Manipulation of Backscattered EM-Waves Using 1-Bit Coding Reflective Surface at *mmWave*

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***Abstract*—This paper presents the design of 1-bit low scattering reflective surface that can efficiently manipulate the shape and level of the backscattered RCS far-field pattern of a metal object at millimeter wave. The proposed 1-bit surface is designed based on reflection phase cancellation principle where the proposed unit cell of a modified Venus-like shape metallic resonator (as "0" element) and its mirrored-unit cell (as "1" element) are randomly distributed across the surface aperture to realize the required phase difference . The proposed surface can scatter (diffuse) the incident EM-wave into several low level lobes in many directions in the half space in front of the surface, and as a result, dramatically reduce the backscattering and RCS. The proposed surface has good backscattering characteristics under both normal and oblique incidence of EM-waves.**

Keywords—Radar Cross Section; Metasurface; mmWave

I. Introduction

Manipulation of backscattering energy of metallic objects, in other word RCS reduction, has received a great interest for long time [1,2]. Using engineered surfaces (also called metasurface) for RCS reduction of a metallic object (and nowadays its called "low observable technology" or "stealth technology") is been a hot topic recently [3]-[6]. Coding metasurface (1-bit and 2-bit) was proposed in [3] at microwave frequencies around 10GHz to reduce the RCS of a bare PEC plate by carefully coding ("0" or "1") the unit cells across the metasurface aperture. In [4] a planar 1-bit coding, 2-bit coding, and multi-bit coding metasurfaces for manipulation (diffusion) of THz waves were proposed. This paper presents the design of 1-bit low scattering reflective (non-absorptive) surface that can efficiently manipulate the backscattered RCS far-field pattern of a metal object at millimeter wave (W-band). The proposed 1-bit surface is designed based on reflection phase cancellation principle where the proposed unit cell of modified Venus-like shape metallic resonator (as "0" element) and its mirrored-unit cell (as "1" resonator") are randomly distributed across the surface aperture to achieve the required phase difference .

II. Unit Cell Design

The unit cell composing the presented 1-bit RCS reducer surface is presented in Fig.1 (a) which is a modified Venus-like metallic resonator. The unit cell (A=2mm, M=0.7mm, N=0.32mm, L=0.6mm, R_{out}=0.5mm, R_{in}=0.35mm) is etched on a dielectric material: ε_r=10.2 and thickness=1.27mm with a

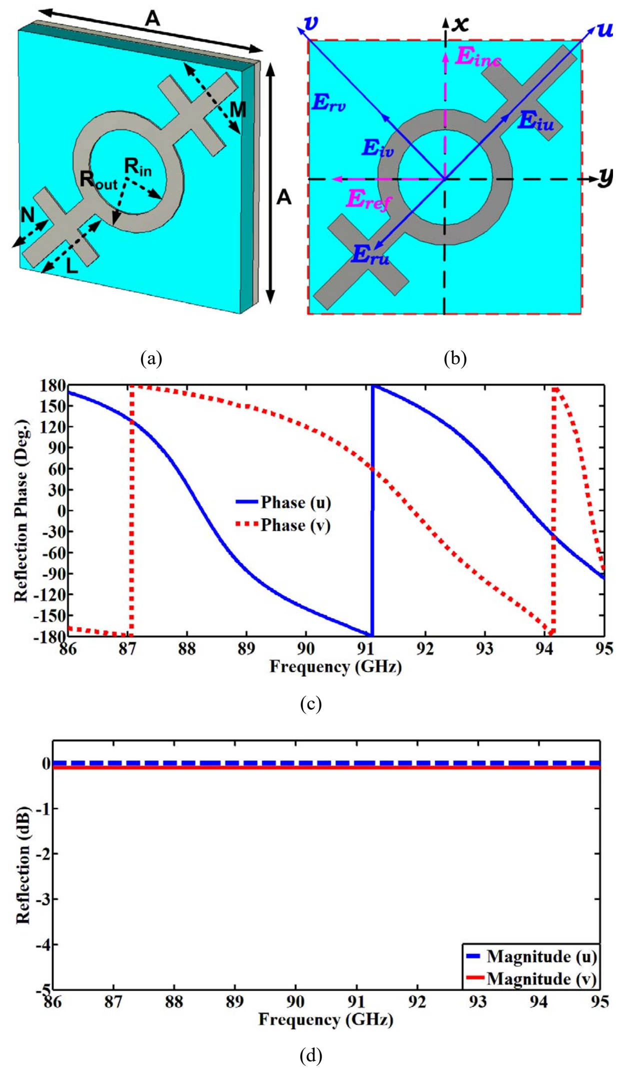
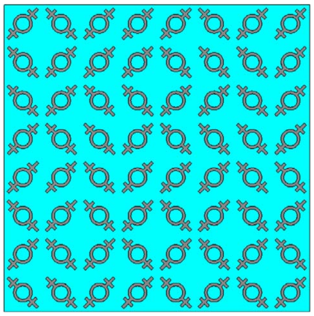


