Field Representation in PBG waveguides

Filippo Capolino*, David R. Jackson, and Donald R. Wilton****

*Department of Information Engineering, University of Siena, 53100 Siena, Italy
**Department of ECE, University of Houston, Houston, TX 77204-4005, USA

Photonic band gap (PBG) structures have been used recently to modify the radiation and modal characteristics of sources located near or within them. For example, such structures have been used to suppress surface-wave propagation on dielectric substrates, obtain highly-directive antenna patterns, and achieve low-loss propagation in the millimeter-wave and optical ranges. A PBG material with a row of defects (missing elements) constitutes a waveguiding structure that provides an attractive alternative to conventional waveguides. The applicability of such materials for constructing devices such as switches, multi/demultiplexers, power dividers, couplers, etc., is also receiving increasing interest.

In the present investigation we examine some fundamental properties pertaining to the field representation from a source within a periodic PBG waveguiding structure. The canonical structure that is chosen consists of an infinite 2D PBG structure, with a row of defects that forms the waveguide channel in the z direction. A line source (in the y direction, parallel to the PBG elements) is placed within the channel to form the excitation. One issue in connection with the field representation is completeness; namely, do the modes of the PBG waveguide form a complete set with which to expand the field of the source? Another fundamental issue is the relationship between the nature of the fields inside the PBG waveguide that are excited by the source, and the stopband properties of the surrounding PBG structure.

An exact solution for the field within the PBG waveguide due to the line source can be obtained numerically using a full-wave periodic method of moments. However, the phenomenology is much easier to understand when a simplified model is used, in which the interaction of higher-order Floquet modes between adjacent rows of elements is neglected. For analyzing wave propagation at an arbitrary angle within the PBG structure, the structure on either side of the channel is modeled as a transmission line (in the x direction) with a periodic distribution of shunt loads. This model allows for a Bloch-wave analysis to be used to model the surrounding PBG structure in a spectral-domain analysis for the field excited by the line source. This in turn allows for an analytical representation of the fields within the PBG waveguide so that the field phenomenology can be conveniently studied.

Particular attention is given to the complex longitudinal wavenumber plane (the k_z plane). The poles in the k_z plane determine the modal excitation within the PBG waveguide. The branch points in the k_z plane determine the nature of the continuous-spectrum field that exists within the waveguide, in addition to the modal field. Because of this continuous-spectrum field, the total field within the PBG waveguide excited by the source is never representable solely by the modes of the waveguide (unlike the case of a source within a conventional waveguide of perfectly conducing walls). However, the continuous-spectrum field decays exponentially away from the source when the surrounding PBG structure is operating in a stopband. When the PBG structure is not operating within a stopband, the continuous-spectrum field decays algebraically instead of exponentially.