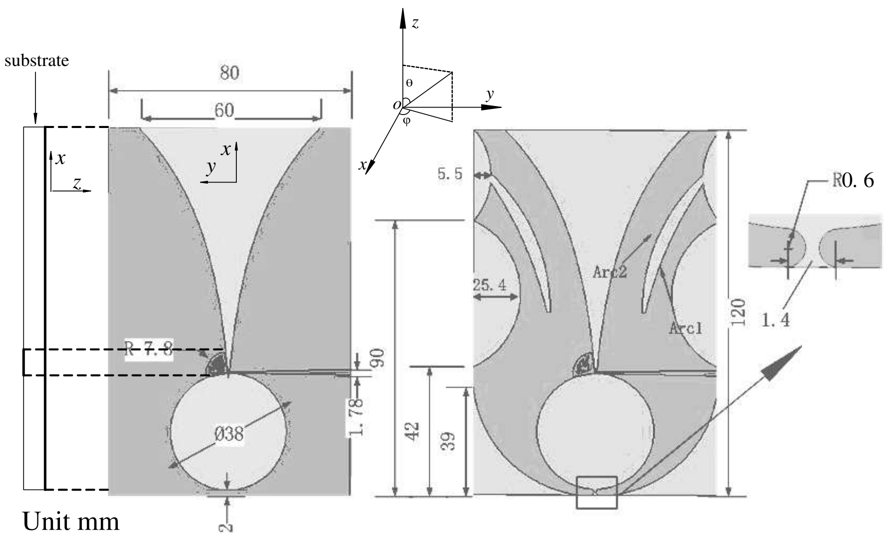
Nowadays, because of high directivity and easily tunable radiation pattern [4, 5], the end-fire antennas are widely used in phased array. Furthermore, the physical aperture of the end-fire array is much reduced compared with the broadside array, which makes the RCS of the end-fire array lower. The antenna unit with low RCS is pivotal to the antenna array on low-observable platforms, which makes the design of antennas with low RCS pressing. Some printed antennas with low RCS have been studied [6–9]. Nevertheless, up to now few papers for RCS reduction of the printed end-fire antennas have been published.

As a typical printed UWB end-fire antenna, the Vivaldi antenna has both the advantages of printed antennas and end-fire antennas [10, 11], which results that it is widely used for satellite communication, remote sensing, microwave imaging, wide band scanning arrays and military applications. So in this paper, the RCS reduction of the Vivaldi antenna will be studied. The area of the metallic coverage of the Vivaldi antenna is always large, which contributes much to the backscattering RCS in perpendicular direction of the antenna surface. Meanwhile, as an electrically large printed antenna, when the Vivaldi antenna is illuminated by the incident wave whose incident electric field has component that is tangent to the surface and in the direction of the surface wave, the surface travelling waves are induced. If the end of the surface is bounded by a discontinuity, the forward current wave is reflected. The backward travelling current wave can contribute significantly to the backscattering in grazing directions [1]. To reduce RCS in perpendicular direction of the antenna surface, the area of the metallic coverage of the antenna where the current amplitude is very small should be decreased [8]. But this method is not quite suitable for the situation when the incident wave is in grazing direction. In this paper, the authors replace the straight edge with arc lines and separate the Vivaldi antenna into two parts by slotting between the circle slotline cavity and end edge to obtain good radiation performance, wide impedance band width, and low RCS in both perpendicular and grazing directions of the antenna surface.

