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Adebowale E. Shadare

Prairie View A&M University

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Matthew N.O. Sadiku[1], Adebowale E. Shadare[2], Sarhan M. Musa[3]
[1,2]Department of Electrical & Computer Engineering, [3]Department of Engineering Technology,
Prairie View A&M University, Prairie View, TX 77446
Email: sadiku@iee.org, shadareadebowale@yahoo.com, smmusa@pvamu.edu

Abstract—Computational electromagnetic (CEM) involves using numerical methods to solve real-life electromagnetic problems. Over the years, a great number of CEM tools have been developed to simulate and to analyze electromagnetic systems. This has been made possible due to the numerous contributions from several institutions, universities, and industries around the world. This paper provides a brief introduction to CEM.

***Keywords**:* computational electromagnetic, numerical electromagnetic

I. Introduction

The modern society we live in heavily depends on electromagnetic (EM) systems such as radio, television, radar, microwave ovens, mobile telephones, satellite communication systems, Internet, motors, generators, computers, transformers, and power networks [1]. EM technologies have also benefited other sciences and technologies and medicine, not to mention arts, humanities, and other aspects of human civilization.

In the beginning, experts in electromagnetic solved problems with pencil and paper, using largely closed form analytical solutions. However, in the last 50 years, the EM community has witnessed a breathtaking evolution in the way we solve and apply EM concepts. With the ever-increasing power and memory of the digital computers, the art of computational electromagnetic has gained momentum.

Computational electromagnetics (CEM) deals with computational methods applied in solving EM problems. It is based on computer implementation of mathematical models of EM systems. CEM tools are useful in analyzing and designing power systems, electrical machines, generators, transformers, microwave networks, and antennas. They are also used in predicting the electromagnetic compatibility (EMC) between complex electronic systems. For this reason, CEM is of increasing importance to the civil and defense sectors [2].

Computational electromagnetics basically involves solving Maxwell's equations [3]:

$$\nabla \bullet \boldsymbol{D} = \rho \qquad (1)$$

$$\nabla \bullet \boldsymbol{B} = 0 \qquad (2)$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t} \qquad (3)$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t} \qquad (4)$$

where **D** and **B** are electric and magnetic flux densities respectively. **E** and **H** are electric and magnetic field intensities respectively. **J** is the electric current density. These quantities are related as follows:

$$\boldsymbol{J} = \sigma \boldsymbol{E}, \qquad \boldsymbol{D} = \varepsilon \boldsymbol{E}, \qquad \boldsymbol{B} = \mu H \qquad (5)$$

where $\sigma, \varepsilon,$ and μ are electrical conductivity, permittivity, and permeability of the media.

Maxwell's equations (1) to (4) define EM wave theory and establish the mathematics of electromagnetic wave-matter interaction. We now discuss the various techniques for solving them.

II. Computational methods

There are seven common numerical techniques used in electromagnetic [4]:

- *Finite Difference Method*: This involves the simple discretization of Maxwell's equations in differential form. The finite-difference time-domain (FDTD) method is one of the most widespread methods in CEM. Although FDTD is efficient, it has difficulties with complex geometries. Applications of FDTD include scattering, antennas, EMC, and photonics [5].
- *Variational Method*: This involves minimizing a functional defining a given problem. Variational methods are of two types: direct and indirect methods. The direct method is the classical Rayleigh-Ritz method, while the indirect methods are usually referred to as the method of weighted residuals: collocation (or point-matching), subdomain, Galerkin, and least squares methods [6].
- *Moment Method*: This method transforms the integral equation of a given problem, by weighted residual techniques, into a matrix equation to be solved numerically. Although this method is suitable for problems involving open regions such as scattering and radiation problems, it has been successfully applied to closed problems such as waveguides and cavities [7].
- *Finite Element Method*: This is a computational technique that divides solution region into non-overlapping meshes (or elements), typically triangles in two dimensions and tetrahedral in three dimensions. It is more powerful than finite different moment methods in handling problems involving complex, inhomogeneous media. The systematic generality of the method makes it possible to develop a general-purpose computer program for solving a wide variety of problems [8], [9].
- *Transmission Line Matrix Modeling*: This is a network model of Maxwell's equations formulated in terms of the scattering of impulses. It is a space- and time discrete model of electromagnetic phenomena, based on the analogy between field

propagation and transmission lines. In the TLM, the discretization of the field involves replacing a continuous system by an array of lumped elements [10,11].

