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Analysis of Combined Conducting and Dielectric Structures of Arbitrary Shapes Using an E-PMCHW Integral Equation Formulation

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I. Introduction

Since electromagnetic scattering from conducting surfaces of arbitrary shapes in a homogeneous medium using an EFIE and the RWG basis functions was reported [1], much effort has been expended on the SIE/MoM formulation exploiting the usefulness of the basis function in modeling surfaces of arbitrary shapes and types, for example, see [2] - [7]. One area of the effort is to apply the method to a finite structure having dielectric and/or conducing bodies.

The scattering from a homogeneous dielectric body has been reported using a PMCHW formulation and RWG basis functions for both electric and magnetic currents [2]. The PMCHW formulation has the advantage that it has been shown to yield resonance-free unique solutions [8].

Analysis of combined conductor and dielectric structures has also been reported [3], [4], where the EFIE was employed for both conducting and dielectric bodies using a new set of basis functions for magnetic currents that are locally orthogonal to the RWG basis functions for electric currents. The EFIE has the internal resonance problem for a closed body, and thus for a dielectric body; however, the application in [3], [4] was principally to thin substrates where the resonance problem may not be significant. The EFIE approach was used there because the extension of the PMCHW formulation for a dielectric body to that for the combined structure did not seem to work [4]. The use of mutually orthogonal sets of basis functions for electric and magnetic currents also has its own disadvantages. One of them is that it increases the matrix fill time for a mostly dielectric structure because it does not allow one to make use of the duality properties of the field operators, which is exploitable otherwise.

In our work modeling dielectric resonator antennas, however, we have found that a direct extension of the PMCHW formulation to the combined structure does appear to work, even for rather extreme geometrical configurations. We have found that an E-PMCHW formulation [9], which employs an EFIE for the conducting part and the PMCHW formulation for the dielectric part using the same RWG basis functions for both electric and magnetic currents, works successfully for the combined structures. In this paper our results are presented with a formalism which applies to arbitrary multi-region combined structures.

II. Formulation

The geometry considered is a general inhomogeneous body with N_R dielectric regions, each of which may have embedded conducting and/or dielectric bodies as well as impressed sources as region R_i does in Fig. 1. The interface between any two regions may also have infinitely thin embedded conducting bodies. The

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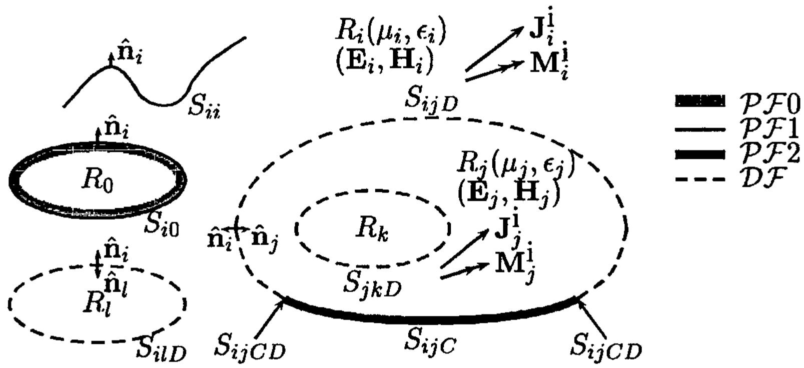

Fig. 1. General geometry under consideration described by various surface types.

regions have permittivities ϵ_i and permeabilities μ_i, where $i = 1, \ldots, N_R$. Both ϵ_i and μ_i may be complex to represent lossy materials. All conductors are considered to be PEC (Perfect Electric Conductor) material. One of the regions, region R_i in Fig. 1, may be of infinite extent and will comprise free space. The total fields in each region are denoted by $\mathbf{E}_i$ and $\mathbf{H}_i$, where $i = 0, 1, \ldots, N_R$, for the electric and magnetic fields, respectively, and $i = 0$ denotes PEC regions with $\mathbf{E}_0 = \mathbf{H}_0 = \mathbf{0}$.

