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Electromagnetic analysis of periodic structures with arbitrary shape using a coupled volume-surface integral equation method

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Abstract
A coupled volume-surface fundamental condition technique is introduced for breaking down subjectively formed intermittent structure of blended dielectric and leading articles. Free space occasional Green's capacity is utilized in the plan of both essential conditions. In the strategy for minutes answer for the indispensable conditions, the objective is discretized utilizing three-sided patches for leading surfaces and tetrahedral cells for dielectric volume. Ewald's strategy is utilized to quicken the assembly of figuring every component in the impedance network. Mathematical outcomes are introduced to show the precision and proficiency of the strategy.

Keywords: Periodic structures, arbitrary shape, volume-surface

Introduction
A coupled volume-surface vital condition technique is introduced for investigating self-assertively molded occasional structure of blended dielectric and directing articles. Free space intermittent Green's capacity is utilized in the detailing of both necessary conditions. In the technique for minutes answer for the indispensable conditions, the objective is discretized utilizing three-sided patches for leading surfaces and tetrahedral cells for dielectric volume. Ewald's technique is utilized to quicken the intermingling of figuring every component in the impedance lattice. Mathematical outcomes are introduced to dem Electromagnetic investigation of intermittent structures has a wide scope of utilization. The unearthly technique for minutes is a force instrument in breaking down intermittent structures [1]. To improve the adaptability in demonstrating different calculations, the Rao-Wilton-Gillison (RWG) [2] three-sided discretization was accounted for in [3]. In this paper, the coupled volume-surface indispensable condition technique [4] is introduced for the electromagnetic wave dispersing from subjectively molded intermittent structures made out of dielectrics and leading items. Free space intermittent Green's capacity is utilized in the definition of both essential conditions. The three-sided patches and tetrahedral components are utilized to work the dielectric and directing items, separately. The coupled essential conditions are explained by the strategy for minutes (MoM) [5] with surface RWG and volume SWG premise capacities [6] discretization. To quickly create the impedance components, Ewald's strategy [7] is utilized to speed the calculation of the intermittent Green capacity because of the way that the occasional Green capacity, which is a summation of arrangement, merges very slowly.onstrate the exactness and productivity of the method.

The surface indispensable condition approach is very appropriate to examining homogeneous dielectric objects or to objects demonstrated by or comprised of homogeneous layers [8, 9]. The typical system in this technique is to set up coupled fundamental conditions as far as comparable electric and attractive flows on the surfaces of the homogeneous districts. For an article comprised of countless layers, fields initiated in any locale are communicated as far as the comparable flows on the contiguous interfaces. An iterative method [9] has been used for illuminating flows on the peripheral surface as far as the flows on inward interfaces. Especially, for the instance of basic items, for example, dielectric chambers [10] and groups of upset [11], the surface coupled fundamental conditions strategy has been widely applied. Be that as it may, when the outside of the scatterer takes on self-assertive shape, a productive demonstrating of the surface calculation and furthermore the surface electric and attractive fields become confounded. A basic and a productive displaying plan is introduced here and is the topic of conversation in this paper with regards to dissipating by self-assertively molded items [12, 13].

Numerical results are presented to demonstrate the efficiency and accuracy of the proposed technique for analyzing the scattering problem of arbitrarily shaped periodic structure.

Theory and Formulation

Consider an arbitrarily shaped three-dimension (3-D) scatter as a unit cell of the periodic structure, which consists of inhomogeneous dielectric material and conducting body. The object is embedded in an isotropic homogeneous background medium with permittivity ε_b and permeability μ_b. The dielectric V region is assumed to have permeability μ_b and complex dielectric constant $\hat{\varepsilon}$ = ε (r) – jσ (r) /ω, where ε(r) and σ (r) are permittivity and conductivity, at r. The incident wave induces volume current $\vec{J}_V$ in the dielectric region V and surface current $\vec{J}_S$ on the surface of conducting body S. Let the radiation from $\vec{J}_S$ and $\vec{J}_V$ be $\vec{E}_S^{sca}$ and $\vec{E}_V^{sca}$ respectively, then

$$\vec{E}_{\alpha}^{sca} = -i\omega\mu_b \int_{\alpha} \overline{\overline{G}}(\vec{r},\vec{r}') \cdot \vec{J}_{\alpha} d\vec{r}', \qquad \alpha = S \text{ or } V \tag{1}$$

where $\overline{\overline{G}} = \left(\overline{\overline{I}} + \nabla\nabla / k_b^2\right)$ exp $\{ik_b |\vec{r}-\vec{r}|\}/4\pi|\vec{r}-\vec{r}'|$ is the 3-D dyadic Green's function, and k_b is the wave number for the background media. The surface integral equation is formed based on the boundary condition, which requires vanishing tangential component of total electric field

$$\vec{E}_V^{sca}(\vec{r}) + \vec{E}_S^{sca}(\vec{r}) + \vec{E}^{i}(\vec{r}), \qquad \vec{r} \in S \tag{2}$$