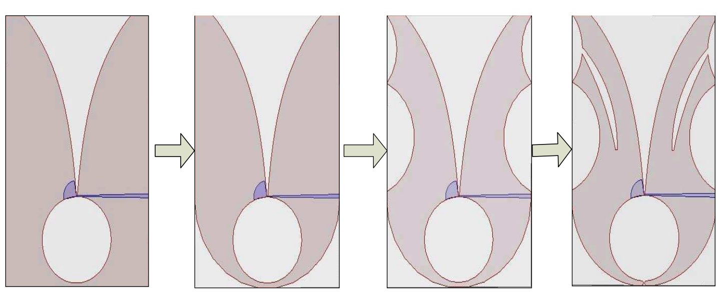
## 2. ANTENNA STRUCTURE AND DESIGN PROCESS

The commonly used Vivaldi antenna was proposed in [12]. A similar antenna is presented in this paper as a reference antenna, which is shown in Fig. 1(a). The proposed antenna is shown in Fig. 1(b). The opening rate of the exponential taper $r = 0.015\,\text{mm}^{-1}$. The size of the rectangle is $120\,\text{mm} \times 80\,\text{mm}$. The two antennas are both printed on the substrate with relative dielectric constant of 2.2 and the thickness of 0.5 mm. The diameter of the circle slotline cavity is 38 mm. The edges of the proposed antenna are modified by three pairs of arcs as shown in Fig. 1. The circle slotline cavity is opened at the end by slotting the metallic coverage between it and the end edge. Arc1 and Arc2 are arcs identified by three points (60, −15), (80, −20), (110, −40) and (60, −15), (88, −26), (110, −40) in $x$-$y$ plane, respectively. Both of the two antennas are fed by a 50 ohm microstrip line. The narrow end of the microstrip is 0.4 mm. All the simulations are carried out using




(a) (b)

**Figure 1.** Geometry of (a) the reference antenna and (b) the proposed antenna.



(a) (b) (c) (d)

**Figure 2.** The process of designing the proposed antenna.

a full-wave EM analysis tool, HFSS_v12 by Ansoft.

In order to show how each of the modified parts works, the process of designing the proposed antenna and its effect on reducing monostatic radar cross section (MRCS) are shown in Figs. 2 and 3.

In Fig. 2, we show the three steps of designing the proposed antenna. In Figs. 3(a)–(c), we can see that the MRCS of antenna b is reduced just in the direction of ($\theta = 60°$, $\varphi = 0°$), while the MRCS of antenna c is reduced in both the directions of ($\theta = 60°$, $\varphi = 0°$) and ($\theta = 60°$, $\varphi = 90°$). The proposed antenna realizes reducing the MRCS in the directions of ($\theta = 60°$, $\varphi = 0°$), ($\theta = 60°$, $\varphi = 45°$) and ($\theta = 60°$, $\varphi = 90°$) at the same time.

In Fig. 4, we show the surface currents induced by different directions and frequencies at which the peaks appear in the RCS curves.

