URSI - RCRS 2022, IIT (Indore), India, 1 - 4 December, 2022

On the Importance of In-house FDTD Codes: Analysis of MIMO Systems and Antenna Near-field Energy Distribution to Modelling of Space-Time Metamaterials

Debdeep Sarkar
Dept. of Electrical Communication Engineering, Indian Institute of Science, Bangalore, Karnataka, India

Ever since the seminal work by Yee carried out in the 1960s [1], FDTD (finite-difference time-domain) method has emerged as a valuable computational electromagnetic (CEM) framework. Compared to many other full-wave techniques like frequency-domain MoM (method of moments) or FEM (finite element method), FDTD does not require matrix inversion. Furthermore, FDTD combined with Fourier Transform provides some unique advantages like wideband S-parameter computation at a single-shot, not requiring meshing of the problem space at each discrete frequency. In spite of the progress and refinements in FDTD simulation paradigm for several complex EM problems, development of in-house conditionally stable FDTD codes can prove to be useful from a problem-solving stand-point. In this article, we revisit some of such cases, where in-house FDTD has been applied on EM problems relevant for the present-day antennas and metamaterial engineers [2]-[6].

In [2], we use the concept of cross-correlation Green's functions (CGFs) in conjunction with the in-house FDTD technique for the calculation of envelope correlation coefficient (ECC) of any arbitrary multiple-input multiple-output (MIMO) antenna system over wide frequency band. The FDTD-CGF-TD scheme as discussed in [2] applies TD (time-domain) signal-processing methods and exhibits significant reduction in ECC computation time for high-frequency resolution requirements. Such FDTD-CGF-TD schemes can overcome the limitations of conventional scattering parameter-based techniques used for quick computation of wide-band ECC matrix of MIMO systems [2]. We further extend the in-house FDTD scheme for the analysis of massive MIMO systems, where the channel eigen-space can be tailored by use of reconfigurable frequency-selective structures [3]. Compared to the traditional Ray-tracing schemes, the FDTD method can better model the electromagnetic (EM) impact of inter-element mutual coupling and spherical wavefront illumination on the wireless MIMO channel properties [3]. In [4], we apply in-house FDTD method in conjunction with infinitesimal dipole modelling (IDM) to provide vital insights into the time-domain evolution of reactive energy and far-field radiated power around antennas. In [5], we deploy FDTD and suitable interpolation schemes to calculate the Poynting localized energy density near any antenna from the near-zone electric and magnetic fields, leading to a new paradigm of "Poynting Localized Energy", which fundamentally different from the classical antenna reactive energy associated with frequency-domain Q-factors of electrically small antennas. Finally, in [6], FDTD analysis is effectively used for the analysis of the exotic properties of time-modulated metamaterial mediums, that can lead to parametric amplification and mixing.

References

[1] K. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media", IEEE Trans. Antennas Propag., vol. AP-14, no. 3, pp. 302-307, May 1966.

[2] D. Sarkar and K. V. Srivastava, "Application of Cross-correlation Green's Function along with FDTD for Fast Computation of Envelope Correlation Coefficient over Wideband for MIMO Antennas," *IEEE Transactions on Antennas and Propagation*, **65**, 2017, pp. 730–740.

[3] D. Sarkar, S. Mikki and Y. Antar, "Engineering the Eigenspace Structure of Massive MIMO Links Through Frequency-Selective Surfaces," *IEEE Antennas and Wireless Propagation Letters*, **18**, 2019, pp. 2701–2705.

[4] D. Sarkar, S. Mikki, K. V. Srivastava and Y. Antar, "Dynamics of Antenna Reactive Energy Using Time Domain IDM Method," *IEEE Transactions on Antennas and Propagation*, **67**, 2019, pp. 1084–1093.

[5] D. Sarkar, S. Mikki and Y. Antar, "Poynting Localized Energy: Method and Applications to Gain Enhancement in Coupled Antenna Systems," *IEEE Trans. on Antennas and Propagation*, **68**, 2020, pp. 3978–3988.

[6] D. Sarkar, *FDTD Analysis of Guided Electromagnetic Wave Interaction with Time Modulated Dielectric Medium*, SpringerBriefs in Electrical and Computer Engineering, Springer Verlag, Singapore, 2022. (ISBN-13: 978-9811916298)