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Radar Cross Section Reduction Using Polarization Cancellation Approach

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Abstract—A new approach is presented to reduce the monostatic radar cross section (RCS) of a metal surface. In this approach, called Polarization Cancelation, the polarization of incident wave is rotated by several angles so that the reflected wave becomes zero in direction of incidence. The characteristics and mechanism of the polarization rotation and RCS reduction are investigated. The presented approach is verified by simulation and measurement results.

1. INTRODUCTION

Radar Cross Section (RCS) reduction is an important issue in many applications such as radar invisibility. Three customary methods to reduce the RCS of a structure use periodically rough metallic surfaces [1], applying radar absorbing material [2] and phase cancelation [3–5]. In Phase Cancelation method, two or more types of unit cells are periodically repeated so that the waves reflected from them are canceled out through their complementary phases.

In this article, polarization cancelation method is introduced to reduce RCS of a metal surface. This method is similar to phase cancelation method except that the reflected waves are canceled out through their complementary polarizations not their complementary phases. Two or more types of unit cells are periodically repeated. Each type of unit cell rotates the polarization of the impinging wave by a specific angle so that the summation of waves reflected from all types of unit cells will be zero.

2. POLARIZATION ROTATION

Consider a particular type microstrip unit cell that reflects two orthogonal linearly polarized impinging waves by 180° phase difference with respect to each other. Fig. 1, shows one unit cell of this particular type, called circularly-polarized unit cells, which have normally been used as the unit cells of circularly polarized reflectarrays [8]. The difference between electrical lengths of two transmission lines in these types of cells is that the reflection coefficient for a y' polarized incident wave becomes minus of that for an x' polarized incident wave.

Now, assume that the incident wave impinging on the particular unit cell is linearly polarized in x direction which has an angle ψ with respect to x' direction, as shown in Fig. 2. Therefore,

$$\vec{E}^i = E^i \hat{a}_x = E^i \cos\psi \hat{a}'_x - E^i \sin\psi \hat{a}'_y \tag{1}$$

where, $\hat{a}'_x = \cos\psi \hat{a}_x + \sin\psi \hat{a}_y$ and $\hat{a}'_y = -\sin\psi \hat{a}_x + \cos\psi \hat{a}_y$ are unit vectors of the unit cell. The reflected wave arising from the circularly-polarized unit cell can be obtained as follows, considering $\mathrm{e}^{j\phi}$ and $-\mathrm{e}^{j\phi}$ as the reflection coefficients in x' and y' directions, respectively.

$$\vec{E}^r = E^i \cos\psi \mathrm{e}^{j\phi} \hat{a}'_x + E^i \sin\psi \mathrm{e}^{j\phi} \hat{a}'_y = E^i \mathrm{e}^{j\phi} \left(\cos(2\psi)\hat{a}_x + \sin(2\psi)\hat{a}_y\right) \tag{2}$$

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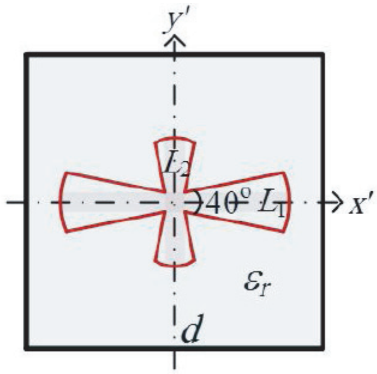

Figure 1. One type of circularly-polarized unit cell suitable for circular polarized reflectarrays as well as polarization rotation [8].

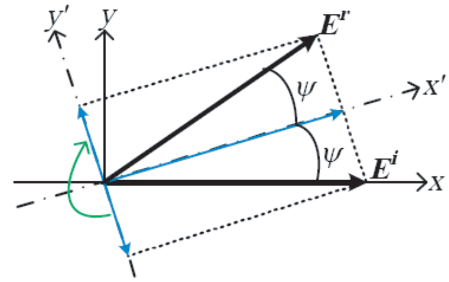

Figure 2. Polarization of a linearly x-polarized impinging wave is rotated 2ψ degree due to unit cell rotation of ψ degree (x' direction versus x direction).

It is seen from Eqs. (1) and (2) that the polarization of the incident wave has been rotated by angle 2ψ, as the reflected wave. So, ψ degree physical rotation of circularly polarized unit cells leads to 2ψ degree polarization rotation.

