IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received November 19, 2017, accepted December 19, 2017, date of publication January 1, 2018, date of current version May 16, 2018.

Digital Object Identifier 10.1109/ACCESS.2017.2788043

In-Band Radar Cross Section Reduction of Slot Array Antenna

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This work was supported in part by the Fundamental Research Funds for the Central University under Grant XJS17110 and in part by the National Natural Science Foundation of China under Grant 61372001 and Grant 51607168.

ABSTRACT A slot array antenna is proposed for both in-band and out-of-band radar cross section (RCS) reduction. The presented slot array antenna is covered by the superstrate consisting of a polarization rotation reflective surface (PRRS). Four different configurations of the PRRS supersrtate are proposed and their effects on radiation and scattering performances of the slot array antenna have been investigated. By optimizing the arrangement of the unit cells of the PRRS, a good RCS reduction in an ultra-wide frequency band from 7 to 40 GHz is achieved. Besides, the in-band RCS of the proposed antenna is reduced by 12.4 dB compared with that of the reference antenna. Moreover, the 10 dB impedance bandwidth of the proposed antenna is enhanced from 3.5% to 14.2% and the gain remains nearly the same. Good agreement between the simulations and experiments is obtained.

INDEX TERMS Antenna, in-band radar cross section reduction (RCSR), polarization rotation reflective surface (PRRS), slot array antenna.

I. INTRODUCTION

In previous decades, stealth technology has been widely applied in low-observable platforms. Because antennas are the main scattering contributors in low-observable platforms, radar cross section (RCS) reduction of antenna has drawn more and more attention [1], [2]. Many methods for antenna RCS reduction have been reported, such as using frequency selective surface (FSS) as the ground of the patch antennas [3], [4], loading electromagnetic band-gap (EBG) structure [5] and radar absorber material (RAM) [6], [7]. However, these methods only work in a relatively narrow frequency band. A periodic resistive surface is proposed to reduce the out-of-band RCS of the slot array antenna in [8]. In [9]–[11], the partially reflective surface (PRS) antennas are proposed for wideband RCS reduction. However, these methods need a high profile.

The polarization rotation reflective surface (PRRS) can be used for wideband RCS reduction by arranging the unit cells in a chessboard configuration [12]. In [13], we have used the PRRS as the superstrate of a slot array antenna to reduce the out-of-band RCS. If the operation band of the PRRS covers that of the slot array antenna, the antenna gain will be significantly decreased. In order to achieve the RCS reduction in a wide band covering the operation band of the slot array antenna, we have investigated how the PRRS influences the radiation and scattering performances of the slot array antenna and proposed a slot array antenna with a specially arranged superstrate.

This paper is organized as follows. Section II describes the topological structure of the proposed slot array antenna and the PRRS used as the superstrate. In Section III, the impacts of different configurations of PRRS on radiation and scattering performances of the slot array antenna are discussed. Then, the comparison between the proposed antenna and reference antenna is presented in Section IV. Finally, the paper is concluded in Section V.

II. DESCRIPTION OF THE PROPOSED SLOT ARRAY ANTENNA

The proposed low-RCS slot array antenna is shown in Fig. 1(a). The antenna consists of a 4×4 slot array, which is backed by a metallic ground and covered by a superstrate

