Propagation of Electromagnetic Waves in Laminated Periodic Composite Structures

Huann-Ke Chiu, Hsiao-Chang Chu, and Chun Hsiung Chen
Department of Electrical Engineering, National Taiwan University,
Taipei, Taiwan 10617

Abstract

A new model based on filament-current and thin-current assumptions together with suitable phase correction is proposed for discussing the electromagnetic fields in a multi-layered and lossy periodic composite structure which has circular conducting fibers embedded in a dielectric matrix. In this study, numerical results for graphite/epoxy (G/E) composites are presented and compared with previous investigation. This new model is useful in characterizing the composite materials even up to the higher frequency range.

Introduction

Advanced composite materials have recently been suggested as substitutes for metals in modern aircraft systems due to their superior mechanical properties. But the shielding and reflection properties of advanced composite materials are significantly different from those of metals, making the study of their electromagnetic characteristics an important issue in electromagnetic compatibility (EMC).

Previous electromagnetic investigations of composite materials were mostly in the lower frequency range in which the fiber spacing is much less than the wavelength. Under such a condition, the composite material may be modeled as a laminated anisotropic medium and bulkily represented by a complex permittivity tensor [1]. But this bulk tensor model is inadequate in analyzing the reflection and transmission characteristics in higher frequency range in which the fiber spacing is comparable to the wavelength.

In higher frequency range, the composite material should be modeled as a lossy periodic structure of having conducting fibers embedded in a dielectric matrix. Recently, a filament-current phase-correction model [2] has been proposed to analyze its higher frequency effect for the TM case. However, only single-layer composite structures are analyzed. In this study, a simplified model is proposed to analyze the plane-wave shielding and reflection properties of a laminated periodic fiber-matrix composite structure.

Formulation

Consider an electromagnetic propagation problem in which a plane wave is obliquely incident upon an N-ply laminated periodic composite structure as shown in Fig. 1. Each individual lamina has conducting fibers of radius a and conductivity σ embedded in a dielectric matrix of thickness t

0-7803-4178-3/97/$10.00

and dielectric constant ϵ_r. The periodic spacing is d and the structure is uniform in $\hat{y}'$ direction.

We first use the filament-current model [2] to discuss the induced current along the fiber direction in each fiber and assume that the fiber current is concentrated along the fiber center. We then use the thin-current model to treat the induced current perpendicular to the fiber direction and assume that the induced current is concentrated on the plane $z' = 0$. Next, the scattering effect of the fibers is dealt with by calculating the scattered field from the induced currents both parallel and perpendicular to the fiber direction. Finally, by including the effect of the dielectric matrix, multiple reflection and transmission at the air-matrix interfaces, as well as the phase correction across the fiber grating [2], one may obtain the reflected and transmitted Floquet mode fields from which the shielding effectiveness (SE) and reflection loss (R) may be calculated.

Results

A comparison of our results for a single-layer G/E composite with those of Lin [1] is shown in Fig. 2. The effect of varing the layer number N is presented in Fig. 3, where the results of Lin [1] are also included. Good agreement between both results again supports the superiority of the bulk tensor model [1] in the lower frequency range ($f < 10^8$ Hz). Fig. 4 shows the effect of varing the incident angle θ for 4-ply G/E composite. Results of the bulk tensor model and the approximate model which only takes the filament current into consideration are also included for comparison. It is found that there is no evident distinction for the incident angle $\theta < 70°$.

Conclusion

A new model based on filament-current and thin-current assumptions together with suitable phase correction has been proposed to analyze the propagation characteristics of a multilayer composite material. This model can efficiently handle the complicated laminated periodic structure with reduced CPU time in computation even up to the higher frequency range.

Acknowledgment

This study was supported by the National Science Council of Taiwan, Republic of China under Grant NSC 86-2213-E-002-020.

References

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[2] H.-C. Chu and C. H. Chen, "Shielding and Reflection Properties of Periodic Fiber-Matrix Composite Structures,'IEEE Trans. Electromagn. Compat., vol. 38, no. 1, pp. 1-6, Feb. 1996.

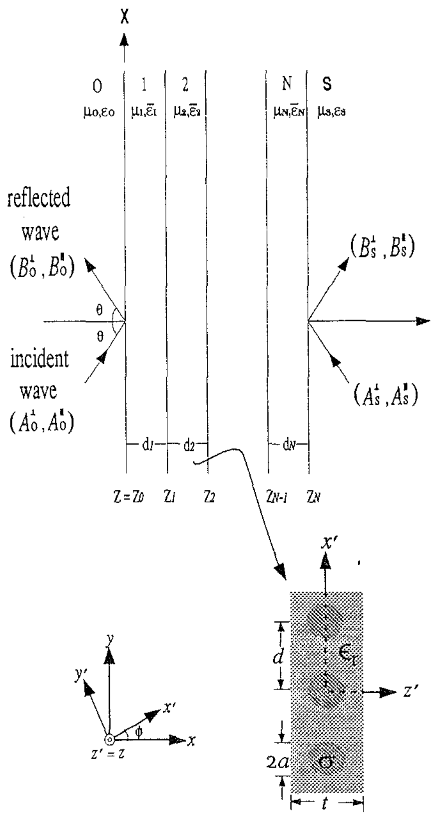

Fig. 1. Geometry of N-ply laminated periodic composite structures.