3. POLARIZATION CANCELATION

Now, we introduce Polarization Cancelation approach to utilize as a new approach to reduce RCS, rather than the conventional Phase Cancelation approach. To this end, a suitable set of rotations for circularly-polarized unit cells is designed so that the sum of all polarization-rotated reflected waves becomes zero. Fig. 3 shows two sets for 2ψ rotation, i.e., set #1: (0, 180) and set #2: (0, 45, 90, 135, 180, 225, 315). Set #1, uses only two polarization rotations which have an abrupt transition between them. However, set #2 uses eight polarization rotations with gradual transition. So, it is expected that the performance of set #2 will be better than that of set #1. Of course, one can design other sets utilizing three, four or other numbers of polarization rotations.

0	0	0	0	180	180	180	180
0	0	0	0	180	180	180	180
0	0	0	0	180	180	180	180
0	0	0	0	180	180	180	180
180	180	180	180	0	0	0	0
180	180	180	180	0	0	0	0
180	180	180	180	0	0	0	0
180	180	180	180	0	0	0	0

(a)

0	45	90	135	180	225	270	315
45	90	135	180	225	270	315	0
90	135	180	225	270	315	0	45
135	180	225	270	315	0	45	90
180	225	270	315	0	45	90	135
225	270	315	0	45	90	135	180
270	315	0	45	90	135	180	225
315	0	45	90	135	180	225	270

(b)

Figure 3. Two sets for 2ψ rotations. (a) set #1: (0, 180), (b) set #2: (0, 45, 90, 135, 180, 225, 315).

4. SIMULATIONS AND MEASUREMENT

The software CST has been used for simulation. We choose circularly-polarized unit cell shown in Fig. 1, although other cells suggested in works such as [6, 7] are usable too. This unit cell is designed at frequency $f_0 = 10\,\text{GHz}$, employing an FR4 substrate with $\varepsilon_r = 4.3$ and thickness 2.6 mm with optimum dimensions $d = 8.75\,\mathrm{mm} = 0.29\lambda_0$, $L_1 = 3.7\,\mathrm{mm}$ and $L_2 = 2.22\,\mathrm{mm}$. Fig. 4 illustrates the phase difference between reflection coefficients of y' polarized and x' polarized incident waves, versus frequency. It is seen that there exists 180-degree phase difference at two frequencies 7.5 and 10 GHz.

Figure 5 shows the simulated RCS reduction with respect to a simple metal ($\frac{4\pi}{\lambda^2}A^2$), versus frequency for two sets #1 and #2, comprising unit cells shown in Fig. 1. It is seen that the RCS reduction of set #2 is better than that of set #1. Hence, set #2 was fabricated containing 24 by 24 cells (nine similar sets next to each other) with overall dimension of $21 \times 21\,\mathrm{cm}^2$, as indicated in Fig. 6. One can conclude from comparing Figs. 4 and 5 that the -10 dB bandwidth of RCS reduction corresponds to about $\pm 35°$ difference from 180° phase difference.

The RCS reduction of the fabricated structure was measured. Fig. 5, also shows the measured RCS reduction of fabricated structure versus frequency. There is a good agreement between simulated and measured results except a frequency shift about 200 MHz. It is observed that the RCS is reduced more than 10 dB from 7.6 to 11.3 GHz, implying a 39% measured bandwidth. This measured bandwidth is a little more or less than that obtained by phase cancellation method. For example, the measured bandwidth in [3] is 32%.

Finally, the 3-D bistatic RCS pattern at 10 GHz is depicted in Fig. 7. Under normal incidence, the RCS is reduced along the principal planes (XZ, YZ), and four main reflected lobes appear along the subordinate planes.

