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BROADBAND RADAR CROSS SECTION REDUCTION OF A RECTANGULAR PATCH ANTENNA

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Abstract—A rectangular patch antenna with two circular apertures, a defected ground structure (DGS), and a shorting post is proposed in this paper. The novel structure can reduce the radar cross section (RCS) of the antenna at its operating frequency. At the same time, the return loss of the proposed antenna is maintained, and the RCSs of the patch antenna at the frequencies outside the operating band are also reduced. The proposed antenna is simulated by using high frequency electromagnetic simulation software. The peak of RCSs is reduced about 7 dB and the broadband RCSs are below −30 dB from 2 to 8 GHz. This result is useful for low-RCS antenna application.

1. INTRODUCTION

Microstrip patch antennas are lightweight, low-profile, conformal and easy of manufacturing, and do not disturb the aerodynamic properties of their platforms. These make them very popular in microwave systems, especially for aerospace applications. Modern aircrafts do not hope to be found by enemy's radar. Radar cross section (RCS) is an important parameter, which decides the stealth ability. The surface of an aircraft can have low RCS by using some radar-absorbing materials or shaping methods. Therefore, antennas are important contributors to the overall RCS signature of a stealth object. Antennas are effective radiators of electromagnetic fields, so it is a contradiction that antennas realize RCS reduction and at the same time maintain their normal functions.

A variety of RCS reduction techniques have been applied to patch antennas. Lumped loading technique has been used to control the RCS of the patch, but the gain of the antenna is often descended. To achieve broadband RCS reduction, a narrow resistive ribbon around the periphery of the patch has been used [1, 2]. By using lossy substrates and shorting post, RCS reduction can be realized [3, 4]. In many applications, antennas with both low RCS and high transmit gain are needed. However, it is difficult for an antenna realizing low RCS while maintaining good radiating characteristics. Some approaches have emerged to try to solve this problem. In [5], a microstrip antenna with a ferrite cover layer has the capability of beam scanning and gain enhancement. By using fractal slot on microstrip patch antenna, the RCS of the antenna can be reduced and the radiation characteristics can be maintained [6].

In this paper, a patch antenna with two circular apertures, a defected ground structure (DGS), and a shorting post is presented. Compared to [4, 5], the proposed antenna is not loaded with ferrite, so the weight of the antenna is light, and the circle aperture, not like fractal slot, is easy to design. But the loss of gain is larger than those of antennas in [4, 5]. The proposed antenna has low RCS in a broadband, good return loss and gain.

2. RCS REDUCTION TECHNIQUES

RCS is usually used to characterize the scattering properties of a radar target. For a target, there is monostatic or backscattering RCS when the transmitter and receiver are at the same location, and there is a bistatic RCS when the transmitter and receiver are not at the same location [7]. In this paper, the monostatic RCS of a rectangular patch antenna is analyzed.

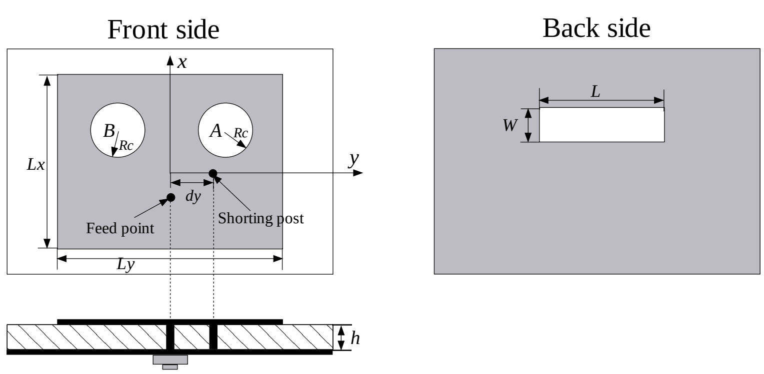


Figure 1. Geometry of the proposed patch antenna.

