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Domain Decomposition Method using Integral Equations and a Boundary Condition Impedance for solving Wave Scattering from Large Platforms Covered by a Thin Dielectric Coat

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Abstract — In this paper, we present a formulation for a domain decomposition method using boundary integral equations in order to solve wave scattering and antenna radiation on large platforms covered by a thin dielectric coat via an impedance boundary condition.

Index Terms — Dielectrics, domain decomposition method, integral equations, wave scattering.

I. INTRODUCTION
The boundary integral equations are very useful to study electromagnetic problems on homogeneous objects. Indeed, solving a problem with the boundary integral equations is very interesting compared to a volume method using partial differential equations because only a surface mesh is required. The size of the problem is considerably reduced. However, the discretization of the integral equations leads to dense matrices with a low condition number, especially if the object is complex. The other drawback is the difficulty to process heterogeneous objects.

The domain decomposition method using integral equations (IE-DDM) [1] is a good preconditioner for the integral equations. Based on the local resolution of the sub-domains, this method is very flexible.

In order to solve a conducting object recovered by a thin dielectric coat, a hybrid FE-BE method is generally used but the required degrees of freedom is high. As an alternative, we use an impedance boundary condition (IBC) [2] described by the Leontovitch model.

II. IE-DDM FORMULATION FOR OBJECTS REPRESENTED BY AN IBC
A. Domain decomposition
The original surface \( \Gamma \) is decomposed in several closed sub-domains. The exterior boundaries, which did exist in the original surface, are covered by a dielectric coat. However, the interfaces linking sub-domains to each other are PEC. In Fig. 1, the sub-domain decomposition is pictured for a cylinder and on the right, a practical example of the domain decomposition of a real aircraft is shown.

![Fig. 1. Illustration of the domain decomposition.](Image)

B. Leontovitch model
The problem to solve is a PEC surface covered by a dielectric coat \((\varepsilon_r,\mu_r)\) as on the left of Fig. 2. Assuming that the propagation in the coat is transverse, the Leontovitch model describes how the coat can be replaced by an impedance boundary condition on the PEC surface which is
\[ \vec{E}_{\text{tg}} = j \sqrt{\frac{\mu}{\varepsilon}} \tan\left(2\pi\delta\sqrt{\varepsilon,\mu}\right) \hat{y} \]. Moreover, magnetic currents have to be considered in integral equations.

C. Linear system

The linear system, detailed in [1], to solve is the following:

\[ (A_l + A_c)x = b \]  

(1)

The matrix \( A_l \) contains the CFIE matrix of the sub-domains and the matrix \( A_c \) links sub-domains to each other. Practically, the linear system is preconditioned by \( A_l \) such as the linear system to solve is:

\[ (I + A_l^{-1}A_c)x = A_l^{-1}b \]  

(2)

III. NUMERICAL RESULTS

The precision of the model and the benefits of his implementation in IE-DDM are presented with the simulation of the wave scattering from an ATR 42 (28,047 degrees of freedom) covered by a dielectric coat \((\varepsilon_r=4,\mu_r=1)\) and illuminated with an incidence \(-z\) by a \(\theta\)-polarized plane wave at frequency \(f=50\,\text{MHz}\). The results are compared with our in-house integral equations solver ELSEM3D.

In Fig. 3, the distribution of surface electric currents is presented: ELSEM3D solution on the left, IE-DDM solution on the right. In Fig. 4, the bistatic radar cross sections (RCS) in the Yaw plane are presented. For both currents and RCS, the IE-DDM resolution fits very well with the reference.

![Fig. 3. Distribution of surface electric currents on an ATR 42 covered by a thin dielectric coat.](image)

In Fig. 5, the number of matrix-vector products to reach the criterion convergence \(\varepsilon=10^{-3}\) is presented. The IE-DDM method solving (2) requires only 35 iterations to reach convergence criterion although a resolution without preconditioner requires more than 500 iterations.

![Fig. 4. Yaw plane bistatic RCS (\(\phi\)-polarization) at 50 MHz.](image)

Fig. 5. Number of outer matrix-vector products.

VI. CONCLUSION

This document presents the implementation of an impedance boundary condition in IE-DDM in order to solve electromagnetic problems on large conducting objects with a thin dielectric coat. The IE-DDM permits to improve drastically the condition number of the linear system.

REFERENCES
