Optik 127 (2016) 6661–6672

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Electromagnetic response of multiple conducting cylinders coated with chiral material

Shakeel Ahmed*, Fazli Manan, Q.A. Naqvi

Department of Electronics, Quaid-i-Azam University, Islamabad, Pakistan

ARTICLE INFO

Article history:
Received 24 February 2016
Accepted 18 April 2016

Keywords:
Scattering
Chiral
RCS
Cylinder
Addition theorem

ABSTRACT

An analytical solution is derived for the scattering of an electromagnetic plane wave from parallel multiple perfect electric conducting (PEC) circular cylinders coated with chiral material. The PEC cylinders and the coating layer are infinite along the axes of cylinders. Parallel polarization has been considered for the analysis. Comparison is carried out between the results for PEC cylinders coated with chiral material and coated with ordinary dielectric material. The numerical results are compared with the published literature and are in good agreement. It has been observed that forward and backward scattered fields of parallel chiral coated PEC cylinders depend on the thickness of chiral coating material, and can be controlled with suitable selection of parameters.

1. Introduction

Electromagnetic scattering from circular cylinder is taken as canonical problem which is important both in theoretical and experimental point of view. It can be used to understand the scattering from cylindrical objects such as pipes, conduits, missiles and fuselage of an aeroplane etc. An irregular surface may also be modelled using the cylinders. Scattering from an array of circular PEC cylinders was studied by Elsherbeni et al. [1].

Boundary conditions for PEC interface [2,3] are

$$\vec{n} \times \vec{E} = 0 \tag{1}$$

$$\vec{n} \cdot \vec{B} = 0 \tag{2}$$

where $\vec{E}$ is electric field and $\vec{B}$ is the magnetic flux density. The electrodynamics of substances with simultaneously negative values of real parts of permittivity and permeability was given by Veselago [4]. In scientific literature such metamaterials are known as double negative (DNG) metamaterial. Scattering of electromagnetic plane waves by a conducting cylinder coated with double negative (DNG) metamaterial is studied by Li and Shen [5]. Irci and Ertürk investigated the transparency and scattering maximization with metamaterial-coated conducting cylinder by considering double positive (DPS), epsilon negative (ENG), mu negative (MNG), and DNG coating layers in their analysis [6]. Ahmed and Naqvi studied electromagnetic scattering from a perfect electromagnetic conductor cylinder coated with a metamaterial having negative permittivity and/or permeability [7].

Bokut et al. and Bohren had studied the electromagnetic waves in chiral media [8–10]. Lakhtakia et al. studied one- and two-dimensional dyadic Green's functions in chiral media [11]. Chiral media are used in many applications involving

* Corresponding author. Tel.: +923015264225.
E-mail addresses: snfawan@yahoo.com (S. Ahmed), fazlikhan@yahoo.com (F. Manan), qaisar@qau.edu.pk (Q.A. Naqvi).

http://dx.doi.org/10.1016/j.ijleo.2016.04.085
0030-4026/

antennas and arrays, antenna radomes, microstrip substrates and waveguides. A chiral object lacks bilateral symmetry. It cannot be superimposed on its mirror image neither by translation nor rotation. This property is called handedness. Objects having the property of handedness are either right-handed or left-handed. Chiral media are optically active. Optical activity is caused by asymmetrical molecular structure which rotates the plane of incident polarized light. The amount of rotation in the plane of polarization is proportional to the thickness of the medium traversed and to the light wavelength. Chiral medium has an effect on the attenuation rate of the right-hand and left-hand circularly polarized waves. Unlike dielectric or conducting scatterers, chiral scatterers produce both co-polarized and cross-polarized scattered fields. Coating with chiral material is used for reducing radar cross-section of targets. The constitutive relations for a non-reciprocal chiral medium are given by

$$\mathbf{D} = \boldsymbol{\epsilon}\mathbf{E} + \mathbf{j}\boldsymbol{\kappa}\sqrt{\epsilon_0\mu_0}\mathbf{H}$$