- *Monte Carlo Method*: This is a nondeterministic numerical approach, unlike the method covered earlier. It can be applied in two ways: simulation and sampling. Simulation refers to the procedure of providing mathematical imitation of real-life random phenomena. Sampling refers to methods of deducing properties of a large set of elements by studying only a small, random subset. In EM, Monte Carlo method is applied as simulation using pseudo-random numbers [12].
- *Method of lines*: This technique involves discretizing a given differential equation in one or two dimensions while using analytical solution in the remaining direction. It is regarded as a special finite difference method since it combines finite different method and analytical method. It is computational efficient, numerically stable, and involves less computational time since only a small discretization is needed [13].

In addition to these methods, there are hybrid methods which combine low-frequency methods such as those covered above with high-frequency methods such as geometric theory of diffraction [14].

III. Computation Tools

Numerical modeling and simulation have revolutionized all aspects of engineering design to the extent that several software packages have been developed. In the 1970s, researchers developed their own computer programs to solve problems since very few commercial solvers existed. Nowadays, the situation is completely different. There are dozens of computational tools are on the market. There is no longer motivation or a justifiable need to develop one's own software tools at universities and in industry. There is growing interest and dependence on commercial software in designing complex electromagnetic problems both in industry and academia. These commercial codes have been attractive due to their ease of use of graphic interface and the ability to model the real structure in its detail. While some of these software are commercial, some are free.

Widely used software packages for CEM include:

- *COMSOL*: This is based on the finite element method. It is a powerful for various physics and engineering applications. More information about COMSOL is available at https://www.comsol.com/
- *Numerical Electromagnetic Codes* (NEC): This is based on the method of moments (MOM) and was developed at Livermore National Laboratory. It has a PC version called MININEC. It is used for frequency domain antenna modeling code of wires and surface structures. NEC2 uses a text interface code and is a widely used 3D code.A free NEC code is 4nec2, which can be found at http://www.qsl.net/4nec2/ Online documentation can be obtained from http://www.nec2.org/
- *High Frequency Structure Simulator* (HFFS): This is based on the finite element method (FEM) and was developed by Ansoft, which was later acquired by Ansys. HFSS offers state-of the-art solver to solve a wide range of EM applications. More information about HFSS can be found in
  http://www.ansys.com/Products/Electronics/ANSYS-HFSS
- *Sonnet*: This provides high frequency 3D planar electromagnetic (EM) analysis of for single and multi-layer planar circuits. Free student version (Sonnet Lite) is available. For more information, visit their website:
  http://www.sonnetsoftware.com/
- *FEKO*: This is an antenna simulation software based on the method of moments. It can be used to calculate the radiation pattern, impedance, and gain of an antenna. For more information, visit their website: http://www.feko.info
- *EMAP*: This is a family of three-dimensional electromagnetic modeling codes developed at the Missouri University of Science and Technology. EMAP3 is a vector FEM code, while EMAP5 is a vector FEM/MoM code.
- *MEEP*: This is a free, open-source finite-difference time-domain (FDTD) simulation software package developed at MIT. MEEP is an acronym for MIT Electromagnetic Equation Propagation. It was first released in 2006 and it can be downloaded from http://ab-initio.mit.edu/meep
- *MaxFem*: This is an open software package for electromagnetic simulation based on the finite element method. The package can solve problems in electrostatics, magnetostatics, and eddy-currents.

Several more CEM software are available on the Web but these are the most popular. These software put powerful tools and techniques, previously available only to full-time theorists, into the hands of engineers not formally trained in CEM. The best method or software package to use depends on the particular problem you are trying to solve. Substantial progress has been made in CEM and further gains have been derived from the availability of these powerful commmercial packages.

IV. Challenges

All CEM techniques have strengths and limitations Since computation involves discritization, errors are inevitable.The computational accuracy is controlled by the algorithm employed and computing facility used. Error induced by the discretization consists of the roundoff and the truncation error. CEM tools can be made more efficient by using scalable multicomputers [15].

There is the need for a well-defined, mature, and robust methodology for validating computational electromagnetic techniques. Validation of the computed results for CEM techniques should always be made because garbage in, garbage out (GIGO). In other words, one should never trust the results of scientific computation unless they are verified or validated, as least in part. The reason for validation is to give confidence in the numerical results. Measured data, analytical solutions or results from other CEM techniques may be used for validating results [16], [17].

For CEM methods to solve large-scale electromagnetic boundary-value problems (such as a full-size aircraft at X band), involving millions of unknowns, a supercomputer or a distributed-memory parallel computer is required. A distributed memory parallel computer is a number of independent computers connected through a high speed network such as the Internet [18]. Multi-scale electromagnetic problems, in which geometries of both electrically large and small features are present, can be solved with software metamaterials [19].

