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RCS REDUCTION OF ARRAY ANTENNAS WITH RADAR ABSORBING STRUCTURES

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Abstract—This paper introduces a radar absorbing structures (RAS) applied to reduce the in-band radar cross section (RCS) of the array antennas. The structure of the RAS is based on square patch structure loaded with lumped resistances. An array with four patch elements was designed and built, and the RAS was located between two adjacent patch elements. The simulated and measured results show that the radiation performance of the array antenna is preserved when RAS is used. At operating frequency, the RCS of array antenna with RAS is obviously reduced compared with that of the original array.

1. INTRODUCTION

Radar cross section (RCS) is a measure of the reflective strength of a radar target, usually represented by the symbol σ and measured in square meters. RCS [1–5] is defined as 4 times the ratio of the power per unit solid angle scattered in a specified direction of the power unit area in a plane wave incident on the scatterer from a specified direction (IEEE standard). As detection and stealth technology develops rapidly, the RCS reduction has been an important problem in military applications and attracted significant attention. However, as a special scattering object, antennas are a major potential source of high radar visibility on stealth objects. The RCS reduction of antennas must preserve the basic radiation properties, which renders the reduction extremely difficult. To this end, a number of new structures and materials are utilized to antenna design to reduce the scattering of the antenna, and many approaches are proposed for RCS reduction such as shaping, coating with radar absorbing materials, and using passive and active cancelation technology. The RCS reduction

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of antennas can be classified into out-of-band frequencies reduction and in-band frequencies reduction. For out-of-band frequencies, there are many approaches to reduce the RCS of an antenna such as the frequency selective surfaces (FSS). While for in-band frequencies, it is more difficult to control the RCS. The key to RCS reduction is how to make the balance between the radiation and the low-scattering characteristics. The application of radar absorbing structures (RASs) is a promising way to solve this problem.

Recently, several RASs have been reported. In [6], high-impedance surfaces (HIS) comprising lossy FSS are employed to design thin radar absorbing structures. In [7], a novel ultra-thin radar absorbing structures using electromagnetic band-gap (EBG) is presented. Furthermore, a RAS element with near unity absorbance is presented in [8], and the structure consists of two metamaterial resonators that couple separately to electric and magnetic fields so as to absorb all incident radiation within a single unit cell layer.

Having advantages of light weight, low profile and ease of manufacture, microstrip antennas are widely used in communication systems. However, they are also easy to be detected due to their considerable RCS. Therefore, many scholars pay more attention to the RCS reduction of microstrip antenna [9–14]. But the RAS has been rarely used in the RCS reduction of array antennas. The reason is that for a patch array antenna design, element space is an important array factor. A large element space results in a higher directivity. However, the element space is generally kept smaller than λ to avoid the occurrence of grating lobes. But the common RAS cannot locate between two adjacent patch elements with the element space smaller than λ. In this paper, we concentrate on reducing the in-band RCS of patch array antenna with a special RAS [15]. The element space is 0.8λ, and the RAS mainly consists of two parts, square patch and lumped resistances. The simulated and measured results show that the radiation performance of the array antenna is preserved when RAS is used. At operating frequency, the RCS of array antenna with RAS has been considerably reduced.

2. RADAR ABSORBING STRUCTURES AND ARRAY ANTENNA WITH RAS

The most popular RAS is based on a periodic array of resistive elements backed by a grounded dielectric spacer. The selected RAS is a one-layer absorber, which is mainly consisted of two parts: square patches and lumped resistances. The configuration of this RAS is shown in Figure 1, in which the lumped resistance is loaded between the

