Constitutive Parameter Extraction of Artificial Materials Based on Metamaterial Technology Using Scattering Coefficients Measured at Oblique Incidence

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Metamaterials are artificial materials, which are commonly structured by a periodic arrangement of resonant elements, such as metallic wires and rings. It is common to assign effective constitutive parameters to a metamaterial, when considering its response to an electromagnetic field with a wavelength that is much larger than the structure's unit cell. Several methods have been suggested for evaluating these parameters; among them are the S-parameters method (X. Chen, T. M. Grzegorczyk, B.I. Wu, J. Pacheco, and J. A. Kong, Phys. Rev. E 70.1, 016608, 2004), and different numerical homogenization methods (D. R. Smith and J. B. Pendry, JOSA B 23.3, 391-403 ,2006, I. Tsukerman, JOSA B 28.3, 577-586, 2011). All proposed methods are either bound to artificial materials that posses diagonal effective permeability and permittivity tensors with simple bi-anisotropic constitutive relation, or interpolate the electromagnetic fields distribution within the unit cell of the periodic structure, which can be used for the retrieval of the constitutive relations.
In this work, a method based on the scattering coefficients data collected from an oblique plane wave incident upon a slab made of an artificial material is examined. The proposed method enables to solve the ambiguity of the effective constitutive parameters without the need to construct and measure any additional reference slabs. The presented method can be practiced using both laboratory equipment and numerical simulation tools. An instructive numerical example, as well as practical artificial material examples will be presented. As in the S-parameters method, the artificial materials' effective constitutive parameters are extracted ambiguously using the derived set of equations. The ambiguity of the extracted constitutive parameters is solved using additional measurement of the same artificial material slab, but at an oblique incidence. Moreover, the artificial material slab's effective thickness can be evaluated as well, simply by adding another measurement at oblique incidence and comparing the slab's effective retrieved impedances.