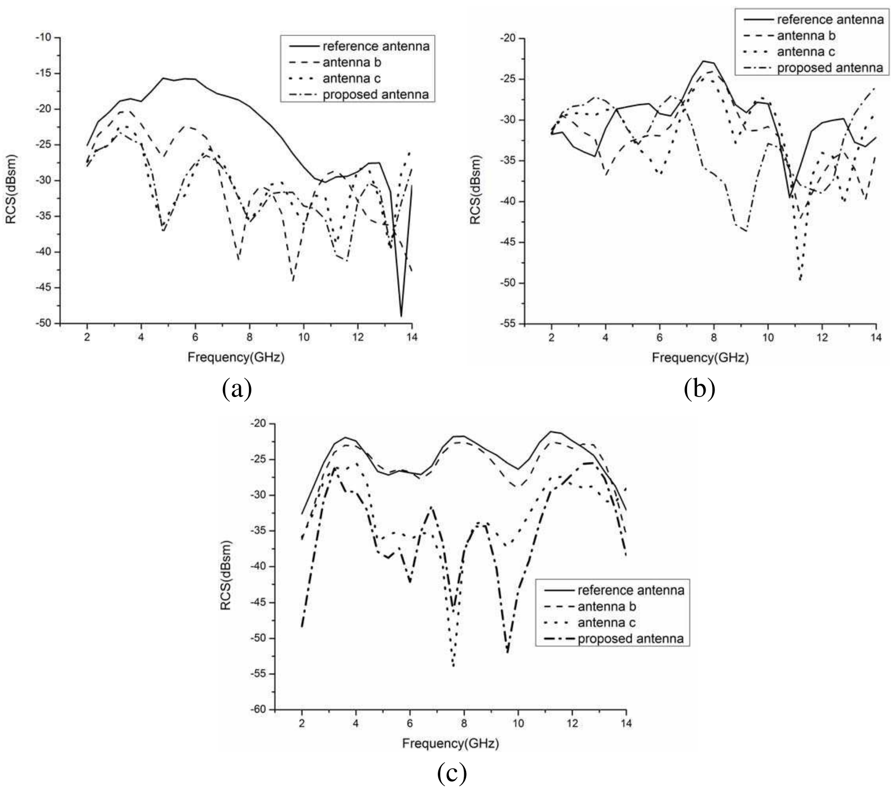



**Figure 3.** Simulated RCS at oblique incidence, (a) the incident angle ($\theta = 60°$, $\varphi = 0°$), (b) the incident angle ($\theta = 60°$, $\varphi = 45°$), (c) the incident angle ($\theta = 60°$, $\varphi = 90°$).

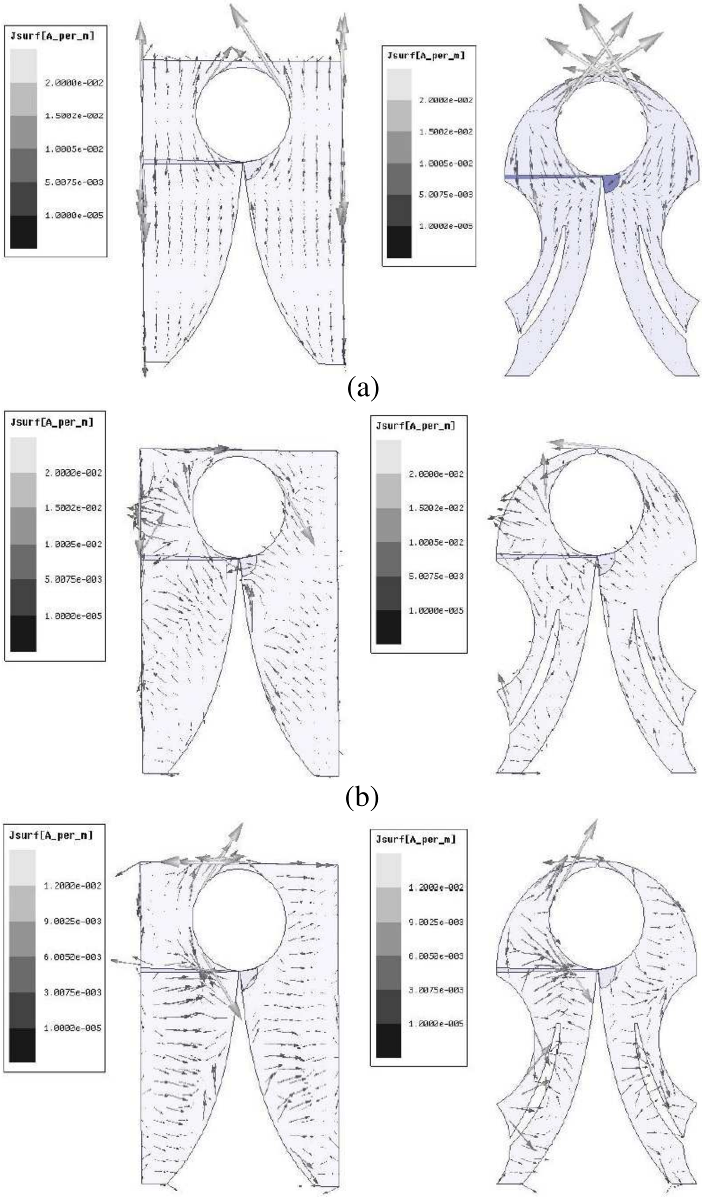



**Figure 4.** Induced current distributions on the reference antenna (left) and proposed antenna (right) at (a) 5 GHz, ($\theta = 60°$, $\varphi = 0°$), (b) 7.8 GHz, ($\theta = 60°$, $\varphi = 45°$), (c) 7.8 GHz, ($\theta = 60°$, $\varphi = 90°$).

