Design of Coding Engineered Reflector for Low Level Diffuse Scattering

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***Abstract*—In this paper the design of non-absorptive, diffusive, coding engineered reflector for EM-wave manipulation at millimeter wave regime is presented. The design principle of the presented 1-bit engineered reflector is based on the combination of the reflection phase cancellation and cross-polarization rotation principles. The proposed surface can efficiently diffuse-back the incident EM-wave with low backward scattering level under both normal and oblique incidence of far-field plane wave. The 1-bit coding engineered reflector is formed by a random distribution of a precisely designed anisotropic unit cell (as "0" elements) and its mirrored unit cell (as "1" elements) with about 180°±37° phase difference between their reflection phases. The cross-polarization rotation introduced by the unit cell and the phase difference (reflection phase cancellation) between "0" and "1" elements across the surface aperture both contributes to EM-wave diffusion in the half-space in front of the presented engineered reflector.**

Index Terms—metasurface, diffuse reflection, millimeter waves.

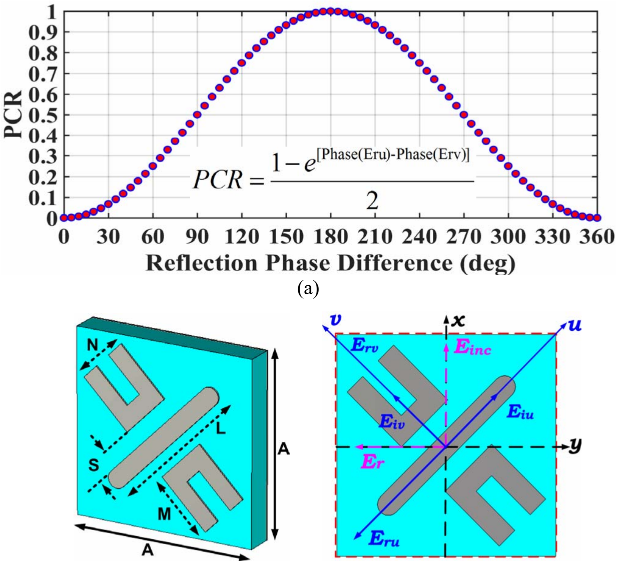
I. INTRODUCTION

In the last decade the design of engineered surfaces of reflection characteristics (low-scattering and diffuse reflection) that mimic a rough surface found in nature have received a considerable attention [1]-[14]. Engineered reflector for backscattered Radar Cross Section (RCS) reduction and scattering control has been a hot topic recently. Diffuse reflection pattern which is an important kind of reflection for RCS reduction can be achieved using an engineered surface that mimic a rough surface found in nature. This can be achieved by randomly distribute the unit cells across the engineered surface aperture which lead to diffuse back the incident EM-wave in to countless directions away from the source [7]-[10].

This paper presents the design of non-absorptive diffusive engineered reflector for EM-wave shaping at millimeter wave regime. An optimized 1-bit coding sequence is used to realize the presented engineered surface which is designed based on reflection phase cancellation, cross-polarization conversion, and coding reflective surface principles. The proposed surface can efficiently diffuse-back the incident EM-wave.

II. DESIGN OF ANISOTROPIC UNIT CELL

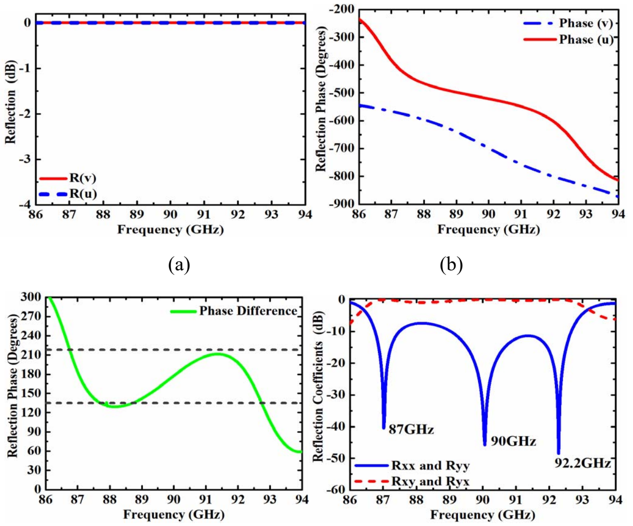
The design of the proposed engineered reflector is based on the cross-polarization conversion ratio (PCR) and a unit cell of special reflection characteristics is required. As can be seen in Fig.1 (a), to have a high efficiency cross-polarization conversion the unit cell should have a phase difference about 180°±37° between its diagonal reflected components. The geometry of the unit cell used in this article is presented in Fig.1 (b) and consists of a cut-wire and two U-shape copper resonators etched on the top side of a grounded dielectric substrate, such structure is anisotropic in the x and y directions. The electric field component (E_{inc}) of the incident plane wave is decomposed into two orthogonal components E_{iv} and E_{iu}. Due to the anisotropy of the unit cell geometry, a certain amount of phase difference will introduced between the reflected components E_{ru} and E_{rv} and if the phase difference ($\text{Phase}(E_{ru})-\text{Phase}(E_{rv})$) is about 180° (±37°) then E_{inc} will be rotated to its orthogonal component and reflected as E_r. Simulation of the proposed anisotropic unit cell is accomplished by using periodic boundary conditions of the commercial 3D software, CST Microwave Studio via F-solver. Figure 2 (a) and (b) shows the magnitude and phase of the EM-wave reflected along u and v axis (E_{rv} and E_{ru}) and as can