As shown in Fig. 1, the antenna is printed on a Rogers duroid 5880 substrate with length of $Ly = 35\,\text{mm}$, width of $Lx = 20.5\,\text{mm}$,

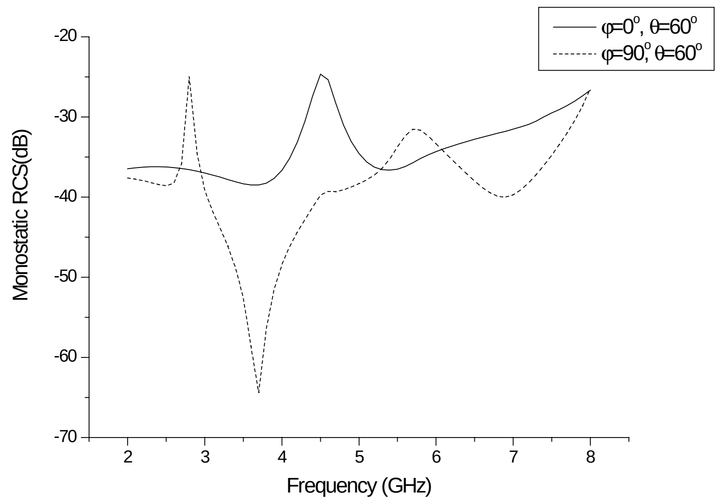


Figure 2. Monostatic RCSs of original antenna for different incident angels.

thickness of $h = 1.1\,\mathrm{mm}$, and relative permittivity of $\varepsilon_r = 2.2$. In our research program, the emphasis is the RCS at 60 degree elevation incident angle. The antenna is illuminated twice by a θ-polarized planar wave. The incident angels are ($\theta = 60°$, $\varphi = 0°$) and ($\theta = 60°$, $\varphi = 90°$), respectively. Fig. 2 shows the monostatic RCSs at these two incident angles. At the antenna resonance frequency 4.6 GHz, the RCS at incident angle $\varphi = 0°$ is much higher than that at incident angle $\varphi = 90°$. In frequency range of $2 \sim 8\,\mathrm{GHz}$, the RCS at incident angle $\varphi = 0°$ is higher than that at incident angle $\varphi = 90°$ for the most part. So we lay a strong emphasis on reducing the RCS at zero degree azimuth incident angle. In this paper, if not mentioned specially, the RCS means monostatic RCS at incident wave angle ($\theta = 60°$, $\varphi = 0°$).

2.1. Circular Apertures

Apertures in a patch antenna can change surface current distribution and reduce the RCS of the patch antenna. In this paper, a rectangular patch antenna with two circular apertures is investigated. In order to keep the same operating frequency, the antenna dimensions are selected to be $Ly = 29\,\mathrm{mm}$ and $Lx = 18\,\mathrm{mm}$. The center positions of the two circular apertures in the patch are A (4 mm, 7 mm) and B (4 mm, −7 mm) respectively, as shown in Fig. 1. Fig. 3 shows the Monostatic

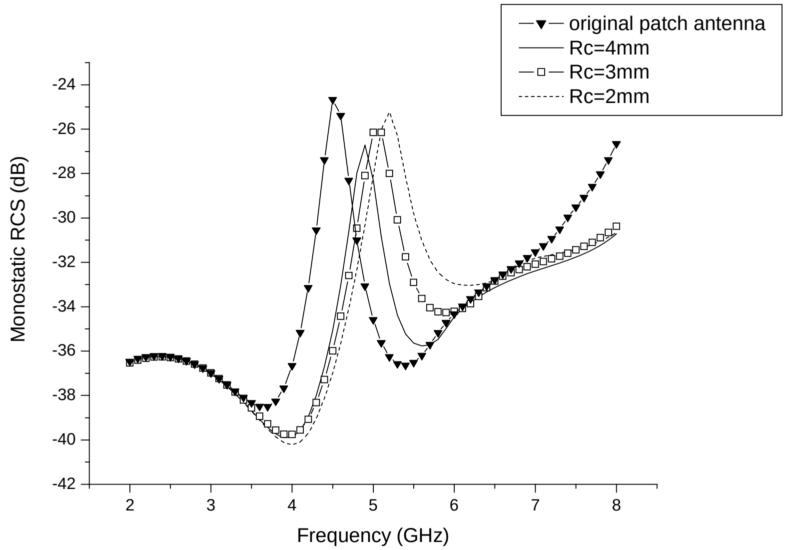


Figure 3. Monostatic RCSs of original antenna and the antenna with two circular apertures, incident angle ($\theta = 60^\circ$, $\varphi = 0^\circ$).