Fig.1. (a) Layout of the unit cell, (b)incident and reflection vectors, (c) reflection phase and (d) magnitude from u- and v-axis.

PEC ground plane. The incident and reflected vectors are presented in Fig.1 (b) which shows that the x-polarized (or y-polarized) incident EM-wave will decompose into two



(a)

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

(b)

Fig.2. (a) Layout of the proposed surface and (b) unit cell distribution map.

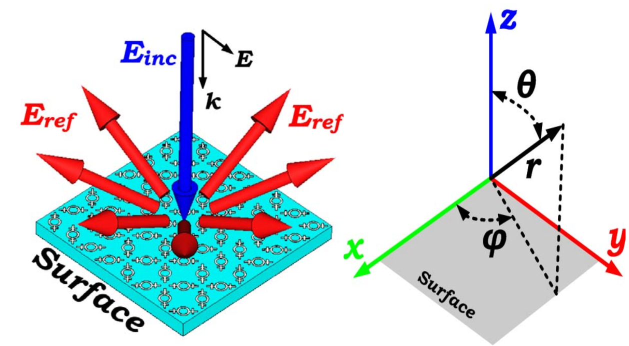
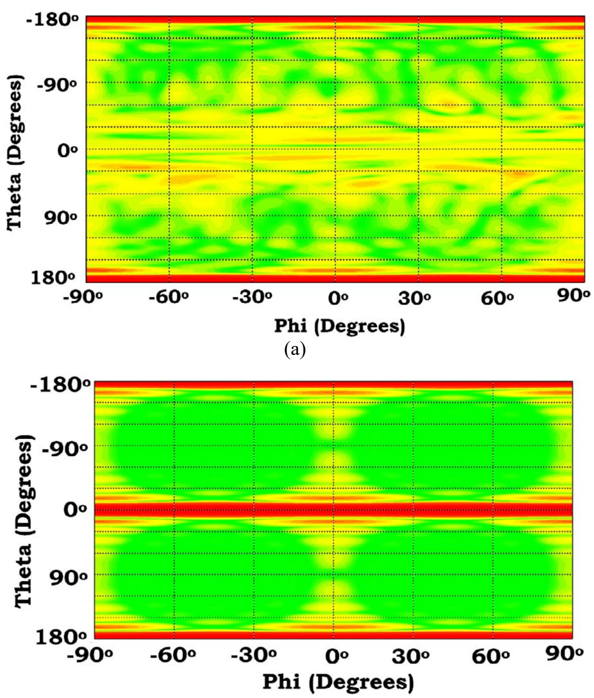


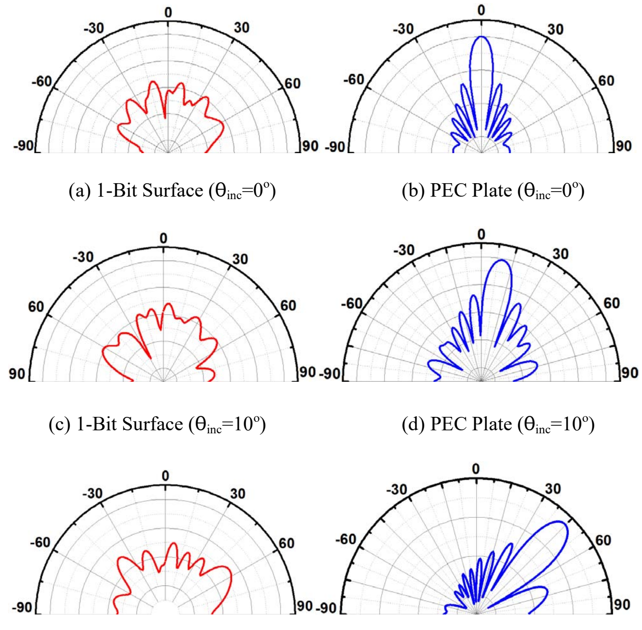
Fig.3. Diffusion mechanisim of the 1-bit surface and its coordinate system.