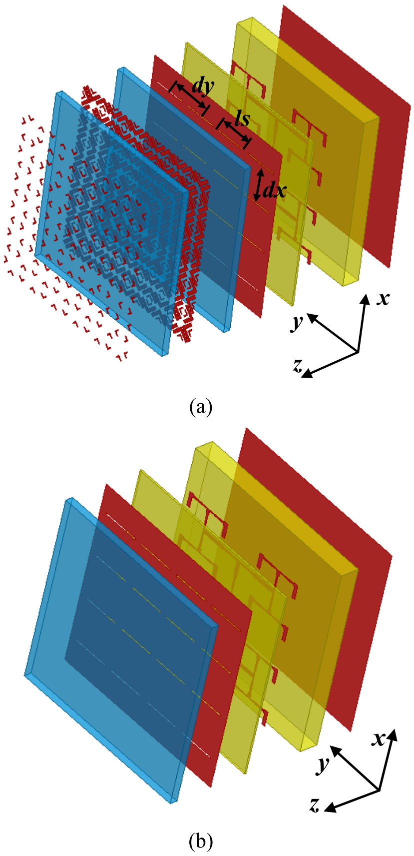

FIGURE 1. Geometry of the (a) proposed and (b) reference slot array antenna.

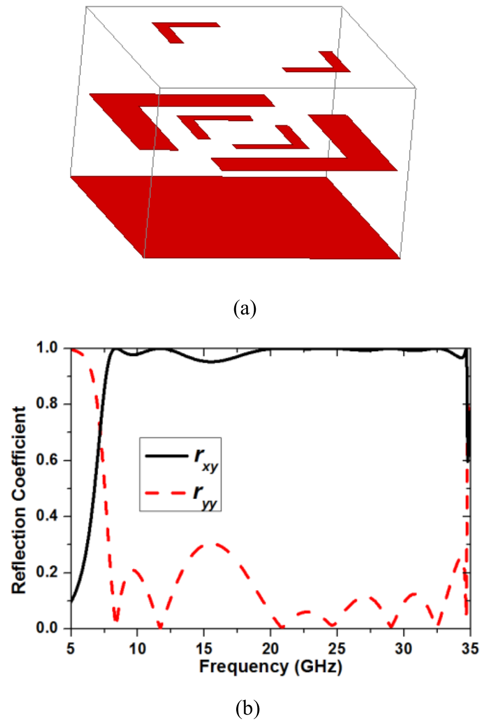

FIGURE 2. (a) Geometry of the unit cell of the PRRS and (b) the reflection coefficients of the PRRS.

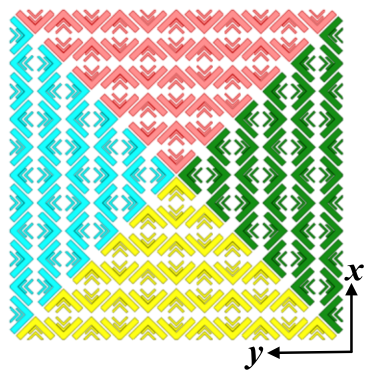

FIGURE 3. Configuration of the proposed superstrate.

of PRRS. The length of the slot *ls* is 10 mm and the distances between the adjacent slots in x- and y-directions are both 12 mm. The relative permittivities of the substrate and superstrate are 2.65 and 2.2 respectively. Fig. 1(b) shows the geometry of the reference slot array antenna resonating at 8.42GHz. It has the same parameters as those of the proposed antenna except for the superstrate. The reference antenna is covered by a dielectric superstrate with a thickness of 2 mm rather than a PRRS structure. The reason why we cover the reference antenna by a dielectric superstrate is to make the transverse dimensions of the two antennas the same. If the reference antenna is not covered by the dielectric superstrate, the transverse dimension of the reference antenna will be larger than that of the proposed antenna when they work at the same frequency. Thus, the comparison of RCS between them will be not fair.

The unit cell of the PRRS used in the proposed antenna is shown in Fig. 2(a). It consists of two layers of patterned metallic patches and a ground. As shown in Fig. 2(b), the working bandwidth of this PRRS is from 7.8 GHz to 34.7 GHz, in which its cross-polarization reflection coefficient is higher than 0.96. The specific parameters and analysis of the PRRS are given in our previous paper [14] in detail.

The proposed configuration of the PRRS used as the superstrate is given in Fig. 3. The unit cells of the PRRS are arranged in four triangle areas with orthogonal directions. When the PRRS is used as the supersrtate, the metallic ground is removed and the slot array antenna works as the ground of the PRRS.