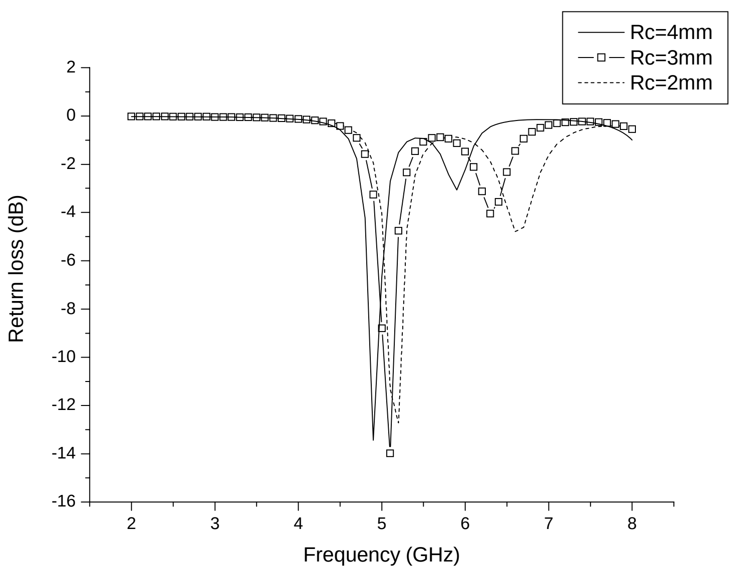


Figure 4. Return losses of antenna with two circular apertures.

RCS versus frequency for different aperture radius. It is clear that the RCS of the antenna with two circular apertures is reduced obviously, compared with the original one. At the same time, with the radius increasing, the RCS reduces gradually. When the radius is larger than 4 mm, the return loss becomes bad, thus we do not consider these conditions. The peak RCS of the antenna with 4 mm-radius circular apertures is −26.71 dB, that is 2.05 dB lower than that of the original one. When frequency is lower than the operating frequency, the RCSs are almost the same. The return losses of the two-circular-aperture antenna, which are displayed in Fig. 4, are not very good and the resonance frequency is shifted with the change of radius.

2.2. Defected Ground Structure

In order to enhance the performance of the antenna, a simple rectangular DGS is considered [8–13]. DGS can constrain the superficial currents, and let the extensive-distributing currents in the ground converge near the two ends of the defected rectangle. That reduces the radiation from the surface currents, therefore reduces the antenna RCS.

Two cases are investigated, one is the DGS with a width of $W = 2$ mm and a length of $L = 10$ mm along y-axis, and the other is the DGS with a length of $L = 4$ mm and a width of $W = 10$ mm along x-axis. The result is shown in Fig. 5. When the incident angle is ($\theta = 60°$, $\varphi = 0°$), the peak RCS of the patch with a DGS along y-axis is reduced more heavily than that of the patch with a DGS along x-axis, as shown in Fig. 5(a). When the incident angle is ($\theta = 60°$, $\varphi = 90°$), the peak RCS of the patch with a DGS along x-axis is reduced more remarkably than that of the patch with a DGS along y-axis, as shown in Fig. 5(b). As for certain frequencies, because of the shift of resonance frequency, the DGS antenna's RCS is higher than before.

2.3. Shorting Post

Shorting post loaded near the center of the patch can improve the performance of antenna. Figs. 6 and 7 show the return losses and RCSs of the patch antenna with shorting post at different positions along x- and y-axis, respectively. Five positions are tested, (0 mm, 0 mm), (0 mm, 2 mm), (0 mm, −2 mm), (2 mm, 0 mm), and (−2 mm, 0 mm). Compared with the original patch antenna, the peak value of RCS is reduced and the RCSs at higher frequencies are much lower than before. From the figures, it is obvious that the position of shorting