The volume integral equation is formed by writing the total electric field $\vec{E}$ in dielectric as the summation of the incident field $\vec{E}^i$ and the scattered field, i.e.,

$$\vec{E}(\vec{r}) = \vec{E}_V^{sca}(\vec{r}) + \vec{E}_S^{sca}(\vec{r}) + \vec{E}^{i}(\vec{r}), \qquad \vec{r} \in V \tag{3}$$

Since the polarization current is related to the total electric field by $\vec{J}_V = j\omega(\hat{\varepsilon}-\varepsilon_0)\vec{E}$, we actually have two unknown functions $\vec{J}_S$ and $\vec{J}_V$ (2) and (3). In the implementation of this paper, $\vec{D} = \varepsilon\vec{E}$ is used as the distribution function in the dielectric. The coupled integral equations are converted into matrix equations using MoM. In this work, the volume of dielectric material and surface of conducting body are discretized into tetrahedral elements and triangular patches, respectively. These elements are used because of their flexibility to model arbitrarily shaped 3-D object. In order to simplify the treatment of conductor-dielectric interface, it is required that the triangular patches coincide with the external faces of tetrahedrons. The surface and volume distribution functions are expanded in terms of 3-D vector basis function that was RWG basis function f^S and SWG basis function f^V, respectively. Using the volume basis function to test (2) and the surface basis function to test (3), the coupled-integral equations are converted into matrix equation system and then solved by an iterative solver.

Note that we have formulated the volume-surface integral equation for a unit cell. To extend the formulation to analyze a periodic structure, the Green's function in (1) is substituted by free space periodic Green's function. The free space periodic Green's function for 2-D periodic arrays is given by

$$G(\vec{r},\vec{r}') = \frac{1}{4\pi}\sum_{m,n=-\infty}^{\infty}\frac{e^{-jkR_{mn}}}{R_{mn}} \tag{4}$$

where R_{mn} =

$$\sqrt{(x-x'-mD_x)^2+(y-y'-nD_y)^2+(z-z')^2}.$$

The term R_{mn} represents the distance between the observation point at (x, y, z) and the periodic source points located in the z' plane. The quantities D_x and D_y represent the periodic spacing of the structure in the x and y directions, respectively. To efficiently evaluate the free space periodic Green's function, the Ewalds method is used. The Green's function in (4) is expressed as a sum of spectral and spatial series such that

$$G = G_1 + G_2 \tag{5}$$

G_1 and G_2 is given by

$$G_1 = \frac{1}{8D_xD_y}\sum_{m,n=-\infty}^{\infty}\frac{e^{-j2\pi(m\xi/D_x+n\eta/D_y)}}{\alpha_{mn}}\cdot\left[e^{2\alpha_{mn}\varsigma}erfc\left(\frac{\alpha_{mn}}{H}+\varsigma H\right)+e^{-2\alpha_{mn}\varsigma}erfc\left(\frac{\alpha_{mn}}{H}-\varsigma H\right)\right] \tag{6}$$

$$G_2 = \frac{1}{4\pi}\sum_{m,n=-\infty}^{\infty}\frac{1}{R_{mn}}\cdot Re\left(e^{-jkR_{mn}}erfc\left(R_{mn}H+\frac{-jk}{2H}\right)\right) \tag{7}$$

Where

$$\xi = x - x', \ \eta = y - y', \ \varsigma = z - z' \tag{8}$$

$$\alpha_{mn} = \begin{cases} \sqrt{\left(\frac{m\pi}{D_x}\right)^2+\left(\frac{n\pi}{D_y}\right)^2-\frac{k^2}{4}}, & \left(\frac{m\pi}{D_x}\right)^2+\left(\frac{n\pi}{D_y}\right)^2 \succ \frac{k^2}{4} \\ j\sqrt{\frac{k^2}{4}-\left[\left(\frac{m\pi}{D_x}\right)^2+\left(\frac{n\pi}{D_y}\right)^2\right]}, & \left(\frac{m\pi}{D_x}\right)^2+\left(\frac{n\pi}{D_y}\right)^2 \prec \frac{k^2}{4} \end{cases} \tag{9}$$

In (5) and (6), erfc(z) is the complementary error function and H is splitting parameter which is given as

H = $\sqrt{\pi/(D_xD_y)}$.

