ELECTROMAGNETIC CHARACTERISTICS OF SIMPLE TARGETS EMBEDDED IN CHIRAL MULTILAYER STRUCTURES

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1. INTRODUCTION

The great potential and usefulness of SAR (Synthetic Aperture Radar) data for several remote sensing applications have been proved over the past few decades. In addition the development of techniques for extracting information carried out by SAR data have been increased. Usually, these techniques are based on stochastic or electromagnetic mathematical models. In the stochastic modeling a SAR data is described by statistical point of view, that is, an SAR image is assumed to be an overcome of a random process. The statistical model most widely used by SAR community is known as multiplicative model [1]. On the other hand, the aim of electromagnetic modeling is the description of the interaction process between an electromagnetic wave and natural targets. This description is done by quantifying the total scattering of all elements that can compound a given target. In this approach, it is taking into account the geometry and the electric properties of the each scattering element as well as the main characteristics (frequency, polarization, incident and scattering angles, among others) of the incident electromagnetic wave.

Using the electromagnetic modeling, natural targets might then be described through a set of interconnected scattering elements, having different sizes and random spatial distribution and orientation [2]. A stratified layered medium containing some scattering elements is another way used to represent a natural distributed target. It is important to mention that the electromagnetic characteristics of each layer will affect the target scattering when the stratified medium is used. The Faraday rotation, which occurs due to the anisotropic characteristic of the ionosphere, is an example of this kind of influence [4]. A forest, on the other hand, was modeled in [3] by two uniaxial dielectric layers. The chirality is another electromagnetic property that can have its influence observed by the radar data, as affirmed by Cloude in [5], for some vegetation types. However, Krogager in [6] was one the first researches that considered the target chirality effect, when he had introduced the scattering matrix of a helix in his target decomposition theorem. Yamaguchi et al. [7] have also used the helix scattering matrix in the four-component decomposition.

The use of electromagnetic properties such as anisotropy and/or chirality establishes a more complex natural target scattering model. However these characteristics generate a more realistic model, increasing the target discrimination capacity by radar images. Therefore, in this work is presented a scattering study of simple target embedded in a stratified multilayer structure having one chiral layer. It is known that the macroscopic effect caused by chirality is a rotation of the polarization plane of linearly incident wave. The analysis is conducted by means of electromagnetic analytical theory, starting from Maxwell's equations until the establishment of the electromagnetic fields that propagate in this structure, including the electromagnetic fields scattered by the stratified structure. Knowing these fields it is possible, for instance, to characterize the structure through its radiation pattern, scattering matrix, polarimetric response as well as radar cross section.

2. MULTILAYER STRUCTURE AND MODELING

The structure under investigation, depicted in Fig. 1, is composed of three isotropic, linear, homogenous layers stacked up in the z direction. It contains one confined chiral (bi-isotropic and reciprocal medium) layer located between free space (the upper layer) and ground (the lower layer). The lower layer of complex permittivity ε_g and complex permeability μ_g occupies the negative-z region. The chiral layer is characterized by thickness ℓ, complex permittivity ε, complex permeability μ and admittance chiral ζ. Perfect electric and magnetic surfaces of infinitesimal thickness, are printed on each interface and act as scattering elements. The layers are assumed to be infinite along the transversal x and y directions. The development is based on a global rectangular coordinate system located on top of the ground layer (interface $z = 0$) lying on the xy-plane.

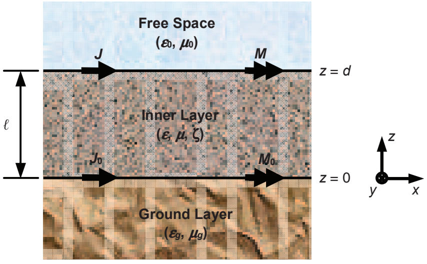


Fig. 1 – A lateral view of the multilayer structure under analysis.

The analysis is carried out by means of the full-wave technique in the spectral domain, developed in [8]. According to this methodology, the structure is treated as a boundary value problem, where electric and magnetic currents located on each interface act as virtual sources of the scattered fields. The corresponding spectral Green's functions are obtained analytically in a closed form. Expressions for the far-zone electromagnetic fields scattered by the multilayer structure are derived by asymptotical evaluation of the Fourier transform using the method of stationary phase.

3. RESULTS

Initially the scattering study is presented in terms of the radiation pattern. The scattering analysis is conducted based on a particular configuration of the stratified structure, in which it is assumed the existence of scattering elements only in the interface between the free-space region and chiral layer. That is, electric and magnetic dipoles are printed on interface $z = d$ (see Fig. 1) and along the x-direction.

In antenna theory the directivity function $\mathbb{D}(\theta, \phi)$ is one of several parameters used to characterize or define an antenna. According to [9] this function is defined as the ratio of the radiation intensity $\mathbb{U}(\theta, \phi)$ in a given direction from the antenna to the radiated intensity average over all direction. The $\mathbb{D}(\theta, \phi)$ is expressed by

$$\mathbb{D}(\theta,\phi) = \frac{4\pi\,\mathbb{U}(\theta,\phi)}{\mathbb{P}_i}, \tag{1}$$

