Broadband Coding Metasurface for Radar Cross Section Reduction

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***Abstract*—In this paper, 1-bit coding metasurface is presented and used to reduce the radar cross section (RCS) of metallic object over a wide frequency range in microwave region. We propose and design a structure-simple unit cell to realize 180° (or π) phase difference, and 4×4 unit cells compose "0" or "1" elements which arrange into a 1-bit coding metasurface. By encoding "0" and "1" elements with particular sequences, the electromagnetic (EM) waves can be manipulated and the coding metasurface can realize different functions. We design two metasurfaces with different coding sequences to reduce the RCS of a target. The simulation results demonstrate that a wideband RCS reduction is achieved by the coding metasurface. For Case I, the RCS reduction is larger than 7 dB from 10.23 to 18.34 GHz and reaches a peak at 12.03 dB. For Case II, the RCS reduction is larger than 7 dB from 10.14 to 19 GHz and reaches a peak at 22.83 dB.**

Keywords*—*coding metasurface; 1-bit; radar cross section (RCS) reduction; broadband

I. INTRODUCTION

Electromagnetic metamaterials, as a kind of new technology, attract more and more attention in recent years. Metamaterials are composed of periodic artificial structures or non-periodic artificial structures and can be described by effective medium theory[1]. Some unique properties of controlling EM waves are able to be obtained, such as negative refraction[2], perfect imaging[3], super-lensing[4], and invisibility cloaking[5, 6]. Owing to the material loss and difficult fabrication, three-dimensional (3D) metamaterial, in the past decade, has evolved into two-dimensional (2D) metasurface, which is much more convenient in practical applications. Moreover, coding metamaterial was proposed in 2014 and can be digitally controlled in order to obtain distinctly different functions[7]. Different from the previous metamaterials or metasurfaces, the coding metamaterials are represented by digital coding instead of medium parameters.

Recently, electromagnetic transparency or invisibility of targets attracts much attention. Coding metamaterial is capable of reducing radar cross section (RCS) after a careful design. A coding metasurface with random coding sequence can randomly scatter the incident wave in multiple directions[8]. There are many published works on RCS reduction based on coding metamaterials in last years[9-14]. Yuan *et. al.* designed a spiral-coded metasurface composed of 8×8 subarrays and achieved a -10 dB RCS reduction from 12.2 to 23.4 GHz[9]. Some optimization algorithms have been used in the design of coding metasurface for RCS reduction, such as ergodic algorithm[10], particle swarm algorithm[11-12] and genetic algorithm[13-14]. However, the requirements of RCS reduction are multiaspects, such as, broad band or multi-frequencies, large RCS reduction, polarization insensitivity, wide incident angles, tunableness and so on.

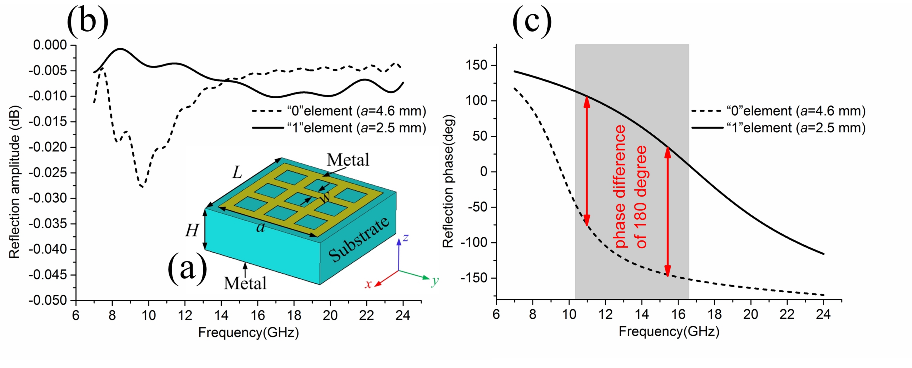

Fig. 1. (a) Scheme of the designed unit cell. (b) Simulated reflection amplitudes of "0" element and "1" element from 7 to 24 GHz. (c) Simulated reflection phases of "0" element and "1" element from 7 to 24 GHz. The grey area presents the band range (from 10.38 to 16.64 GHz) in which the phase difference of the designed "0" element and "1" element ranges from 160° to 200°. The two red double arrow lines indicate the phase difference of the designed "0" element and "1" element is accurately 180° at 10.94 and 15.35 GHz.

In this paper, we propose and design a unit cell for coding metasurface with 180° phase difference in a broad band. Two kinds of arrangements of "0" and "1" elements are presented for the realization of the RCS reduction. An ultra-wideband RCS reduction greater than 7 dB is achieved in the frequency range from 10.23 to 18.34 GHz (56.77% bandwidth) for Case I and from 10.14 to 19 GHz (60.81% bandwidth) for Case II, respectively.

