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Scattering from a DNG coated PEMC cylinder buried beneath a sinusoidal/flat surface

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ABSTRACT

Scattering of electromagnetic wave from a DNG coated perfect electromagnetic conductor (PEMC) cylinder buried below a slightly rough sinusoidal surface is investigated. This is a generalization of different earlier solved such problems involving PEC/PEMC coated/non-coated cylinder buried below flat/rough surface. The initial reflected and transmitted field from the sinusoidal surface are evaluated using Small Perturbation Method (SPM). All the interactions between the object and the sinusoidal surface have been taken into account using spectral plane wave representation of fields (SPRF). The effect of geometrical and physical parameters on the scattering pattern is observed.

1. Introduction

Electromagnetic scattering has been an important research area due to its numerous applications. The introduction of meta materials, such as PEMC, DNG and Chiral, has defined new problems for the researchers in this area [1]. The fact that the scattered field from meta materials has both co and cross polarized components makes the study of scattering more challenging. Double negative (DNG) meta materials introduced by Veselago [2], attracted electromagnetic community lately, after Shelby [3] realized a DNG material for microwave regime. These materials possess interesting properties such as direction of Poynting vector antiparallel to the direction of phase velocity and anomalous refraction [4]. Ever since several applications of DNG materials have been reported in designing lens, resonators [5] and waveguides [6]. A perfect electromagnetic conductor (PEMC) material, characterized by admittance parameter M, is a generalization of both PEC and PMC materials [7]. PMC corresponds to $M = 0$ while PEC is obtained as the limit $M \to \pm\infty$. A planar PEMC boundary can be realized by placing a layer of bi-isotropic or a gyrotropically anisotropic medium on a PEC plane [8]. The realization of the curved PEMC boundary, a circular cylinder has been proposed in [9]. The possible applications are polarization transformers, field pattern purifiers for aperture antennas, and radar scatters. The boundary conditions for the PEC and PMC are given by following equations

$$\mathbf{n} \times \mathbf{E} = 0, \quad \mathbf{n} \cdot \mathbf{B} = 0\,(\text{PEC}) \tag{1}$$

$$\mathbf{n} \times \mathbf{H} = 0, \quad \mathbf{n} \cdot \mathbf{D} = 0\,(\text{PMC}) \tag{2}$$

where $\mathbf{n}$ denotes the unit vector normal to the boundary surface. These boundary conditions are special cases of the more general PEMC boundary conditions

$$\mathbf{n} \times (\mathbf{H} + M\mathbf{E}) = 0 \tag{3}$$

$$\mathbf{n} \cdot (\mathbf{D} - M\mathbf{B}) = 0 \tag{4}$$

The problem of free space scattering from circular cylinder coated with DNG meta-material has been addressed by many researchers [10–14]. The core of the cylinder is taken to be PEC in [10,11]. It has been reported that transparency and maximizing scattering can be achieved from these coated cylinders [11]. The problem of free space plane wave scattering from a PEMC cylinder coated with DNG meta material is the topic of interest in [12]. Scattered field from a PEMC elliptic cylinder coated with an isotropic and homogeneous dielectric–magnetic material was observed in [13]. Ghaffar et al. [14] studied the scattering from plasma coated PEMC cylinders. Scattering from PEMC cylinder buried beneath a flat interface has been investigated by [15]. Shahzad et al. [16] obtained the scattered field from a PEMC cylinder coated with DNG meta-material buried below a flat interface.

Rough surface is introduced to better approximate the air-ground interface. Different models are available in literature to study scattering from rough interface [17]. Generally, Small Perturbation Method (SPM) [18] and Kirchhoff approximation [19] are

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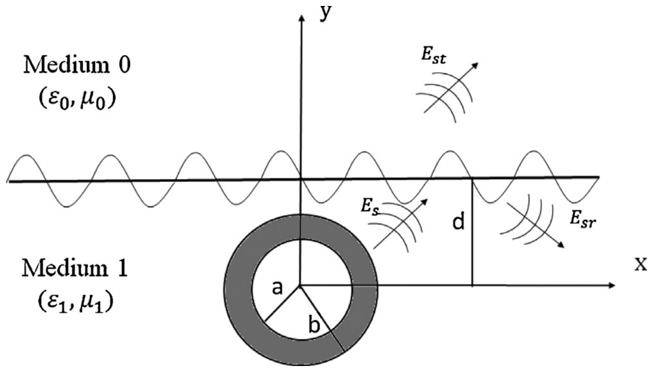

Fig. 1. Decomposition of field components in each medium.

used to study scattering from rough surface with small and large roughness, respectively. A study to determine the region of validity of each method is done in [20].

Scattering from a dielectric cylinder buried below a rough surface has also been investigated by many [21–24]. Lawrence and Sarabandi [21] used asymptotic techniques to solve the integrals, whereas, Cylindrical Wave Approach (CWA) is used by Fiaz et al. [22]. A localized rough surface is assumed while studying scattering from buried dielectric cylinder in [23]. Extended Boundary Condition method with T-matrix algorithm were used to study the scattering from dielectric cylinder in multi layered rough interfaces by Kuo and Moghaddam [24].

The problem at hand, a PEMC cylinder coated with DNG meta material buried under rough interface, is an extension and generalization of different earlier solved problems.

