Spectral FDTD:
A Novel Approach in the Analysis of Periodic Structures

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Periodic structures have recently been the focus of many researchers. The periodicity of these structures is either in one, two or three directions. These structures are inherently infinite, and cannot be directly analyzed. However, because of the periodic nature of these structures, their analysis can be reduced to that of a unit cell by incorporating the periodic boundary condition (PBC).

To implement the PBC, one needs to take into account the delay that fields encounter as they travel across the unit cell. This task is straightforward for frequency domain techniques (e.g. MoM), and has not been considered straightforward for the time domain techniques (e.g. FDTD). The reason is that the direct implementation of PBC in time domain needs the knowledge of the future value of fields at the present time, which is not easy to access in a causal system. The implementation in frequency domain is easy because the time delay translates to a phase shift in frequency domain.

Our novel approach referred to as “spectral FDTD” is a time domain technique but still the implementation of PBC in this method is as straightforward as its implementation for frequency domain methods. The reason behind the successful implementation of this technique is that we fix the wavenumbers of wave in the direction of periodicity. As a result, waves have no time delay traveling in that direction of space and PBC can be directly implemented by multiplying the appropriate phase shift similar to its implementation in frequency domain methods. Although, the application of “constant wavenumber” or “spectral” methods for solving the eigenvalue problems is not new, the extension of their applications for solving the excitation problems is not widely used in literature. In our work, we go one step further and use these methods to solve for the excitation problems.

The 2D version of spectral FDTD is used to solve for the plane wave incident on open planar structures with the periodicity in two directions. In this method, the PBC is implemented to truncate the structure in the two directions, and the third open direction is truncated using perfect matched layer (PML). Because of using constant wavenumber in the directions of periodicity and “no delay” feature of waves in those directions, the implementation of PBC for the oblique incident wave is as straightforward as its implementation for the normal incident wave. This technique shows a superb applicability over many existing techniques (e.g. split field technique) developed for the same purpose. The method gives a stable solution over the entire incident angles whereas other available time domain techniques do not work for grazing incidents. Its application for electromagnetic band gap structures shows a thorough characterization of the periodic structure over the entire range of incident angles and a wide band of frequencies.

A 3D version of spectral FDTD is developed for the analysis of structures with the periodicity in three directions. In this method, wavenumbers are kept constant in three directions and PBC is directly implemented in time domain in three directions. Similar to the implementation in two directions, the “no delay” feature of waves makes it possible to implement PBC directly in time domain. The method is successfully implemented to compute the effective permittivity of arbitrary shaped array of inclusions applicable for meta-material characterizations.