II. Coding Metasurface Design

A. Unit Cell Design

In order to achieve 180° phase difference in a wide frequency range, we design an isotropic unit cell with simple structure as shown in Fig. 1(a). The subwavelength unit cell of the coding metasurface is composed of two-layer metallic structures separated by a dielectric substrate plate with a thickness H=2 mm. The top layer is a simple metallic structure and the bottom one is a metallic ground. The dielectric substrate is made of F4B with dielectric constant 2.65 and the loss tangent 0.001. The sidelength of unit cell is set to L=6 mm, the thickness of metallic structure is t=0.018 mm, and the width of metallic wire is set to w=0.5 mm.

Figs. 1(b) and (c) show the simulated reflection amplitudes and phases when the sidelength of the metallic structure a=4.6 mm and a=2.5 mm, respectively. The phase difference is approximately 180° in a broad band. In particular, from 10.38 GHz to 16.64 GHz, the phase difference ranges from 160° to 200° (it is accurately 180° at 10.94 GHz and 15.35 GHz). In addition, the reflection amplitudes of the designed unit cells are greater than -0.028 dB and get a peak of -0.00073 dB. Here, we use 4×4 unit cells with dimension a=4.6 mm as the "0" element and these with a=2.5 mm as the "1" element.

B. Metasurface Design for RCS Reduction

As we known, the radar cross section (RCS) of a planar or cylindrical metallic object has a strong reflection in the back scattering direction. In fact, the invisibility cloak is one device to reduce RCS by guiding EM waves to propagate around the target, and the absorber is another device for reducing RCS by absorbing the energy of EM waves. Nevertheless, the coding metasurface with specific sequence also has the ability to redistribute the incident beam into numerous directions.

Here, we present two kinds of coding metasurfaces with different sequences for RCS reduction. The first case is an 8×8 random sequence of "0" and "1" elements illustrated in Fig. 2(a), and the simulated model illustrated in Fig. 2(b), which total covers an area of 192×192 mm^2.

To verify the RCS reduction and diffusion effects of Case I, the simulation results of three-dimensional (3D) scattering patterns under normal incidence at 10.94 GHz and 15.35 GHz are presented in Figs. 2(c) and (d), respectively. It is observed that the coding metasurface redirects the incident EM wave to most directions, and makes significant reductions in RCS.

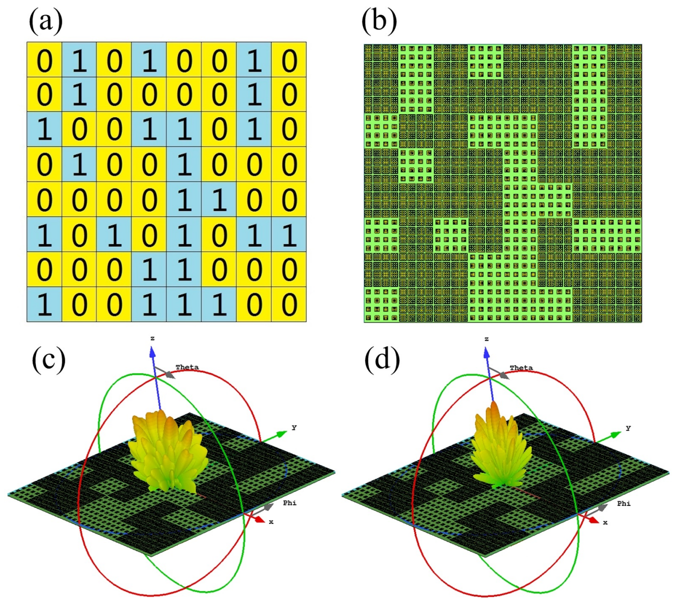

Fig. 2. (a) Structure diagram of Case I coding metasurface. (b) Simulated model of Case I coding metasurface. (c) Simulated reflected beams of Case I coding metasurface at 10.94 GHz. (d) Simulated reflected beams of Case I coding metasurface at 15.35 GHz.

To further verify the RCS reduction and diffusion effect of our designed unit cells for coding metasurface, we utilize a 8×8 optimized coding sequence 00110101 in both the horizontal and vertical directions mentioned in [7] as shown in Fig. 3(a). The simulated model of Case II is illustrated in Fig. 3(b), which also covers an area of 192×192 mm^2.

