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Parameter reconstruction of materials with off-diagonal anisotropy using the state transition matrix method

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ABSTRACT

An effective non-iterative method is developed for determination electromagnetic parameters of complex materials with anisotropy. Unlike the existing methods, the proposed method can extract the electromagnetic tensor parameters of materials with off-diagonal anisotropy using co- and cross-polarized reflection and transmission without using iterative procedures. Useful analytical expressions are derived for extracting the medium parameters of materials with off-diagonal anisotropy. The advantage of the method is that it uses state transition matrix and its properties in order to avoid nonlinearity and complexity of the problem. The method can work very well for dispersive materials since it is based on frequency-by-frequency extraction. The proposed method is validated by extraction of the complex permittivity and permeability tensors of two typical anisotropic materials.

1. Introduction

Electromagnetic characterization of materials is an important issue in many fields such as microwave engineering, bioengineering, electronics, remote sensing, medical treatments, civil engineering and concrete industry. Recently, increasing attention on metamaterials has been paid due to their exciting physical behaviors and potential applications. Generally, due to the nature of the engineered composites, metamaterials exhibit complex, dispersive, and anisotropic electromagnetic material properties. Such materials find various applications in antenna, microwave devices, and radar absorbers [1–3]. It is important for the anisotropic properties of these materials to be accommodated when characterizing constitutive parameters for use in the design process.

Different methods, each with its unique advantages and limitations, have been introduced to characterize the materials' properties [4]. Due to the relative simplicity, broad frequency coverage, and higher accuracy, transmission–reflection techniques are the most widely used broadband measurement techniques. A variety of retrieval methods for obtaining isotropic permittivity and permeability through the inversion of measured scattering-parameters are available in literature [5–9]. A review of different approaches has been presented in [10]. These methods make use of analytic formulas connecting measured S-parameters to material parameters or optimization schemes. However, in more complex materials (e.g. anisotropic or bianisotropic), deriving analytic formulas connecting measured S-parameters to material parameters is generally difficult and even impossible.

The interaction of electromagnetic fields with anisotropic materials has been well described in the literature [11], and several techniques for the characterization of these materials have been introduced [12–22]. However, most these methods such as free-space and waveguide fixture have been designed and implemented for characterizing materials with diagonal permittivity and permeability tensors and the existence of off-diagonal entries in the material tensors has not been addressed. In addition, recent attempts at measuring electromagnetic parameters of materials with off-diagonal anisotropy have mainly relied on fully numerical optimization techniques, wherein the constitutive material parameters are determined by minimizing the difference between the measured and the theoretically computed reflection and transmission coefficients. These techniques, though, are often time consuming due to slow convergence and existence of spurious solutions. Therefore, for general anisotropic specimens, where the material tensor parameters are complex, a new approach is needed.

Within this framework, the aim of this study is to present an analytic methodology based on the state transition matrix method to the characterization of materials with off-diagonal anisotropy. Transition matrix method has been well described in forward scattering problems anisotropic and bianisotropic media, over the years [23–25]. Recently, its application in the formulation for inverse scattering problems including isotropic chiral layers has

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