It shows that the induced currents are changed and their amplitudes are reduced. Especially, the induced surface currents along and against the direction of the incident wave is greatly reduced which inhibits the backward travelling wave scattering.

## 3. ANTENNA PERFORMANCE

The two antennas are fabricated as shown in Fig. 5. In this study, the electric fields of the incident plane waves are all $\theta$ polarized, with incident angles ($\theta = 0°$, $\varphi = 0°$), ($\theta = 60°$, $\varphi = 0°$), ($\theta = 60°$, $\varphi = 45°$), and ($\theta = 60°$, $\varphi = 90°$). Measured and simulated VSWR of the reference and proposed antennas are shown in Figs. 6 and 7 respectively, which shows a good agreement between the measured

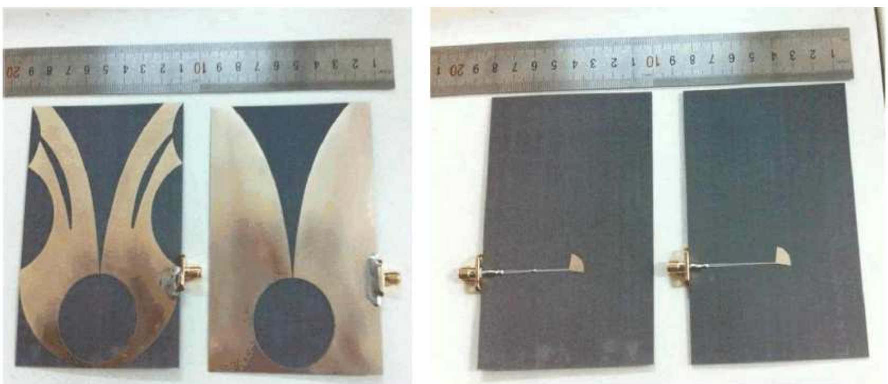


**Figure 5.** Pictures of the proposed and reference antennas.

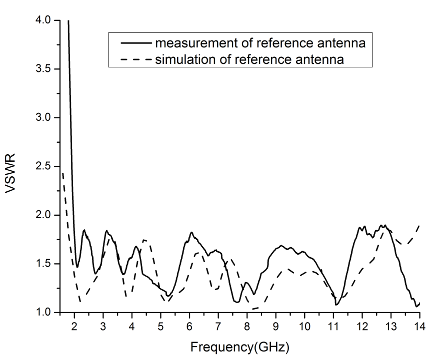



**Figure 6.** Measured and simulated VSWR of the reference antenna.

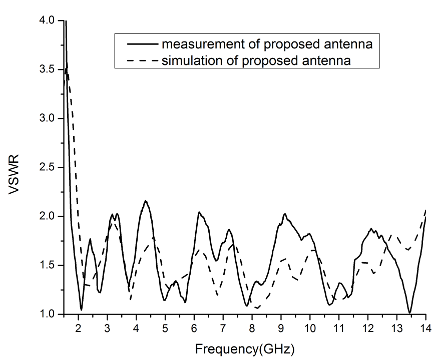



**Figure 7.** Measured and simulated VSWR of the proposed antenna.

and simulated results. The gain curves of the two antennas are shown in Fig. 8. The gain of the proposed antenna is higher than that of the reference antenna in most of the impedance bandwidth. At the frequency points where the gain of the proposed antenna is lower than that of the reference antenna, the difference between them is less than 0.5 dBi.