$$\mathbf{B} = -\mathbf{j}\boldsymbol{\kappa}\sqrt{\epsilon_0\mu_0}\mathbf{E} + \boldsymbol{\mu}\mathbf{H}$$

where ϵ_0 and μ_0 are the premittivity and permeability of the free space, respectively. The permeability is the magnetic parameter. The chirality or the Pasteur parameter κ is dimensionless. The imaginary unit j shows the frequency domain character for these equations and it is due to the time harmonic convention $e^{-j\omega t}$. The degree of handedness of the material is measured by the Chirality parameter κ. The κ sign changes for the mirror image of the material.

Lakhtakia et al. and other researchers investigated the electromagnetic chirality and its applications [12–24]. Scattering from cylindrical objects was studied by many investigators [25–29].

Lakhtakia introduced the concept of nihility [30,31]. Following the work by Lakhtakia, Ahmed and Naqvi studied the directive EM-radiation of a line source in the presence of a coated nihility cylinder [32] and nihility cylinder coated with a chiral layer [33]. Lakhtakia et al. studied nihility cylinder and perfect lenses [34–37]. Tretyakov et al. investigated waves and energy in chiral nihility [38] while Cheng et al. studied waves in planar waveguide containing chiral nihility metamaterial [39]. Qiu et al. investigated chiral nihility effects on energy flow in chiral materials [40].

In this paper, parallel circular cylinders coated with homogeneous, isotropic and linear chiral layer are considered. For simplicity, electric field vector for incident plane wave is taken parallel as well as perpendicular to the axes of PEC cylinders, that is; both TE and TM cases are taken. The method of eigenfunction expansion is applied.

Appropriate boundary conditions are applied at interfaces in the geometry. Using the large argument approximation of Hankel function, the bistatic echo widths in the far zone are calculated. The addition theorem of Hankel functions is used to represent the local coordinate in global coordinates. For the verification of analytical formulation and numerical code, the plots (numerical results) are compared with the published work. We have used e^{-jwt} time dependence which is suppressed through out the analysis.

2. Analytical formulation

The geometry of problem used for present analysis is shown in Fig. 1. It contains multiple parallel PEC circular cylinders, each coated with a layer of chiral medium. Thickness of the layer is also assumed to be same and uniform along the entire length of each cylinder. Each chiral coated PEC cylinder is of infinite length and is placed in free space. For simplicity, we assume that axes of the cylinders are coincident with z-axis of the local coordinate system. The radius of each PEC cylinder without coating is a whereas radius of cylinder with coating is b.

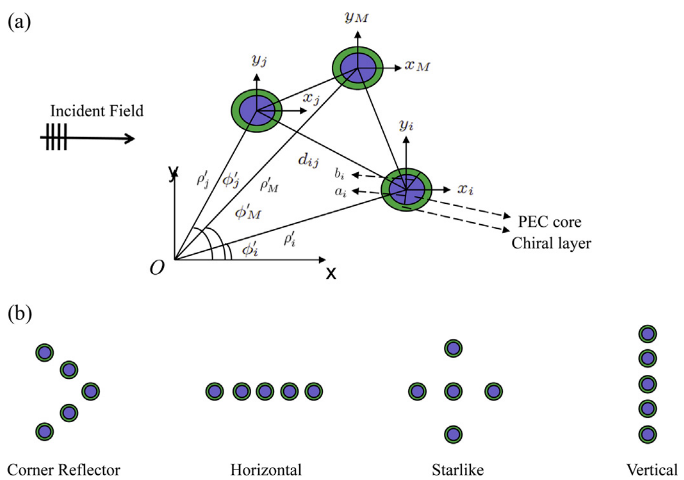

Fig. 1. (a) Geometry of chiral coated PEC circular cylinders. (b) Configurations of chiral coated PEC circular cylinders.