High-Order Modal Contributions to the Resonant Electromagnetic Interaction with an Ensemble of Electrically Small Objects

Kristopher T. Kim* and Bradley A. Kramer
Antenna and Electromagnetics Technology Branch
Sensors Directorate
Air Force Research Laboratory, Wright-Patterson AFB, OH, 45433-7320, USA

The physics of the electromagnetic interaction with an ensemble of electromagnetically small objects finds numerous applications that are as diverse as phased-array antennas, frequency-selective surfaces, artificial materials, and wave propagation through rain, to name a few. In this work, we examine the importance of high-order modal contributions to the electromagnetic properties of an ensemble made of densely packed, electromagnetically small, magneto-dielectric spheres, when the interrogating frequency is near one of the resonance frequencies of the ensemble. Away from the resonance frequencies, much of the electromagnetic properties of the ensemble can be accounted for by taking into account only the dipole-field interactions between the spheres. Indeed a number of useful models based on the dipole-only approach have been developed to account for the bulk properties of an ensemble.

Our approach is based on the Foldy-Lax, T-matrix, self-consistent, multiple-scattering formalism, which provides a convenient mechanism for including an arbitrary number of modes. We have augmented this formalism with a regularization method that effectively suppresses the ill-conditioning of the interaction matrix that results when higher-order multipole fields are included. We show that, while the dipole-field-only approach works quite well when the interrogating frequency is away from the resonance frequencies of an ensemble, higher-order multipole-field contributions do play an unexpectedly significant role in establishing the overall EM properties of the ensemble when the frequency is near one of the resonance frequencies. We were able to validate our numerical results with several commercial and in-house computational electromagnetics (CEM) software based on the method of moments and the finite element method.

.