EL5623 – Finite Elements for Electrical Engineering

By: Francisco de Leon January-May 2011
Office: LC 255
Wednesdays 3:00 to 5:40 PM Room: JAB 773

Objective: At the end of the term the participants will understand the principles of the finite element method and will apply the method to the solution of electromagnetic design problems. Class examples will include: cables, transformers, motors, generators, transmission lines and antennas. Since the theoretical material is completely general students are encouraged to work examples and projects of their own interest.

Syllabus: Introduction to finite elements. A refresher of basic concepts of electromagnetism. Introduction to the solution methods of partial differential equations. Comparative summary of the solution methods for Maxwell equations. Finite elements, Garlekin and least squares approaches. Description of some commercial software packages. This is a hands-on course where the students work assignments and final projects using the finite elements software COMSOL Multiphysics.

Perquisites: MA2122, PH2004, EE3604, and EE3824. Preferable: PH 3234, MA4413.

- **Textbook:**
  João Pedro A. Bastos and Nelson Sadowski, "Electromagnetic Modeling by Finite Element Methods", CRC Press, 2003.

Reference Books:

- Roger W. Pryor, "Multiphysics Modeling Using COMSOL: A First Principles Approach", Jones & Bartlett Publishers, Inc.; 1st edition, 2009. ISBN-13: 978-076377999.
- Matthew N.O. Sadiku, "Numerical Techniques in Electromagnetics", Second Edition, CRC Press, 2001.
- H.M. Schey, "Div, Grad, Curl, and all that", W.W. Norton & Company, Inc., 1973.
- P. P. Silvester & R. L. Ferrari, "Finite elements for electrical engineers", Cambridge University Press, 1996.
- N. Ida, "Engineering Electromagnetics", Springer-Verlag, 2000.
- J. K. Sykulski, "Computational Magnetics", Chapman & Hall, 1995.
- B. J. Reece and T. W. Preston, "Finite Element Methods in Electrical Power Engineering, Oxford University Press, 2000.
- Nicola Bianchi, "Electrical Machine Analysis Using Finite Elements", CRC Taylor & Francis Group, 2005.
- Sheppard J. Salon, "Finite Element Analysis of Electrical Machines", Springer, 1995.

Syllabus

Lecture 1. A Refresher of Electromagnetism. Basic Concepts of Electricity and Magnetism. Electromagnetic Properties of Materials. Div, Grad, Curl and All That. Maxwell Equations. Interpretation of Maxwell Equations. COMSOL.

Lecture 2. A Refresher of Electromagnetism (continued). Field Classification. Electrostatic and Magnetostatic Fields. Static Electromagnetic Fields. Quasi-Static Fields. Complete Electromagnetic Field. Interface Relationships. Solution of Simple Examples Using COMSOL.

Lecture 3. Introduction to the Solution Methods of Partial Differential Equations. Classification of Second Order PDE's. Laplace Equation. Poisson Equation. Diffusion Equation. Initial and Boundary Conditions. Solution of Laplace Equation in the Dirichlet Rectangle using COMSOL.

Lecture 4. Summary of Solution Methods for Maxwell Equations. Closed Form Solutions. Numerical Solutions. Finite Differences. Finite Elements. Moment Methods. Reluctance Networks. Transmission-Line-Matrix Methods. Coupled Fields. Monte Carlo Methods. Method of Lines. Physical Methods. Experimental Methods.

Lecture 5. Introduction to Finite Elements. Finite Elements in One Dimension. Power Distribution and Minimization. Piecewise Approximation. Finite Element Matrices. Total Power Minimization. Solution Errors.

Lecture 6. Finite Elements. Domain Discretization. Variational Methods. Collocation Method. Weighted Residuals. Garlekin Method. Least Squares Method.

Lecture 7. Finite Elements (continued). Solution of Laplace Equation. Solution of Poisson Equation with Example. Solution of the Diffusion Equation with Example.

Lecture 8. *Mid-Term Exam*.

Lecture 9. Use of Commercial Programs. Pre-Processing: Drawing of the Model. Automatic Mesh Generator. Field Maps & Interpretation of Results. Post-Processing. Losses. Energy Stored. Inductance. Capacitance.

Lecture 10. Electric and Magnetic Fields of Round Solid Conductors. Steady Analysis of the Eddy Currents. Electrostatic Fields. Skin Effect. Effect of Stranding. Effect of Sectoring. Proximity Effect. Semi-conductive Screens. Cable Sheaths and Armors.

Lecture 11. Electric and Magnetic Fields in the Transformer Window. Quasi-Static Fields (Induction). Effect of Height/Width Aspect Ratio. Effect of Winding Interleaving. Electrostatic Barriers. Clearing Distances. Leakage Impedance. Insulation System.

Lecture 12. Magnetic Flux Distribution in a Synchronous Generator. Steady State Electromagnetic Wave. Field Penetration during Short Circuit. Sub-Transient, Transient and Synchronous Inductances.

Lecture 13. Parallel Conductor Transmission Line with AC Excitation. Conductors with Different Shapes: Cylindrical, Twisted Pair, Coaxial, Parallel Plate. Calculation of Line Parameters. Curvilinear Waveguide. Discontinuities in Waveguides.

Lecture 14. Field Around an Electrostatic Dipole and a Hertzian Dipole. Fields around Antennas: Small Loop, Long Straight Wire, Arbitrary Shape Wire, and Monopole.

Week 15. Final exam - presentation of projects.

Schedule:

Classes: Jan 26, Feb 2, 9, 16, 23, Mar 2, 9
No class: Mar 16 (spring break)
Mid-term: Mar 23
Classes: Mar 30, Apr 6, 13, 20, 27, May 4
Project presentation: May 11

Grading:

Mid-Term: 40% - March 23, 2011
Project: 60% - May 11, 2011

The project consists in producing a paper in the IEEE format with the following sections:

I. Abstract – 10%
II. Introduction – 10%
III. Theoretical Considerations (short) – 5%
IV. Simulations – 30%
V. Observations, Conclusions and Recommendations – 40%
VI. References – 5%