Homogenization of Electromagnetic Metamaterials: Uncertainty Principles and a Fresh Look at Nonlocality

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We show that artificial magnetism of electromagnetic metamaterials has limitations and is subject to at least two general uncertainty principles. First, the stronger the magnetic response, the less accurate ("certain") the predictions of any local homogeneous model. Second, if the magnetic response is strong, then no local effective medium theory can accurately reproduce the transmission and reflection parameters and, *simultaneously*, power dissipation in the material. Our theoretical analysis is illustrated with numerical examples. We show, in addition, that periodic structures cannot be accurately homogenized in higher bands if evanescent modes are included into consideration.

The accuracy of homogenization can be significantly higher in *nonlocal* models. As an example, about an order-of-magnitude improvement in the accuracy of transmission and reflection coefficients for a periodic layered structure is demonstrated.

In all homogenization theories, we emphasize the importance of *interface boundary conditions* in addition to dispersion relations. This is particularly challenging for nonlocal models, where translational invariance of the integral kernel breaks down near interfaces. A fresh look at these issues favors real-space models over more traditional reciprocal-space ones.