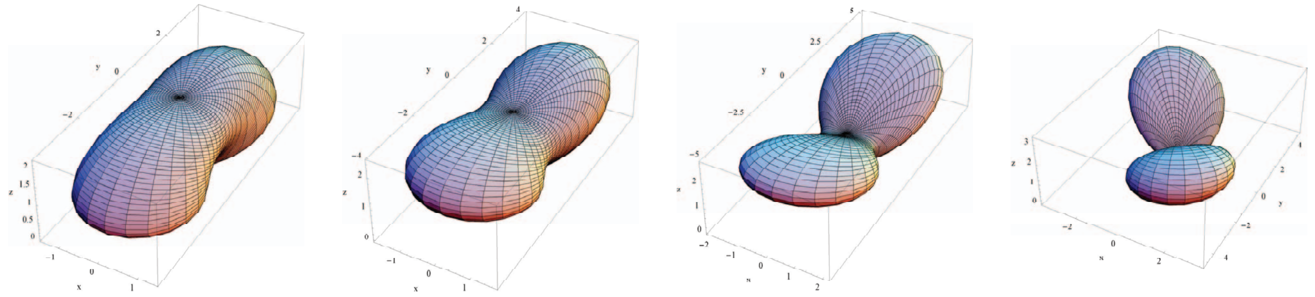
with $\mathbb{P}_i = \int_{\Omega} \mathbb{U}(\theta,\phi)\,d\Omega$ representing the average radiated power within the solid angle Ω and the $\mathbb{U}(\theta, \phi)$ function being defined, for a multilayer structure, as

$$\mathbb{U}(\theta,\phi) = \frac{1}{2\eta_0}\left(\frac{k_0 \cot\theta}{2\pi}\right)^2 \left\{ \left| \mathbb{e}_{0z}(k_{xe}, k_{ye}) \right|^2 + \eta_0^2 \left| \mathbb{h}_{0z}(k_{xe}, k_{ye}) \right|^2 \right\}, \tag{2}$$

where η_0 is the intrinsic impedance of free-space, $k_{xe} = k_0 \sin\theta\cos\phi$ and $k_{xe} = k_0 \sin\theta\sin\phi$ are the stationary phase points, k_0 is the wave number of the exciting wave and $\mathbb{e}_{0z}$ and $\mathbb{h}_{0z}$ are the longitudinal components of the spectral far scattered electromagnetic fields [10].

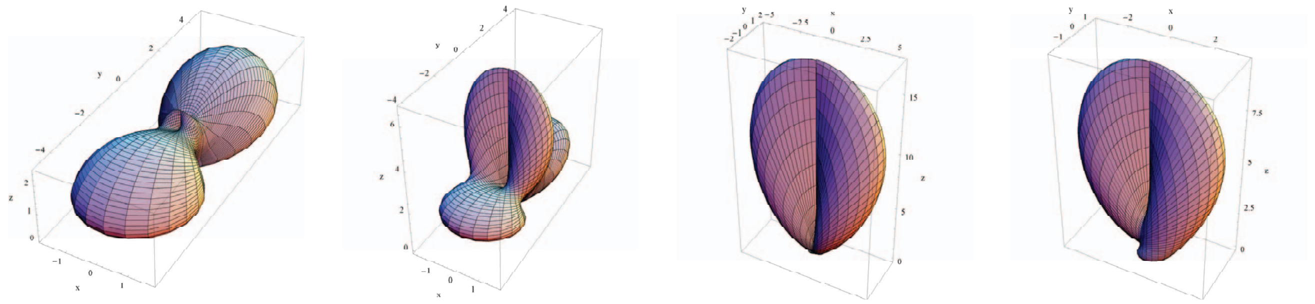
Considering the mentioned particular configuration structure of Fig. 1 and assuming that the size of dipoles are infinitesimal the function $\mathbb{D}(\theta, \phi)$ is promptly computed. The directivity function for a structure characterized by $\varepsilon_r = 2$, $\mathrm{tg}\delta = 0$, $\ell = 32$ mm, $\varepsilon_{rg} = 1$ and $\mathrm{tg}\delta_g = 1.0\times10^{+15}$ as dielectric parameters values, it was evaluated at 2.25 GHz for printed infinitesimal electric and magnetic dipoles. The respective three-dimensional graphic of $\mathbb{D}(\theta, \phi)$) are illustrated in Figs. 2 and 3 for four values of chiral admittance ($\zeta \in \{0.0, 1.0, 2.0, 3.0\}$ mS). It can be noted when $\zeta = 0.0$ mS means an achiral layer, i.e., a layer without chirality characteristic (the ordinary isotropic medium).

From these figures it can be notice that the radiation patterns are completely different for both dipoles. It is an expected fact due to the dissimilar electromagnetic feature of the dipoles. Theoretically, the radiation pattern can be used to differentiate structures which present these kinds of dipoles. Furthermore, it can be observed, for both dipoles, that the shapes as well as the radiation levels are significantly modified by the variation of the inner layer chiraility. Besides these cited modifications it is also noted that the chirality impinges a rotation on the radiation pattern. This rotation angle is measured relative to the radiation pattern point which presents the maximum value. Using the achiral case as reference the computed rotation angles were, respectively for admittance chiral equal to 1.0, 2.0 and 3.0 mS, –5°, 6° and 37° for the structure containing the electric dipole and –7°, 84° and 76° for the structure having the magnetic dipole. It is important to mention that the scattering analysis based on the radar cross and polarimetric response are being evaluated and it will be presented in the full paper.



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

Fig 2 – Three-dimensional graphic of $\mathbb{D}(\theta, \phi)$ for infinitesimal electric dipole: (a) $\zeta = 0.0$ mS, (b) $\zeta = 1.0$ mS, (c) $\zeta = 2.0$ mS and (d) $\zeta = 3.0$ mS.



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

Fig. 3 – Three-dimensional graphic of $\mathbb{D}(\theta, \phi)$ for infinitesimal magnetic dipole: (a) $\zeta = 0.0$ mS, (b) $\zeta = 1.0$ mS, (c) $\zeta = 2.0$ mS and (d) $\zeta = 3.0$ mS.

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