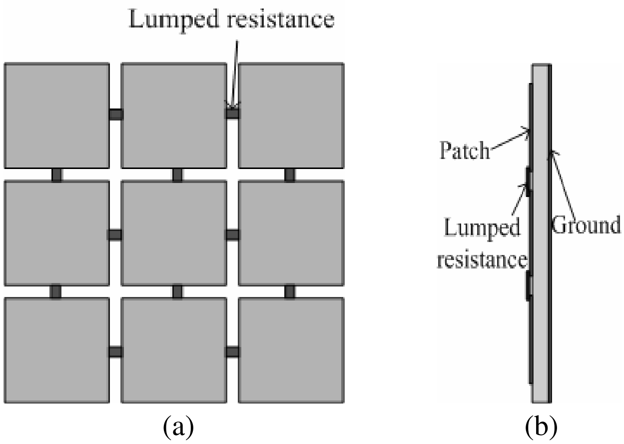


Figure 1. Geometry of the RAS. (a) Top view. (b) Side view.

adjacent patches of the RAS in two directions. The detailed absorbing principle of the RAS is presented by Bregar et al. [16]. Generally, the incident wave is significantly reduced in the material layer. However, a significant part of the incident wave can be reflected at the air-absorption-sheet interface, so the characteristics of the patch of RAS have to be adjusted in order to eliminate this front reflection and achieve sufficient absorption. Moreover, the lumped resistances can further reduce the level of absorption and alter the resonated frequency range of the RAS. Material layer can be made from either dielectric or soft-magnetic materials with an appropriate loss tangent, and its value must be larger than zero, such as FR-4 (Epoxy Glass Cloth) material, etc. Since each material has its advantages and disadvantages, the selection of materials is mainly dependent on the situation in real application.

The operating frequency band of the patch array antenna in this study is from 5.5 GHz to 6 GHz, so the absorbing bandwidth of RAS should cover this frequency band. The simulations are implemented using an analysis software Ansoft HFSS 11, which is based on the finite element method (FEM) algorithm. Simulated absorption property of the infinite periodic RAS is shown in Figure 2. Furthermore, for the RAS applied to the RCS reduction, there is a deviation between the infinite units and finite units. Here the finite periodic RAS is applied to the in-band RCS reduction, so it should adjust the parameters of the RAS to cover the operating frequency band after the first simulation. The final parameters of RAS unit cell are designed as follows: The substrate is 3 mm thick with dielectric constant of 4.4, and the loss

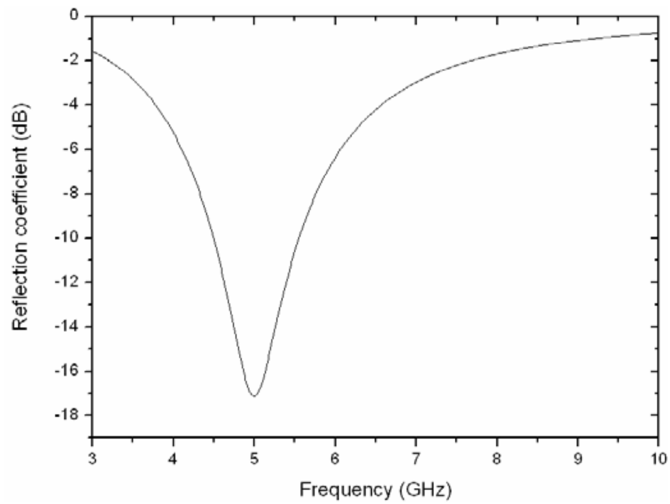


Figure 2. The simulated reflection coefficient of the RAS.

