A Periodic Surface Integral Formulation for Single-Layer Composite Structures (TE Case)

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Abstract

A periodic surface integral formulation for TE case is proposed to treat the transmission and reflection characteristics of a single-layer periodic composite structure which has square conducting fibers embedded in a dielectric matrix. This formulation makes use of the equivalence principle to represent the unknown electric and magnetic currents over the material discontinuity interfaces, and then uses the structure periodicity and Poisson summation formula to reduce the problem to a periodic cell. In this preliminary study, convergence study and comparison with the previous published results are included to confirm the accuracy of the new formulation.

Introduction

Advanced composite materials have recently been suggested as substitutes for metals in modern aircraft systems due to their superior mechanical properties. But the reflection and transmission properties of advanced composite materials are significantly different from those of metals, which necessitates the intensive studies of their electromagnetic characteristics.

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

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 periodic surface integral formulation [2] has been proposed to analyze its higher frequency effect for the TM case. In this study, the periodic surface integral formulation is extended to treat the electromagnetic properties of a composite structure for the TE case.

Formulation

Consider a single-layer periodic composite structure as shown in Fig.1. As suggested by [2], the equivalence principle is applied to decompose the original problem into three equivalent problems. The original problem as

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depicted in Fig.2 has three boundaries Γ_1, Γ_2, and Γ_f. Here, the equivalent electric and magnetic currents are introduced over the boundaries Γ_1 and Γ_2 to support the discontinuity in the tangential fields, but only the electric current is introduced over the fiber-matrix interface Γ_f by using the surface impedance approximation [2].

For the TE case with H-field along $\hat{z}$ direction, the magnetic current is along $\hat{z}$ direction and the electric current is in the transverse direction. Thus, the scattered magnetic field H^s may be expressed as

$$H_i^s(\vec{\rho}) = -j\omega\epsilon_i \int_\Gamma G_i^o(\vec{\rho},\vec{\rho}\,')M(\vec{\rho}\,')dl' + \int_\Gamma [\hat{n}' \cdot \nabla' G_i^o(\vec{\rho},\vec{\rho}\,')]J(\vec{\rho}\,')dl' \quad (1)$$

where $\vec{\rho}$ and $\vec{\rho}\,'$ denote the field and source points, respectively. Here Γ is the path along which the equivalent sources $\vec{J}$ and $\vec{M}$ may exist, and $i = 1,\ 2,$ or 3 is associated with region 1, region 2, or the dielectric material in region 3, respectively. The Green's function in (1) is associated with the zero order Hankel function of second kind.

By incorporating the Floquet expressions and applying Poisson summation formula into (1), we may finally obtain five surface integral equations only over the cell boundary B, in which

$$\begin{aligned} H_i^s(x,y) &= \sum_{n=-\infty}^{\infty} \{\frac{1}{2\alpha_{ni} d} \int_B [-j\omega\epsilon_i M(x',y') + \hat{n}' \cdot (jk_n\hat{x} \pm \alpha_{ni}\hat{y})J(x',y')] \\ &\quad \cdot e^{jk_n x' \pm \alpha_{ni} y'} dl'\} \cdot e^{-jk_n x \mp \alpha_{ni} y} \qquad , \quad \begin{matrix} y > y' \\ y < y' \end{matrix} \end{aligned} \quad (2)$$

where

$$k_n = k_1 \sin\theta + \frac{2n\pi}{d} = k_1 \sin\theta_n \ , \ \alpha_{ni} = \begin{cases} j\sqrt{k_1^2\epsilon_i - k_n^2} & \text{if } k_1^2\epsilon_i > k_n^2 \\ \sqrt{k_n^2 - k_1^2\epsilon_i} & \text{if } k_1^2\epsilon_i < k_n^2 \ . \end{cases} \quad (3)$$

The five surface integral equations are solved numerically by the method of moments with pulse bases and point-matching. Then, we can obtain a matrix equation for the unknown electric and the magnetic currents. By a substitution of these currents into (2), we can calculate the reflected and transmitted fields everywhere. The total reflected power P_r, transmitted power P_t, and dissipated power P_d are given by

$$P_{r,t} = \sum_n \frac{|\ H_{1,3}^s(n)\ |^2 \cos\theta_n}{|\ H^{inc}\ |^2 \cos\theta} \ , \quad P_d = 1 - P_r - P_t \quad (4)$$

where θ_n is defined by (3) and $H_{1,3}^s(n)$ are the fields for the nth Floquet mode.