(a)

(b)

Fig.4. 2D plot of the backscattred energy of (a) the proposed 1-bit random distribution surface and (b) a bare PEC plate.



(a) 1-Bit Surface (θ_{inc}=0°) (b) PEC Plate (θ_{inc}=0°)

(c) 1-Bit Surface (θ_{inc}=10°) (d) PEC Plate (θ_{inc}=10°)

(e) 1-Bit Surface (θ_{inc}=45°) (f) PEC Plate (θ_{inc}=45°)

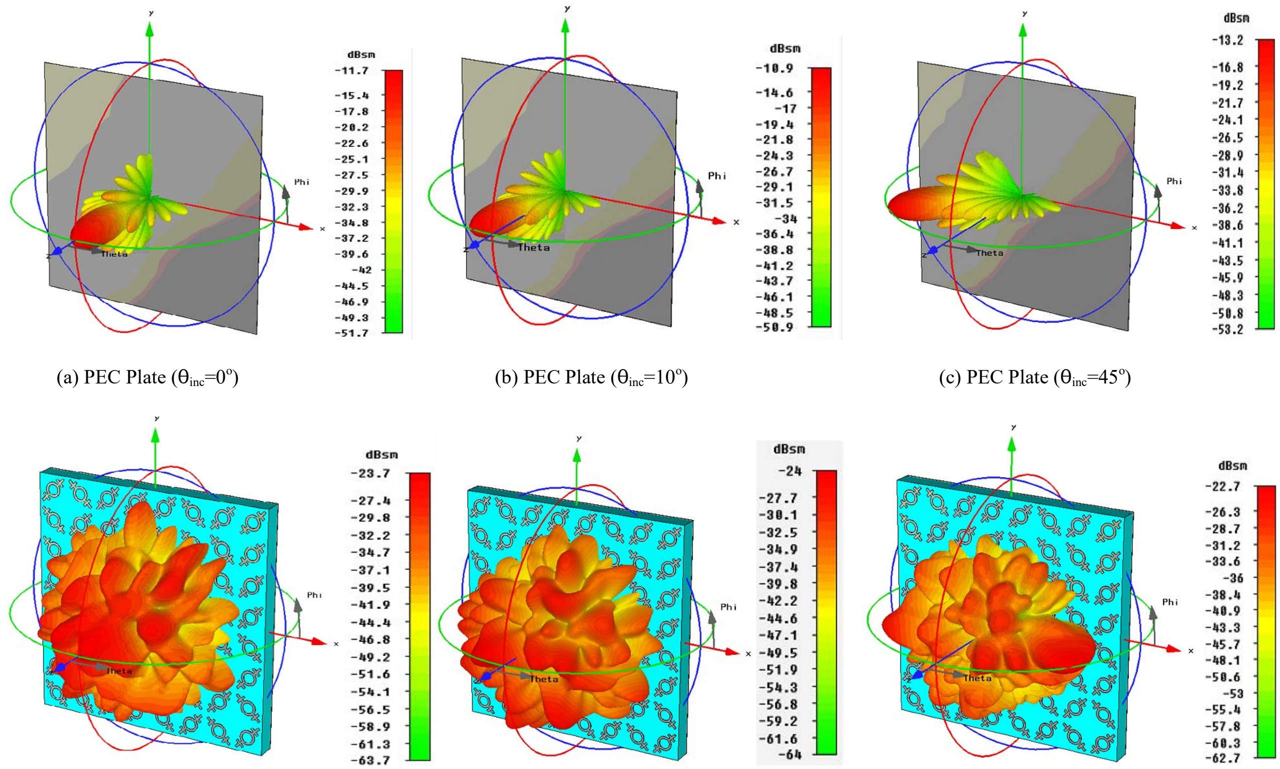
Fig.5. Scattering patterns of the optimized 1-bit coding surface in and its eqivalent PEC plate under normal and oblique incidence.

orthogonal components along u- and v-axis. The reflection characteristics (phase and magnitude) of those two components (E_{rv} and E_{ru}) along u- and v-axis are computed using F-solver of CST Microwave Studio and the results are presented in Fig.1 (c) and (d) which shows that there is a clear and continuous reflection phase difference between E_{rv} and E_{ru} (compared to E_{iv} and E_{iu}) with strong reflection magnitude from about 86GHz-95GHz.