Simulated antenna radiation patterns of the two antennas at

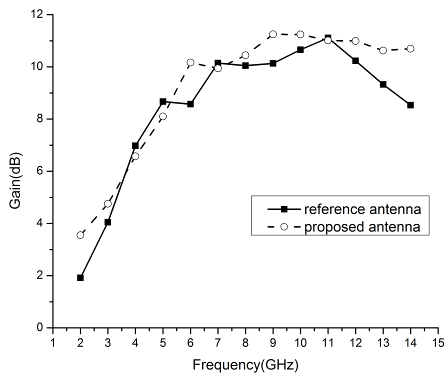
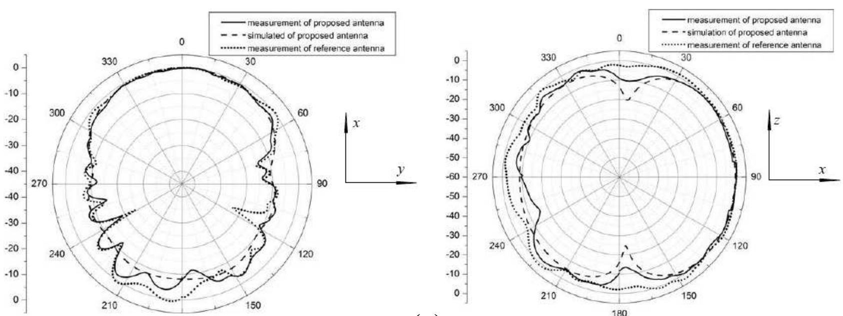
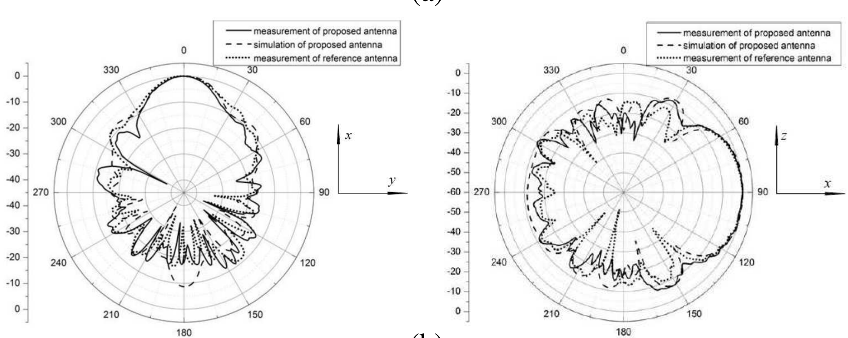


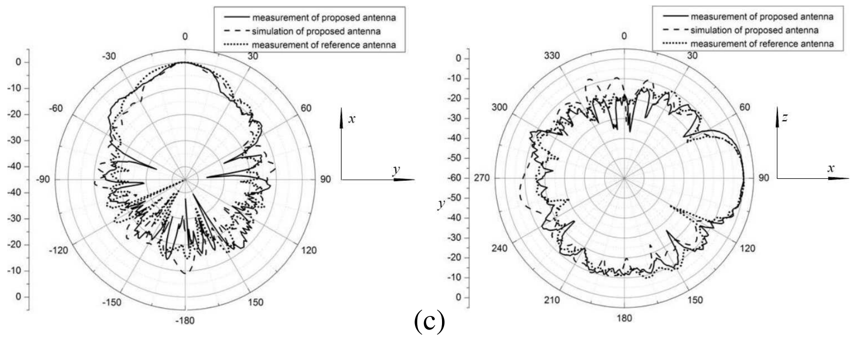

**Figure 8.** Gain curves of the reference and proposed antenna.




(a)

