Study on the Scattering Properties of an Artificial Electromagnetic Hard Surface

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Abstract— An artificial electromagnetic hard surface realized by the longitudinally oriented metal strips loaded on a grounded dielectric substrate is proposed. Electromagnetic scattering properties of the proposed structure are analyzed for both transverse magnetic (TM) polarization and transverse electric (TE) polarization, where TM polarization is defined by the polarized direction of the incidence electric field E parallel with the metal strips. The scattering properties of a high impedance surface (HIS) with similar structure are also proposed for comparison. In the case of the HIS, radar cross section (RCS) reduction over broad angles can be obtained for TE polarization, but get worse for TM polarization. While in the case of the hard surface, RCS reduction at the whole considered angles can be obtained for TE polarization, and almost invariable for TM polarization, which has the potential advantages in antenna design and stealth technique. To explain this phenomenon, the bistatic RCS are also analyzed. And the scattering reduction is estimated by comparing the mono- and bistatic scattering patterns of the hard surface loaded and unloaded metal cube.

1. INTRODUCTION

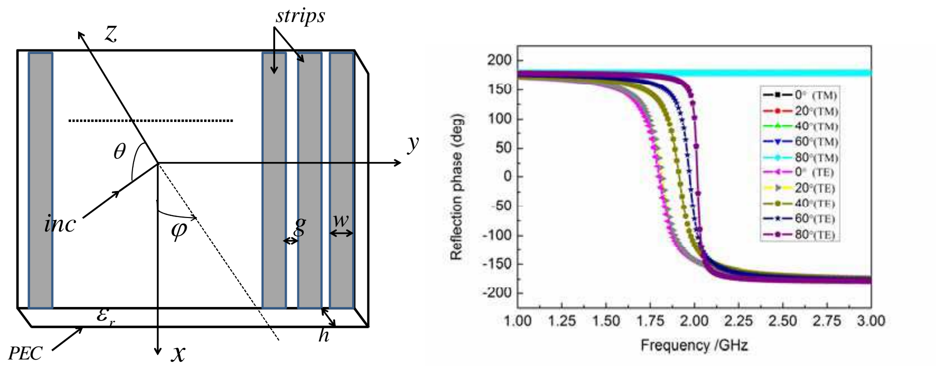
The concepts of artificially soft and hard surfaces were introduced to characterize the general way certain surfaces interact with electromagnetic waves [1]. The surface is direction dependent and polarization independent. These surfaces act upon on EM wave as a perfect electric conductor (PEC) for one linear polarization and a perfect magnetic conductor (PMC) for the other [2]. A widely known soft surface is the quarter-wavelength deep transversely corrugated surface used in hybrid-mode feed horns and the typical feature of this surface is that the wave no matter how polarized can't propagate along the surface [3]. Correspondingly the typical feature of an ideal hard surface is that a wave of any polarization is allowed to propagate along the surface [3]. Hard surface mainly have two important applications. One important applications of hard surface is in horns with low cross polarization and high aperture efficiency [3–8]. Another is the reduction of unwanted scattering from certain structures like struts [9] and axial supports of rear-radiating feeds [10] in prime-focus reflector antennas [3].

In this paper, we introduce a method for reducing RCS over a wide range of incident angles based on the characteristic of the hard surface. We use a simple hard surface structure which is a surface with longitudinally oriented metal strips on a grounded dielectric substrate. As we known, the PEC only support the wave which is vertical polarization (i.e., TM-case) along the surface, however the hard surface support the wave both vertical polarization and horizontal polarization (i.e., TE-case). The hard boundary can be used to obtain strong radiation fields along the surface for any polarization [11]. So, when the wave incident on the hard surface, radiation along the hard surface is stronger than that along the PEC. And the hard surface structure is lossless, so some of the incident energy is transformed to the surface that the RCS is reduced.

