Research of Composite Electromagnetic Scattering from Targets and Rough Surface Basing on the Efficient Numerical Algorithm

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Abstract— Some studies of composite electromagnetic scattering from targets and rough surface are implemented by using the Propagation-Inside-Layer-Expansion (PILE) combined with the Forward-Backward Method (FBM) hybrid scheme. Multiply targets and rough surface case is considered. The composite scattering integral equations are bulit. The formation mechanisms of the EPILE+FBM scheme including the self- and multal coupling inductions between targets and rough surface are analyzed. The accuracy and efficiency of the hybrid algorithm are verified. The applications of this scheme for the specific type of targets are carried out. The scattering results under different parameters, such as different target size, different roughness, etc., are investigated. The important scattering phenomena and characteristics are discussed and corresponding conclusions are obtained. The presented hybrid scheme will make sense to the domains of electromagnetics, remote sensing, radar surveillance, target recognition, optics, material science, etc..

1. INTRODUCTION

Electromagnetic scattering issues under land/sea environment has been concerned over past several years. Usually, the actual land/sea surfaces are not ideally flat, but are rough more or less, hence, the actual target and land/sea surface electromagnetic scattering are the target and rough surface electromagnetic scattering problem. For implementing the scattering analysis, significant contributions have been made and some important analytical, numerical, and hybrid algorithms have been presented, such as the SPM, the KA, the MOM [1], the FMM [2, 3], the FEM, the FDTD, the hybrid SPM+MOM technique [4], the hybrid KA+MOM technique. These methods are of respective advantages, some of them are computationally very fast, some of them are rather accurate in results, some of them are very efficient for single rough surface scattering, and some of them are rather suitable for the target and rough surface composite senses, etc., which have been widely applied and effectively promote the progress in electromagnetics research. Recently, owing to special academical and engineering demands, developing the numerical algorithms that are both efficient and accurate, and are compatible with more target and rough surface composite senses has becoming an important research subject, within which, one important contribution is the Propagation-Inside-Layer Expansion (PILE) and its hybrid scheme, that was firstly presented by N. Déchamps et al. [5]. This method, which shows high efficiency and accuracy, is able to handle problems configured with a huge number of unknowns. In this paper, the EPILE combined with FBM scheme is attempted to study more complex targets and rough surface composite scattering. The brief theory and formulations of this scheme are given, the accuracy and efficiency of it is confirmed, then, typical numerical results are exhibited and corresponding remarks are addressed.

2. BRIEF THEORY AND FORMULATIONS

Generally, electromagnetic scattering analysis should be implementated under the primary premise of reasonably modelling about the target or rough surface. Series of rough surface and targets composite senses have been aimed and modelled in our recent study. Taking the multiply targets both above and below the rough surface composite sense for example, and basing on the Ewald-Oseen' extinction theorem and electromagnetic boundary conditions for this composite sense, the scattering electric field integral equations (EFIE) (for TE case, HH polarization) and magnetic field integral equations (MFIE) (for TM case, VV polarization) can be obtained. The EFIE and MFIE can be furhter converted into the matrix equation, according to the inspirtion of the matching technique and basis function schemes [1–3]. Usually, when the number of samples for the target, and the length of the rough surface increases, the computational cost of solving the matrix equation using the MOM with CGM [6], or the direct LU inversion becomes prohibitive, herein, the EPILE and FBM combinated scheme is presented to speed up the scattering calculation. When implementing the EPILE to study the composite electromagnetic scattering, the inverse matrix of global impedence matrix $\bar{\mathbf{Z}}$ [5, 6] can be partitioned into four blocks $\bar{\mathbf{Z}}1$, $\bar{\mathbf{Z}}2$, $\bar{\mathbf{Z}}3$, $\bar{\mathbf{Z}}4$ as follows,

