Chapter 1

Computational Modeling of Antennas

1.1 Introduction

The finite-difference time-domain (FDTD) method is a computational procedure for solving Maxwell?s equations that is based on a clever algorithm first proposed by Kane S. Yee in 1966 [1]. When Yee proposed his algorithm, the method was computationally intensive in terms of both storage and run time, and only problems of very modest size could be solved using the best computational facilities (mainframe computers). Since then the power of computers has steadily increased, as has the popularity of the FDTD method. The first comprehensive analyses of practical antennas using the method were performed during the early 1990?s, and today such computations are routinely performed on personal computers [2]-[6].

The purpose of this article is to introduce the reader to the rudiments of the FDTD method as applied to practical antennas. It is hoped that after viewing the article, the reader will understand the power and limitations of the method and be in a position to decide whether or not the FDTD method is suitable for analyzing his/her antenna problem. Because of the limited space, we cannot provide the details for implementing the method in a computer program. Readers interested in writing their own program are referred to reference [7] for the details; others may wish to use one of the commercially available FDTD computer codes.

1.2 The Basic FDTD Algorithm

In the Yee algorithm, both space and time are discretized, with the increments in space for rectangular coordinates being $\Delta x, \Delta y, \Delta z$ and the increment in time being Δt [8], [9].

Figure 1.1: Schematic drawing showing the computational volume, FDTD spatial lattice, and unit cell.

Figure 1 is a schematic drawing showing a typical volume in which Maxwell?s equations are to be solved. The volume is divided into unit cells each of volume. The electromagnetic constitutive parameters ($\epsilon = \epsilon_r \epsilon_o$, $\mu = \mu_r \mu_o$, σ) can vary from cell to cell, and they are used to define different objects within the volume [1]. The six components of the electromagnetic field $(E_x, E_y, E_z; H_x, H_y, H_z)$ are distributed over a unit cell (Yee cell) as shown in the inset. Notice that all of the components are located at different points within the cell, and the components of H are displaced from those of E by one half of a spatial increment, e.g., $\Delta x/2$. Although not shown in the figure, the components of H are also evaluated at points displaced by one half of a time increment, viz, $\Delta t/2$, from those of E.

The partial derivatives in Maxwell?s equations are approximated by ratios of differences, for example,

$$\frac{\partial E_x}{\partial z} \approx \frac{\Delta E_x}{\Delta z}, \frac{\partial H_y}{\partial t} \approx \frac{\Delta H_y}{\Delta t} \tag{1.1}$$

[1]Here we mention only simple materials with constant permittivity, permeability, and electrical conductivity. In the FDTD method there are techniques to handle more complicated materials, such as those with dispersive and anisotropic properties [9].

Bibliography

[1] Leslie Lamport, *LaTeX: a document preparation system*, Addison Wesley, Massachusetts, 2nd edition, 1994.

[2] K. S. Yee, "Numerical Solution of Initial Boundary Value Problems Involving Maxwell?s Equations in Isotropic Media," IEEE Trans. Antennas Propagat., Vol. AP-14, pp. 302-307, May 1966.

[3] J. G. Maloney, G. S. Smith, and W. R. Scott, Jr., ?Accurate Computation of the Radiation from Simple Antennas Using the Finite-Difference Time-Domain Method,? IEEE Trans. Antennas Propagat., Vol. AP-38, pp. 1059-1068, July 1990.

[4] J. J. Boonzaaier and C. W. Pistorius, ?Thin Wire Dipoles ? A Finite-Difference Time-Domain Approach,? Electronics Lett., Vol. 26, pp. 1891-1892, 25 October, 1990.

[5] D. S. Katz, M. J. Picket-May, A. Taflove, and K. R. Umashankar, ?FDTD Analysis of Electromagnetic Wave Radiation from Systems Containing Horn Antennas,? IEEE Trans. Antennas Propagat., Vol. AP-39, pp. 1203-1212, August 1991.

[6] 5. P. A. Tirkus and C. A. Balanis, ?Finite-Difference Time-Domain Method for Antenna Radiation,? IEEE Trans. Antennas Propagat., Vol. AP-40, pp. 334-340, March 1992.

[7] R. J. Luebbers and J. Beggs, ?FDTD Calculation of Wide-Band Antenna Gain and Efficiency,? IEEE Trans. Antennas Propagat., Vol. AP-40, pp. 1403-1407, November 1992.