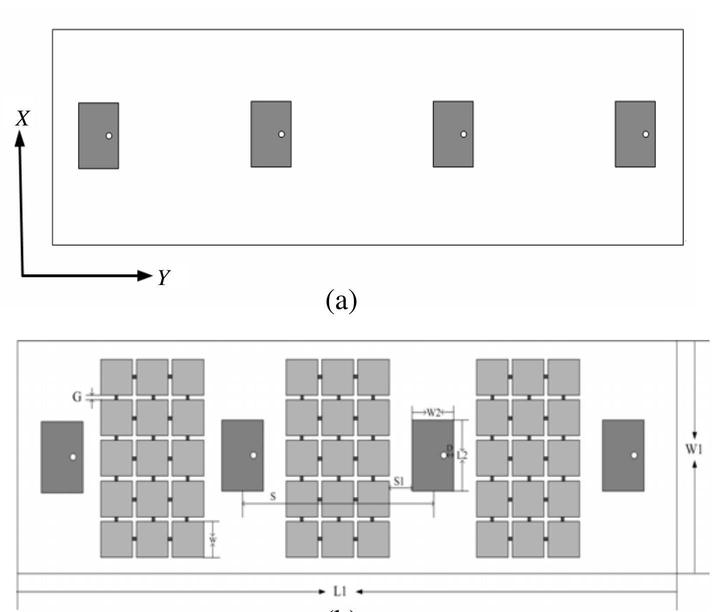


Figure 3. Geometry of patch array antenna. (a) Without RAS. (b) With RAS.

tangent is 0.02. The width of square patch is 7.5 mm, and the gap between adjacent edges of two square patches is 1 mm. Then the lumped resistances are loaded between the patches of the RAS in two directions. The value of the lumped resistance is 150 Ω.

The practical array of microstrip antenna with 1×4 patch elements is shown in Figure 3(a). The selected central frequency was 5.7 GHz. The height of the substrate was also 3 mm, and the dielectric constant was 4.4. The element space is 0.8λ. The array antenna is fed by coaxial feed.

The purpose of this paper is to propose a radar absorbing structure to reduce the RCS of the patch array antenna. In order to reduce the RCS of the array antenna without loss of radiation performance, three periods of RAS were embedded between two adjacent patch elements, as shown in Figure 3(b). A distance between the radiating patch and the RAS is designed which will have minimal effect on the patch. The detailed configuration and design values of the 1×4 patch array antenna are listed in Table 1. Figure 4 shows the photograph of the patch array antenna with and without RAS.

Table 1. Design parameters and values.

Parameter	Value (mm)	Parameter	Value (mm)
$W1$	48	D	1.6
$L1$	150	S	42
$W2$	10.8	$S1$	3.5
$L2$	16.4	W	7.5
G	1		

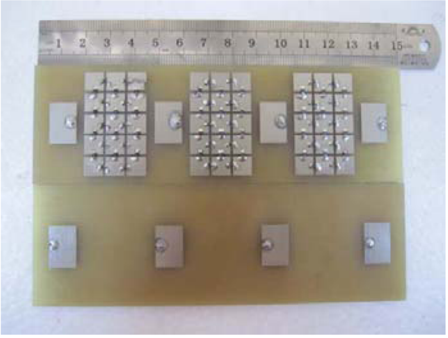


Figure 4. The photograph of the patch array antenna with and without RAS.

3. RESULTS

The radiation patterns and the return loss of two arrays with and without RAS in the same size are measured in anechoic chamber. The measurement of central frequency was taken at about 5.65 GHz which is in the absorbing band of the RAS. Figure 5 shows the return loss comparison for two arrays. According to the results, the accurate measured central frequency was slightly lower than the simulated, probably because the dielectric constant of the used dielectric layer is not accurate. Both of the measurements of two arrays resonate at almost 5.65 GHz. Figure 6 shows the comparison of the simulated patterns of two arrays. Figure 7 shows the comparison of the measured patterns of two arrays. The dot line indicates the patterns of the array with RAS, and the straight line is that of the original array antenna. In both of the E-plane and H-plane, the forward power received by RAS array antenna is almost the same as the original array antenna. In E-plane, a degradation of the side lobe level of the array emerges mainly because the interaction of the RAS with patch elements. A certain asymmetry of the pattern is mainly due to the error of measurement. The simulated and measured results demonstrate that the radiation characteristics of the patch array antenna with RAS are preserved.

