Perturbation Theory Applied to Dielectric Metamaterial Resonators

Salvatore Campione[(1)], Larry K. Warne* [(1)], Lorena I. Basilio[(1)],
William L. Langston[(1)], and Michael B. Sinclair[(1)]
(1) Sandia National Laboratories, P.O. Box 5800 Albuquerque NM 87185 USA

Metallic resonators exhibit high intrinsic Ohmic losses that hinder their applicability to resonant metamaterials operating at infrared and higher frequencies. As a promising alternative building block, dielectric resonators, supporting low-loss displacement currents, could be used to develop low-loss resonant metamaterials. Dielectric resonators support electric and magnetic modes, usually at different frequencies. The design of dielectric resonators with degenerate (i.e. overlapping in frequency) magnetic and electric modes for directional scattering and negative-index metamaterial applications usually requires the ability to perturb one or both types of modes in order to induce alignment of the magnetic and electric properties at a given frequency. The resonator design technique presented in this paper aims to minimize both the losses and the size of the unit cell, particularly in the case of high frequencies such as the infrared or visible. Our results are fully scalable across any frequency bands where high-permittivity dielectric materials are available, including microwave, THz, and infrared frequencies.

The designs discussed in this paper are based on degenerate-mode (the fundamental magnetic and electric modes are aligned in frequency) dielectric resonators which rely on only a single-particle resonator and thereby do not require physical or electrical extensions of the unit cell. Cavity-perturbation techniques (Warne et al., IEEE Trans. Antennas Propagat., 61, 2130-2141, 2013; Warne et al., Progress In Electromagnetics Research B, 44, 1-29, 2012) are used to arrive at the types of inclusions (in terms of material, polarization, and placement) that are necessary to realize a degenerate dielectric resonator, as well as to derive simple formulas which can be used for the design of these types of resonators. Rigorous electromagnetic simulations of the degenerate resonators are also provided for comparison to the theoretical derivations. Promising metamaterial applications such as directional scattering and Huygens' metasurfaces, and high-quality factor Fano metasurfaces are also discussed.

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