$$\begin{aligned}
\bar{\mathbf{Z}}1 &= \left[\bar{\Re}_1 - \bar{\Re}_2 \cdot \left(\bar{\Re}_3\right)^{-1} \cdot \bar{\Re}_4\right]^{-1}, \quad \bar{\mathbf{Z}}2 = -\left[\bar{\Re}_1 - \bar{\Re}_2 \cdot \left(\bar{\Re}_3\right)^{-1} \cdot \bar{\Re}_4\right]^{-1} \cdot \bar{\Re}_2 \cdot \left(\bar{\Re}_3\right)^{-1} \\
\bar{\mathbf{Z}}3 &= -\left(\bar{\Re}_3\right)^{-1} \cdot \bar{\Re}_4 \cdot \left[\bar{\Re}_1 - \bar{\Re}_2 \cdot \left(\bar{\Re}_3\right)^{-1} \cdot \bar{\Re}_4\right]^{-1}, \\
\bar{\mathbf{Z}}4 &= \left(\bar{\Re}_3\right)^{-1} - \left(\bar{\Re}_3\right)^{-1} \cdot \bar{\Re}_4 \cdot \left[\bar{\Re}_1 - \bar{\Re}_2 \cdot \left(\bar{\Re}_3\right)^{-1} \cdot \bar{\Re}_4\right]^{-1} \cdot \bar{\Re}_2 \cdot \left(\bar{\Re}_3\right)^{-1}
\end{aligned}$$

in which, the $(\bar{\Re}_1)^{-1}$ accounts for the local interactions on the targets, $(\bar{\Re}_3)^{-1}$ accounts for the local interactions on the rough surface, $\bar{\Re}_2$ propagates the resulting field on the rough surface toward the targets (surface-targets coupling), and $\bar{\Re}_4$ propagates the resulting field on the targets toward the rough surface (targets-surface coupling). To decrease the computing cost and speed up the calculation of term $(\bar{\Re}_3)^{-1}\xi_3$ (ξ_3 denotes the induced unknown vector on the rough surface), the fast iterative strategy-FBM [7, 8] can be sequentially applied. Then, the induced unknown vector ξ_3 and the impedance matrix $\bar{\Re}_3$ can be further decomposed as the following forms,

$$\xi_3 = \xi_3^f + \xi_3^b, \quad \bar{\Re}_3 = \bar{\Re}_3^f + \bar{\Re}_3^d + \bar{\Re}_3^b$$

Detalied description and operation of FBM can refer to [7, 8]. Substituting related reaction terms into composite scattering fields, the bistatic scattering coefficient (BSC) [1–8] can be obtained.

3. SELECTIVE NUMERICAL RESULTS AND DISCUSSIONS

Series of numerical results about the formational algorithm have been obtained. Considering the space limitation, herein, some selective numerical results are listed and corresponding discussions are given. The incident frequency is 3 GHz. Algorithm is tested on computer with 4 GB memory and Microsoft Windows operation system. All listed curves are expresseded in decibel (dB) scale.

Figure 1 shows the comparison of BSC by the EPILE+FBM and MOM (CGM). The cylindrical targets above/below, and Gaussian spectrum rough surface are chosen. 100 surface realizations are statistic. The incident angle is set as 0°. For simplicity, some other parameters are not listed here (similarly hereinafter). It is obvious that, the scattering curves match well with each other for both HH and VV polarization, the Relative Residual Error (RRE) [5, 6] is far less than 10^{-3}. The average computational time by EPILE+FBM is about 45 seconds (S), by MOM (CGM) is 320 S. Similar time gap also can be found by other numerical computations, hence, comparing with the typical accurate numerical algorithm-MOM, the accuracy and efficiency of the EPILE+FBM is indicated.