[8] J. G. Maloney and G. S. Smith, ?Modeling of Antennas,? Chapter 7 in A. Taflove, Editor, Advances in Computational Electrodynamics, The Finite-Difference Time-Domain Method, pp. 409-460, Artech House, Boston, 1998. Also, J. G. Maloney, G. S. Smith, E. Thiele, O. Ghandi, N. Chavannes, and S. Hagness, Chapter 14 in A. Taflove, and S. Hagness, Editors, Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd Edition, pp. 607-676, Artech House, Boston, 2005.

[9] , An Introduction to Classical Electromagnetic Radiation, Cambridge University Press, Cambridge, UK, 1997.

[10] A. Taflove and S. C. Hagness, Editors, Computational Electrodynamics: The Finite-Difference Time-Domain Method, Artech House, Boston, 2005.

[11] J. B. Schneider and C. L. Wagner, ?FDTD Dispersion Revisited: Faster-Than-Light Propagation,? IEEE Microwave and Guided Wave Let., Vol. 9, pp. 54-56, Feb. 1999.

[12] S. Gedney, ?An Anisotropic Perfectly Matched Layer-Absorbing Medium for the Truncation of FDTD Lattices,? IEEE Trans. Antennas Propagat., Vol. AP-44, pp. 1630-1639, December 1996.

[13] S. Gedney, ?Perfectly Matched Layer Absorbing Boundary Conditions,? Chapter 7 in A. Taflove and S. C. Hagness, Editors, Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd Edition, pp. 273-328, Artech House, Boston, 2005.

[14] K. L. Shlager and G. S. Smith, ?Near-Field to Near-Field Transformation for Use With FDTD Method and Its Application to Pulsed Antenna Problems,? Electronics Lett., Vol. 30, pp. 1262-1264, 4th, August, 1994.

[15] K. L. Shlager and G. S. Smith, ?Comparison of Two Near-Field to Near-Field Transformations Applied to Pulsed Antenna Problems,? Electronics Lett., Vol. 31, pp. 936-938, 8th, June, 1995.

[16] G. S. Smith, ?A Direct Derivation of a Single-Antenna Reciprocity Relation for the Time Domain,? IEEE Trans. Antennas Propagat., Vol. AP-52, pp. 1568-1577, June 2004.

[17] J. G. Maloney, M. P. Kesler, and G. S. Smith, ?Generalization of PML to Cylindrical Geometries,? 13th Annual Review of Progress in Applied Computational Electromagnetics, Monterey, CA, pp. 900-908, March 1997.

[18] G. S. Smith and T. W. Hertel, ?On the Transient Radiation of Energy from Simple Current Distributions and Linear Antennas,? IEEE Antennas Propagat. Magazine, Vol. 43, pp. 49-62, June 2001.

[19] T. W. Hertel and G. S. Smith, ?On the Convergence of Common FDTD Feed Models for Antennas,? IEEE Trans. Antennas Propagat., Vol. AP-51, pp. 1771-1779, August 2003.

[20] R. W. P. King, The Theory of Linear Antennas, pg. 20, Harvard Univ. Press, Cambridge, MA, 1956.

[21] J. G. Maloney, K. L. Shlager, and G. S. Smith, ?A Simple FDTD Model for Transient Excitation of Antennas by Transmission Lines,? IEEE Trans. Antennas Propagat., Vol. AP-42, pp. 289-292, February 1994.

21. S. Dey and R. Mittra, ?A Locally Conformal Finite-Difference Time-Domain (FDTD) Algorithm for Modeling Three-Dimensional Perfectly Conducting Objects,? IEEE Microwave and Guided Wave Lett., Vol 7, pp. 273-275, September 1997.

22. A. Taflove, M. Celuch-Marcysiak, and S. Hagness, ?Local Subcell Models of Fine Geometrical Features,? Chapter 10 in A. Taflove and S. C. Hagness, Editors, Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd Edition, pp. 407-462, Artech House, Boston, 2005.

23. S. Gedney, F. Lansing, and N. Chavannes, ?Nonuniform Grids, Nonorthogonal Grids, Unstructured Grids, and Subgrids,? Chapter 11 in A. Taflove and S. C. Hagness, Editors, Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd Edition, pp. 463-516, Artech House, Boston, 2005.

