MLFMA Modeling of Metamaterials Containing Split-Ring Resonators†

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Electromagnetic modeling of large metamaterial structures with the multilevel fast multipole algorithm (MLFMA) is reported. Metamaterials are the subject of this study since they display unusual electromagnetic properties. Metamaterials are constructed by embedding inclusions into host media, usually in a periodic fashion. We take into account that these periodic structures have actually finite extent and exhibit interface properties. Without resorting to homogenization methods, we accurately model large numbers of inclusions in order to understand the scattering, interaction, and transmission properties of these structures. Accurate modeling and solution of these large and three-dimensional structures translate into very large computational problems. In this study, we employ MLFMA for the iterative solution of large matrix equations resulting from the electric-field integral equation (EFIE) formulations.

The metamaterial structures investigated in this study consist of stacked multiple layers of periodic patterns of conducting split-ring resonators (SRRs) and wires. Feature sizes are selected in the micron scale in order to obtain left-handed (LH) properties with both negative permittivity and permeability around 100 GHz. In addition to modeling various composite metamaterial (CMM) structures involving both SRRs and wires, we also model SRR-only, wire-only, and the so-called closed-ring resonator (CRR) structures. We compare our computational results against measurement results obtained in the same frequency range. (Gökkavas et al., "Experimental demonstration of a left-handed metamaterial operating at 100 GHz," Research Report, Bilkent University, submitted to *Phys. Rev. Lett.*, 2005.) Concepts of near-field and far-field transmission coefficients are defined and used in comparisons with the experimental results.

Computational power provided by MLFMA can be used to model not only large metamaterial structures composed of regularly spaced SRRs and wires, but also various other types of inclusions. Effects of disorder, misalignment, and aperiodicity can also be studied in metamaterials containing irregularly spaced inclusions. Since the periodicity and the feature sizes of the inclusions are usually much smaller than the wavelength, solutions of even large geometries of metamaterials require low-frequency adjustments to MLFMA.

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