ECE 4803: Computational Methods for Microelectronics

TERM: SPRING 2024 : 3:30-4:45 MW : VL C457

DESCRIPTION:

In this class, students will learn the fundamentals behind two computational techniques – Finite Difference Time Domain (FDTD) and Finite Element Method (FEM). They will then use what they learn from these numerical techniques to explore different topics of microelectronics through basic 1-D, 2-D, and 3-D simulations that helps to illustrate various applications ranging from microelectronic circuits and devices, electromagnetics, solid-state physics, and quantum mechanics.

COURSE OUTCOMES:

- Demonstrate competence in creating simulations with two computational techniques – Finite Difference Time Domain (FDTD) and Finite Element Method (FEM).
- Apply numerical methods to simulate ordinary and partial differential equations (PDEs) and gain insight into numerical errors that can occur in simulation.
- Evaluate computational choices in order to balance minimization of error and computing resources, such as memory allocation and run-time performance.
- Perform stability analysis and produce convergence solutions for various types of PDEs using FDTD.
- Identify issues related to boundary value problems using finite element methods (FEM).
- Apply numerical techniques to perform basic simulations on microelectronics circuits, interconnects, and linear and non-linear devices.
- Apply numerical techniques to perform basic simulations to demonstrate electromagnetic, quantum mechanics, and statistical mechanics phenomenon.

Overall, students in this class would gain a solid foundation in computational techniques and numerical methods that can be applied to various fields, including microelectronics, electromagnetics, solid-state physics, and quantum mechanics. They would also learn how to choose appropriate numerical methods and evaluate their results, helping them to become more effective problem solvers in their chosen field.

REQUIRED TEXTBOOKS:

Gilbert Strang, **Computation Science and Engineering**, Wellesley-Cambridge Press, Nov. 1, 2007. ISBN 0-96-140881-2

SUPPLEMENTAL REFERENCES (Certain sections to be put on reserve at the library)

Steven Chapra, Raymond Canale, ***Numerical Methods for Engineers: Fifth Edition***, McGraw-Hill Higher Education, Copyright 2006. ISBN 0-07-124429-8.

Dennis Sullivan, ***Electromagnetic Simulation Using the FDTD Method***, IEEE Press, John Wiley & Sons, 2000.

Dennis Sullivan, ***Quantum Mechanics for Electrical Engineers***, IEEE Press, John Wiley & Sons, 2012.

Jin, ***The Finite Element Method of Electrogmagnetics*** (2nd edition), John Wiley, 2002.

Thomas Holland and Patrick Marchand, ***Graphics and GUIs with MATLAB***, 3rd edition 2003.

Ram-Mohan, ***Finite Element and Boundary Element Applications in Quantum Mechanics***, Oxford University Press, 2002.

Taflove, ***Computational Electrodynamics: The Finite-Difference Time-Domain Method*** (3rd edition), Artech House, 2005.

TIME: MW 3:30PM – 4:45PM

CLASSROOM: VL C457 (*note final exam will be in the same location*)

CREDITS: Three Hours

PROFESSOR: Dr. Jeffrey Davis, Office Klaus Building 3314

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OFFICE HOURS: TBD

IMPORTANT DATES THIS SEMESTER:

ASSIGNMENTS & GRADING:

Homework Problems	(20%)
Quiz I (TBD)	(20%)
Quiz II (TBD)	(20%)
Class Participation	(10%)
Final Project and Presentation	(30%)

(oral presentations constitute the final during final exam week)

Final grades will be assigned according: A = [90, 100] ; B = [80,90) ; C = [70,80) ; D =[50,70) ; F = [0,50].

MISSING TESTS: If you must miss a test or quiz for a serious condition, you must let me know as soon as you know that you cannot attend. Any excused absence must be accompanied by proper documentation.

ACADEMIC HONESTY: Although students are encouraged strongly to work together to learn the course material, all students are expected to complete exams and program projects individually by following all instructions stated in conjunction with the exams and programs. Students MAY NOT copy code from others in any way. Students MAY NOT use solutions that others have developed as the basis for your solutions. However, students ARE allowed to discuss the problems with others, including fellow students, teaching assistants, and the instructor. Periodically, automatic plagiarism detection algorithms will be used to compare source code against all students in the course. You ARE allowed to solicit and obtain help in design and debugging your solutions. You CAN show others your **BROKEN** code and ask for advice about why it is not working or how to make it work better. But to be totally clear, you MUST implement your own solution. If someone helps you, you still MUST enter every line of code of your solution personally, and you MUST fully understand every part of your submission. Students should be prepared to explain each homework assignment and their work when demoing selected homeworks to the TA. All conduct in this course will be governed by the Georgia Tech honor code. Additionally, it is expected that students will respect their peers and the instructor such that no one takes unfair advantage of any other person associated with the course. Any suspected cases of academic dishonesty will be reported to the Dean of Students for further action. The URL for the GT honor code is: http://www.policylibrary.gatech.edu/student-affairs/academic-honor-code

FINAL INSTRUCTIONAL CLASS DAYS NOTIFICATION:
You will possibly have your last project that is due on April 25, 2024.
"For all courses, graded homework or assignments, lab reports, course projects, demonstrations, studio reviews, and presentations may be due during these two days, provided that they are listed on the syllabus at the start of the semester."

ACCOMMODATIONS: If you have any learning disabilities that require special assistance, please obtain documentation from the Office of Disability Services for Tech Students (disabilityservices.gatech.edu).

ATTENDANCE POLICY: Attendance in class is strongly encouraged, and class discussions may contain useful technical or administrative information. Students are also encouraged to read the GT catalog on attendance: https://catalog.gatech.edu/rules/4/.