Any two adjacent regions are separated by a conducting (S_{ijC}, type $\mathcal{PF}2$) or dielectric (S_{ijD}, type $\mathcal{DF}$) surface, where i, $j = 1, \ldots, N_R$, $i \neq j$, respectively. An auxiliary surface consisting only of triangles with boundaries lying on the curve formed by the junction of a $\mathcal{PF}2$ and a $\mathcal{DF}$ is defined and denoted by S_{ijCD}. This surface requires special treatment in the equivalent problems. The interface between a non-zero thickness conducting body and a dielectric region forms another surface type denoted in the same way (S_{i0}, type $\mathcal{PF}0$). An infinitely thin conducting body in a dielectric region forms yet another type of surface (S_{ii}, type $\mathcal{PF}1$). Thus, there are four types of surfaces as shown in Fig. 1. However, the types $\mathcal{PF}0$ and $\mathcal{PF}1$ are treated differently only at a surface/surface junction. In our present problem, where only junctions S_{ijCD} exist, both of them are denoted by S_{i0} and $\mathcal{PF}0$ and treated in the same way henceforth.

According to the equivalence principle [10], the original problem can be decomposed into N_R auxiliary problems, one for each dielectric region. To obtain the auxiliary problem for region R_i, the impressed sources of the original problem are retained only in region R_i and the boundaries of the region are replaced by equivalent surface currents radiating in a homogeneous medium with the constitutive parameters of region R_i. Electric currents are used for the conducting surfaces, while electric and magnetic currents are used for the dielectric boundaries. The electric and magnetic currents appearing on opposite sides of a dielectric interface in different auxiliary problems are taken equal in magnitude and opposite in direction to assure the continuity of the tangential components on these boundaries. In this procedure, the fields produced within the region boundaries by the equivalent currents and the impressed sources in region R_i must be the same as those in the original problem, while the zero field is chosen to be produced outside these boundaries. Then, the electric and magnetic currents on S_i^C, the closure surface of the region R_i, are $\mathbf{J}_i = \hat{\mathbf{n}}_i \times \mathbf{H}_i$ and $\mathbf{M}_i = \mathbf{E}_i \times \hat{\mathbf{n}}_i$, respectively. A system of surface integro-differential equations is obtained by enforcing the boundary conditions of continuity of the tangential fields on the conducting and dielectric surfaces as follows

$$\mathbf{E}_i|_{\tan} = 0, \qquad \text{on } S_{i0} \tag{1}$$

$$(\mathbf{E}_i - \mathbf{E}_j)|_{\tan} = 0, \qquad \text{on } S_{ijD} \tag{2}$$

$$(\mathbf{H}_i - \mathbf{H}_j)|_{\tan} = 0, \qquad \text{on } S_{ijD} \tag{3}$$

$$\mathbf{E}_i|_{\tan} = 0, \qquad \text{on } S_{ijC} \tag{4}$$

$$\mathbf{E}_j|_{\tan} = 0, \qquad \text{on } S_{ijC}. \tag{5}$$

$$(\mathbf{E}_i - \mathbf{E}_j)|_{\tan} = 0, \qquad \text{on } S_{ijCD} \tag{6}$$

These equations represent the E-PMCHW formulation [9].

III. Numerical Results

A test case similar to one used in [4] is shown in Fig. 1. A dielectric cylinder (0.3-m radius and 0.6-m height, $\epsilon_r = 2$) is used instead of the dielectric cone of [4] because the geometry generation portion of our code does not currently support triangulation of a cone. A PEC disk is separated by a distance s from the dielectric cylinder top. Results are shown for the bistatic RCS for different values of s, including the case when the PEC disk lies directly on the cylinder top. It should be noted that the results were obtained in single precision and that excellent agreement is obtained. It should also be noted that in [4] the PEC in the $s = 0$ case is treated as an overlapping surface resulting in three unknown currents (two electric currents and one magnetic current), while the $s = 0$ case in our formulation yields a different set of integral equations with only two unknown currents (the two electric currents on opposite sides of the PEC).