2. HARD SURFACE DESIGN

The proposed hard surface is based on the unit cell described in [12]. It is shown in Fig. 1(a). A grounded dielectric substrate, with relative dielectric permittivity $\varepsilon_r = 10.2$ and a thickness of $h = 2\,\mathrm{mm}$ is used. The width of the strip is $w = 20\,\mathrm{mm}$, and the width of the gap is $g = 0.8\,\mathrm{mm}$. For this structure, the reflection phases for both TE and TM polarization over different incidence angles are given in Fig. 1(b). For TM polarization, the metal strips provide a hard boundary and the reflection phase is 180 degree. For TE polarization, this structure provides a hard boundary and the reflection phase is 0 degree around 2 GHz over different incident angles, and can be widely considered as artificial magnetic conductor (AMC) [13]. The basic property of the soft and hard surface (SHS) boundary is: a plane wave field is reflected from the generalized SHS plane so that its TE (linearly polarized E-field parallel along the surface y-axis) component is reflected as from a

PMC plane while its TM component is reflected as from a PEC plane [14]. Finally we can achieve the hard surface.



(a) (b)

Figure 1: (a) 3D schematic diagram of the hard surface. (b) Reflection phase of the hard surface with different incidence angles for TM and TE polarized case.

3. ANALYSIS OF MONOSTATIC AND BISTATIC RCS

A hard surface 624×624 mm with 30 unites is used for RCS discussion. Both TM and TE polarization incident wave are considered, and incidence angle θ starts from $-90°$ to $90°$ in the plane of φ=0°. Then the monostatic RCS of a metal cube (the height $h' = 2$ mm) with hard surface is calculated. A PEC metal cube ($h' = 2$ mm) of the same size, i.e., 624×624 mm, is calculated under the same conditions as above for comparison. For TE-polarization, the input impedance of the square patches HIS equals to that of the hard surface [15]. So, RCS of a square patches HIS (Fig. 2) with the same parameters under the same conditions is also presented for comparison (Fig. 3).

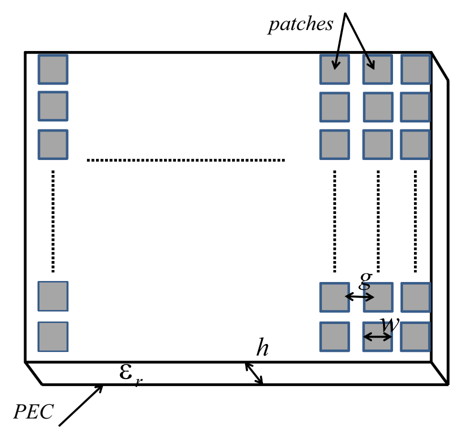
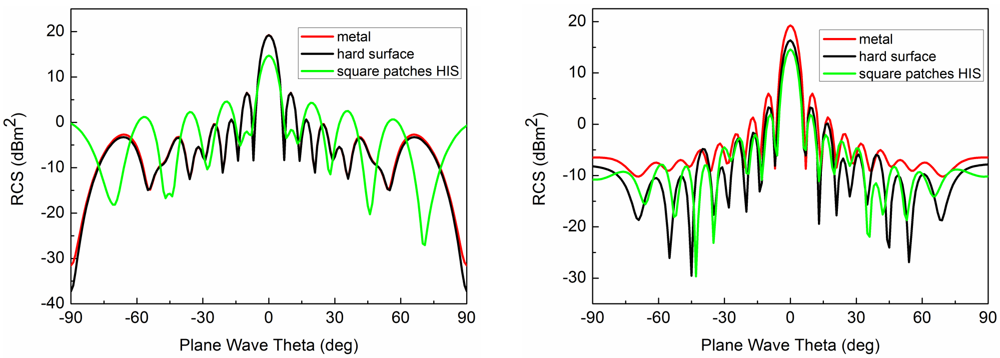


Figure 2: 3D schematic diagram of the square patches HIS.