The RAS is embedded between two adjacent patch elements to reduce the RCS of the array antenna when it works, so the RCS reduction mainly covers the operating frequency band. The

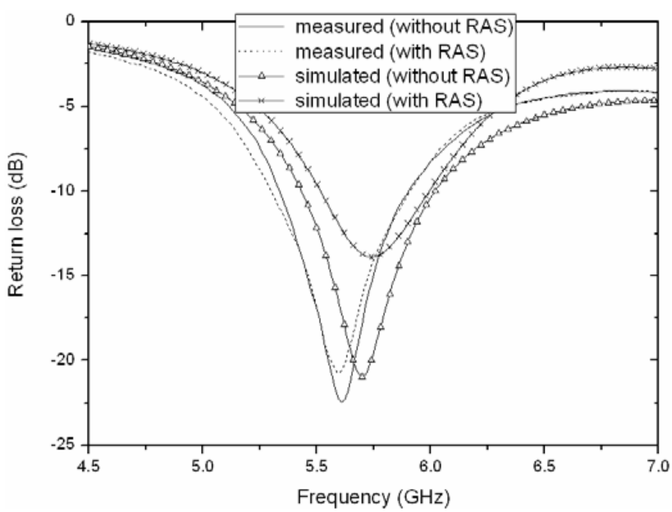


Figure 5. Return loss comparison for two patch arrays.

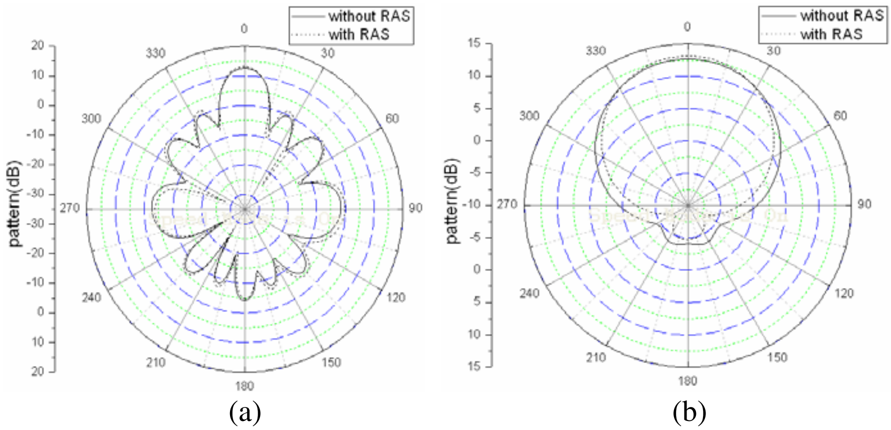


Figure 6. The comparison of the simulated pattern of two arrays. (a) E-plane. (b) H-plane.

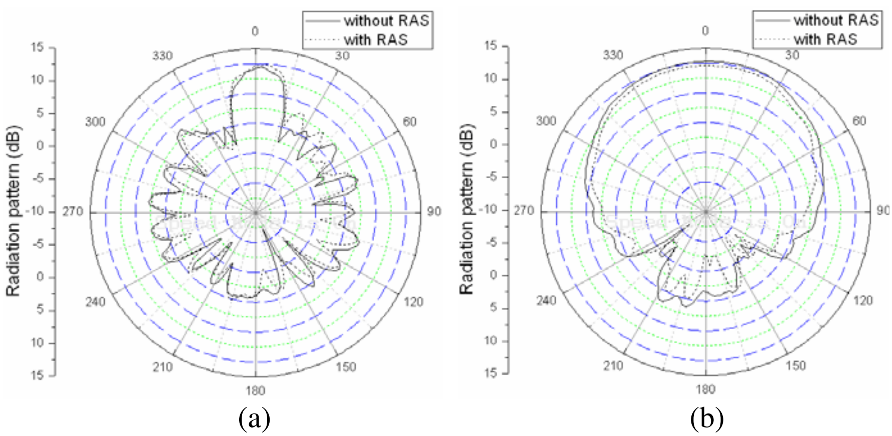


Figure 7. The comparison of the measured pattern of two arrays. (a) E-plane. (b) H-plane.

array antenna is terminated with matched load. Figure 8 shows the comparison of the monostatic RCSs of the two arrays in the same size, and the incident wave is perpendicular to the ground plane of the array antenna. From Figure 8, it can be seen that there is an evident RCS reduction of the patch array antenna with RAS, about 9.4 dB reduction at operating frequency.