V. Conclusion

Computational electromagnetics is the interdisciplinary field that combines electromagnetics and scientific computing. The main objective is to gain insight and understanding based on computer implemented mathematical models of Maxwell's equations. The field is young, constantly evolving and changing. It has become a major design approach in both industrial and academic research.

The state-of-the-art in CEM is advancing rapidly. This advancement is facilitated by some specialized journals on CEM. These include *IEEE Transactions on Microwave Theory and Techniques*, *Progress in Electromagnetic Research* (PIER), *Journal of Electromagnetic Waves and Applications (JEMWA)*, *Applied Computational Electromagnetics Society Journal*, and *Journal of Computational Physics*.

References

i. *A. T. Bondeson, T. Rylander, and P. Ingelstrom, Computational Electromagnetics. New York: Springer, 2005, p.1.*

ii. *M. Lin and D. W. Walker, "GECEM: A portal-based grid application for computational electromagnetics," Future Generation Computer Systems, vol. 24, Feb. 2008, pp. 66–72.*

iii. *M. N. O. Sadiku, Elements of Electromagnetics. New York: Oxford University Press, 6th ed., 2015, pp. 407-427.*

iv. *M. N. O. Sadiku, Numerical Techniques in Electromagnetics with MATLAB, Boca Raton, FL: CRC Press, 3rd ed., 2009.*

v. *A. Taflove and S. C. Hagness, Computational Electrodynamics: the Finite-Difference Time-Domain Method. Boston, MA: Artech House, 3rd edition, 2005.*

vi. *L. Cairo and T. Kahan, Variational Techniques in Electromagnetics. New York: Gordon & Breach, 1965.*

vii. *R. F. Harrington, Field Computation by Moment Methods. Hoboken, NJ: Wiley-IEEE Press, 1993.*

viii. *P. P. Silvester and R. L. Ferrari, Finite Elements for Electrical Engineers: Cambridge, UK: Cambridge UniversityPress, 3rd ed., 1996.*

ix. *J. M. Jin, The Finite Element Method in Electromagnetics. New York, NY: Wiley, 3rd ed., 2014.*

x. *C. Christopoulos, The Transmission-Line Modeling Method (TLM). New York: IEEE Press, 1995.*

xi. *P. Saguet, Numerical Analysis in Electromagnetics: The TLM Method. Hoboken, NJ: Wiley-ISTE Press, 2012.*

xii. *M. N. O. Sadiku, Monte Carlo Methods for Electromagnetics. Boca Raton, FL: CRC Press, 2009.*

xiii. *R. Pregla, Analysis of Electromagnetic Fields and Waves: The Method of Lines. West Sussex, UK: Wiley, 2008.*

xiv. *L. N. Medgyesi-Mitschang and D. S. Wang, "Hybrid methods in computational electromagnetics: a review," Computer Physics Communications, vol. 68, 1991, pp. 76-94.*

xv. *J. S. Shang, "Computational Electromagnetics," ACM Computing Surveys, Vol. 28, No. 1, March 1996, pp. 97-99.*

xvi. *S. Lange, M. Schaarschmidt, and F. Sabath, "An approach on quality assurance in computational electromagnetic," Proc. of the 2014 International Symposium on Electromagnetic Compatibility (EMC Europe 2014), Gothenburg, Sweden, pp. 240-245, September 2014.*

xvii. *IEEE Electromagnetic Compatibility Society, IEEE Recommended Practice for Validation of Computational Electromagnetics Computer Modeling and Simulations. New York: IEEE, February 2011.*

xviii. *S. Velamparambil, W. C. Chew, and J. Song, "10 Million Unknowns: Is It That Big?" IEEE Antennas and Propagation Magazine, vol. 45, no. 2, April 2003, pp.43-58.*

xix. *O. Ozgun and M. Kuzuoglu, "Software metamaterials: Transformation media based multiscale techniques for computational electromagnetic," Journal of Computational Physics, vol. 236, 2013, pp. 203–219.*

About The Authors

Matthew N.O. Sadiku is a professor at Prairie View A&M University, Texas. He is the author of several books and papers. He is an IEEE fellow. His research interests include computational electromagnetics and computer networks.

Adebowale Shadare is a doctoral student at Prairie View A&M University, Texas. He is the author of several papers. His research interests are in smart grid EMC, computational electromagnetics and computer networks.

Sarhan M. Musa is a professor in the Department of Engineering Technology at Prairie View A&M University, Texas. He has been the director of Prairie View Networking Academy, Texas, since 2004. He is an LTD Spring and Boeing Welliver Fellow.