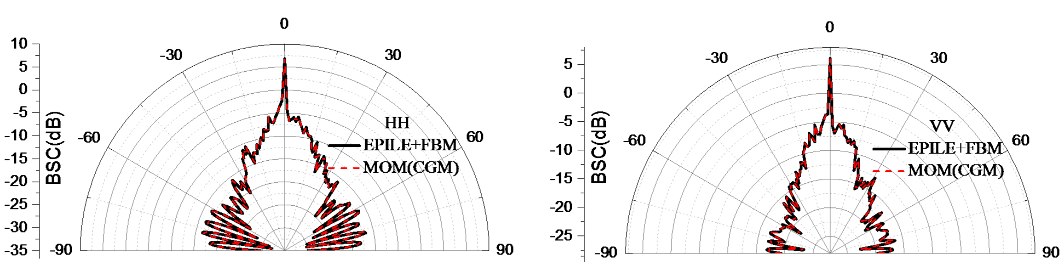

Figure 1: The BSC versus the scattering angle (EPILE+FBM and MOM (CGM)).

The BSC versus scattering angle with different radius size Ru of target above is exhibited in Fig. 2. It is shown that, with the increasing of Ru, the specular coherent scattering changes slightly, while the incoherent scattering at non-specular region increases evidently, due to the fact that, the coupling scattering between the 'target above' and the 'rough surface' is increased simultaneously.

The influence of different rough surface rms height δ on the BSC is investigated in Fig. 3. Obviously, with increasing of δ, in specular direction, the coherent scattering decreases, while at non-specular domain, the incoherent scattering increases evidently, especially at the backward direction. This phenomena can be explained in this way: the bigger rms height leads to the rougher surface, and results in the stronger coupling scattering intensity between target and rough surface.

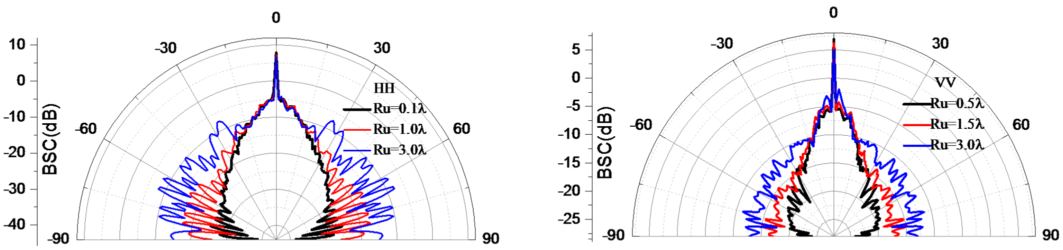

Figure 2: The BSC versus the scattering angle (different Ru).

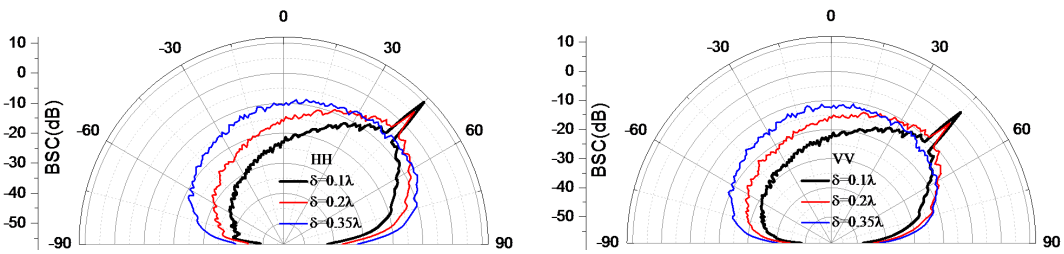

Figure 3: The BSC versus the scattering angle (different δ).

The influence of other more target and rough surface parameters, such as different height of target above, different depth of target below, different horizontial distance of target above/below, different size, correlation length and spectrum of rough surface, etc., have also been numerically investigated and analysed, considering the space limitation, they are temporarily not listed herein.

4. CONCLUSIONS

This paper discuss the implement of efficient numerical algorithm-the EPILE combined with FBM hybrid scheme in studying the rough surface and targets composite electromagnetic scattering. The formation mechanisms of this scheme is briefly introduced. The accuracy and efficiency of this algorithm is verified. Influence of typical targets and rough surface parameters in BSC is investigated by using the EPILE+FBM and corresponding scattering characteristics are analyzed.

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