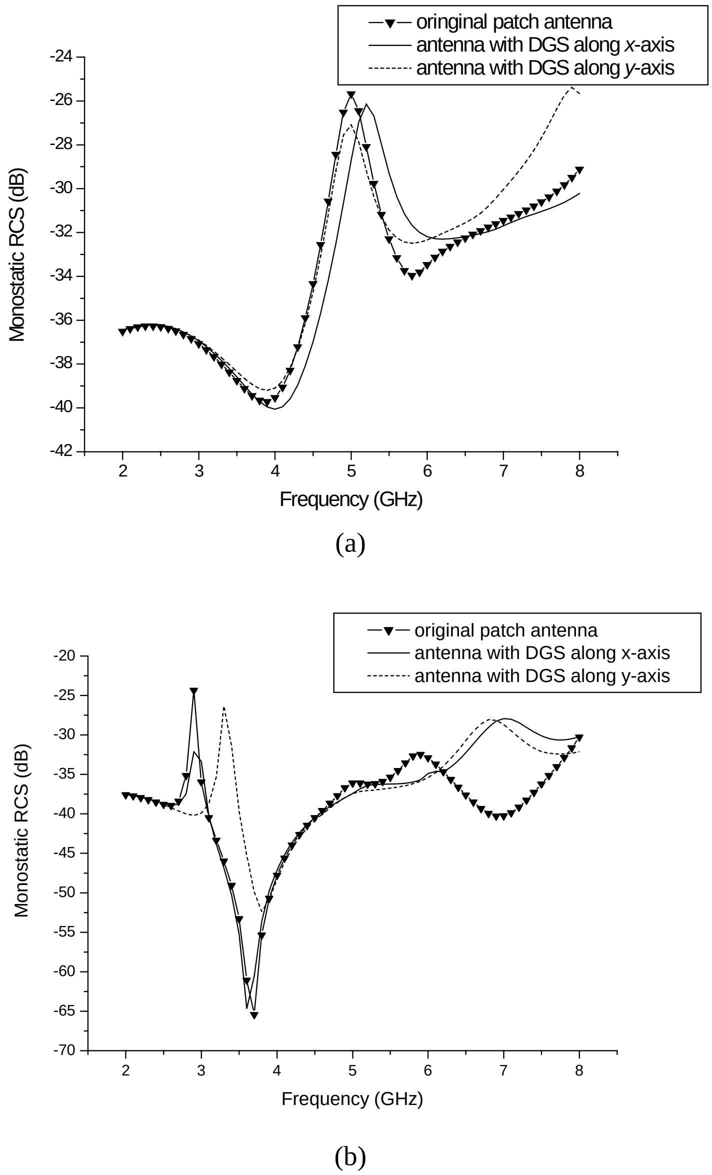
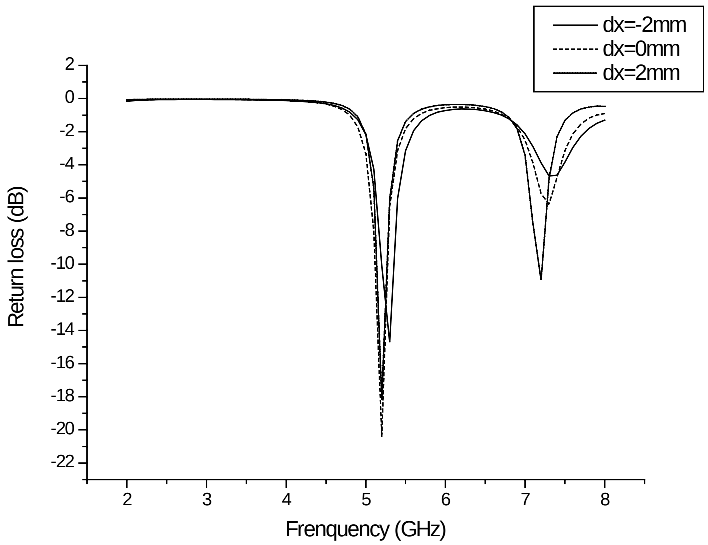
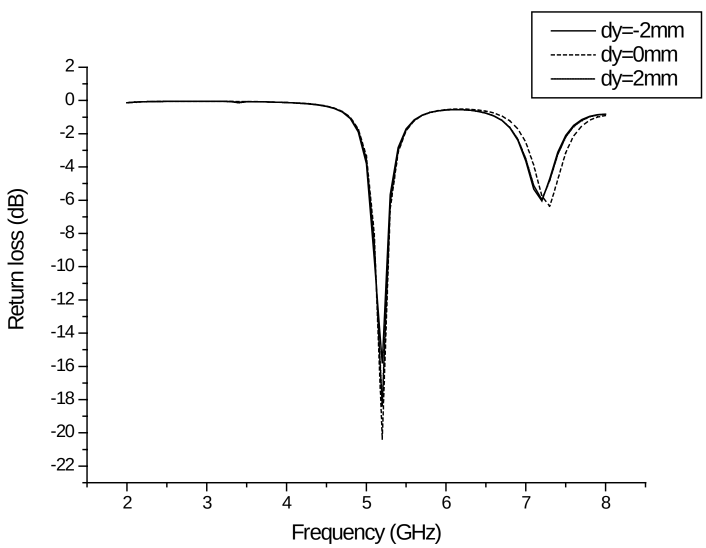


Figure 5. Monostatic RCS of original antenna and the antenna with a DGS. (a) incident angle ($\theta = 60°$, $\varphi = 0°$), (b) incident angle ($\theta = 60°$, $\varphi = 90°$).