As a second test case we have considered a very thin phantom dielectric sheet ($\epsilon_r = 1$) with a PEC plate on the bottom surface of the sheet as shown in Fig. 3. Bistatic RCS results are shown for different sheet thicknesses t and are compared with results for the PEC plate alone. Note that the plate dimensions are on the order of one-half wavelength and are greater than 13,000 times the sheet thickness in all cases. For the $t = 0.00003$ m case one observes that the agreement with the PEC alone case is quite good, while numerical problems are beginning to appear for smaller thicknesses.

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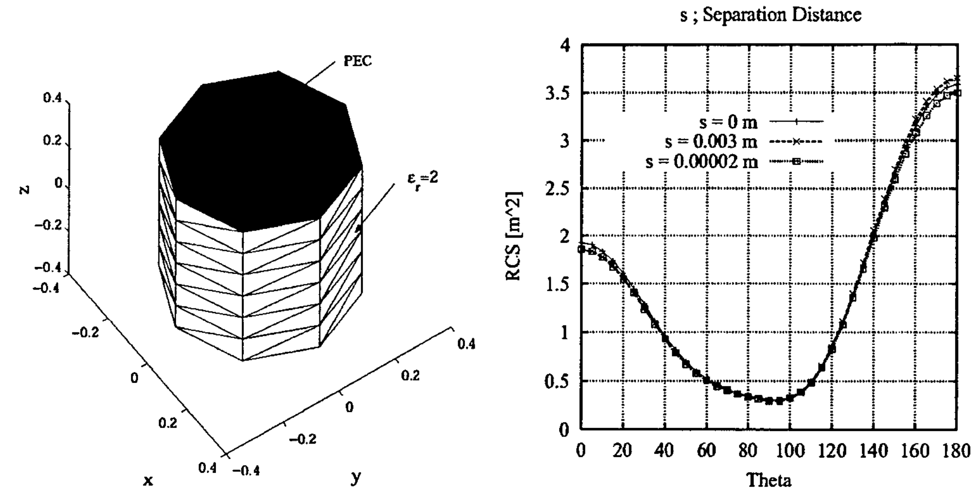

Fig. 2. PEC plate with dielectric cylinder of $\epsilon_r = 2$ ($f = 300$ MHz, $\theta^{inc} = \phi^{inc} = 0°$).

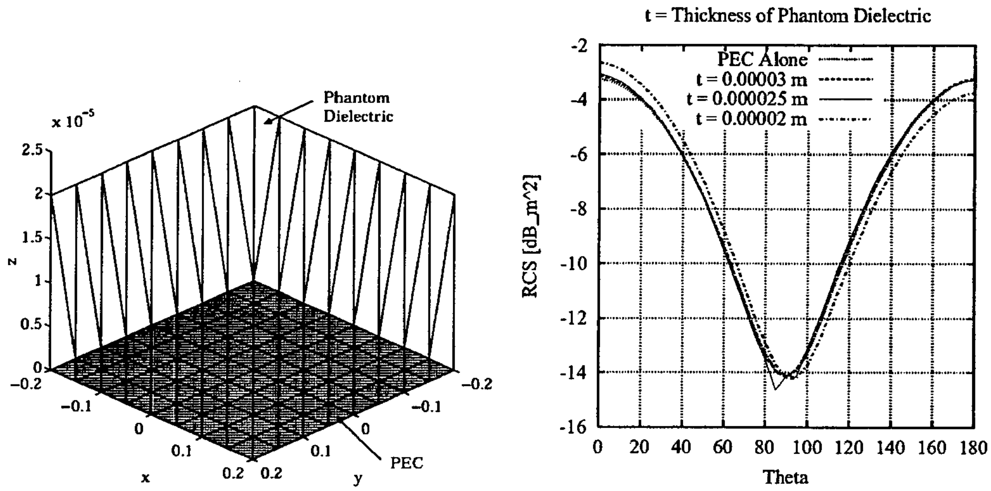

Fig. 3. PEC plate with thin phantom dielectric coating ($f = 300$ MHz, $\theta^{inc} = 45°, \phi^{inc} = 30°$, $E_\theta = 1, \phi^{obs} = 0°$).

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