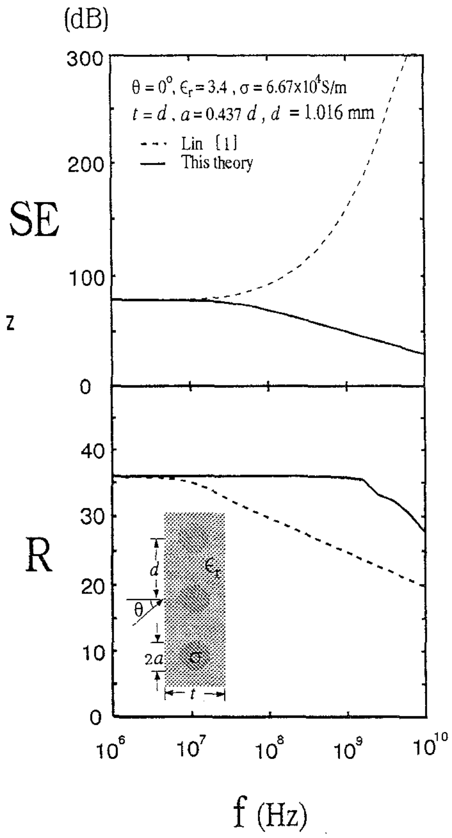

Fig. 2. Comparison of shielding effectiveness (*S*E) and reflection loss (***R***) for single-layer G/E composite with those of Lin [1].

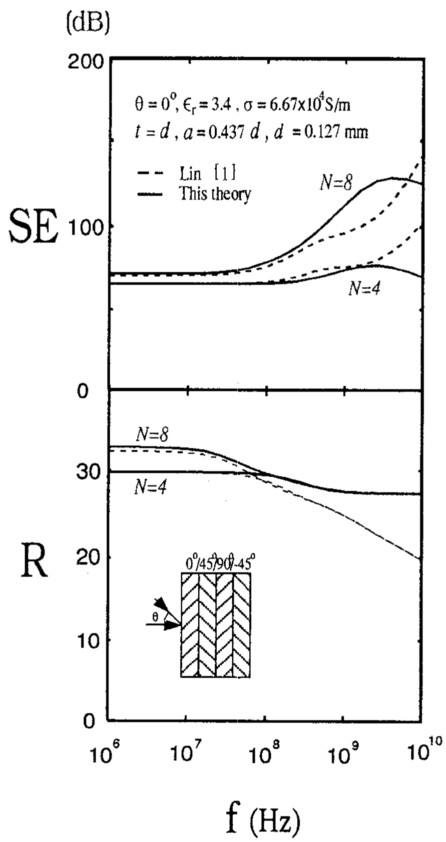

Fig. 3. SE and ***R*** of G/E composite with N (number of layers) as parameters. Also included are results of Lin [1] for comparison.

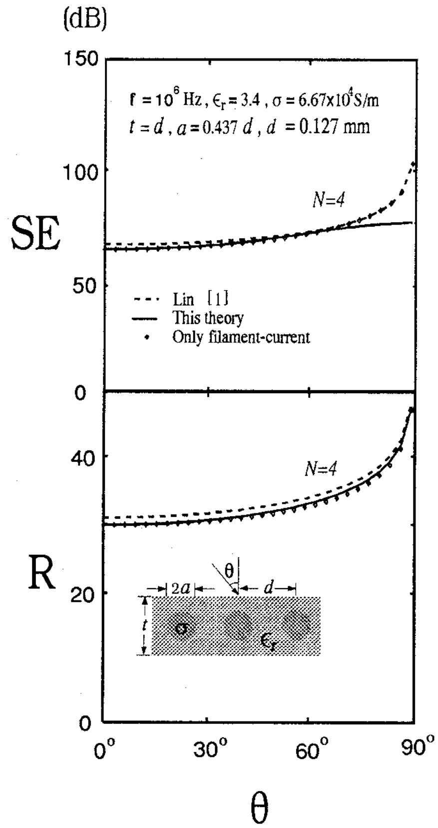

Fig. 4. SE and ***R*** of 4-ply G/E composite with different incident angle θ. Results of Lin [1] are also included for comparison.