Reflection-type 1-bit coding metasurface based on polarization conversion for broadband RCS reduction

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Abstract. This paper proposed a 1-bit coding metasurface which based on polarization conversion for broadband RCS reduction. The coding metasurface were composed of digital '0' and '1' elements which formed by two semicircle structure and its mirror, respectively. The simulation confirmed that the unit cell can realize the polarization conversion; Moreover, the PCR was more than 90% at 7.7-18.3 GHz. Meanwhile, the phase difference of '0' and '1' element was exactly π at full band. So, the coding metasurface can scatter the energy of incident electric magnetic in all other directions, it successfully realized the RCS reduction.

Keywords: coding metasurface; polarization conversion; RCS reduction.

1. Introduction

Radar cross section (RCS) is important physical quantity to describe the electric magnetic wave scattering intensity of an object^[1]. Low RCS can reduce the probability of the target being detected. Thus, reducing RCS has become a study focus of military field.

The basic RCS reduction theory of coding metasurface rely on the antenna theory^[2,3]. By combining the perfect magnetic conductor (with 0 phase) and the perfect electric conductor (with π phase), in general, they are named digital '0' and '1' element, respectively^[4,5]. The reflection waves will cancel out when the electric magnetic plane waves incident normally, thus, the RCS was reduced finally.

This paper structured digital '0' and '1' element by introducing polarization conversion principle ^[6-8]. That is, design a unit cell and use it to form a 3×3 array named '0' element, then, rotate the unit cell by 90°, similarly, use it to form a 3×3 array named '1' element, finally, combine the '0' and '1' element to form a 1-bit coding metasurface.

2. The design of the coding metasurface unit cell

The unit cell of the coding metasurface is showed in figure 1, which is similar to a sandwich. The upper and the bottom are copper, and the middle layer is F4B (the relative permittivity is 2.65) with a thickness of h=3.5mm. The copper electrical conductivity is 5.8×107 S/m and the thickness is 0.017mm. The inner radius and outer radius of the upper copper is r1=3.5mm, r2=4mm, the gap between of the two semicircle is d=1.36mm.



Fig. 1 The unit cell of the coding metasurface

We obtained the co-polarization, cross-polarization reflection coefficients and the polarization conversion ratio of the unit cell by simulation software. As shown in figure 2a, the

ISSN:2790-1688 Volume-8-(2023) cross-polarization reflection coefficients achieve 1.0 almost at 7.4-19.4 GHz. This result indicates that the unit cell of the coding metasurface can realize the electromagnetic waves polarization conversion. In order to indicate quantitatively the properties of the polarization conversion, we defined the concept of the polarization conversion ratio (PCR), $PCR = \frac{r_{xy}^2}{r_{xy}^2 + r_{xx}^2}$. The figure 2b

shown that the PCR of the unit cell, the simulation indicated it can realize more than 90% PCR at 7.7-18.3 GHz.



Fig.2 (a) co-polarization and cross-polarization reflection coefficients. (b) The polarization conversion ratio of the unit cell.

The mechanism of polarization conversion is shown in figure 3. The electromagnetic waves directions are marked by x- and y-axes, the anisotropic axes are marked by u- and v-axes. When the y-polarized wave is incident on the surface of the unit cell, it has two orthogonal equal components, that is $E_{ui} = E_{vi}$. For example, if v-polarized incident wave excite electric resonance, v-direction can be look as perfect electric conductor (PEC), reflective wave E_{vr} and incident wave excite magnetic resonance, u-direction can be look as perfect magnetic conductor (PEC), reflective wave E_{vr} and incident wave excite magnetic resonance, u-direction can be look as perfect magnetic conductor (PMC), reflective wave E_{ur} and incident wave E_{ui} have no phase difference now, that is in-phase. Finally, the reflective wave E_{r} is changed to x direction, this means the y-polarized incident wave is converted to x-polarized reflected wave.



Fig. 3 The mechanism of polarization conversion

However, whether it is electric or magnetic depended on the surface current distributions. Similarly, the unit cell can convert the x-polarized wave to y-polarized wave and the principle is the same. We simulated the reflection coefficients and phase difference of u- and v-direction using the CST software. As shown in figure 4, the reflection coefficients of u- and v-polarized wave achieved 1.0 almost; meanwhile, the phase difference between them is nearly π . The results confirmed the polarization theory mentioned above.



Fig. 4 Reflection coefficients and phase difference of u- and v-direction

3. The design of the coding metasurface

The coding metasurface was composed of 8×8 super-unit-cells, and each super-unit-cell('0' or '1' element) consists of an 3×3 array of unite cell. The coding metasurface sequence and configuration were shown in figure 5.



Fig. 5 The coding metasurface sequence and configuration

The phase of '0' and '1' element was simulated, as shown in the figure 6, the phase difference of '0' and '1' element is exactly π at full band. Therefore, an ultra-broadband RCS reduction of the proposed coding metasurface is expected. The figure 7 shows the metasurface simulation results of mono-static RCS reduction. A larger than 10 dB reduction was achieved over the wide band frequency ranged from 10.7-18.9 GHz, especially, the RCS reduction can reach to 22 dB at 12.3 GHz. It is noteworthy that the RCS reduction based on the polarization conversion. The 3D plots of the scattering pattern of the coding metasurface at 12.3 GHz was shown in figure 8. It is very obvious that the simulated coding metasurface can scatter the energy of incident electric magnetic in all other directions, therefore, the coding metasurface we proposed has the ability to steal the electric magnetic waves.



Fig. 6 The reflection phase of '0', '1' element and the phase difference of them.



Fig. 7 The simulated mono-static RCS reduction of the coding metasurface illuminated by normally incident electric magnetic wave at different frequencies.



Fig. 8 The far-field scattering patterns for the reflection-type 1-bit coding metasurface under the normal incidence of electric magnetic wave at 12.3 GHz frequencies.

Conclusion

This paper designed a 1-bit coding metasurface based on polarization conversion for broadband RCS reduction. Which was composed of two semicircle structure and its mirror. We simulated the PCR of the unit cell, it was confirmed that this structure has the high PCR. Finally, we designed the coding metasurface using the unit cell and its mirror, the simulated results proved the 1-bit coding metasurface can scatter the energy of incident electric magnetic in all other directions, so it successfully realized the RCS reduction.

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