III. DISCUSSION OF THE IMPACT OF THE PRRS ON RADIATION AND SCATTERING PERFORMANCES OF THE SLOT ARRAY ANTENNA

In order to investigate how the configurations of the PRRS influence the radiation and scattering performances of the slot array antenna, we have designed four different configurations of the PRRS which are shown in Fig. 4. The principle of RCS reduction using PRRS is given in Fig. 5. $\vec{E}_i$ and $\vec{E}_r$ represent the electric field intensity of the incident and scattered

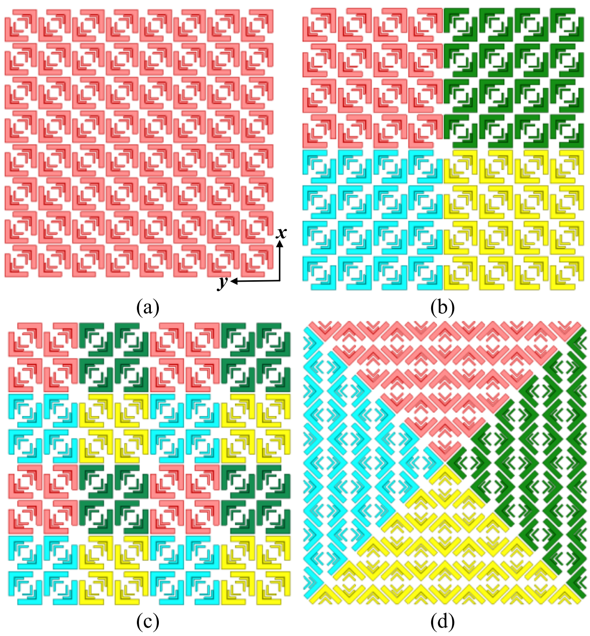

FIGURE 4. Different configurations of the superstrate. (a) Conf.1. (b) Conf.2. (c) Conf.3. (d) Proposed.

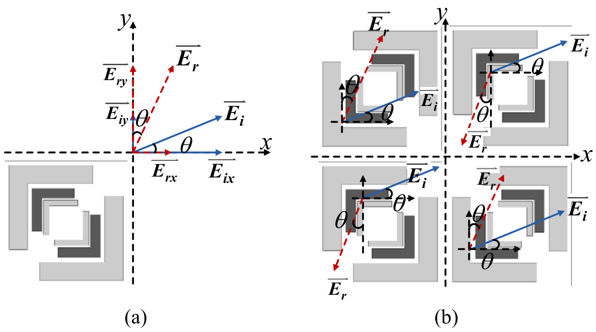

FIGURE 5. Decomposition of the electric field of the normal incident wave when the unit cells of the PRRS are arranged (a) in one direction and (b) in orthogonal directions.

waves respectively. When the unit cells of the PRRS are arranged in the same direction, the magnitude of $\vec{E}_r$ is equal to that of $\vec{E}_i$, as shown in Fig. 5(a). When the incident wave is x-/y-polarized, the co-polarization RCS can be reduced while the total RCS remains the same. However, when the unit cells of the PRRS are arranged in orthogonal directions as shown in Fig. 5(b), the electromagnetic (EM) waves reflected from different parts will be cancelled with each other and both the co-polarization RCS and total RCS reduction can be obtained.

The co-polarization RCS of the slot array antenna covered by the four different configurations of PRRS is shown in Fig. 6. It can be seen that the smaller the period of the PRRS is, the less RCS reduction is obtained in low frequency range. When the period of the PRRS arranged in the same direction is two (Conf. 3), the RCS reduction is less than 2dB in the frequency range from 7GHz to 10 GHz. So in order to obtain a good RCS reduction in the operation frequency band of the slot array antenna, the period of the PRRS should be at least four.