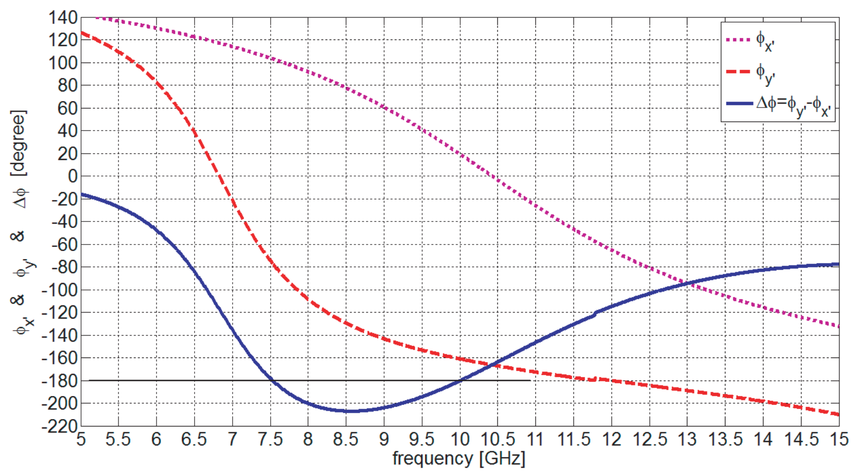

Figure 4. Phase difference between reflection coefficients of y' polarized and x' polarized incident waves, for unit cell shown in Fig. 1.

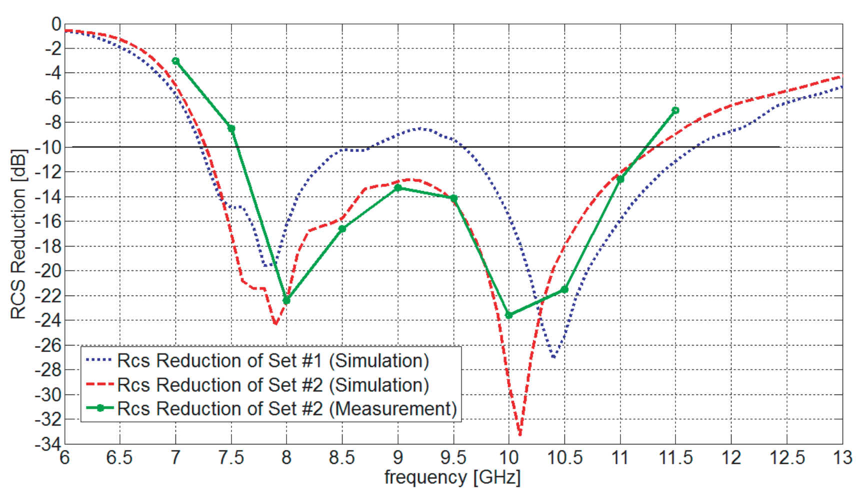

Figure 5. Simulated and measured RCS reduction versus frequency.

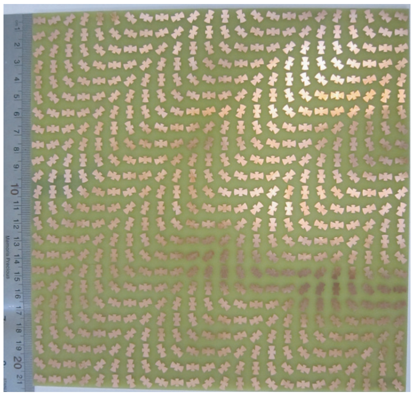

Figure 6. Fabricated structure obtained by nine structure of set #2.

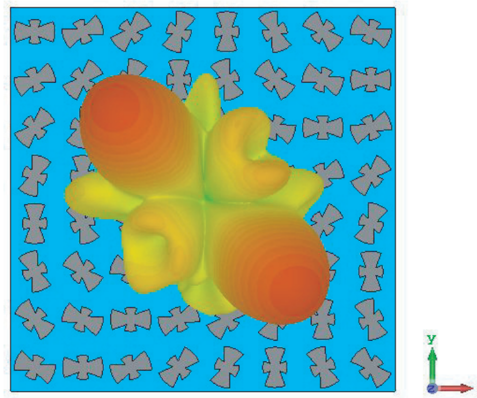

Figure 7. The 3-D bistatic scattered fields at 10 GHz under normal incidence to the structure of set #2 (top view). The energy of incident wave is scattered in four main directions rather than backward direction.

5. CONCLUSION

Polarization Cancelation approach was introduced to reduce the monostatic radar cross section (RCS) of a metal surface. In this approach, the polarization of incident wave is rotated by several angles so that the reflected wave becomes zero in direction of incidence. A set including eight angles of polarization rotations was designed, and then simulated and fabricated. A 39% RCS reduction bandwidth was measured within frequency band of 7.6 to 11.3 GHz.

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