EE 599: Numerical Techniques for Modeling and Optimization of Nanophotonic and Radio-Frequency Devices
(30953)

Units: 4

Spring 2021—Tues/Thurs. 3:00-4:50 PM

Location: TBA

Instructor: Constantine Sideris
Office: EEB328
Office Hours: Tues/Thurs, 2:00-3:00 pm (over Zoom).
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Course Description

Modern electromagnetic devices are very challenging to design due to the lack of closed-form solutions to Maxwell's equations and large number of degrees of freedom. Nanophotonic devices and high-frequency microwave or radio-frequency (RF) devices, both which are very relevant today in the fields of silicon photonics and wireless communications, are especially difficult to model properly since they fall into the regime where both lumped model and ray optics approximations fail to yield accurate results. For such applications, the devices must be solved via discretization and numerical solution of Maxwell's equations. Recently, inverse design has emerged as a powerful automated design methodology which couples optimization algorithms with numerical simulation algorithms and enables the design of new, high-performance devices from "scratch" given only target specifications and design fabrication constraints as input parameters. Inverse design tied with modern simulation techniques offers an effective approach for tackling the challenging electromagnetic design problems of today.

This will give a one-semester graduate-level introduction to several different methods for solving Maxwell's equations numerically as well as optimization algorithms used for inverse design of electromagnetic devices. Finite difference methods in both the time and frequency domains, the Finite Element Method, and Integral Equation methods will be covered. Numerous examples drawing from modern applications, primarily in nanophotonics and microwave electronics, such as metallic antennas and dielectric nanophotonic waveguides, will be demonstrated. Global optimization algorithms, such as Genetic Algorithms and Particle Swarm Optimization, as well as local gradient-based search algorithms will be introduced.

Learning Objectives and Outcomes

Students who complete this class will learn how to write their own algorithms for solving and numerically optimizing electromagnetic devices. Students will also be introduced to commercially available electromagnetic simulation software, specifically Ansys HFSS and Lumerical FDTD Solutions, and will be taught how to properly use these software packages to model complicated electromagnetic systems.

Prerequisite(s): None
Co-Requisite(s): None

Recommended Preparation: Knowledge of a high-level computer programming knowledge such as C, C++, or MATLAB/Python at the levels of EE155L, EE455L, or EE301L respectively. Basic knowledge of PDE's and electromagnetics, such as as the level of EE370L, would be helpful for deeper understanding, although not required for successfully completing the course.

Course Notes

All lecture notes for this class, assignments, and any suggested additional reading will be posted on the Blackboard site.

Technological Proficiency and Hardware/Software Required

Must have a knowledge of MATLAB or any other programming language such as Python or C/C++.

Required Readings and Supplementary Materials

There are no required textbooks for this class, although the following are recommended references:

Numerical techniques in electromagnetics, Matthew, Sadiku, CRC Press, 2000.

Numerical Electromagnetics: The FDTD Method, Umran S. Inan and Robert A. Marshall, Cambridge University Press, 2011

Computational Electrodynamics: The Finite-Difference Time-Domain Method, Allen Taflove and Susan C. Hagness, 3rd ed., Artech House, 2005

Integral equation methods for electromagnetics. Kubilay Sertel and John Volakis. The Institution of Engineering and Technology, 2012.

Description and Assessment of Assignments

Six problem sets will be assigned at 2 week intervals. These will mostly involve implementation (in Matlab, Python, C or any other programming language) and demonstration of concepts taught earlier in the class. Full code for every assignment must also be included with submission. Assignments should be handed in before lecture on the day they are due. Late assignments will be penalized at 10% credit reduction per day except with a medical excuse. There will be no exams; however, there will be a final project handed out during the 12th week of class. The project will be worth 30% of the total grade and students may either work alone or in teams of two. Students must hand in project report, source code, and give a 10 minute presentation during the final week of class.

Final Project

Instead of a final exam, there will be a final project.

- Final project teams will be 1-2 students each.
- Topics can be suggested by the students or taken from a list of suggested topics to be provided and should involve simulating and/or optimizing an electromagnetic structure.
- Each team will produce the following with percentage of the overall project grade shown:
    - Oral presentation: 10%, due week 15
    - Project report: 65%, due week 16
    - Commented source code: 25%, due week 16
- Final presentations will take place during the last week of classes.

Grading Breakdown

Assignment	% of Grade
Problem Sets	70
Project	30

Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	Readings and Homework	Deliverable/ Due Dates
Week 1	Introduction to class. The Finite-Difference method, 1D Finite-Difference Time-Domain (FDTD) method	HW1 out	
Week 2	2D FDTD method and the Perfectly Matched Layer (PML)	HW2 out	HW1 due
Week 3	Poynting vector, power flux, and dispersion, waveguides, mode		

	excitations, and the mode overlap integral		
Week 4	Total-Field Scattered-Field (TFSF) method	HW3 out	HW 2 due
Week 5	1D and 2D Finite-Difference Frequency Domain (FDFD) methods		
Week 6	3D FDTD and FDFD methods	HW 4 out	HW 3 due
Week 7	Numerical Waveguide Mode solvers, Near-field to Far-field Transformations and Antennas		
Week 8	1D and 2D Finite Element Methods	HW 5 out	HW 4 due
Week 9	Integral Equations for Metallic Wires		
Week 10	2D surface and volume Integral Equations	HW 6 out	HW5 due
Week 11	Genetic Algorithms and Particle Swarm Optimization		
Week 12	Gradient-based optimization, the adjoint method	**Project Out**	HW 6 due
Week 13	Inverse design of 2D nanophotonic devices		
Week 14	Parallel programming, Introduction to commercial simulation software		
Week 15	**Project Presentations**		
FINAL	**Project Report + Codes Due**		

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

Support Systems:

Student Health Counseling Services - (213) 740-7711 – 24/7 on call
engemannshc.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-4900 – 24/7 on call
engemannshc.usc.edu/rsvp
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED) | Title IX - (213) 740-5086
equity.usc.edu, titleix.usc.edu
Information about how to get help or help a survivor of harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants. The university prohibits discrimination or harassment based on the following protected characteristics: race, color, national origin, ancestry, religion, sex, gender, gender identity, gender expression, sexual orientation, age, physical disability, medical condition, mental disability, marital status, pregnancy, veteran status, genetic information, and any other characteristic which may be specified in applicable laws and governmental regulations.

Bias Assessment Response and Support - (213) 740-2421
studentaffairs.usc.edu/bias-assessment-response-support
Avenue to report incidents of bias, hate crimes, and microaggressions for appropriate investigation and response.

The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

USC Support and Advocacy - (213) 821-4710
studentaffairs.usc.edu/ssa
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.
Diversity at USC - (213) 740-2101
diversity.usc.edu
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
dps.usc.edu, emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call
dps.usc.edu

Non-emergency assistance or information.