Results

Accuracy of the new approach results is tested by comparison with those of Gedney [3], Fig.3 for the grating composed of perfectly conducting corrugated surface and Fig.4 for perfectly rectangular conductors. Good agreement among these results supports the accuracy of the proposed theory.

Single-layer graphite/epoxy composites will be dealt with in the near future. In particular, numerical results such as reflected, transmitted, and dissipated powers will be presented to illustrate, in detail, the effects of frequency, incident angle, fiber width, fiber conductivity, and embedding matrix dielectric constant etc.

Conclusion

A periodic surface integral formulation for single-layer composite structures under TE case is proposed, based on the equivalence principle together with the periodic Green's function technique. This formulation can handle any shape of the periodic structure as long as the surface integral can be integrated numerically. By introducing the unknown electric and magnetic currents only over the boundary surfaces, the unknowns are much reduced in comparison with the volume integral formulation and the computational efficiency can be greatly improved. One defect of this formulation is the use of the surface impedance approximation which is inadequate in lower frequency.

Acknowledgment

This study was supported by the National Science Council of Taiwan, Republic of China under Grant NSC 85-2213-E-002-001.

References

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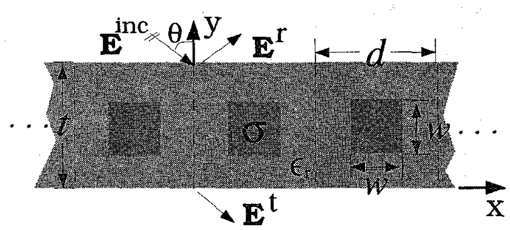

Fig.1. Geometry of single-layer periodic composite structures.

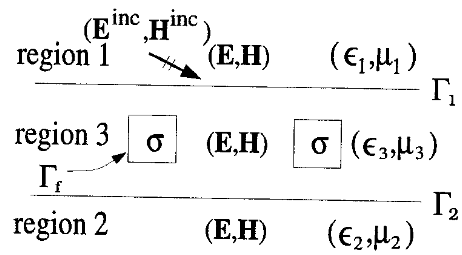

Fig.2. Original problem in equivalence principle.

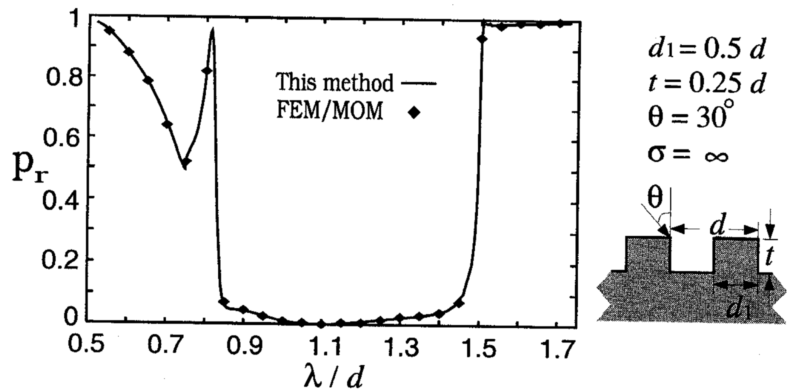

Fig.3. Comparison with those of Gedney [3] (TE case).

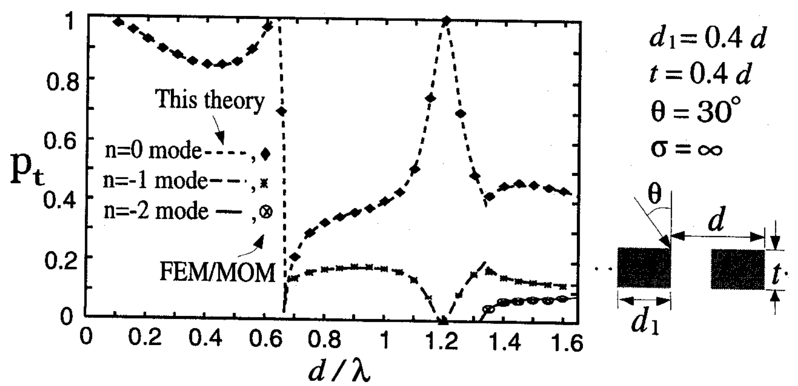

Fig.4. Comparison with those of Gedney [3] (TE case).