STUDENT-FACULTY EXPECTATION AGREEMENT: At Georgia Tech we believe that it is important to strive for an atmosphere of mutual respect, acknowledgement, and responsibility between faculty members and the student body. See https://policylibrary.gatech.edu/student-affairs/academic-honor-code an articulation of some basic expectation that you can have of me and that I have of you. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, I encourage you to remain committed to the ideals of Georgia Tech while in this class.

Detailed Topics Outline
ECE 4803
Computational Methods for Microelectronics

I. Finite Difference Methods

A. Ordinary Differential Equations (ODE)

1. ODE Review
    - Initial Value Problems
    - Boundary-Value
    - Eigenvalue Problems
2. 1^{st} Order Methods
    - Euler Method
3. Order of Numerical Error
    - Taylor Series
    - Truncation Error
    - Local vs Global error
4. Explicit vs Implicit Methods
    - 1^{st} Order Euler Explicit vs. Implicit
    - Introduction to Stability Issues
5. 2^{nd} Order Methods
    - Trapezoidal Method
    - 2^{nd} order Runge-Kutta Method
6. Higher Order Methods
    - 4th Order Runge-Kutta Method
7. Higher Order Differential Equation
    - Equivalence to Set of First Order Equations

Microelectronics Applications Incorporated into this Section
- *1. RC Circuits*
- *2. RLC Circuits*

3. VLSI Circuit with Transistor Load
4. RC Ladder Circuit

B. Partial Differential Equations (PDE)

1. 2nd Order PDE Classification
 Elliptic , Parabolic , Hyperbolic
2. PDE Problem Types
 Initial Value Problems (IVP)
 Boundary Value Problems (BVP)
 Initial-Boundary Value Problems
 BVP for Laplace Equations (Dirichlet, Neumann, Robin Boundary Conditions)
3. 1st Order Hyperbolic Equation: One-Way Wave Equations
 1st Order Forward Difference Approximation
 Von Neumann Stability Analysis
 Central Difference Stability Catastrophe
 1st Order: Lax-Fredrick
 2nd Order Method: Lax-Wendroff
4. 2nd Order Hyperbolic Equation: 1-D Wave Equation
 Distributed LC Lines (Lossless Transmission Lines)
 2nd Order Central Difference Approximation
 Numerical Dispersion
 Magic Time Step and 1-D Wave Equation
 Transmission Lines with Various Loads
 Transmission Lines with Junctions

Microelectronics Applications Incorporated into this Section
1. General Wave Equation – EM Radiation
2. Quantum Mechanical Gaussian Wave Packets Propagation
2. Lossless Transmission Lines
3. Impact of Different Transmission Line Terminations

5. Parabolic Equations: Diffusion Equation
 1st Order: Simple Implicit
 2nd Order: Crank-Nicolson

Microelectronics Applications Incorporated into this Section
1. Distributed RC lines
2. Minority Carrier Diffusion Equation
3. Heat Equation

6. Elliptic Equations: Laplace's Equation
 2-D Central Difference Approximations
 Dirichlet & Neumann BC's
 Volume Control Approach

Microelectronic Applications Incorporated into this Section
1. PN Junction Electrostatics of Depletion Region
2. Complex Capacitance Calculation for Multiple Conductors
3. Electrostatic Simulations with Multiple Dielectrics

II. Finite Element Method (FEM)

A. Method of Weighted Residuals (WR)
 Definition of Residual
 Collocation Method

Subdomain Method
Least Square Method

B. Galerkin's Method of WR
Basis Functions (Interpolation or Trial Functions)
Linear Nodal Basis Functions
Definition of Element

C. FEM Example – 1-D Poisson Equation
Dirichlet and Neumann Boundary Conditions

D. FEM Example– Time Independent Schrodinger Equation
Overview of Eigenvalue Problems
Variable Potential Functions

E. 2-D FEM Using Galerkin's Method

Meshing and Adaptive Meshing
Global and Local Coefficient Matrix
Dirichlet and Neumann BCs

Microelectronic Applications Incorporated into this Section★
1. Laplace Equation Revisited - Electrostatics
2. Time Independent Schrödinger Equations and 1-D and 2-D PIB
3. Time Dependent Schrodinger Equations and Arbitrary Potentials

Possible Microelectronic Application Topics That Could be Included in this Class

- Numerical Solutions to Circuit Equations (RC, RLC, transistor circuits)
- 1-D and 2-D Propagation of Electromagnetic Waves
- Diffusive Distributed RC lines
- Heat Equation
- Minority Carrier Diffusion Equation
- PN Junction Depletion Region Electrostatics
- Electrostatic Simulation (Laplace Equation)
  Impact of uniform charge distribution
  Floating Conductor Simulations for Nanocomposites
  Multiple Dielectric Simulations
- Oscillation of Electric Charges and Polarization of EM waves
- Time Dependent Schrodinger's Equation
  Free Space Propagation
  Gaussian Wave Packet, Dispersion, and Packet Spreading
  Electron Striking Potential Barrier and Quantum Tunneling
  Calculation of Expectation Values
- Time Independent Schrodinger Equation and Eigenvalue Equations
  1-D, 2-D, and 3D Quantum Wells
- Circuit Simulation
- Electromagnetic Scattering from PEC
- VLSI Interconnect Modeling
- Variations on Kronig-Penney Band Structure
- Fermi-Dirac Integrals
- MOSFET Device Simulation
- Acoustical and Optical Phonons
- Schrodinger-Poisson Self-Consistency
- Time Independent Schrodinger Equation
  - Harmonic Oscillator
  - Hydrogen Atom (radial wave functions)