vertical plane and the horn return loss at the input port has been compared with measurements. For the second case, the results provided by the hybrid technique have been compared with those yielded by the CST Microwave Studio. In both cases, the radiation pattern and the return loss predicted by hybrid technique shows good agreement with the measurement and with the results provided by the CST Microwave Studio.

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Electromagnetic Characterization of Biaxial Bianisotropic Media Using the State Space Approach

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***Abstract*—The electromagnetic characterization method based on the state space approach, which has been proposed for parameter retrieval of uniaxial chiral composites is extended in order to extract the electromagnetic parameters of biaxial bianisotropic media as well. The properties of state transition matrix of a biaxial bianisotropic layer are presented as two theorems, and the formulation of the proposed electromagnetic characterization method is then provided. The proposed approach reduces nonlinearity and complexity of the problem by considering properties of the state transition matrix. The validity of the method is verified using analysis of a bianisotropic specimen. The results show that the proposed technique allows for a characterization at oblique incidences.**

***Index Terms*—Biaxial bianisotropic media, electromagnetic characterization, state space approach.**

I. INTRODUCTION

The interaction of electromagnetic waves with complex electromagnetic structures has generated an enormous research interest over the years. Due to the need for special electromagnetic properties, artificial structures, such as bi-isotropic and bianisotropic, classified as materials exhibiting magneto-electric coupling, are suggested. Bianisotropic media are studied for various applications such as waveguides [1], polarization transformers [2], absorbers [3] and backward wave media [4].

With the increased interest in artificial electromagnetic structures, various methods have been proposed for retrieving the effective electromagnetic parameters of such artificial structures [5]–[7]. A commonly used scattering parameter method is generally based on the inversion of reflection and transmission parameters of a plane wave incident on the structure to give electromagnetic parameters. Most attempts for electromagnetic characterization of materials at oblique incidence or accounting for anisotropy or bianisotropy have relied on simplifying assumptions or using fully numerical optimization methods and curve fitting techniques [8]–[11]. Therefore, it seems that for media where the material tensor parameters are complex, a new approach is needed.

The state space approach or 4×4 transition matrix method is a commonly used method for the analysis of scattering from planar layered generalized anisotropic or bianisotropic media [12]–[14], which its application in the inverse scattering problems has not been reported in the literature. Recently, a parameter retrieval technique based on the state space approach for the electromagnetic characterization of uniaxial chiral structures has been introduced [15]. The main difference between this approach and conventional retrieval methods is direct calculation of the propagation constant and impedance of the modes supported by the medium. This feature effectively allows avoiding nonlinearity and complexity of the problem.

The objective of this work is to characterize biaxial bianisotropic media using the state space approach. In [15], only normal incidence

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