Design of A Wideband Coding Metasurface for RCS Reduction

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***Abstract*—A wideband polarization conversion unit cell based on metal cut-wire structure is proposed and investigated. This unit cell yields above 90% polarization conversion ratio from 6-14GHz, in reasonable agreement with theoretical prediction. We can encode it in regular and random arrangements, which can be used to explore the reduction mechanism of RCS. At normal incidence of *x*- and *y*- polarized waves, the RCS reduction of metasurfaces are more than 10 dB from 6 GHz to 14 GHz in the simulations. Further, the metasurfaces are single-layered, polarization-insensitive for TE and TM waves. This design is expected to provide efficient components in application for stealth field technology.**

Keywords—polarization conversion; scattering pattern; random coding; RCS reduction

I. INTRODUCTION

As an artificial periodic or non-periodic two-dimensional (2D) planar form of metamaterials, metasurface is composed of basic units consisting of subwavelength scale [1-4]. Because of the ability to control reflection/refraction wavefront of electromagnetic waves, it can be widely used in radar stealth. In radar stealth technology, to reducing the possibility of object detection, we mainly change the characteristics of radar echo signal, and radar cross section area (RCS) is an important physical quantity to measure the radar echo capability of a target. We can design the suitable structure of metasurfaces to achieve RCS reduction [5-8].

In recent years, because of the tremendous potential in military field, the metasurface composed of artificial magnetic conductor with low RCS has attracted great attention from researchers. This kind of metasurface just reflects the incident waves into the backward space, which greatly reduces the detected possibility of metasurface by infrared devices [9-11]. As the important part of metasurface, phase gradient metasurface introduces an artificial wave vector into the interface to control the propagation direction of reflected wave. To suppress the normal strong scattering of metasurface, we can design a series of polarization conversion coding metasurfaces composed of “0” and “1” units to achieve the RCS reduction at normal incidence [12-15].

In this paper, we designed a class of 1 bit regular coding metasurfaces and a random coding metasurface to analyze and verify the RCS reduction characteristics. The designed metasurfaces present the characteristics of wide band range, polarization-insensitive for TE and TM waves, and the RCS of the metasurfaces are reduced by an average of 10 dB in the frequency range of 6-14 GHz.

II. RESULTS

A unit cell is proposed based on a metal cut-wire structure, as shown in Figure 1(a), it can be assumed as “0” unit. Then, we rotate this structure counterclockwise by 90° to get unit cell as shown in Fig. 1(b), which can be assumed as “1”. The whole unit cell can be divided into three parts, where the period is p=10 mm. The front layer is the copper film with metal cut-wire structure, length and width of the rectangular are l = 10 mm and w = 1.6 mm. The middle layer is FR4 film with the thickness of 3.5 mm, the dielectric constant and the loss tangent are 4.3 and 0.025. The back layer of copper film has the same thickness compared with the front metal structure. As shown in Figure 1(c), the unit cell can achieve a linear polarization conversion in a range of 6-14GHz. The cross-polarization reflection coefficients (r_{yx} and r_{xy}) are greater than 0.85, and the co-polarization reflection coefficients (r_{xx} and r_{yy}) are basicilly less than 0.3. $\Delta\varphi_{10}$ is the corresponding phase difference of “0” and “1” units. The cross-polarization phase difference $\Delta\varphi_{10} = \pm 180^{\circ}$ in the range of 4-16 GHz, which indicatesthe phase gradient of designed metasurface is 180°.

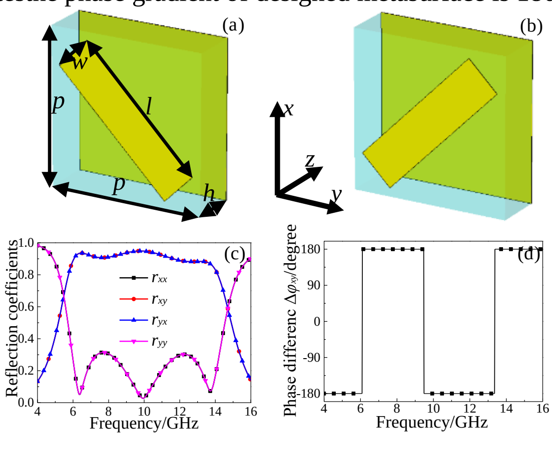

Fig. 1. (a) The unit cell structure of element “0”; (b) the unit cell structure of element “1”; (c) the reflection coefficient of elements “0” and “1”; (d) the reflection phase difference of elements “0” and “1”.

This bandwidth enhancement results from the superposition of multiple polarization conversion peaks, mainly due to the Fabry-Perot-like resonance cavity inside the two metallic layers. The incident EM wave prompted an overlap of resonances, co-polarization wave interference cancellation, and cross-polarization wave interference superposition.