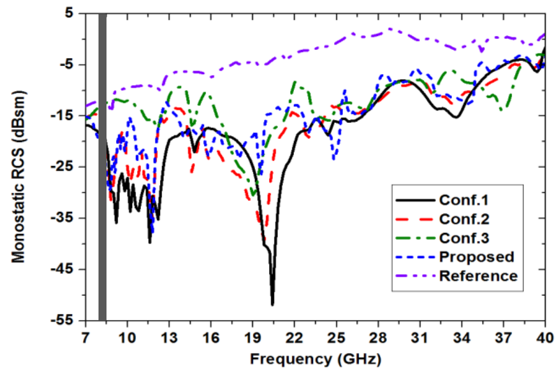

FIGURE 6. Co-polarization RCS of the reference antenna and the slot array antenna covered by the four different configurations.

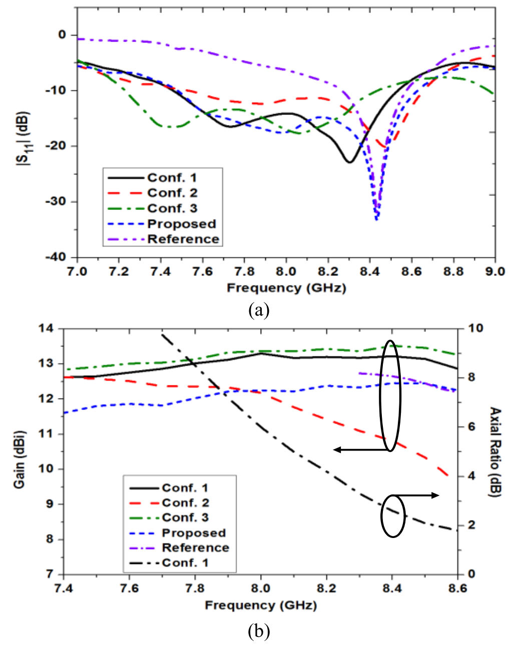

FIGURE 7. Radiation performance of the reference antenna and the slot array antenna covered by different PRRS superstrates: (a) $|S_{11}|$, (b) gain and AR.

The $|S_{11}|$ and gain of the slot array antenna covered by the four different PRRS supersrtates are shown in Fig. 7. It can be seen from Fig. 7(a) that all the configurations of the PRRS can enhance the impedance bandwidth of the slot array antenna. That's because the PRRS is generated by the slot and one more resonant frequency appears.

However, the gain of the antenna is significantly affected by the superstrate, as shown in Fig. 7(b). It can be seen that the gain of the antenna covered by Conf.1 is higher than that of the reference antenna. It is worth noting that the antenna covered by Conf.1 is circularly polarized (CP) and its axial ratio (AR) is less than 3dB at 8.42GHz. When the PRRS is generated by the x-polarized incident wave, the surface current distribution on the unit cell of the PRRS at 8.42 GHz

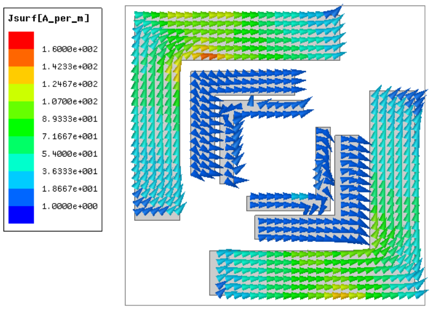

FIGURE 8. **The surface current distribution on metallic parts of the unit cell of the PRRS at 8.42GHz.**

is shown in Fig.8. It can be seen that there are two orthogonal surface currents with equal magnitude when the PRRS is generated by x-polarized EM field, which will generate two orthogonal electronic fields with equal magnitude. When the phase difference between the two orthogonal electronic fields is 90 degree, a CP EM wave is generated.

