COMPUTATIONAL ELECTROMAGNETICS

With Emphasis on the Finite-Difference Time-Domain Method

EE635

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INTRODUCTION

The field of computational electromagnetics has become one of the fastest growing fields in science and engineering. This fact can be attributed to a number of reasons such as:

- Computer power is growing at a very high rate making the solution of very large problems possible within acceptable amount of memory storage and execution time.
- The wide spreading introduction of electrical and electronic instruments which are based on electromagnetic concepts in modern life points to the need for systematic testing and radiation analysis of these instruments.
- Technology transformation from military to civil sectors (e.g., medical, telecommunications, remote sensing) has resulted in new structures and applications requiring tremendous efforts in testing and reliability analysis.
- With major breakthroughs in this field and the great developments in numerical techniques and methods which enhanced the reliability and accuracy of numerical solutions, the society of computational electromagnetics has grown by many folds in just the last decade.

The need for numerical techniques and solutions and computational tools is serious because of the following concerns:

- With the complicated structure and material being used in recent technologies, improved models that incorporate physical phenomena, nonlinear behaviors and higher order and multidimensional effects can not be solved analytically. In fact, the analytical solution is only possible for limited classic-type problems.
- Traditionally, the design and characterization of new structures and circuits have relied on measurements. This empirical approach requires extensive experimental data to establish a good basis for design.
- Numerical techniques provide a great potential for exploring new ideas and structures. They also provide valuable insight into different aspects of the problems. Experiments can be a later stage to validate the numerical solution.

COURSE OBJECTIVES

The main objectives of this course are:

- Introduce the subject of computational techniques and numerical methods to the EE graduate students.

- Utilize the computer power at KFUPM and strengthen the use of computers in design and education.
- Develop expertise in the field of computational electromagnetics in particular and numerical methods in general.
- Complement the shortage in the EE graduate (and undergraduate in the future) curriculum which improves the image of the EE department within the KFUPM community and at large.
- Offer EE graduate students opportunities to pursue their MS and PhD research in this field, through solving real-life technological problems.

Upon taking this course, students are expected to benefit the following:

- Build a background in numerical methods to be used in their research work and future studies and careers.
- Understand the concept of modeling and the treatment of numerical solutions.
- Explore an ever-increasing area of research with state-of-the-art techniques and methods.
- Be exposed to the recent (and hot) technological developments in the field of electromagnetics, especially in photonics and telecommunications.

COURSE DESCRIPTION

Review of basic Electromagnetics (EM) theory and Partial Differential Equations (PDEs). Finite-difference approximation of PDEs. The Finite-Difference Time-Domain Method (FDTD). The Yee's mesh. Scalar Formulation of the FDTD method. 2D and 3D propagation and scattering problems. Related topics including numerical stability and dispersion, boundary conditions, nonhomogeneous structures, dispersive and nonlinear materials, etc. Introduction to other methods such as the finite-element method, the method of lines, beam propagation method and the moments method. Application and comparison of different methods and techniques in practical problems such as antennas, microwave devices and circuits and optics.

COURSE WORK

Projects (4):	60%
Final Project:	40%

COURSE REQUIREMENTS

Programming language (preferably FORTRAN 77/90 and C).
Visualization Aid (experience in MATLAB will be fine).
Programming skills.
Basic Electromagnetics. (Maxwell′s equations, EM waves, mode theory, etc.).

COURSE PREREQUISITES

MATH 301 (or equivalent)
EE 340 (or equivalent)
Consent of Instructor

COURSE OUTLINE

SUBJECT	NUMBER OF WEEKS
Part I:	1
Review of EM theory.	
Review of PDEs.	
Part II:	
The Finite-Difference method.	2
Electrostatic problems.	
The Finite-Difference Time-Domain method.	4
Scalar wave equation (2D & 3D).	
Maxwell′s equations and the Yee′s mesh.	
2D wave propagation.	
2D scattering problems.	
Extension to 3D cases.	
Related topics.	2
Numerical stability.	
Numerical dispersion.	
Gridding.	
Boundary conditions.	
Dispersive, nonlinear and gain materials.	
Parameter extraction.	
Part III:	3
The Finite-Element method.	
Beam Propagation Method.	
The Method of Lines.	
The Moments Method.	
Part IV:	
Case Studies.	3
Antennas.	
Microwave devices and circuits.	
Optics.	
Electro-Optics.	
Other selected topics.	

SUGGESTED TEXTBOOK

A. Taflove and S. C. Hagness, *Computational Electrodynamics: The Finite-Difference Time-Domain Method, 2nd Ed.* Norwood, MA: Artech House, 2000.

D. Sullivan, *Electromagnetic Simulation Using the FDTD Method.* IEEE Microwave Theory and Techniques Society, 2000

BASIC REFERENCES

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- W. Huang, S. Chu, A. Goss and S. Chaudhuri, “A scalar finiti-difference time-domain approach to guided-wave optics,” IEEE Photonics Tech. Lett., vol. 3, pp. 524-526, June 1991.
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- J. P. Berenger, “Perfectly matched layers for the absorption of electromagnetic waves,” J. Comput Phys., vol. 114, No. 2, 1994.
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- D. Sheen, S. Ali, M. Abouzahra and J. Kong, “Application of the three-dimensional finite-difference time-domain method to the analysis of planar microstrip circuits,” IEEE Trans. Microwave Theory Tech., vol. 38, pp. 849-857, 1990.