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Spectral-Element Spectral-Integral (SESI) Method for Electromagnetic Scattering from 1-D Bloch (Floquet) Periodic Structures in 2-D Layered Media

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In recent years, electromagnetic scattering (EM) from periodic structures in layered media has found a wide variety of applications in frequency selective surfaces (FSSs), array antennas, metasurfaces, and photonic crystals, etc. The development of appropriate computational modeling tools is an essential task for the fast and accurate characterization and design of such structures.

The finite-element method (FEM) is a preeminent method for modeling the inhomogeneous media and bounded regions; the boundary-integral equation (BIE) method is suitable for homogeneous media and open regions and can be extended into planar layered media easily through the layered medium Green's function (LMGF). However, it is challenging to simulate the scattering from inhomogeneous and anisotropic periodic structures in layered media by using only one single methodology such as either FEM or BIE methods. Hybrid techniques combining two or more different methods are effective for simulating these EM scattering problems. The well-known hybrid finite-element boundary-integral (FEBI) method combines the FEM with the BIE method to satisfy the exact radiation boundary condition (RBC) with only a few unknowns added while maintaining the FEM versatility.

Here we have developed an efficient hybrid scheme called the spectral-element spectral integral (SESI) method [1] by combining the spectral element method (SEM) and spectral integral method (SIM), based on the philosophy of the FEBI. The SEM is a high-order basis function version of FEM based on the Gauss-Lobatto-Legendre (GLL) nodes, which combines the advantages of the high accuracy of the spectral method and the geometric flexibility of the FEM [2]. The SIM is a fast surface integral equation method with spectral accuracy by using the fast Fourier transform (FFT) algorithm [3]. The SESI separates the computational domain into multiple SEM subdomains containing scatterers and SIM subdomains containing layered media. Only the SEM subdomains need to be discretized, while the SIM serves as an exact RBC of the SEM subdomains and can be rapidly evaluated with only $O(N \log N)$ complexity for the inverses of the BI matrices by explicit algebraic division, thus leading to rapid computation and accuracy improvement. The 2-D periodic layered medium Green's function (PLMGF) is derived for the SIM in order to simulate EM scattering from an arbitrary number of layers. It is the electric field response due to the periodic infinite phased array of line sources and is expressed in terms of slowly-converging series. To speed up this PLMGF for the SESI method, Poisson's summation formula is used to convert the 2-D PLMGF to a spectral-domain representation that exhibits exponential convergence.

In the presentation, we will first review the SESI method, then several numerical examples will be presented to show the advantages of this hybrid method over the traditional FEM and FEBI method.

References

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[3] J. Liu and Q. H. Liu, "A spectral integral method (SIM) for periodic and nonperiodic structures," *IEEE Microw. Wireless Compon. Lett.*, vol. 14, no. 3, pp. 97-99, March 2004, doi: 10.1109/LMWC.2004.824806.