When the PRRS arranged like Conf.2, the left-handed and right-handed CP waves radiated from the four different parts will be canceled with each other. As a result, the antenna gain of the antenna covered by Conf.2 is significantly reduced by 2.41dB compared with that of the antenna covered by Conf.1. It can be referred from Fig.4 that the PRRS can't work at 8.42GHz when the period is two since the RCS of the antenna covered by Conf.3 is not reduced. So there are no CP waves generated and as a result the gain will not be decreased. For the case of proposed configuration of PRRS, the x-polarized EM field radiated from the slot is along the diagonal direction of the unit cells of the PRRS. In such a situation, only x-polarized electronic field can be generated. As a result, the gain of the antenna will not be significantly reduced.

The comparison of the radiation and scattering performances between the reference antenna and the slot array antenna covered by different configurations of PRRS at 8.42GHz is given in Table 1. It can be seen that both the antenna covered by Conf.1 and proposed antenna have good radiation performance and in-band co-polarization RCS reduction. However, the structure of Conf.1 can only reduce co-polarization RCS under x-/y-polarized incident waves while the proposed structure can reduce both the co-polarization and total RCS of the antenna under arbitrary polarized incident waves. Furthermore, the superstrate arranged as Conf.1 converts the linearly polarized (LP) EM waves to CP EM waves, which is undesirable. The gain of the antenna covered by Conf.2 is significantly reduced

TABLE 1. **Comparison of the radiation and scattering performances between the reference antenna and slot array antenna covered by PRRS.**

	Gain (dBi)	Relative Bandwidth	In-band co-polarization RCS (dBsm)
Conf.1	13.22	13.39%	-19.67
Conf.2	10.81	13.7%	-20.30
Conf.3	13.51	15.3%	-12.50
Reference	12.65	3.5%	-11.95
Proposed	12.45	14.20%	-24.32

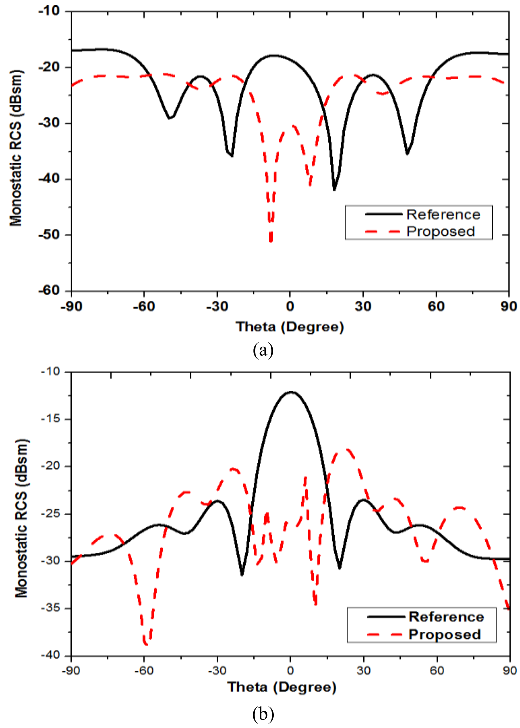

FIGURE 9. **Monostatic RCS of the reference and proposed antennas for oblique impinging plane waves in xoz-plane with (a) x-polarization and (b) y-polarization.**

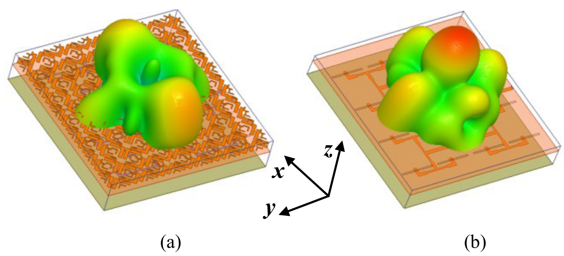

FIGURE 10. **Bistatic RCS at 8.42GHz: (a) proposed antenna and (b) reference antenna.**