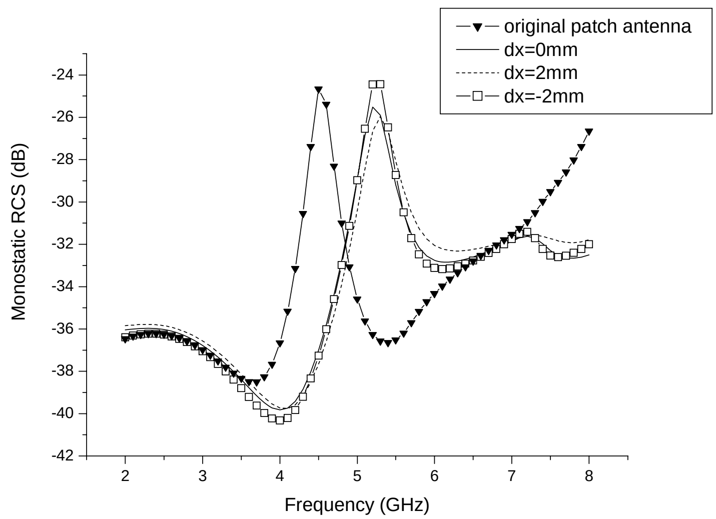


(a)

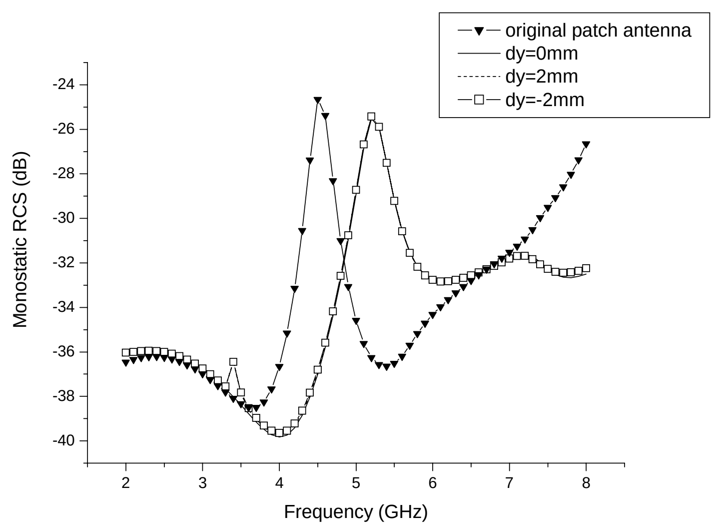


(b)

Figure 6. Return losses of the antenna loaded with shorting post at different positions. (a) Shorting post along x-axis, (b) Shorting post along y-axis.



(a)



(b)

Figure 7. Monostatic RCSs of the antenna loaded with shorting post at different positions, incident angle ($\theta = 60°$, $\varphi = 0°$). (a) Shorting post along x-axis, (b) Shorting post along y-axis.

post, which is near the center of the patch, has little influence on the RCS of the antenna.

3. OPTIMIZING RESULTS

Combining the three techniques mentioned above, a patch antenna with two circular apertures, a DGS and a shorting post is designed. Both of the circular apertures centered at the points A (4 mm, 7 mm) and B (4 mm, −7 mm) have a radius of 4 mm. The DGS is centered at (6 mm, 0 mm) with a width of $W = 6$ mm, and a length of $L = 10$ mm along y-axis. The shorting post is at the center of the patch.