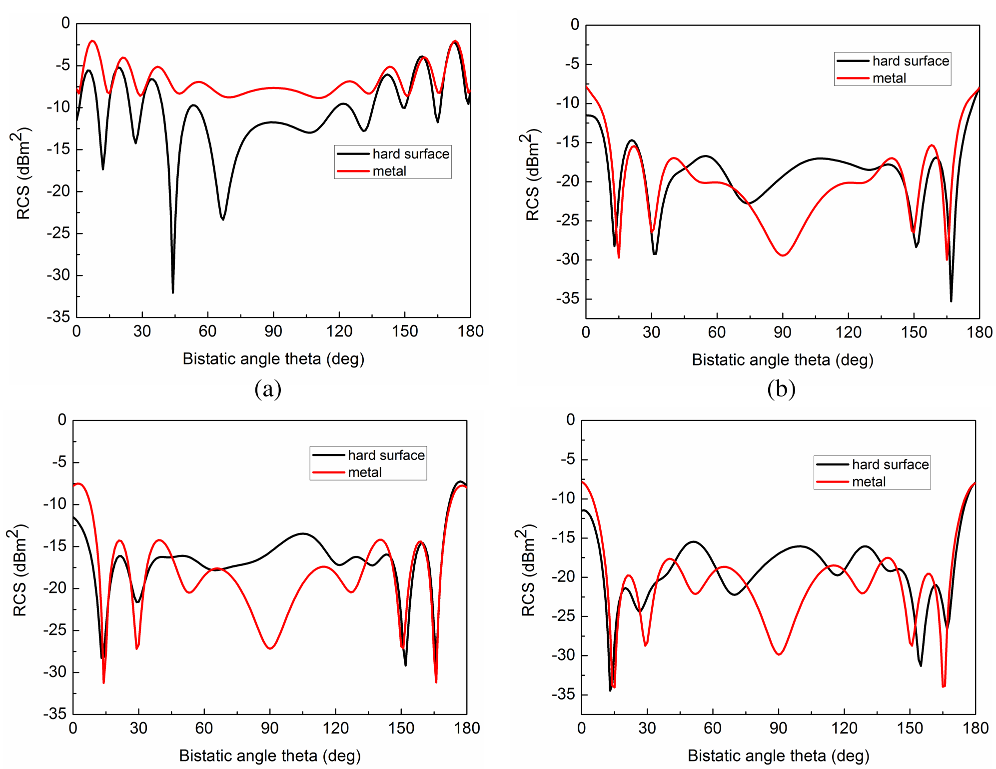
It can be seen from Fig. 3 that in the case of the HIS, RCS reduction at broad angles can be obtained for TE polarization, but get worse for TM polarization. While in the case of the hard surface, RCS reduction at the whole considered angles can be obtained for TE polarization, and almost invariable for TM polarization. This can be explained given that both AMC (square patches HIS at 2 GHz) and hard surface support the TE polarization wave along the surface. While for TM polarization, the square patches HIS acts like AMC (at about 2 GHz) which not support the TM polarization wave along the surface and the hard surface acts like PEC.

For analyzing monostatic RCS reduction, the bistatic case is investigated next. Fig. 4 is the bistatic RCS of the hard surface at frequency 2 GHz under TE polarization, incidence wave angles at θ=45°, φ=0°. In Fig. 4(a), bistatic angles phi at 0°, it corresponds to the monostatic RCS when bistatic angles theta at 45° and the monostatic RCS have about 25 dB reduction. From Figs. 4(b), (c), (d) it can be seen that when incidence wave angles fixed and bistatic angles phi at 75°, 100°, 275°, the RCS of hard surface is higher than the metal about 10dB when bistatic theta is at 90°. We also can find that at many other bistatic angles phi (data not shown) the RCS of hard surface is higher than the metal when bistatic theta is at 90°. While at other bistatic angles theta, the RCS of hard surface is almost equal to metal. So, we obtain strong radiation fields along hard surface and it can deduce that the reduction of the energy at bistatic θ=45° is transformed to bistatic θ=90°, i.e., the surface.



(a) (b)

Figure 3: Monostatic RCS amplitude as a function of incidence angles theta. (a) The RCS of TM polarization for metal, hard surface and square patches HIS at 2 GHz. (b) The RCS of TE polarization for metal, hard surface and square patches HIS at 2 GHz.



(a) (b) (c) (d)

Figure 4: Bistatic RCS amplitude as a function of Bistatic angles theta. (a) Bistatic angles phi at 0°. (b) Bistatic angles phi at 75°. (c) Bistatic angles phi at 100°. (d) Bistatic angles phi at 275°.

4. CONCLUSIONS

The scattering properties of an artificial electromagnetic hard surface and a square patch HIS have been investigated. The basic properties have been derived by studying the RCS varies with polarization and incidence angle. When the plane of the incident wave is paralleled to the strips and for TE polarization, the hard surface has almost all direction RCS reduction. It can be concluded that radiation fields along the hard surface is stronger than metal by analyzing the bistatic RCS. Some energy of incident wave is transformed to the surface. While for TM polarized incident wavethe RCS almost have no change. It corresponds to the characterization of hard surface. Thus the simple hard surface structure proposed could be used in stealth technique.

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