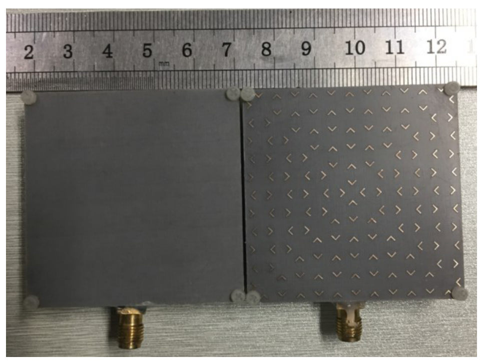

FIGURE 11. **Photograph of the reference and proposed antennas.**

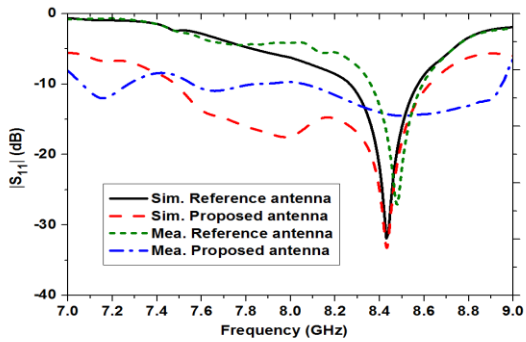

FIGURE 12. Simulated and measured $|S_{11}|$ of the antennas.

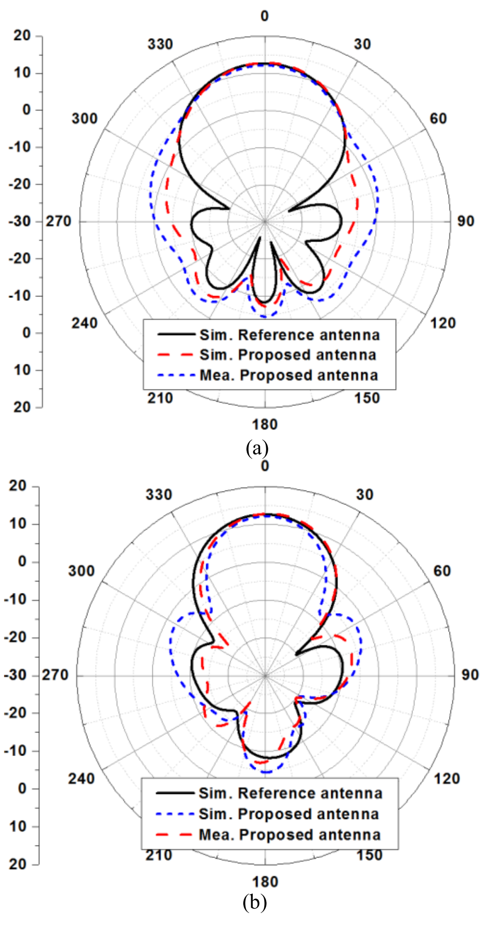

FIGURE 13. Simulated and measured radiation patterns at 8.42GHz in (a) xoz-plane, and (b) yoz-plane.

