A Domain Decomposition Finite Difference Time Domain (DD-FDTD) Method for Solving the Scattering Problem from Very Large Rough Surfaces

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***Abstract* - A Domain Decomposition Finite Difference Time Domain (DD-FDTD) method is proposed to solve the problem of electromagnetic scattering from very large rough surfaces. The coupling to the Huygens' surface above a specific subdomain from induced currents on the rough surface in adjacent subdomains is determined by using the reciprocity theorem. The normalized radar cross sections (NRCS's) obtained with the DD-FDTD method match well with those using the conventional FDTD method.**

***Index Terms* — FDTD, domain-decomposition, scattering, rough surface.**

I. Introduction

The scattering problems with very large rough surfaces have been widely discussed [1]-[3], for example, in the application of synthetic aperture radar (SAR) and radar image reconstruction. Analytical models have been developed over decades, including the Kirchhoff approximation (KA) [2], small slope approximation (SSA) [3], small perturbation method (SPM) [4], two-scale model (TSM) [5], phase perturbation technique (PPT) [6], and so on.

Numerical techniques, such as method of moments (MoM) and finite-difference time-domain (FDTD) method, have also been applied to these scattering problems. The computational time of MoM dealing with N unknowns can be proportional to N^2 if an iterative matrix solver is used, and to N^3 if a direct matrix solver is applied. The multilevel fast multipole algorithm (MLFMA) [7] has been used to reduce the computational time to O(N log N).

In this work, a two-dimensional domain-decomposition (DD) FDTD method is proposed to deal with the problem of scattering from large rough surfaces with PEC or lossy dielectric medium.

II. Numerical Scheme

Fig.1 shows the top view of the two-dimensional domain decomposition scheme. The computational domain is enclosed by a perfect matching layer (PML), and is decomposed into 9 subdomains in this example.

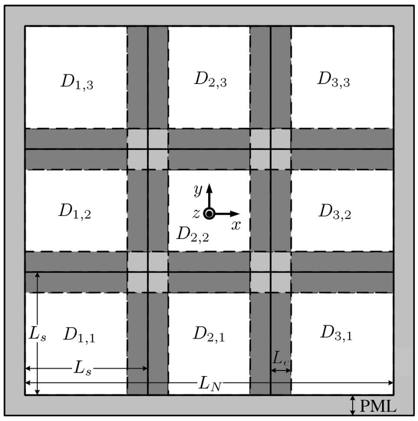

Fig. 1. Top view of two-dimensional domain decomposition scheme. The white regions represent regions without tapering. The dark gray regions represent the taper regions between two adjacent subdomains. The light gray squares represent the area where two taper regions overlap.

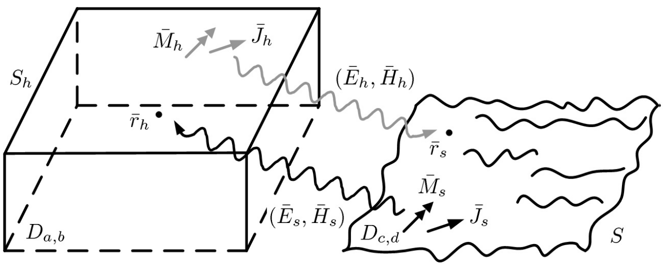

Fig. 2. Coupling from surface currents on an adjacent subdomain (S) to the Huygens' surface (S_h).

The coupling between the rough surface (S) in an adjacent subdomain to the Huygens' surface (S_h) above a given subdomain, as shown in Fig.2, can be calculated by employing the reaction integral based on the reciprocity theorem.

III. NUMERICAL RESULTS

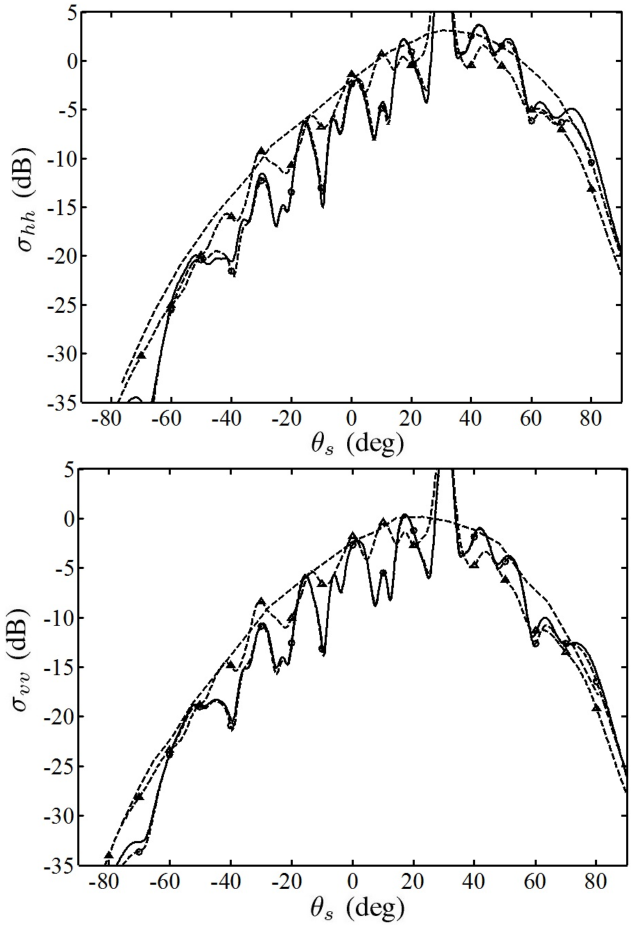

Fig. 3. Normalized RCS of a Gaussian rough surface with an area of 32 λ x 32 λ ; $h_{rms} = 0.16\lambda$, $l_c = 0.95\lambda$, $\theta_i = 30°$, $\phi_i = 0°$, $\phi_s = 0°$, $\varepsilon_r = 4\text{-}j$, $r_a = 3.73\lambda$. -----: RLCA3 in [8], --△--: averaged over 20 realizations using FDTD, --o--: averaged over 4 realizations using FDTD, ——: averaged over 4 realizations using DD-FDTD with 3 x 3 subdomains.

Fig.3 shows the normalized RCS of a Gaussian rough surface made of lossy dielectric, with an area of 32 λ x 32 λ and roughness parameters, $h_{rms} = 0.16\lambda$, $l_c = 0.95\lambda$. The average over 4 realizations using the DD-FDTD method matches well with those using the conventional FDTD method. The normalized RCS characteristics obtained with both DD-FDTD and conventional FDTD methods match well with those derived by using the reduced local curvature approximation of third order (RLCA3) [8].

IV. CONCLUSION

A Domain Decomposition Finite Difference Time Domain (DD-FDTD) method has been proposed to simulate the scattering from large rough surfaces comprised of either PEC or lossy dielectric medium. The computational domain is decomposed into many subdomains of manageable size for the conventional FDTD methods, and the coupling between adjacent subdomains is calculated by using the reaction integral and reciprocity theorem. The scattering from a Gaussian rough surface of area 32 λ x32 λ has also been simulated to demonstrate the effectiveness of this method.

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