Figure 9 shows the analysis of the monostatic RCS reduction under different incident angles. The RCS simulated is taken at 5.7 GHz. The

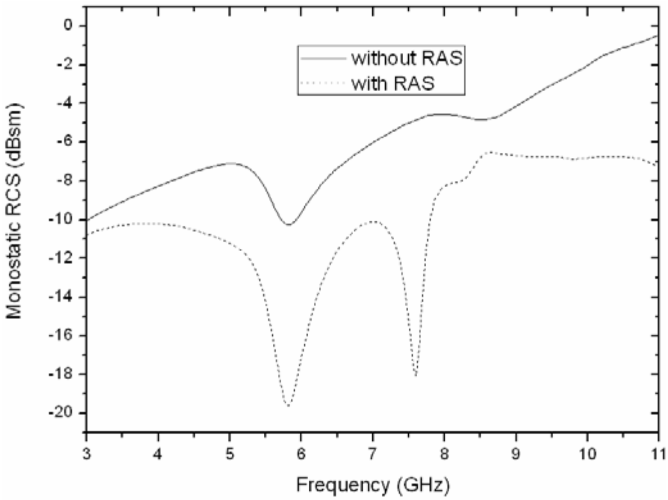
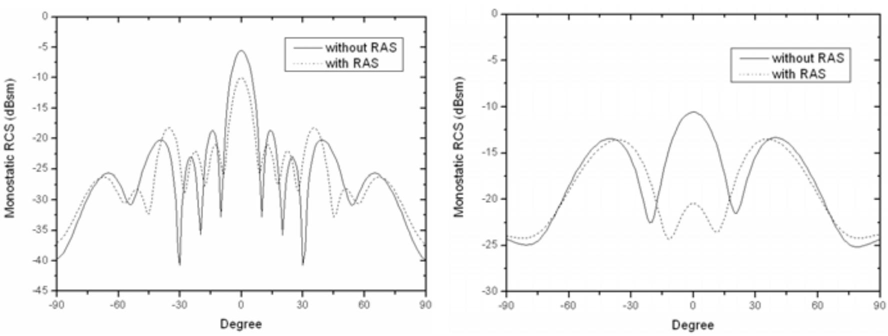


Figure 8. The comparison of the monostatic RCS of two arrays.



(a) (b)

Figure 9. RCS Comparison for two array antennas under different incident angles ($f = 5.7\,\text{GHz}$). (a) E-plane. (b) H-plane.

incident wave can be reflected at the air-absorption-sheet interface and lose in the substrate layer, which leads to the RCS reduction. When the coaxial feed is used to the excitation, the RAS is negligibly low in the main lobe, so the RCS can be reduced, and the performance of the patch array antenna is preserved. In Figure 9(a) for the E-polarized case, the polarization of incident wave is parallel to X direction (the coordinate is shown in Figure 3(a)). It can be seen that there is an evident RCS reduction of array antenna with RAS in the angular region $-20^\circ \leq \theta \leq 20^\circ$. Figure 9(b) gives a comparison of the simulated

RCSs of two array antennas for H-polarized case. The polarization of incident wave is parallel to Y direction. RCS reduction is obtained in the angular region $-20^\circ \leq \theta \leq 20^\circ$.

The simulated results show that the RAS can absorb incident wave effectively in the angular region $-20^\circ \leq \theta \leq 20^\circ$ in the operation band, and the patch array antenna with RAS has low RCS characteristic.

4. CONCLUSION

A RAS is introduced to the in-band frequency RCS reduction of microstrip patch array antennas. A patch array antenna of 1×4 elements integrated with RAS was designed and tested. The experimental results show that the RAS can absorb the incident wave effectively, and the monostatic RCS of the array antenna with RAS is significantly reduced in operation band. Meanwhile, the performance of the patch array antenna is preserved when RAS is used.

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