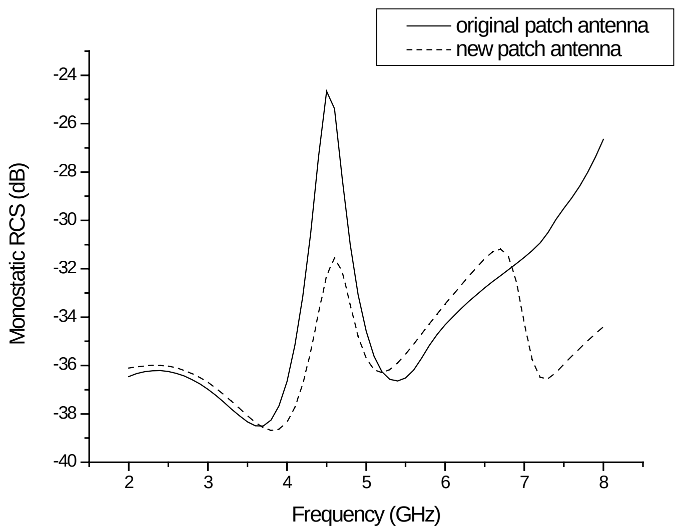


Figure 8. Monostatic RCSs of original patch antenna and the proposed antenna, incident angle ($\theta = 60°$, $\varphi = 0°$).

Figure 8 depicts the RCSs of the new antenna and original rectangular patch antenna in the frequency range of $2 \sim 8$ GHz. The peak RCS of the optimized structure at the operating frequency now is −31.54 dB, which is reduced by 6.88 dB contrasted against the RCS of original antenna mentioned in Fig. 2. The RCSs at higher frequencies are also reduced. The maximum is only −31.19 dB. Even if the second peak of the original antenna is not appeared in the specified frequency range, the second peak RCS of the optimized one is lower by 4.54 dB than the second maximum RCS of original one. At lower frequencies, RCS has a small increase. But, compared with the overall RCS reduction over $2 \sim 8$ GHz, the RCS increase at low frequencies is negligible. Because of structure change, the resonance frequencies are not the same. Therefore, the peaks of RCSs are not at the same frequency, and at certain frequencies, the RCS of the new structure is higher than before. The max value of increased RCS is 1.1 dB at frequency of 6.7 GHz. In conclusion, the monostatic RCS as a whole is below -31 dB in the frequency range of $2 \sim 8$ GHz.

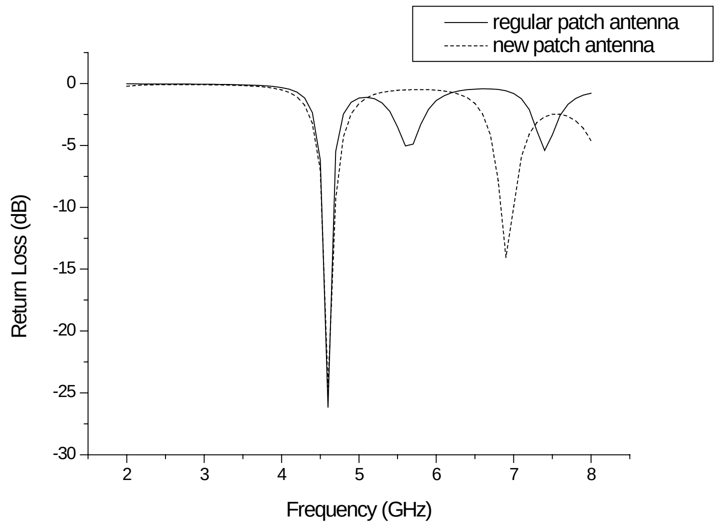
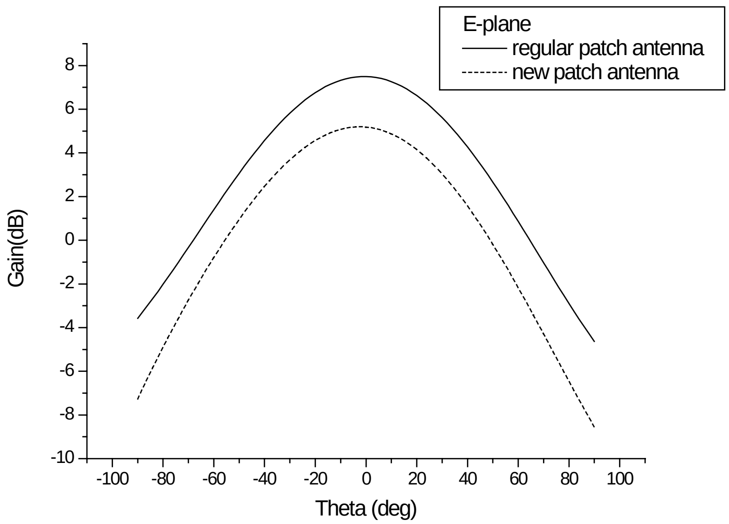


Figure 9. Return losses of original antenna and the proposed antenna.

