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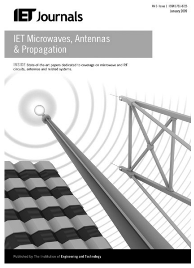

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Analytical relations for achieving zero reflection in anisotropic materials

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Abstract: Complete transparency and zero reflection condition in anisotropic materials are investigated, and are undertaken in an analytical study. First, the relations related to multilayer anisotropic media in linear structures are stated, and then, through these relations, zero reflection from layered structures composed of conventional materials and/or metamaterials are studied. The authors have formulated a rule for zero reflection from anisotropic media, and have presented various aspects of such structures from the viewpoints of frequency and the angle of incidence, and have created complete transparency in them.

1 Introduction

The problem of the interaction of electromagnetic waves with isotropic and anisotropic layers has long been a subject of interest because of its wide range of applications in various areas such as geophysics, locating underground resources, microstrip radiators and absorbent coatings. The latter case is of remarkable significance, and has gained much more consideration from researchers. Although there have been important anisotropic materials like ferrites, recently, the problem is being reconsidered because of novel metamaterials and their applications in the reduction of radar cross section (RCS).

Initial works on the subject were based on 4×4 characteristic matrix of a single anisotropic slab [1, 2]. Later efforts include generalisation of the problem for stratified structures by different methods [3–5]. Morgan *et al.* [6] paid attention to a numerical solution, and introduced an efficient and simple algorithm for this case. Others proposed various techniques based on eigenvalue computation, Ricatti differential equation and transmission line method [7–11], which are more complex. The characteristic matrix algorithm [1, 2] had a serious drawback and showed instability for thick layers compared with wavelength. To avoid this instability which was because of the numerical finite difference algorithm, the use of a hybrid matrix of the structure is suggested [12].

The method we will use in this paper will bring us to the recursive relations with which we are familiar in isotropic media. Their application to anisotropic media is still based on matching the field components with one another. In fact, expanding the application scope of these relations to include anisotropic media as well as isotropic ones is what this paper will concern itself with. We will arrive at the intended application through the resulting relations.

On the other hand, by realising negative permittivity and permeability, the application of isotropic metamaterials in reducing electromagnetic scattering was shown via coupling with conventional isotropic materials [13–16].

We will present a method in this paper for analysing multilayer anisotropic structures, and, using this method, we will go on to consider an important problem concerning RCS, that is, zero reflection.

This problem is related to transparency; for example, glass reflects the infrared spectrum but is transparent against visible light, or many of the objects that reflect visible light are transparent against radio frequency waves. When both sides of a structure are surrounded by air or free space, it is possible that the structure becomes transparent for a part of the electromagnetic spectrum. This transparency might be because of the fact that there is no electromagnetic activation in that particular spectrum, which is related to the atomic and molecular structure of the material. In another case, transparency can be the result of the organisation of a number of different layers in order to make the reflection zero and maximise electromagnetic wave transmission to the other region. In this case the inner most medium is active in the working section of the electromagnetic spectrum and affects the fields. Our approach in this paper is related to the second type of transparency.

The above mentioned quality can be employed in different applications. As an example for the visible light spectrum, sturdy structures can be built that are transparent against visible light and can be used in buildings with transparent walls. Furthermore, as an example for the electromagnetic spectrum, machines can be manufactured that are transparent against electromagnetic waves, such as military tools and vehicles made, instead of metal, of sturdy multilayer materials that are transparent against radar waves. Another example can be the making of regulatory filters for filtering a specific frequency, polarisation or angle of incidence.

This transparency has been shown by Alu and Engheta [17] using metamaterials and left-handed isotropic materials; in this paper, it will be shown for anisotropic materials, and its qualities will be studied.

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