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# Scattering reduction of perfectly electric conductive cylinder by coating plasma and metamaterial

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ABSTRACT

This paper presents the radar cross section (RCS) reduction of scattering of perfectly electric conductive (PEC) cylinder coated with plasma and metamaterial by finite-difference time-domain (FDTD) method. Two coating schemes of the cylinder were studied to find better RCS reduction performance. One is to put the plasma layer at the outside and the other is to put the metamaterial layer outside. The influence of plasma's thickness and collision frequency was studied. The calculation results show that in the low frequency ($f$ = 3 GHz), the target realizes a considerable RCS reduction in a wide bistatic angular range. In the high frequency ($f$ = 18 GHz), the reduction performance is not as good as low frequency. The results also show that by the effect of plasma and metamaterial, the reduction performance is much better than coated with plasma.



## 1. Introduction

When electromagnetic wave is propagating in plasma, there will be energy loss resulting from the collision of electrons in plasma with the neutron particles. Therefore, plasma can be used to reduce the scattering of target. However, the pure plasma only has electric loss and there is no magnetic loss. Thus, the impedance match between free space and the plasma cannot be fulfilled well and the mismatch can result in significant reflection between the boundary.

Metamaterial is a category of artificial material which has some features not found in natural material. In a narrow sense, it represents double negative material (DNG), which was firstly proposed by Veselago in 1968 [1]. At the beginning, this kind of material was only hypothetical and the physical matter was not discovered. Pendry bring the idea into reality by split resonant ring (SRR) structure in 1996 and 1999. There are some unusual effects in DNG material, such as negative refraction, inverse Cherenkov effect and inverse Doppler effect. He put forward in electromagnetic cloak and made it possible to achieve complete invisible in 2006 [2].

The plasma's effect of scattering reduction was widely studied during these years. The attenuation characteristics of plasma from the experiment was studied [3,4]. The propagation features of electromagnetic waves in plasma was calculated [5–7]. The electromagnetic scattering characteristics of the metal cylinder covered by plasma was analyzed [8]. The propagation of electromagnetic wave under the interaction of plasma and absorbing materials was discussed [9].

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This paper tries to combine the effect of DNG and plasma to get a better scattering reduction. The perfectly electric conductive (PEC) cylinder with DNG and plasma coated was studied to find better performance. The numerical simulation method is finite-difference time-domain (FDTD), which was very suitable for the complex medium calculation. When simulating the dispersive media, auxiliary differential equation (ADE) method was utilized. The influence of frequency of plasma and thickness was considered in the simulation.

There are two schemes in coating the PEC cylinder by plasma and metamaterial. One is to put the plasma layer outside and the other one is to put to the metamaterial layer outside. Both schemes are studied in this paper and the results show the reduction effect.

## 2. Formulation

DNG and plasma are both dispersive media. The dissipative Drude dispersion model is used to simulate the two media in this paper [10]. The relative permeability and permittivity of Drude model are

$$\varepsilon_r(\omega) = 1 + \frac{{\omega_e}^2}{\omega(j\nu_e - \omega)} \tag{1}$$

$$\mu_r(\omega) = 1 + \frac{{\omega_m}^2}{\omega(j\nu_m - \omega)} \tag{2}$$

where $\omega_e$ and $\omega_m$ are the oscillation frequency of electronic plasma and magnetic plasma, respectively, $\nu_e$ and $\nu_m$ are the collision frequency of electronic plasma and magnetic plasma, respectively, $\omega$ is the angular frequency of the incident wave. For DNG media, if $\varepsilon_r = \mu_r = -1$, then we have $\nu_e = \nu_m = 0$ and $\omega_e = \omega_m = \sqrt{2}\omega$.

We can get the constitutive relationship

$$\boldsymbol{D} = \varepsilon_0 \boldsymbol{E} + \frac{\varepsilon_0 {\omega_e}^2 \boldsymbol{E}}{j\omega\nu_e - \omega^2} \tag{3a}$$

$$\boldsymbol{B} = \mu_0 \boldsymbol{H} + \frac{\mu_0 {\omega_m}^2 \boldsymbol{H}}{j\omega\nu_m - \omega^2} \tag{3b}$$

The electric polarization $\boldsymbol{P}$ and the magnetic polarization $\boldsymbol{M}$ are introduced, which are

$$\boldsymbol{P} = \frac{\varepsilon_0 {\omega_e}^2 \boldsymbol{E}}{j\omega\nu_e - \omega^2} \tag{4a}$$

$$\boldsymbol{M} = \frac{\mu_0 {\omega_m}^2 \boldsymbol{H}}{j\omega\nu_m - \omega^2} \tag{4b}$$

(4) can be expressed as

$$(j\omega\nu_e - \omega^2)\boldsymbol{P} = \varepsilon_0 {\omega_e}^2 \boldsymbol{E} \tag{5a}$$

$$(j\omega\nu_m - \omega^2)\boldsymbol{M} = \mu_0 {\omega_m}^2 \boldsymbol{H} \tag{5b}$$

By inverse Fourier transformation, we have

$$\frac{\partial^2 \boldsymbol{P}}{\partial t^2} + \nu_e \frac{\partial \boldsymbol{P}}{\partial t} = \varepsilon_0 {\omega_e}^2 \boldsymbol{E} \tag{6a}$$

$$\frac{\partial^2 \boldsymbol{M}}{\partial t^2} + \nu_m \frac{\partial \boldsymbol{M}}{\partial t} = \mu_0 {\omega_m}^2 \boldsymbol{H} \tag{6b}$$

which can be written as

$$\frac{\partial \boldsymbol{J}}{\partial t} + \nu_e \boldsymbol{J} = \varepsilon_0 {\omega_e}^2 \boldsymbol{E} \tag{7a}$$

$$\frac{\partial \boldsymbol{K}}{\partial t} + \nu_m \boldsymbol{K} = \mu_0 {\omega_m}^2 \boldsymbol{H} \tag{7b}$$

where $\boldsymbol{J}$, $\boldsymbol{K}$ are polarization electric current and polarization magnetic current density, respectively, which are

$$\boldsymbol{J} = \frac{\partial \boldsymbol{P}}{\partial t} \tag{8a}$$

$$\boldsymbol{K} = \frac{\partial \boldsymbol{M}}{\partial t} \tag{8b}$$

which are auxiliary differential equations to simulate dispersive media.