EE599: Methods of Applied Physics I

USC Viterbi School of Engineering
4 Units | Tue, Thu 2:40-4:30pm | Location: Online | Fall 2020

Instructor: Chia Wei (Wade) Hsu, cwhsu@usc.edu
Office Hours: Mon 1pm - 3pm | Location: Online

Grader/TA: TBD

Course Webpage: https://blackboard.usc.edu

Course Description

This course introduces numerical and analytical methods for solving and analyzing physics-based problems, emphasizing methods that can tackle not just simplified pedagogical problems but also complex problems that arise in practical applications. The types of problems covered include:

- Linear response problems and eigen problems, with examples from light scattering, resonances, photonic band structures.
- Linear and nonlinear initial-value problems, with examples from wave propagation in waveguides/fibers and laser dynamics.
- Stochastic differential equations, with examples from laser noise/linewidth and amplifiers.

The assignments are mini-projects and a final project where students write codes to solve a particular problem. Through the examples in class and in the mini-projects, students will also learn about physical phenomena such as Anderson localization, photonic band gaps, solitons, modulation instability, chaos, and laser linewidth.

Learning Objectives

Upon successful completion of this course a student will be able to

- Translate linear partial differential equations into matrix equations for numerical solution.
- Solve scattering problems and eigen problems of complex systems.
- Solve linear and nonlinear initial-value problems of complex systems.
- Analyze the stability of a dynamic system.
- Quantitatively model noise and stochastic processes.

Prerequisite: No required course, but the student must be familiar with differential equations and have basic experience with computer programming.

Recommended preparation: Familiarity with wave equations.

Required Materials: Lecture notes prepared by instructor, to be posted on Blackboard.

Required Software: MATLAB, available to USC students at https://software.usc.edu/matlab/, will be used in class.

Supplementary Materials

Supplementary (not required) materials are taken from the following textbooks:

1) John D. Joannopoulos, Steven G. Johnson, Joshua N. Winn, and Robert D. Meade, *Photonic Crystals: Molding the Flow of Light* (2nd edition), Princeton University Press (2008); ISBN 9780691124568; freely available online at http://ab-initio.mit.edu/book/photonic-crystals-book.pdf
2) Jian-Ming Jin, *Theory and Computation of Electromagnetic Fields* (2nd edition), Wiley (2015); ISBN 9781119108047; freely available with USC account at https://ebookcentral.proquest.com/lib/socal/detail.action?docID=4043026&pq-origsite=primo
3) Peter J. Olver, *Introduction to Partial Differential Equations*, Springer (2014) (2016 printing with typo corrections); ISBN 978-3319020983; freely available online within USC internet at https://link-springer-com.libproxy1.usc.edu/book/10.1007/978-3-319-02099-0
4) Govind Agrawal, *Nonlinear Fiber Optics* (6th edition), Elsevier Academic Press (2019); ISBN 978-0-12-817042-7; freely available online within USC internet at https://www-sciencedirect-com.libproxy2.usc.edu/book/9780128170427/nonlinear-fiber-optics
5) J. C. Butcher, *Numerical Methods for Ordinary Differential Equations* (3rd edition), Wiley (2016); ISBN 978-1-11-912153-4; freely available with USC account at https://ebookcentral.proquest.com/lib/socal/detail.action?docID=4591869&pq-origsite=primo
6) Peter E. Kloeden & Eckhard Platen, *Numerical Solution of Stochastic Differential Equations*, Springer (1992); ISBN 978-3-662-12616-5; freely available online within USC internet at https://link-springer-com.libproxy2.usc.edu/book/10.1007%2F978-3-662-12616-5

Grading Breakdown

20% Mini-project 1
20% Mini-project 2
20% Mini-project 3
20% Final project presentation
20% Final project write-up

Assignment Description

- There will be **3 mini-projects** where the student explores a given problem using techniques taught in the corresponding module of the class. In each mini-project, the student will be guided through a series of tasks, which will involve writing codes to simulate the problem, exploring different scenarios, and analyzing the data. The submission will include the code, data plots, and accompanying texts. The student can use the language of his/her choice, though the examples used in class will be in MATLAB.
- There will be **one final project** the student chooses a topic of his/her own interest to explore (with guidance from the instructor). It should involve techniques learned in this class. The problem can be to reproduce results in the published literature with some extensions, or a new problem. The student should pick the topic of the final project and discuss with the instructor by Thur 11/3. Every student will present their results during and the last week of class, and write a report that is 3-6 pages long in the style of a single-spaced double-column journal paper. The presentations and report should have the fellow classmate as the target audience. The presentations will take place on Tue 12/8 at 2:40pm, and each student has 15 minutes to present. The write-up will be due on Wed 12/9.

Assignment Submission Policy

- All assignment will be submitted on Blackboard, as code files and PDFs.
- Late Policy: Late assignment will not be accepted except for institution-established emergency reasons. Credit for such late assignment is with the discretion of the instructor.

