An Analytical Model of Electromagnetic Propagation through a Finite Cascade of Planar Lattices of Conducting Disks

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Artificial 3D crystal structures implemented by stacking multiple layers of planar 2D lattice of thin conducting disks have been widely used in many areas like electromagnetic band gap (EBG) materials and artificial dielectrics, due to the low-cost and well-developed printed circuit board (PCB) technique. While the low-frequency (quasi-static) characteristics of such structures can be described by the traditional effective-medium theory, their high frequency responses are generally to be determined by numerical methods. Recently an analytical approach has been attempted by using the transfer-matrix method and by treating each planar disk lattice as a shunt susceptance (C.A. Kyriazidou, H.F. Contopanagos, W.M. Merrill, and N.G. Alexopoulos, *IEEE Trans. Antennas and Propagation*, **48**, 95-106, 2000). The method is limited by the fact that the spacing between two successive lattice planes or the layer thickness has to be large enough so that all evanescent modes can be neglected, which results in very bulky structures if a large number of layers are needed. To overcome this limit, a new analytical model has been developed in this work by dropping the shunt susceptance approximation.

Under the small-disk assumption, the interaction between a conducting disk and an electromagnetic wave can be represented by the radiation of an electric and a magnetic dipole with the dipole moments to be determined (R.E. Collin and W.H. Eggimann, *IRE Trans. Microwave Theory Tech.*, **9**, 110-115, 1961). As a result, the scattering of an incident EM wave by the 3D periodic disk array can be determined by the total radiation of the equivalent 3D electric dipole array and the 3D magnetic dipole array. Since the electric (magnetic) polarization relies on the total field (incidence plus radiation) at the disk location and the latter is, in turn, proportional to the dipole moments, equations that describe such relationships can be formulated, from which the dipole moments can be determined. Once the equivalent dipole moments are obtained, all transmitted and reflected waves can be calculated analytically. The scattered field expression has the form of the Floquet mode expansion and, therefore, can also be used for multi-mode transmission and reflection. The energy relationship among the incident, transmitted, and reflected waves is also derived, which can be used to verify the theoretical model. Numerical results are presented and a comparison has been made between this method and the above approach. A full-wave finite element simulation is also conducted (using HFSS code) to examine the accuracy of the proposed method and to show that the evanescent modes can’t be neglected when layer thickness is quite small compared to the wavelength.