III. 1-Bit RCS Reducer Surface Deaign

In order to realize the binary elements of the 1-bit coding across the proposed reflective surface aperture, one can use the reflection phase difference between E_{rv} and E_{ru} of the unit cell presented in the previous section. To realize this reflection phase difference between the adjacent cells across the proposed surface aperture, the unit cell is considered as "0" element and its mirrored-unit cell are considered as "1" element. In this way the adjacent unit cells will have about 180^o+37^o reflection phase difference between their E_{rv} and E_{ru} components and phase cancellation occur.

To validate this hypothesis, RCS reducer surface is designed as shown in Fig.2 (a) and as can be seen the "0" element and "1" element are distributed randomly across the proposed surface aperture according to the unit cell distribution map in Fig.2 (b). It is important here to mention that the shape and level of the backscattered RCS far-field pattern is function to unit cell distribution. In this paper MATLAB code based on the random function in MATLAB is used to find the best unit cell distribution. Other techniques such as genetic algorithm [6]



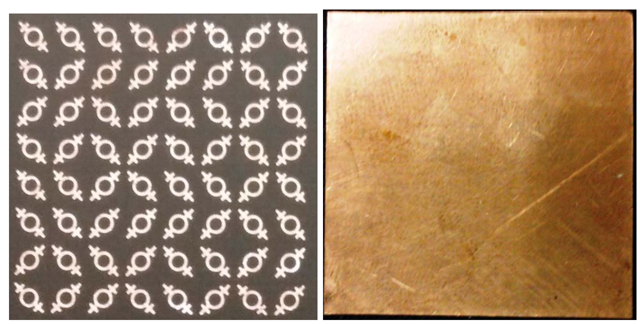
(a) PEC Plate (Θ_{inc}=0^o) (b) PEC Plate (Θ_{inc}=10^o) (c) PEC Plate (Θ_{inc}=45^o)

(d) 1-Bit Surface (Θ_{inc}=0^o) (e) 1-Bit Surface (Θ_{inc}=10^o) (f) 1-Bit Surface (Θ_{inc}=45^o)

Fig.6. 3D Scattering patterns of the optimized 1-bit coding surface in and its eqivalent PEC plate under normal and oblique incidence.

and particle swarm optimizations [4] are also possible. The goal here is to diffuse back the incident energy in many directions as shown in Fig.3 so RCS will be reduced in all directions in the half space in front of the surface. The 2D field distribution of the backscattered energy of the proposed surface (and its equivalent PEC plate) under normal incidence in the area in front of the surface is computed using T-solver of CST Microwave Studio and the results are presented in Fig.4. As can bee seen in the case of a bare PEC plate, the incident energy will be reflected in the same direction of the incoming waves as a single directive lobe according to Snell's law of reflection. On the other hand, for the 1-bit surface case the backscattered energy is distributed on half space in front of the 1-bit surface as many low level lobes in many directions. To more understand the backscattering characteristics of the 1-bit surface the polar RCS far-field patterns under both normal and oblique incidence of plane wave are computed and the results are presented in Fig.5 for Θ_{inc}=0^o, 10^o and 45^o. As can be seen in all cases the 1-bit surface diffuses back the incident energy with low level. Thus, the backward RCS will be significantly suppressed. The 3D scattering far-field patterns of the 1-bit surface and its equivalent PEC plate of same size are computed using T-solver of CST Microwave Studio and the results are presented in Fig.6.

For experimental verification of the proposed 1-bit low scattering reflective surface, a sample is fabricated using PCB technology as shown in Fig.7. The fabricated sample is consists of 8×8 unit cells and occupied an area of 16×16 mm^2. The scattering characteristics of the proposed surface are being measured now and the measured results will be presented during the conference.



(a) (a)

Fig.7. (a) Fabricated 1-bit random surface and (b) a bare PEC plate.

IV. Conclusion

In this paper, the design of 1-bit low scattering (non-absorptive) reflective surface that can significantly reduce the backscattered RCS far-field pattern of a metal object under both normal and oblique incidence of a plane-wave at millimeter wave is presented. The proposed 1-bit RCS reducer surface is designed based on reflection phase cancellation principle. All backscattering results show that the 1-bit Surface can efficiently reduce the RCS of a metal object with very promising RCS reduction characteristics.

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