Fast Wideband Scattering Analysis Based on IE-ODDM and Cubic Polynomial Inter/Extrapolation

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***Abstract*—A fast wideband electromagnetic scattering analysis method based on the overlapped domain decomposition method for integral equation (IE-ODDM) and cubic polynomial inter/extrapolation is proposed. During the frequency sweeping process, the impedance matrix is fast generated by a cubic polynomial inter/extrapolation method. In order to reduce the memory requirement, IE-ODDM is implemented for the analysis of electrically large problems. Numerical example is provided to demonstrate the validity and efficiency of the proposed method.**

Keywords—electromagnetic (EM) scattering; integral equations (IE) ; overlapped domain decomposition method(ODDM) ; wideband.

I. Introduction

Integral equation combined with the method of moments (MoM) has been a very powerful tool for accurately predicting electromagnetic (EM) radiation and scattering problems. However, traditional MOM technique is inherently limited because the matrix usually requires $O(N^2)$ memory where N is the number of unknowns, and it needs $O(N^2)$ operations to perform matrix-vector multiplication (MVM) via an iterative solver. Hence, the complexity of MoM blocks its application to the analysis of scattering from electrically large objects.

Many instruments have been proposed to accelerate the solving procedure of the MoM, such as the multilevel fast multipole algorithm (MLFMA) [1], the FFT-based algorithms (the P-FFT [2], the FGG-FG-FFT [3], etc.), the IE-ODDM [4]. There is a strong desire to efficiently simulate the frequency response over a given bandwidth. However, one still has to run the simulation code at each frequency sample point in a given bandwidth. It is time-consuming at each frequency sample point in frequency domain. Some kinds of effort have been done to achieve this goal. Model-based parameter estimation (MBPE) [5], model order reduction [6], interpolation methods and extrapolation methods [7], etc., have been developed. Some of these methods are not suitable for the electrically large targets.

In this paper, a fast frequency sweeping method based on IE-ODDM combined with cubic polynomial inter/extrapolation is developed to solve the wideband EM scattering problems. With this method, only one fixed mesh grid of the target at the highest frequency is required for all different frequency samples at which the scattering will be calculated. All impedance matrices corresponding to different frequencies can be fast generated via cubic polynomial inter/extrapolation during the wideband simulation. In order to reduce the storage for an electrically large problem, the overlapped domain decomposition method as a choice is utilized.

II. Principle and Formula

A. Inter/Extrapolation Scheme

The EM scattering problem of perfect electrically conducting (PEC) object can be analyzed using by the electric field integral equation (EFIE) , the magnetic field integral equation (MFIE) and the combined field integral equation (CFIE). The surface integral equation is transformed into a matrix equation by using Rao-Wilton-Glisson (RWG) basis functions. The impedance matrix can be obtained at each f within the frequency range $[f_l, f_h]$, whose element is denoted by Z_{mn} [7]. The modified version of matrix element [7] employed here is

$$\tilde{Z}_{mn}(f_r) = Z_{mn}(f_r) f_r e^{j2\pi f_r R_{mn}} \tag{1}$$

where $f_r = f / f_h \ (f_r \in [f_l / f_h, 1])$ is the normalized frequency, and the distance between the RWG elements S_m and S_n is R_{mn}. $\tilde{Z}_{mn}(f_r)$ is composed of a quadratic polynomial in f_r and its frequency behavior can be achieved by cubic polynomials. The modified matrices at $y_i = f_i / f_h \ (i = 0,1,2,3;\ f_i \in [f_l, f_h])$ which are optical frequency samples are generated primarily in the cubic polynomial inter/extrapolation method under invest‒igation. The inter/extrapolation formula for each f_r is expressed as

$$\tilde{Z}_{mn}(f_r) = \sum_{i=0}^{3} \tilde{Z}_{mn}(x_i) \varphi_i(f_r) \tag{2}$$

where

$$\varphi_i(f_r) = \prod_{j=0, j\neq i}^{3} \frac{f_r - y_j}{y_i - y_j} \tag{3}$$

B. The Overlapped Domain Decomposition Method for Integral Equation

The entire surface of the object is first divided into many surfaces, i.e., subdomains, as is shown in Fig. 1. The light blue region Γ_i is i th subdomain. Subdomain Γ_i needs to be extended with its buffer region Γ_{bi} (the yellow region). $\Gamma_i{}'$ consisting of Γ_i and Γ_{bi} is used to represent the extended domain. Finally, $\overline{\Gamma}_i = \Gamma - \Gamma_i{}'$ is called i th complementary subdomain. The exact process of the IE-ODDM is not stated here, the readers may refer to the literature [4].

III. Numerical Results

Numerical example is given to demonstrate the efficiency and accuracy of IE-ODDM with cubic polynomial inter/extrapolation. When necessary, FGG-FG-FFT and MLFMA are also employed as the reference.

Here, we consider the electromagnetic scattering by a PEC cube with dimensions $10\lambda_h \times 3\lambda_h \times 0.5\lambda_h$, as shown in Fig. 2. The incidence angle is $(\theta^{in}, \phi^{in}) = (0^o, 0^o)$. The surface of the cube is partitioned into three subdomains. In such cases, the frequency varies from 6 to 30 GHz. The cube surface is modeled by with 16,644 triangle patches with the average edge size of $0.1\lambda_h$, yielding 24,966 unknowns. The frequency increment of $\Delta f = 1$ GHz is considered.

Plotted in Fig. 3 are the RCS results at the scattering direction $(\theta^S, \phi^S) = (60^o, 0^o)$ obtained from IE-ODDM with cubic polynomial inter/extrapolation, the FGG-FG-FFT, MLFMA and direct IE-ODDM, respectively. It shows that the RCS results computed by the proposed method agree very well with those by FGG-FG-FFT, MLFMA and direct IE-ODDM.

The CPU time for filling matrix is cut down by a factor of 5.02. In this example, it costs about 2.54 hours using the proposed method at the whole frequency band, and 12.75 hours using direct IE-ODDM.

IV. Conclusion

A new fast frequency sweeping method using both IE-ODDM and cubic polynomial inter/extrapolation is proposed. It fuses both the benefits of IE-ODDM and the fast frequency sweeping method based on cubic polynomial inter/extrapolation. It can not only reduce the unknowns, but also accelerate the impedance matrix filling process. Thus, it can efficiently accelerate the process of frequency sweeping.

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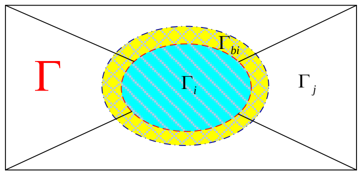

Fig. 1. Partition diagram for the domain decomposition.

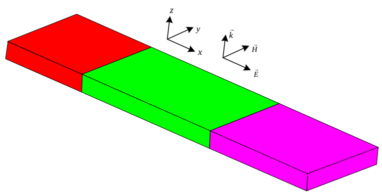

Fig. 2. Geometry of a PEC cube with $10\lambda_h \times 3\lambda_h \times 0.5\lambda_h$.

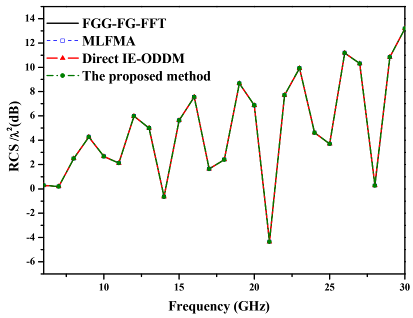

Fig. 3. The RCS of the PEC cube under different frequencies.

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