Numerical Results

As shown in Fig.1, a periodic structure with rectangular conducting patches on a dielectric substrate ε_r is considered. The patch has dimensions 0.254cm and 1.35cm while the periodicities are D_x = 0.76cm and D_y = 1.52cm. The thickness of dielectric substrate is d = 0.5cm. The structure is discretized into 99 tetrahedron elements for dielectric substrate and 8 triangular elements for conducting patch with 254 unknowns.

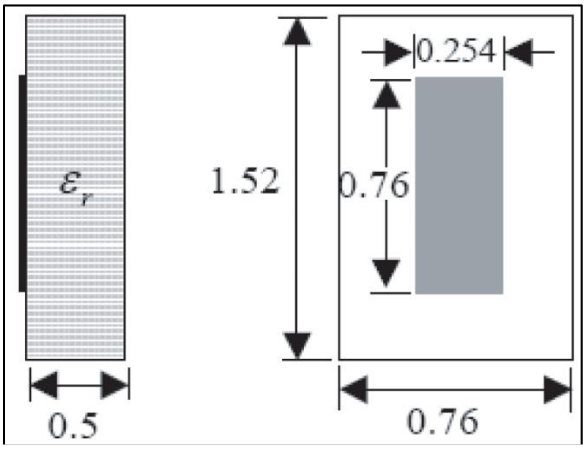

Fig 1: Side and front view of the unit cell of the Periodic structure consisting of conducting patches on a dielectric substrate.

The first comparison analysis is performed for the freestanding periodic structure (ε_r = 1). The reflection coefficient for a plane wave normally incident on the structure is shown in Fig.2.

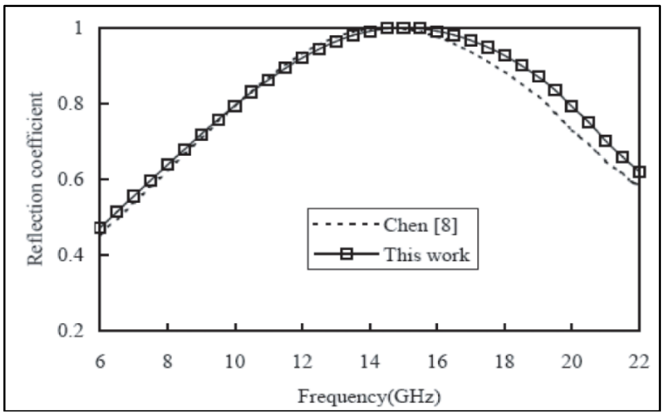

Fig 2: Frequency behavior of the reflection coefficient form a freestanding periodic structure with rectangular conducting patches.

The reflection is seen to peak around 15GHz. As can be seen, the results obtained here are in good agreement with those of Chen [14]. As shown in Fig.3

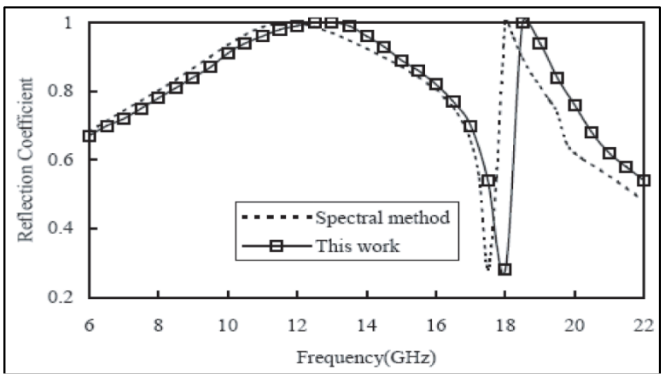

Fig 3: Frequency behavior of the reflection coefficient form a periodic structure with rectangular conducting patches ε_r = 2.

Gives the reflection coefficient for the same structure with dielectric substrate ε_r = 2. The reflection is seen to peak around 12GHz. It can be found that the numerical results from this work agrees well with that calculated by the spectral method.

Conclusion

The couple volume-surface basic condition for electromagnetic dispersing from discretionarily molded intermittent structures is fathomed utilizing the strategy for minutes. The composite metallic and dielectric object is displayed with blended three-sided surface fix and the tetrahedral volume work. Mathematical outcomes are introduced to exhibit the precision of the proposed strategy. Later on, the methodology introduced is proposed to break down the intermittent structure made out of inhomogeneous dielectric material.

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