(a)

(b) (c)

Fig. 1. (a) PCR curve versus phase difference. (b) Prospective view of the anisotropic unit cell: ε_r=10.2, L=2.3, A=2, g=0.2, S=0.35, M=1.3, N=0.6 and dielectric h=1.27 (all in mm). (c) The incident and reflected wave vectors.



(c) (d)

Fig. 2. Unit cell reflection characteristics: (a) magnitude and (b) phase of E_{ru} and E_{rv} reflection coefficients and their reflection phase difference (phase (E_{rv}) – phase (E_{ru})) in (c). (d) co- and cross- polarization reflections of the unit cell.

be seen a very strong reflection is achieved with a continuous reflection phase. Moreover, there is about 180°±30° phase difference between E_{rv} and E_{ru} as shown in Fig. 2 (c) and this phase difference is because of the anisotropy of the unit cell geometry.

The cross-pol and co-pol reflection coefficients are calculated and the results are presented in Fig.2 (d) and as can be seen a strong cross-pol rotation occurs under both x- or y-polarized incident EM-wave.

The anisotropic unit cell has three plasmon resonances at 87 GHz, 90 GHz, and 92.2 GHz, the surface current distribution on the metallic resonator and in the ground plane at each plasmon resonance is monitored as exhibited in Fig.3. As can be seen at the first (87 GHz) and third (92.2 GHz) plasmon resonances the induced surface current flowing direction on the metallic resonator and the ground plane has opposite (anti-parallel) direction when compared to each other and forming a magnetic dipole (according to Faraday's law) thus those to frequencies would be considered as magnetic resonances. At the second plasmon resonance (90 GHz), the induced surface currents on the metallic resonator and the ground plane have the same direction which is forming an electric dipole. This means that this plasmon resonance can be considered as an electric resonance. A cross-polarization converter surface using the proposed unit cell is designed as shown in Fig.4 (a)

III. 1-BIT ENGINEERED REFLECTOR DESIGN

The design strategy of the 1-bit engineered surface presented in this article consists of three steps: (1) design of highly reflective anisotropic unit cell exhibiting strong cross polarization rotation, (2) optimize the unit cell dimension such that the unit cell can introduce the required 180° phase difference between its diagonal reflected components, (3) generate the optimum 1-bit coding sequence or unit cell distribution map and construct the surface. The operating mechanism of the presented engineered surface is to diffuse (scatter) back the incident energy away from the source by redistributing the reflected energy on many low-level lobes in countless directions by realizing an 180°±30° reflection phase difference between the reflection coefficients of any adjacent

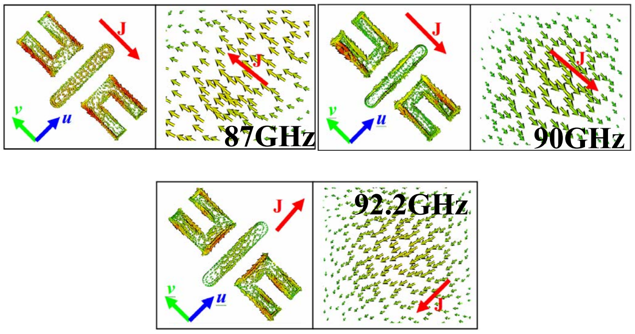
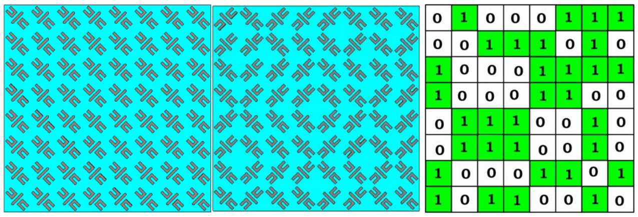