- A PEMC cylinder buried beneath a flat surface [15].
- A DNG coated PEMC cylinder buried beneath a flat interface [16].
- A DNG coated PEC cylinder buried beneath a rough surface [25].
- A PEMC cylinder buried beneath a rough surface [26].

All of these solutions become special cases of the result produced in this work. In Section 2, theoretical formulation of the problem is given. Numerical results are given in Section 3. Finally, some conclusions are drawn.

2. Problem description and theoretical formulation

A PEMC buried cylinder coated with a DNG media is shown in Fig. 1. The radius and the depth of the coated cylinder are b and d, respectively.

A sinusoidal surface is given by:

$$f(x) = A\cos\left(\frac{2\pi}{\lambda_s}x\right) \quad (5)$$

where A and λ_s are the amplitude and the period of the surface, respectively.

An unit amplitude E-polarized field is incident from medium 0 on the sinusoidal surface at an angle θ_i with the horizontal axis and it is given by

$$E_i = e^{-i\left(k_x^i x - k_{oy}^i y\right)} \quad (6)$$

We can express the initial reflected and transmitted field, above and below the surface, respectively by using the first order SPM [21].

$$E_r = \sum_{p=-1}^{1} \gamma_{0p}\left(k_{px}\right) e^{i\left(k_{0y}^i + k_{0py}\right)d} e^{-i\left(k_{px}x + k_{0py}y\right)} \quad (7)$$

$$E_t = \sum_{p=-1}^{1} \tau_{0p}\left(k_{px}\right) e^{i\left(k_{0y}^i - k_{1py}\right)d} e^{-i\left(k_{px}x - k_{1py}y\right)} \quad (8)$$

where $\gamma_{0p}(k_{px})$ is given by

$$\gamma_{0p}\left(k_{px}\right) = \begin{cases} \dfrac{k_{0py} - k_{1py}}{k_{0py} + k_{1py}} & p = 0 \\ \dfrac{iAk_{0y}^i(k_0^2 - k_1^2)}{(k_{0y}^i + k_{1y}^i)(k_{opy} + k_{1py})} & p = \pm 1 \end{cases} \quad (9)$$

and

$$\begin{cases} k_{px} = k_x^i + \dfrac{2\pi p}{\lambda_s} & p = 0, \pm 1 \\ k_{jpy} = \sqrt{k_j^2 - k_{px}^2} & j = 0, 1 \end{cases} \quad (10)$$

The transmission coefficients $\tau_{0p}(k_{px})$ is given by

$$\tau_{0p}\left(k_{px}\right) = \begin{cases} \dfrac{2k_{0py}}{k_{0py} + k_{1py}} & p = 0 \\ \dfrac{iAk_{0y}^i\left(k_0^2 - k_1^2\right)}{\left(k_{0y}^i + k_{1y}^i)(k_{opy} + k_{1py}\right)} & p = \pm 1 \end{cases} \quad (11)$$

For unperturbed case $p = 0$ and for perturbed case $p = \pm 1$. The contribution relevant to rough surface approaches to zero as perturbations (rms height h) becomes small, i.e. $h < \lambda_0/(8\cos\theta_i)$, according to Rayleigh criterion.

The transmitted field will be incident on the cylinder to produce the initial scattered field in medium 1. It can be calculated by applying the boundary conditions at each interface. The boundary conditions at $\rho = a$ and $\rho = b$ are given as

$$\begin{aligned} &H_{2z}^c + ME_{2z}^c = 0, && \rho = a, && 0 \le \phi \le 2\pi \\ &H_{2\phi}^c + ME_{2\phi}^c = 0, && \rho = a, && 0 \le \phi \le 2\pi \\ &H_{1\phi}^i + H_{1\phi}^s = H_{2\phi}^c, && \rho = b, && 0 \le \phi \le 2\pi \\ &E_{1z}^i + E_{1z}^s = E_{2z}^c, && \rho = b, && 0 \le \phi \le 2\pi \\ &E_{1\phi}^s = E_{2\phi}^c, && \rho = b, && 0 \le \phi \le 2\pi \\ &H_{1z}^s = H_{2z}^c, && \rho = b, && 0 \le \phi \le 2\pi \end{aligned} \quad (12)$$

While imposing the boundary conditions, the incident field E_z^i should be written in term of Bessel functions and the corresponding magnetic field H_ϕ^i can be obtained using the Maxwell's relation.

The co-polarized scattered field is given by:

$$E_{1z}^s = \sum_{n=-\infty}^{\infty} i^{-n} a_n H_n^{(2)}(k_1\rho) e^{in(\phi - \phi_i)} \quad (13)$$

The corresponding magnetic field is given by

$$H_{1\phi}^s = -\frac{1}{i\eta_1} \sum_{n=-\infty}^{\infty} i^{-n} a_n H_n^{(2)\prime}(k_1\rho) e^{in(\phi - \phi_i)} \quad (14)$$

where prime represents derivative with respect to argument.

The cross-polarized components of the scattered field are given by

$$H_{1z}^s = -\frac{1}{i\eta_1} \sum_{n=-\infty}^{\infty} i^{-n} b_n H_n^{(2)}(k_1\rho) e^{in(\phi - \phi_i)} \quad (15)$$

$$E_{1\phi}^s = \sum_{n=-\infty}^{\infty} i^{-n} b_n H_n^{(2)\prime}(k_1\rho) e^{in(\phi - \phi_i)} \quad (16)$$