Electromagnetic Characterization of Uniaxial Chiral Composites Using State Transition Matrix Method

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***Abstract*—An analytic frequency domain technique is presented for reconstructing constitutive parameters of uniaxial chiral media. First, forward analysis of the problem is discussed using 4 × 4 transition matrix method. Based on this analysis, a procedure is illustrated for retrieving all the constitutive tensor parameters of uniaxial chiral slab. In the proposed retrieval method, scattering parameters (reflection and transmission coefficients) are employed for plane wave incident normally on a uniaxial chiral slab. This characterization algorithm is based on the state transition matrix and its properties, discussed as two proven theorems. Unlike conventional methods, in this method it is not necessary to directly consider complicated eigenpolarizations of the uniaxial chiral medium resulting in complexity. To validate the proposed method, constitutive tensor parameters of two dispersive uniaxial chiral composites are retrieved at microwave frequencies. The results showed that when the scattering parameters combined with the properties of state transition matrix, they could provide a powerful technique for characterizing uniaxial chiral composites.**

***Index Terms*—Parameter reconstruction, state transition matrix method, uniaxial chiral composites.**

I. Introduction

STUDY and characterization of artificial composite structures as important topics in electromagnetic research have been the subject of many studies over the years. Applications of such structures in microwave and millimeter wave regimes have prompted a renewed interest over the last decade which has led to introduction of a wide application in different microwave devices such as cavities, resonators, waveguides, lenses [1]–[4] and has allowed for the realization of negative refraction index [5].

Studying artificial chiral media is a recognized subject which dates back to the last decades [6]. Recently there has been considerable interest in using such composites to obtain giant optical activity and negative refraction [7]–[14]. Two important properties are supposed for chiral media; the first one is optical activity, which could rotate polarization plane of a linearly polarized wave propagating through it. The second property is circular dichroism, which is attributed to different absorption of right and left circularly polarized waves inside the chiral medium.

Isotropic chiral media form a special subgroup of bianisotropic media where constitutive parameters are no longer tensors. A special type of bianisotropic chiral media is axially chiral uniaxial medium [6]. A uniaxial chiral medium can be realized by doping parallel miniature wire spirals into a host dielectric [15], [16]. One of the well-known applications of uniaxial chiral medium is in polarization transformers, in which any polarization can be transformed into any other polarization [17].

The interaction of electromagnetic fields with different chiral media, (e.g., isotropic, uniaxial bianisotropic, inhomogeneous) has been fully discussed in the literature [18]–[21]. In addition, parameter retrieval of an isotropic chiral slab along with a well-known methodology for retrieving electromagnetic parameters using normal incidence scattering parameters has been widely discussed in the literature [22], [23]. Such a method has the advantage of being applied to both simple and complicated structures and can be used in both simulation and experiment.

Characterization of bianisotropic media using scattering parameters has been discussed by many researches. An excellent review of such different approaches was presented in [24]. Briefly, these methods are based on either simplifying assumptions (e.g., lossless condition) or using fully numerical optimization approaches [25]–[27]. Recently, a semianalytical method was presented in [24] for the characterization of uniaxial chiral media. In that relatively complicated and detailed method, a full-wave method was used; so that, first, complicated eigenwaves of the wave equation in a uniaxial chiral layer was derived and the general form of electric and magnetic fields inside such an environment was determined. Then, using the boundary conditions of the problem, a set of 14 equations was obtained, by solving which constitutive parameters of the slab was retrieved.

The objective of the present work is to characterize uniaxial chiral media using the state transition matrix method. A procedure is presented for retrieving all the constitutive tensor parameters of uniaxial chiral slab using scattering parameters based on the state transition matrix. The proposed method is mainly based on the properties of state transition matrix discussed as two simple but efficient theorems. In the proposed method, it is not necessary to consider complicated eigenpolarizations of the uniaxial chiral medium resulting in deriving complex equations.

Organization of this paper is as follows. In Section II, analysis of forward problem is reviewed. Section III presents and proves some useful properties of the state transition matrix. Section IV deals with the formulation of parameter retrieval technique in

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