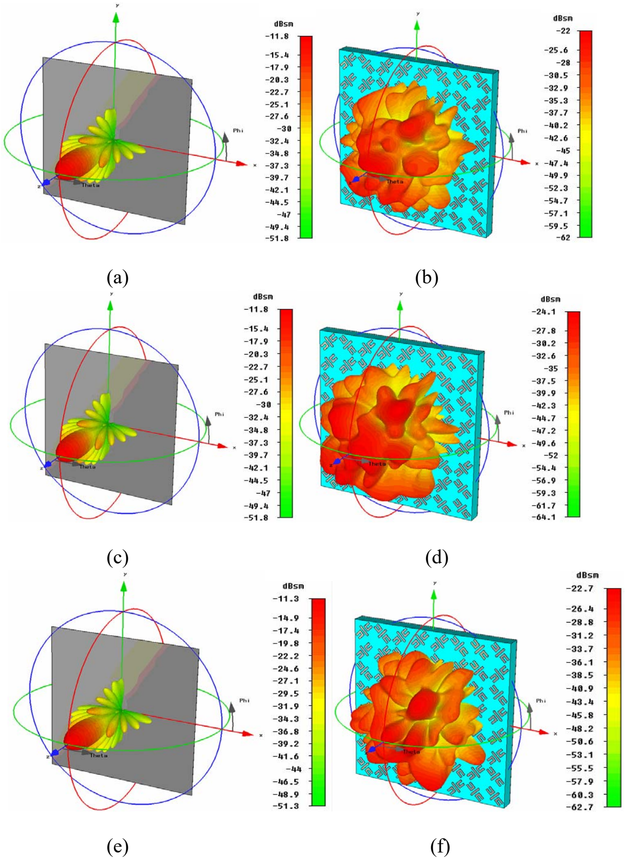
Fig. 3. Surface current distributions on metallic parts of the anisotropic unit cell at the plasmon resonance frequencies.



0	1	0	0	0	1	1	1
0	0	1	1	1	0	1	0
1	0	0	0	1	1	1	1
1	0	0	0	1	1	0	0
0	1	1	1	0	0	1	0
0	1	1	1	0	0	1	0
1	0	0	0	1	1	0	1
1	0	1	1	0	0	1	0

(a) (b) (c)

Fig. 4. (a) Layout of the cross-pilariztion converter surface. (b) The proposed 1-bit engineered reflector. (c) The optimized computer-generated unit cell coding sequence.



(a) (b)

(c) (d)

(e) (f)

Fig. 5. The 3D RCS scattering patterns of PEC plate and 1-bit engineered reflector: (a,b) 88.2GHz, (c,d) 88.4GHz and (e,f) 92.2GHz.

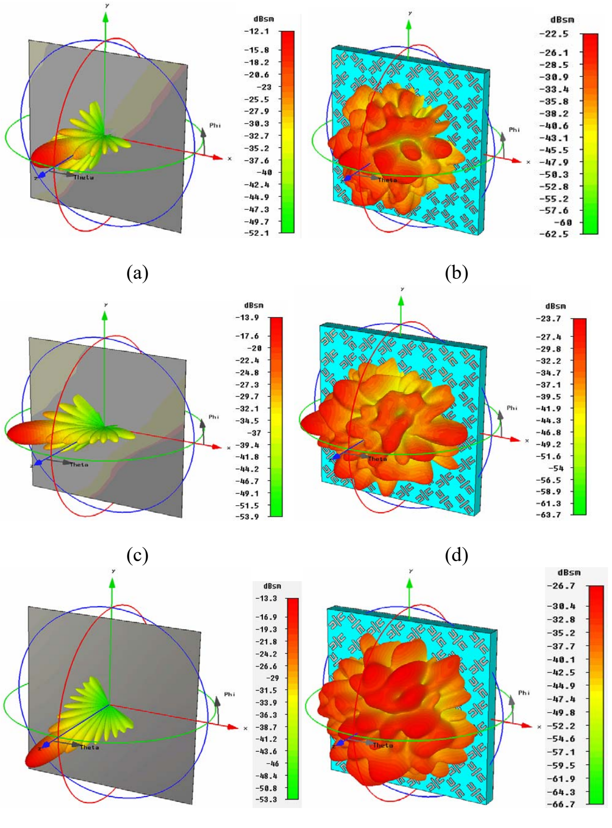


Fig. 6. The 3D RCS scattering patterns of PEC plate and 1-bit engineered reflector under oblique incidence: (a,b) θ_{inc}=15°/ ϕ_{inc}=0°, (c, d) θ_{inc}=45°/ ϕ_{inc}=0°, and (e,f) θ_{inc}=45°/ ϕ_{inc}=45°.