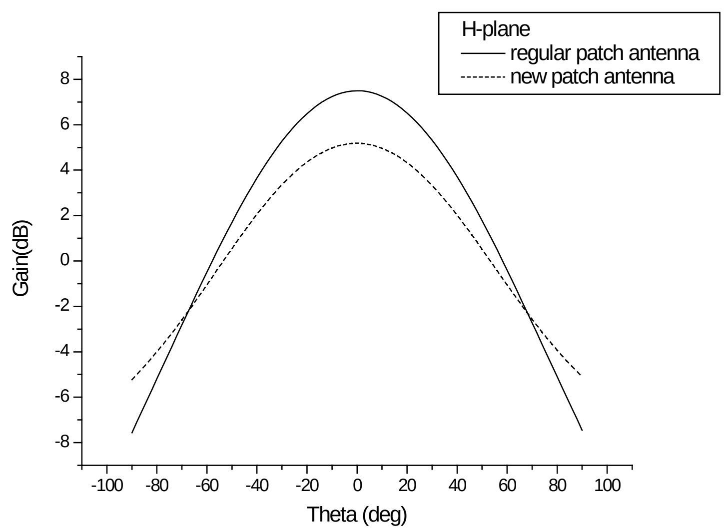
Figure 9 shows that return loss of the new antenna is improved further. The bandwidth is changed from 3.3% to 3.9%. Fig. 10 depicts the E-plane and H-plane gains of the two antennas. Gain of the improved low-RCS antenna is 5.20 dB, decreased by 2.3 dB. The gain loss is mainly from DGS, which increases the backside radiation. Although the gain is decreased, it is acceptable by our research program. The direction of the antenna's radiation is not changed.

Finally, the change of the RCS is analyzed when the incident angle is ($\theta = 60°$, $\varphi = 90°$). In Fig. 11, the RCS peak of the new patch antenna is -29.5 dB, which is reduced by 4.5 dB. Near 6 GHz, the RCS is also reduced heavily. Though RCS is increased near 3.6 GHz, the value is also lower than -65 dB, which is the minimum of the RCS in the frequency range of $2 \sim 8$ GHz. The increase has little influence to the overall RCS reduction.

From Fig. 8 and Fig. 11, the RCS peak of the new antenna is less acute than before. As a whole, the RCS is reduced heavily.



(a)



(b)

Figure 10. Gains of original antenna and the proposed antenna. (a) E-plane, (b) H-plane.

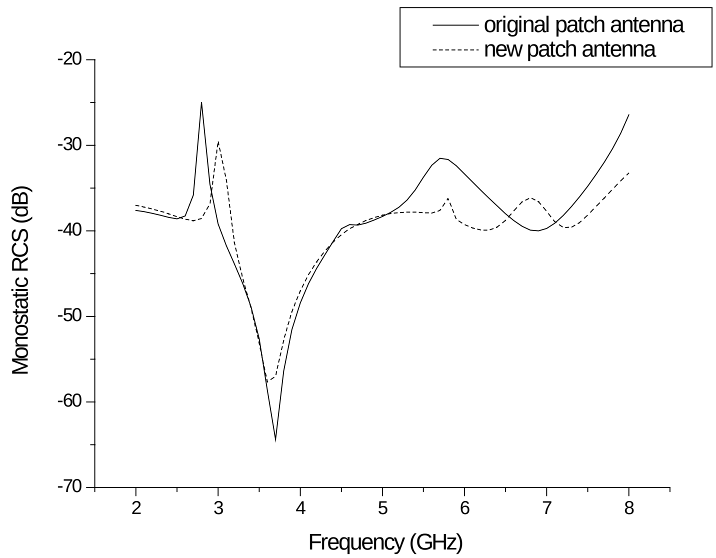


Figure 11. Monostatic RCSs of original patch antenna and the proposed antenna, incident angle ($\theta = 60^\circ$, $\varphi = 90^\circ$).

4. CONCLUSION

In this paper, an antenna with two circular apertures, a DGS and a shorting post is proposed. Circular aperture and DGS can reduce RCS at the operating frequency. Shorting post can reduce RCS at frequencies outside the operating band. The RCS of the new antenna is reduced in a large frequency range, while the antenna's direction and return loss are not changed and the decrease of gain is acceptable.

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