To satisfy the periodic boundary required for element simulation, we use a supercell containing 5×5 basic units and design a series of coding forms to explore the RCS reduction characteristics of metasurface. Figure 2(a-d) shows the scattering characteristic diagram of different coding form at 10 GHz with the size of 400×400 mm^2. For coding 00/00 or 11/11 as shown in Fig. 2(a), the energy scattering direction is upright, we can see the normal scattering capability is very strong. For coding 01/01 as shown in Fig. 2(b), the energy scattering diverging to both side. Energy scattering of 01/10 in Fig. 2(c) diverged to four direction, and the normal scattering capability was relatively weak. As to random coding metasurface in Fig. 2(d), we can see the main lobe is obviously decreased compared to coding 01/10, and produces many side lobes.

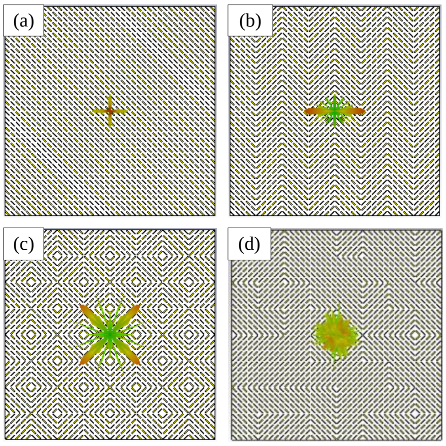

Fig. 2. The normalized field intensity patterns of the scattering of (a) 00/00 or 11/11; (b) 01/01; (c) 01/10; and (d) random distribution at 10 GHz for the coding metasurface.

As shown in Figure 3(a), the monostatic RCS in all arrangements are given when *x*- or *y*-polarized wave is normally incidence on metal surface and metasurface. Figure 3(b) shows a broadband 10 dB RCS reduction in the range of 6-14GHz, excluding the 00/00 and 11/11. The RCS reduction nearly between 9.5GHz and 11GHz is more than 15 dB, and the RCS reduction presents a maximum at 10GHz under 01/01 and random coding, compared with a maximum at 10.5GHz under 01/10 coding.

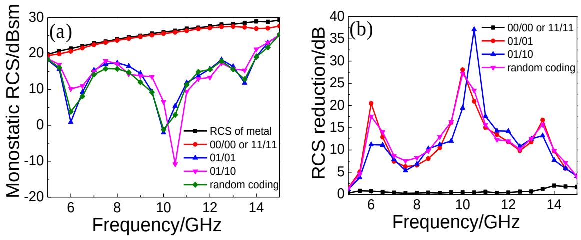

Fig. 3. Simulated results of a series of coding metasurfaces: (a) monostatic RCS of coding metasurfaces and metal; (b) RCS reduction of coding metasurfaces.

To further study the characteristics of RCS reduction, we compare the scattering properties of the 01/10 and random coding at 10GHz. As shown in Figure 4(a), we can see the scattering characteristic of 01/10 coding metasurface compared with metal plate, the main lobe energy is suppressed with enhancing the scattered energy of other two side lobes, so we can achieve the RCS reduction at normal incidence. As shown in Figure 4(b), the scattering characteristic of random coding metasurface is distributed into all direction, which provides a greater scattering performance in a large range of reflected angle compared with 01/10. Based on the above results, it can be suggested that the polarization conversion metasurface can realize RCS reduction in a wide frequency range, and we can adjust the scattering field dynamically to scatter the reflected waves uniformly.

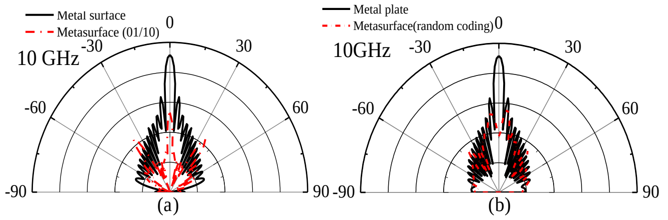

Fig. 4. Scattering patterns of coding metasurface and metal plate in the *XOZ*-plane at 10GHz: (a) 01/10; (b) random coding.

III. SUMMARY

In summary, a polarization conversion basic unit is designed, which can realize a wideband linear polarization. Then, a series of coding metasurfaces were designed, we watch the scattering patterns of different coding sequence to explore the reduction mechanism of RCS. At normal incidence of *x*- and *y*- polarized waves, the RCS reduction of part metasurfaces are more than 10 dB from 6 GHz to 14 GHz in the simulations, and these metasurfaces provide a polarization-insensitive incident angle for TE and TM waves. Our design can potentially be implemented in stealth field technology.

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