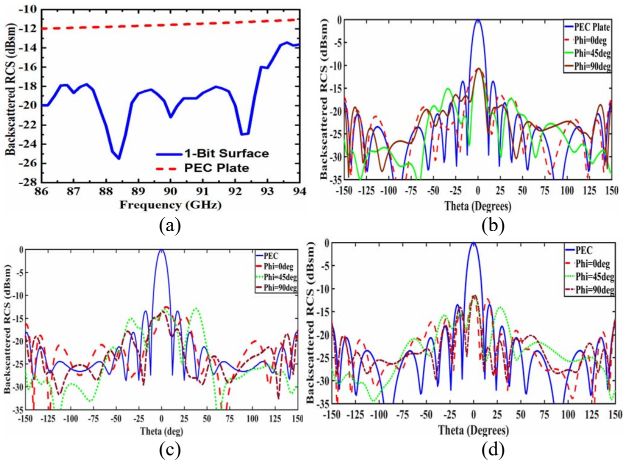


Fig. 7. (a) RCS reduction of the engineered surface. (b) , (c) and (d) are the Cartesian plot of the backscattered RCS patterns at 88.2GHz, 88.4GHz and 92.2GHz, respectively.

anisotropic unit cells across the engineered surface aperture [9]-[10]. To achieve this, the phase difference properties between E_{rv} and E_{ru} and cross-pol rotation of the unit cell presented in the previous section are used here to achieve the necessary phase cancellation across the engineered surface aperture. In this work, this phase difference is obtained by simply using the unit cell and its mirrored unit cell together as shown in Fig.4 (b). Supposing that a linearly x- or y-polarized EM-wave is incident on the presented surface in Fig.4 (b), then it would completely be converted into its orthogonal one, and as result of the reflection phase difference between the reflected waves from the unit cell and its mirrored unit cell the backscattered energy will be reduced and diffused. To validate this hypothesis, an engineered surface is designed based on the concept of coding metasurface in [10] where those two unit cells are employed to generate the "0" and "1" elements of the coding sequence. In this article the optimum unit cell distribution or coding sequence is achieved using MATLAB code and the1-bit engineered reflector has an overall size of 16×16 mm and contains 8×8 unit cells as shown in Fig.4 (c). The three dimensional (3D) RCS scattering patterns of the presented 1-bit engineered reflector and its equivalent PEC plate are obtained by full wave simulation software CST microwave studio (T-solver) and the results are presented in Fig. 5. As can be seen under normal incidence of x- or y-polarized far-field plane wave propagating along -*z* direction, the 1-bit engineered surface have a lower level and different shape of patterns when compared to that of a bare PEC plate with same dimensions. The backscattered energy is reflected into various directions in form of several lobes in the half space in front of the reflector which mimicking the diffusion phenomenon. Unlike the single reflected lobe of the PEC plate, the diffusion scattering leads to both monostatic and bistatic RCS reductions and this diffusion-like scattering can be invoked by the destructive interference of the radiations from each constituent unit cell. Further more, the scattering patterns of the engineered surface under oblique incidence are computed as well and the results are presented in Fig.6. For comparison purposes, identical simulations are conducted with a PEC plate of equivalent geometry. Here three cases are considered when (θ=15° , φ=0°), (θ=45° , φ=0°), and (θ=45° , φ=45°). As can be seen in Fig. 6 the engineered surface keep having low level of diffuse reflection in all cases compared to the PEC plate for which the incident energy will be reflected according to Snell's law of reflection. Figure 7 (a) shows a clear RCS reduction of the presented engineer surface compared to a bare PEC plate and Fig.7 (b), (c) and (d) shows the far-field RCS Cartesian patterns at different frequencies.

IV. CONCLUSION

The design an engineered reflector based on reflection phase cancellation, cross-polarization conversion, and coding reflective surface principles is presented and investigated both numerically and experimentally. The anisotropic unit cell composed the engineered reflector has three resonant frequencies (87GHz, 90GHz, and 92.2GHz). The proposed engineered can effectively manipulate the backscattered RSC patterns and mimic a rough surface. Furthermore, the reflected energy would take a diffuse pattern like under both normal and oblique incidences.

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