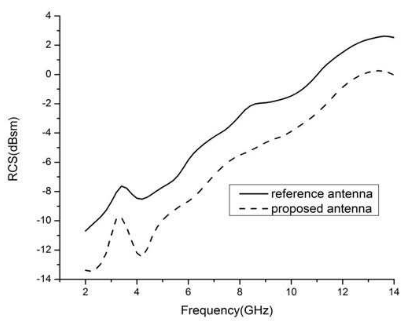



(b)

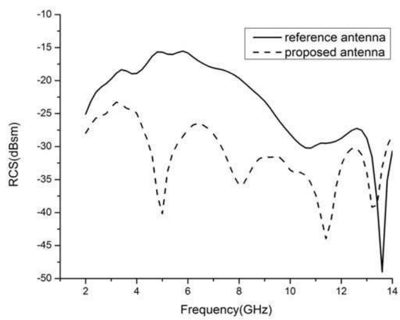



(c)

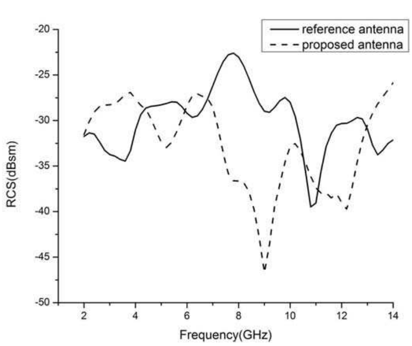
**Figure 9.** Simulated and measured radiation patterns of the reference antenna and proposed antenna in $E$-plane (left) and $H$-plane (right) at (a) 3.0 GHz, (b) 8.0 GHz, (c) 13.0 GHz.



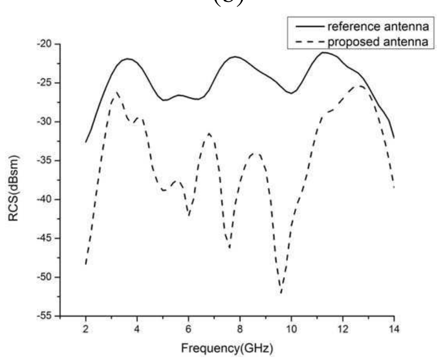

(a)




(b)




(c)




(d)

**Figure 10.** Simulated RCS at normal and oblique incidence, (a) the incident angle ($\theta = 0°$, $\varphi = 0°$), (b) the incident angle ($\theta = 60°$, $\varphi = 0°$), (c) the incident angle ($\theta = 60°$, $\varphi = 45°$), (d) the incident angle ($\theta = 60°$, $\varphi = 90°$).

3.0 GHz, 8.0 GHz, 13.0 GHz, in the principal cuts, $E$- and $H$-planes, which correspond to $x$-$y$ and $x$-$z$ planes, are shown in Fig. 9. It can be seen in Figs. 9(a)–(c) that the agreement between the two antennas is good, which shows that the proposed antenna has the stable radiation behavior across the UWB band as the reference antenna does.

Figures 10(a)–(d) show the simulated RCS curves of the proposed and reference antennas at different incident angles. When the incident angles are ($\theta = 0°, \varphi = 0°$), ($\theta = 60°, \varphi = 0°$), and ($\theta = 60°$, $\varphi = 90°$), it can be seen from Figs. 10(a), (b) and (d) that the RCS of the proposed antenna are obviously reduced over the whole UWB frequency band, compared with the reference antenna. From Fig. 10(c), we can see that when the incident angle is ($\theta = 60°$, $\varphi = 45°$), the peak RCS at 7.8 GHz has been greatly reduced and the RCS curve has good performance from 4.5 GHz to 13 GHz.

## 4. CONCLUSION

A novel Vivaldi antenna has been proposed in this paper. The bandwidth and radiation properties of the proposed antenna was analyzed and experimentally verified. The RCS of the proposed antenna is lower than that of the reference antenna in both perpendicular and oblique directions. All the results illuminate that the proposed Vivaldi antenna is a good candidate for printed end-fire antennas requiring low RCS.

## ACKNOWLEDGMENT

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