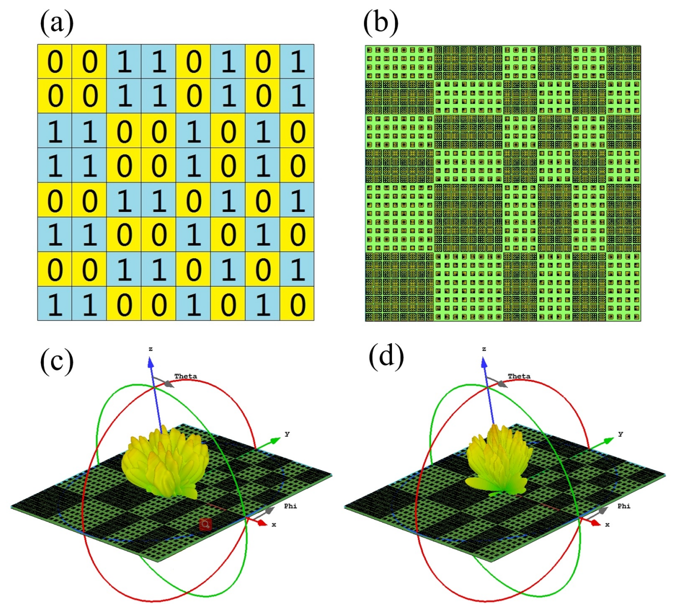

Fig. 3. (a) Structure diagram of Case II coding metasurface. (b) Simulated model of Case II coding metasurface. (c) Simulated reflected beams of Case II coding metasurface at 10.94 GHz. (d) Simulated reflected beams of Case II coding metasurface at 15.35 GHz.

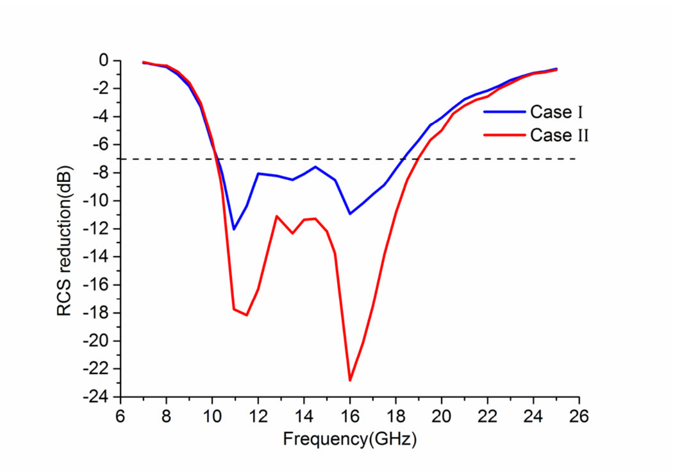

Fig. 4. The simulated results of RCS reductions of Case I and Case II coding metasurface over a wide frequency range from 7 to 25 GHz, respectively. The dash line denotes the -7 dB RCS reduction. The frequency range of Caes I coding metasurface greater than 7 dB RCS reduction is from 10.23 to 18.34 GHz, and the frequency range of Caes II is from 10.14 to 19 GHz.

The simulated results of 3D scattering patterns for Case II under normal incident at frequency 10.94 GHz and 15.35 GHz are shown in Figs. 3(c) and (d), which also illustrate a good performance of RCS reduction. It is observed that the effect of RCS reduction of Case II coding sequence is a little better than Case I by comparing Figs. 3(c) and (d) to Figs. 2(c) and (d).

C. *Result Analysis of Two Cases*

Fig. 4 illuminates the simulated results of RCS reductions of Case I and Case II coding metasurfaces over a wide frequency band ranging from 7 to 25 GHz. An ultra-wideband RCS reduction greater than 7 dB is obtained in the frequency range from 10.23 to 18.34 GHz for Case I (56.77% relative bandwidth) and from 10.14 to 19 GHz for Case II (60.81% relative bandwidth), respectively. In addition, the maximum RCS reduction is 12.03 dB at 10.94 GHz for Case I, and 22.83 dB at 16 GHz for Case II. The two peaks in RCS reduction curves show that the most sufficient cancelation happens when the reflection phase difference of “0” and “1” elements is accurately 180°. The RCS reduction is obtained under a large phase difference approximately 180°±40°. It is noteworthy that the -7 dB RCS reduction band is in accordance with the results predicted by the reflection phase of unit cells. Comparing the simulation results of Case I to those of Case II, as shown in Fig. 4, the RCS reduction of Case II is greater than that of Case I almost at all frequencies, which indicates that the coding sequence plays an important role in RCS reduction.

III. Conclusion

In summary, two kinds of 1-bit coding metasurfaces arranged by “0” and “1” elements were proposed for RCS reduction. The simulated results demonstrated that the designed coding metasurfaces are capable of reducing RCS over a wide frequency range. For Case I, the RCS reduction is greater than 7 dB from 10.23 to 18.34 GHz, and for Case II, the RCS reduction is larger than 7 dB from 10.14 to 19 GHz.

Acknowledgment

This work was supported by the National Science Foundation of China (61522106, 61631007, 61571117, 61501117, and 61501112), the Foundation of National Excellent Doctoral Dissertation of China (201444), and the 111 Project (111-2-05).

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