An Improved Numerical Method for Scattering from Dielectric Rough Surfaces

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The need for numerical methods in studying electromagnetic scattering from rough surfaces is well established. The most commonly used numerical method is the surface integral equation method and its solution by the method of moments (MoM). Conventional implementation of MoM requires O(N^3) operations, where N is the number of surface unknowns. When N is large, as frequently encountered in studying electromagnetic scattering from rough surfaces, in particular at near grazing incidence, given the high computational complexity of conventional implementation of MoM, fast numerical methods are called for and several have been proposed in the literature.

One popular approach among these methods is the iterative forward-backward method (FBM) for both PEC [1] and dielectric rough surfaces [2]. In FBM, electric and magnetic equivalent surface current densities are split into forward and backward components, a treatment naturally giving rise to an iterative solution scheme. Its computational complexity is O(N^2), and its iterative process converges very fast, except that for extremely rough surfaces.

However, the computational efficiency achieved in FBM can not be taken for granted to be applicable to universal roughness conditions. For instance, for typical value of dielectric constant for sea water at microwave frequencies, it is reported that FBM shows significantly slow convergence, and it often fails to converge for very and extremely rough surfaces, in particular for HH polarization. The fact that the relative residual error defined by FBM was fixed to 10^-2 indicates that the convergence issue can be even more severe if a more restrictive value for the relative residual error is used, say 10^-4 as commonly used in the literature. In dealing with computational complexity of FBM, the spectral acceleration (SA) [3] technique was combined to reduce the computational complexity to O(N). However, there is a price to pay. The FBM-SA scheme is found sensitive to the approximation error induced by SA by extensive numerical simulations. It often fails to converge for cases where FBM converges.

In this work we propose an efficient and accurate iterative numerical approach to analyze EM scattering from 1-D dielectric rough surfaces. It is based on a new splitting of the impedance matrix Z to improve the asymptotic convergence rate of the resultant iterative system. The structure of split matrix is then fully explored, in combination with the application of an identity for inverse of block matrix, to further reduce the computational and storage complexity. The embedded matrix vector product is computed using the spectral acceleration technique. Although the current work is in the same line of our previous approach on impedance matrix splitting [4][5], the way of matrix splitting is much improved, hence the new approach is more advantageous in two aspects: 1) the asymptotic convergence rate is better, in particular for the TE case; 2) solution of the inner iteration is no longer through time and memory consuming GMRES, rather the FBM-SA technique can be conveniently used to reduce run time and memory requirement.

Extensive numerical simulations demonstrate a couple of appealing features of this proposed method for Gaussian surface with Gaussian spectrum: 1) For HH polarization, the proposed method is about 4~6 times as fast as FBM-SA. For VV polarization, the proposed method is more computationally efficient except for the few cases when the rms slope is 0.55 and the rms height is not larger than 0.5 wavelengths. 2) It improves appreciably converges properties over FBM-SA. To be more specific, for HH polarization, the proposed method extends the convergent rms slope to 1.5 from 0.77 across the rms height range from 0.3 to 5 wavelengths. For VV polarization, the proposed method extends the convergent rms slope to 0.77 from 0.55 across the above rms height range. These features indicate that the proposed method can be effectively used to analyze EM scattering from 1-D dielectric Gaussian surface with Gaussian spectrum.

References

1. D. Holliday, L. L. DeRaad, and G. C. St-Cyr, "Forward–backward: A new method for computing low-grazing angle scattering," *IEEE Trans. Antennas Propagat.*, vol. 44, pp. 722–729, May 1996.
2. A. Iodice, "Forward–backward method for scattering from dielectric rough surfaces," IEEE Trans. Antennas Propagat., vol. 50, pp. 901–911, July 2002.
3. H.-T. Chou and J. T. Johnson, "A novel acceleration algorithm for the computation of scattering from rough surfaces with the forwardbackward method," Radio Sci., vol. 33, pp. 1277–1287, 1998.
4. B. Liu, Z.Y. Li, and Y. Du, "A fast numerical method for scattering from dielectric rough surfaces", *IEEE Trans. Antennas Propagat.*, in revision.
5. Y. Du and B. Liu, "A numerical method for electromagnetic scattering from dielectric rough surfaces based on the stochastic second degree method", *Progress In Electromagnetics Research,* PIER97, pp. 327-342, Oct.2009.