Metamaterials Modeling Using FDTD-PLRC Method with CPML Absorbing Walls: An Antenna Design Investigation

Hossein Mosallaei
ECE Department, Northeastern University, Boston, MA
hosseinm@ece.neu.edu

In recent years there have been significant amount of research in the area of functional metamaterials. Different material properties such as Double Negative (DNG), Double Positive (DPS), Epsilon Negative (ENG), and Mu Negative (MNG) parameters have been investigated and many novel applications for them in the areas of RF and optical systems have been proposed. However, in most of these designs the frequency dispersive behavior and loss of the metamaterials, which in fact have a considerable effect in the practical designs, have been ignored.

The goal of this paper is to present a powerful modeling engine based on Finite Difference Time Domain (FDTD) technique to characterize *real* metamaterials having frequency dispersive ε-μ properties. The frequency-dependent behavior of a material is incorporated into the FDTD equations with the use of Piecewise Linear Recursive Convolution (PLRC) approach [1]. At any point in a linear dispersive medium, the time domain electric flux density $\mathbf{D}(t)$ and magnetic flux density $\mathbf{B}(t)$ are respectively represented using the following convolutions forms:

$$\mathbf{D}(t) = \varepsilon_0 \varepsilon_\infty \mathbf{E}(t) + \varepsilon_0 \chi_e(t) * \mathbf{E}(t), \quad \mathbf{B}(t) = \mu_0 \mu_\infty \mathbf{H}(t) + \mu_0 \chi_m(t) * \mathbf{H}(t). \qquad (1)$$

A recursive formulation is used to approximate a linear interpolation for the above equations. The results are then integrated into the conventional Yee discretized FDTD equations to comprehensively model the dispersive ε-μ materials. To efficiently terminate the FDTD domain a newly developed Convolutional Perfectly Matched Layered (CPML) absorbing walls based on the Complex Frequency Shifted (CFS) method is applied [2]. The CPML is based on the stretched-coordinate form of the PML. It is more accurate, more efficient, and better suited for the application of domains with generalized materials. Basically, the CPML operates only on the filed intensities and has nothing to do with the $\mathbf{D}$ - $\mathbf{E}$ and $\mathbf{B}$ - $\mathbf{H}$ constitutive relationships. This provides a very powerful approach for characterizing 3D complex metamaterials.

The FDTD-PLRC with CPML walls will be applied to a variety of metamaterials to understand their physics and explore their potential applications for antenna designs. The design of antennas printed on dispersive dielectric-magnetic materials will be investigated, and the effects of the frequency dispersive material parameters on the antenna performance, mainly, input impedance will be highlighted. Both positive and negative constitutive parameters will be considered, and their advantages for antenna designs with enhanced radiation characteristics will be addressed.

References

[1] D. F. Kelley and R. J. Luebbers, “Piecewise linear recursive convolution for dispersive media using FDTD,” *IEEE Trans. Antennas Propagat.*, vol. 44, no. 6, pp. 792-797, June 1996.
[2] J. A. Roden and S. D. Gedney, “Convolutional PML (CPML): An efficient FDTD implementation of the CFS-PML for arbitrary media,” *Microwave Optical Tech. Lett.,* vol. 27, no. 5, pp. 334-339, Dec. 2000.