24. A. C. Cangellaris and D. B. Wright, ?Analysis of the Numerical Error Caused by the Stair-Stepped Approximation of a Conducting Boundary in FDTD Simulations of Electromagnetic Phenomena,? IEEE Trans. Antennas Propagat., Vol. AP-39, pp. 1518-1525, October 1991.

25. R. Holland, ?Pitfalls of Staircase Meshing,? IEEE Trans. Electromagnetic Compatibility, Vol. 35, pp. 434-439, November 1993.

26. T. W. Hertel and G. S. Smith, ?Analysis and Design of Two-Arm Conical Spiral Antennas,? IEEE Trans. Electromagnetic Compatibility, Vol. 44, pp. 25-37, February 2002.

27. T. W. Hertel and G. S. Smith, ?On the Dispersive Properties of the Conical Spiral Antenna and Its Use for Pulsed Radiation,? IEEE Trans. Antennas Propagat., Vol. AP-51, pp. 1426-1433, July 2003.

28. J. D. Dyson, ?The Characteristics and design of the Conical Log-Spiral Antenna,? IEEE Trans. Antennas Propagat., Vol. AP-13, pp. 488-499, July 1965.

29. K. L. Shlager, G. S. Smith, and J. G. Maloney, ?Accurate Analysis of TEM Horn Antennas for Pulse Radiation,? IEEE Trans. Electromagnetic Compatibility, Vol. 38, pp. 414-423, August 1996.

30. R. T. Lee and G. S. Smith, ?On the Characterteristic Impedance of the TEM Horn Antenna,? IEEE Trans. Antennas Propagat., Vol. AP-52, pp. 315-318, January 2004.

31. R. T. Lee and G. S. Smith, ?A Design Study for the Basic TEM Horn Antenna,? IEEE Antennas Propagat. Magazine, Vol. 46, pp. 86-92, February 2004.

32. K. L. Shlager, G. S. Smith, and J. G. Maloney, ?Optimization of Bow-Tie Antennas for Pulse Radiation,? IEEE Trans. Antennas Propagat., Vol. AP-42, pp. 975-982, July 1994.

33. E. Chang, S. A. Long, and W. F. Richards, ?An Experimental Investigation of Electrically Thick Rectangular Microstrip Antennas,? IEEE Trans. Antennas Propagat., Vol. AP-34, pp. 767-772, June 1986.

34. H. Abdallah, W. Wasylkiwskyj, K. Parikh, and A. Zaghloul, ?Comparison of Return Loss Calculations with Measurements of Narrow-Band Microstrip Patch Antennas,? ACES Journal, Vol. 19, pp. 184-186, November 2004.

35. D. R. Jackson and N. G. Alexopoulos, ?Simple Approximate Formulas for the Input Resistance, Bandwidth, and Efficiency of a Resonant Rectangular Patch,? IEEE Trans. Antennas Propagat., Vol. AP-39, pp. 407-410, March 1991.

36. S. Chebolu, R. Mittra, and W. D. Becker, ?The Analysis of Microwave Antennas Using the FDTD Method,? Microwave Journal, Vol. 39, pp. 134-150, January 1996.

37. J.G. Maloney, P.H. Harms, M.P. Kesler, T.L. Fountain, and G.S. Smith, ?Novel, Planar Antennas Designed Using the Genetic Algorithm,? 1999 USNC/URSI Radio Science Meeting, Orlando, FL, pg. 237, July 1999.

38. J.G. Maloney, M.P. Kesler, P.H. Harms, T.L. Fountain, and G.S. Smith, ?The Fragmented Aperture Antenna: FDTD Analysis and Measurement,? Millennium Conference on Antennas and Propagation (AP 2000), Davos, Switzerland, 4 pages, April 2000.

39. J.G. Maloney, M.P. Kesler, P.H. Harms, and G.S. Smith, Fragmented Aperture Antennas and Broadband Ground Planes, U.S. Patent, No. 6,323,809 B1, November 27, 2001.

40. L. N. Pringle, P. H. Harms, S. P. Blalock, G. N. Kiesel, E. J. Kuster, P. G. Friederich, R. J. Prado, J. M. Morris, and G. S. Smith, ?A Reconfigurable Aperture Antenna Based on Switched Links Between Electrically Small Metallic Patches,? IEEE Trans. Antennas Propagat., Vol. AP-52, pp. 1434-1445, June 2004.