Course Schedule: A Weekly Breakdown

Date	Topics	Deliverables
Week 1 8/25,27	Tue: Introduction. Wave equations. finite difference schemes. Matrix representation of differential operators in 1D. Frequency-domain eigen problems. Anderson localization in 1D. Thur: Bloch periodic boundary condition. Distributed Bragg reflector (DBR) and its band structure. Kronecker outer product. Matrix form of 2D differential operators.	
Week 2 9/1,3	Tue: Eigen problem in 2D. Photonic band structure. Scattering problems. Volume source. Outgoing boundary condition in 1D. Finite-difference dispersion. Thur: Transmission through Fabry-Perot etalons. Resonant transmission and absorption. Resonant modes as complex-frequency eigenmodes in nonlinear eigenvalue problem. Targeted eigen solver.	
Week 3 9/8,10	Tue: Huygens' principle. Total-field/scattered-field (TF/SF) approach for scattering problems. Equivalent source. Thur: Perfectly matched layer (PML). Stretched-coordinate PML through analytic continuation to complex coordinate.	
Week 4 9/15,17	Tue: PML reflections, discretization, and implementation. Thu: PML tests. Open systems in 2D. Waves from a point source. Failure for extended line sources.	
Week 5 9/22,24	Tue: Generating plane waves with TF/SF. Finite-difference dispersion in 2D. Scattering from dielectric square. Waveguide modes. Thu: Exciting waveguide modes with equivalent sources. Transport through a waveguide bent. Flux and flux conservation.	
Week 6 9/29,10/1	Tue: Scattering/absorption/extinction cross section. Differential scattering cross section and radar cross section. Thu: Near-field-to-far-field (NF2FF) transformation. Green's function of homogeneous media in 1D and 2D.	Mini-project 1 due on 9/29: Narrow band-pass filter using DBR with defect
Week 7 10/6,8	Tue: Implementation of NF2FF for arbitrary distance. Radial and angular dependence of scattered flux. Thu: Far-field limit. Fraunhofer distance. Scattering amplitudes. Optical theorem.	

Week 8 10/13,15	Tue: Metalenses. Diffraction orders. Propagating and evanescent waves. Angular spectrum propagation. Moving average filter. Thu: Symmetry operators and how to exploit symmetries. Nonlinear Schrödinger equation (NLSE).	
Week 9 10/20,22	Tue: NLSE in pulse propagation. Diffraction/dispersion length and nonlinear length. Solitons. Thu: Conservation laws in NLSE. Propagating NLSE with finite difference methods. Forward-difference propagation (ie, Euler's method). von Neumann stability analysis. Center difference propagation.	
Week 10 10/27,29	Tue: Stability criterion with center difference. Numerical experiments: fundamental & higher-order solitons, soliton perturbations, soliton attractions & repulsions. Thu: Split-step Fourier method (SSFM). Lie splitting & symmetric Strang splitting. DTFT & periodic summation. Nyquist–Shannon sampling criterion & aliasing.	Mini-project 2 due on 10/27: Flat lens with a metasurface
Week 11 11/3,5	Tue: Implementation of SSFM. Modulation instability. NLSE in 1+2 dimensions. Thu: SSFM in 1+2D. Wave function collapse. Soliton in 1+2D.	Final project topic due on 11/3.
Week 12 11/10,12	Tue: Numerical integration of ordinary differential equations. Runge–Kutta methods; second-order, fourth-order, and adaptive RK smethods. Thu: Shooting method for boundary-value problem. Bisection method for root finding. Numerical solution of soliton in 1+2D. Intro to stochastic systems.	Mini-project 3 due on 11/12: Fiber optical communication with solitons
Week 13 11/17,19	Tue: Probability space. Random variables. Poission and Wiener stochastic processes. Thu: Stochastic differential equations. Riemann integral, Itô integral and Stratonovich integral. Additive and multiplicative noises.	
Week 14 11/24	Tue: Euler–Maruyama method. Itô's formula and stochastic Taylor expansion. Milstein method. Strong and weak orders of convergence.	
Final Week	Final project presentations at 2:40pm on Tue 12/8. Final project write-up due on Wed 12/9 by end of day.	Final project

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:

Counseling and Mental Health - (213) 740-9355 – 24/7 on call
studenthealth.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 and Services (RSVP) - (213) 740-9355(WELL), press "0" after hours – 24/7 on call
studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED)- (213) 740-5086 | Title IX – (213) 821-8298
equity.usc.edu, titleix.usc.edu
Information about how to get help or help someone affected by 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. The university also prohibits sexual assault, non-consensual sexual contact, sexual misconduct, intimate partner violence, stalking, malicious dissuasion, retaliation, and violation of interim measures.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity |Title IX for appropriate investigation, supportive measures, 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
uscsa.usc.edu
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.