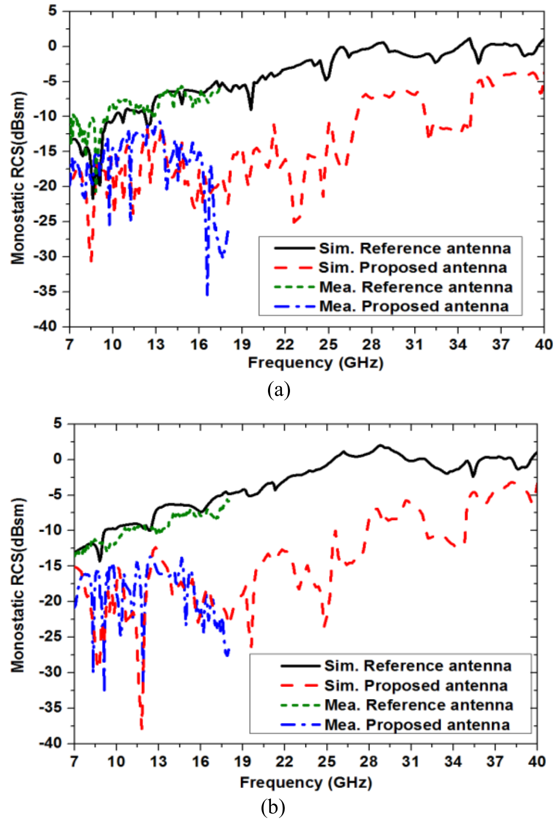

FIGURE 14. Mesearued RCS of the reference and proposed antennas for the normally impinging plane waves with (a) x-polarization and (b) y-polarization.

and the in-band RCS of Conf.3 is only reduced by 0.55dB. So the proposed structure of the PRRS is selected as the final solution balancing the radiation and scattering performances of the slot array antenna.

The monostatic RCS under oblique incident waves and the bistatic RCS of the proposed antenna at 8.42 GHz have also been investigated. The comparison of the monostatic RCS between the reference antenna and proposed antenna is shown in Fig. 9. It can be seen that the monostatic RCS is reduced in the angle range of ± 15 degree for both x- and y-polarized incident waves. Regardless of the dielectric loss, the PRRS is lossless and the scattered energy has not been reduced. So in order to investigate the energy distribution of the scattered energy, the comparison of the bistatic RCS at 8.42GHz between the reference antenna and the proposed antenna is given in Fig. 10. It can be seen through the comparison that the main lobe of scattered pattern is significantly reduced and two side lobe arise in x direction, which indicates that the energy is scattered to the non-threatening directions.

IV. EXPERIMENTAL RESULTS

The reference and proposed antennas are fabricated and measured to validate the simulated results. The photograph of the reference and proposed antennas are shown in Fig. 11. The S-parameters of the fabricated antennas are measured using the vector network analyzer Agilent N5230C, and the radiation and scattering performances are measured in the microwave anechoic chamber.

The simulated and measured $|S_{11}|$ is shown in Fig. 12. It can be seen that the measured $|S_{11}|$ of proposed antenna shifts to the higher frequency. It is caused by the installation error and the air gap between the superstrate and the slot array antenna. Fig.13 shows the radiation patterns in xoz- and yoz-planes. The measured gain of the proposed antenna is 0.3dB lower than the simulated results. It may be caused by the SMA connector and the dielectric loss.

The simulated and measured RCS of the reference and proposed antennas for the normally impinging plane waves is given in Fig. 14. Due to the restrictions of the test conditions, the RCS are not measured in the frequency range higher than 18 GHz. It can be seen that the RCS is significantly reduced from 7GHz to 40GHz and a reasonable agreement between the simulated and measured results is obtained, which indicates the good scattering performance of the proposed antenna.

V. CONCLUSION

In this paper, a slot array antenna with wideband RCS reduction covering its operation band has been proposed. The effects of different configurations of the PRRS superstrate on the radiation and scattering performances of the slot array antenna have been investigated. By optimizing the configuration of the PRRS, a good RCS reduction and a reasonable gain are obtained. The results show that the proposed antenna has a good RCS reduction from 7GHz to 40GHz while the in-band RCS is reduced as much as 12.4dB. The designed prototype is fabricated and measured. Good agreement is obtained between the simulations and the experiments, which shows that the proposed antenna has a promising low-RCS performance.

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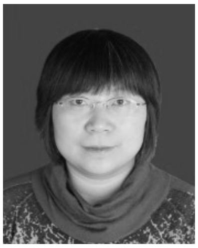

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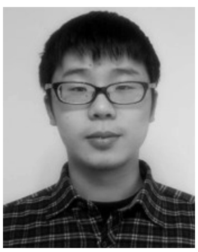

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