From Qubits to Quantum Sensors: A Practical Course

EEL 6935 Section 29241
Class Periods: MWF, 7, (1:55 PM - 2:45 PM)
Location: MAEA 0327
Academic Term: Spring 2024

Instructor:
Elham Heidari
El.heidari@ufl.edu
Office Hours: Friday, 10:30-12 pm, 3235 Malachowsky Hall

Teaching Assistant/Peer Mentor/Supervised Teaching Student:
Please contact through the Canvas website

Course Description
Traditional sensors and detectors can be found in a wide range of applications, from automobiles to cameras and from heat sensors to light detectors. Advances in noise and measurement theory have ushered in a new paradigm in the field of quantum metrology. Quantum measurement devices allow us to extract the maximum amount of information from our environment. This development has opened up new possibilities in various domains, including machine learning, autonomous navigation, security monitoring, data processing, and communication systems.

Course Pre-Requisites / Co-Requisites
EEL 5486 (Electromagnetic Field Theory and Applications I)
Introductory electromagnetism (Maxwell's equations and electromagnetic waves), vector calculus and differential equations. Helpful, but not required

Course Objectives
This comprehensive course delves into the core principles underlying today's quantum sensors and detectors. It will explore the constraints imposed by quantum noise, offering students a nuanced understanding of its limitations. The central objective of this course is to equip students with a thorough and critical grasp of emerging applications that merge quantum and classical technologies. By the end of the course, students will have the skills needed to construct quantum sensors and detectors.
Upon successful completion of this course, students will have gained proficiency in the following areas:
✓ Understanding the Theory of Quantum Noise
✓ Working with Superconducting Single-Photon Detectors
✓ Grasping the Foundations of Quantum Metrology
✓ Comparing the Operating Principles of Quantum and Classical Detectors
✓ Implementing Quantum Sensing Devices such as Magnetometers and Interferometers
✓ Mastering the Theory of Quantum Coherence
This curriculum is designed to provide both theoretical knowledge and practical skills, opening doors to a multitude of applications in machine learning, autonomous navigation, security monitoring, data processing, and communication systems.

Materials and Supply Fees
Not applicable

Required Textbooks and Software
There is no required textbook for this course. Students will find the material covered in the course and provided references to be self-contained. The slides contain references to specific books and research papers.

Recommended Materials
- Title

- Author
- Publication date and edition
- ISBN number

Course Schedule

Week 1: Introduction to the course and acquaintance: Class Overview
Week 2: Bosons vs. Fermions: concept
Week 3: Bosonic Harmonic Oscillator: concept of Pauli Matrix equivalent to Bosonic Particles and used it to calculate the Unitary Operators / HW1 releases
Week 4: Two-state quantum system (Qubit): Eigenvalues of Hamiltonian, Time Dependence, Rabi formula, Bloch equations/ HW 2 releases/ project release
Week 5: Fluctuation-Dissipation Theorem: Brownian Motion, Thermal noise in a resistor, general and classical model/ HW1 due
Week 6: Quantum Fluctuations: Klein–Gordon equation
Week 7: Classical Detectors: (Evanescent wave interaction, Micro-resonators and photonic band gap, etc.)
Week 8: Single Photon Avalanche Detectors: Passive/Active quenching circuits, Photon counting and saturation, Dark count rate/ HW 2 due /Project release
Week 9: Midterm
Week 10: Quantum Interference and Entanglement: physical properties such as position, momentum, spin, and polarization performed on entangled particles/ HW 3 releases
Week 11: Quantum Non-Demolition Measurement: Experimental detection of gravitational waves/ HW 4 releases
Week 12: Optical and mechanical resonators: Classical description of resonators Basics of elasticity Mechanical dissipation/ HW 3 due
Week 13: Quantum dynamics: Quantum equations of motion Quantum theory of the optomechanical cooling, strong coupling regime.
Week 14: Quantum correlations: Homodyne detection Displacement sensing gravitational wave detection Optomechanical squeezing Entanglement in cavity optomechanical systems/ HW 4 due Project due
Week 15: Final exam

Attendance Policy, Class Expectations, and Make-Up Policy

Excused absences must be consistent with university policies in the Graduate Catalog (https://catalog.ufl.edu/graduate/regulations) and require appropriate documentation. Additional information can be found here: https://gradcatalog.ufl.edu/graduate/regulations/

Evaluation of Grades

Assignment	Total Points	Percentage of Final Grade
Homework Sets (10)	100 each	15%
Quizzes (4)	100 each	15%
Midterm Exam	100	30%
Final Exam	100	30%
Review Paper	100	10%
		100%

Assignment and in-class quiz contributions make up 20% of the grade. Submitting assignments after the deadline will lead to a deduction of 25% for each delayed day. The midterm exam, accounting for 20% of the grade, will encompass classroom discussions, oral remarks, tackled problems during lessons, along with homework and quiz issues. Students must thoroughly understand these areas. An assigned project forms 25% of the overall score. Students are required to pick, discuss, and present a research topic from the course relative's domain, ideally linked to their end-of-term project. Presentation evaluations will be based on a) Articulation of the issue, elaboration of its

resolution, and examination of outcomes (be they experimental or simulated), b) Quality of responses to posed questions, c) Slide content quality.
The final presentation, worth 20% of the grade, should revolve around quantum sensing topics covered in the course. This project should encompass:

- the rationale behind the topic.
- Relevant background information.
- the chosen technical methodology.
- Outcomes observed.
- Discussions on findings.
- Final takeaways.

Also, there would be a final exam, with 30% of the total score which covers the topics presented in the class after midterm and the same rules of midterm would be applied to the final exam. Offering a 15% bonus score enhances students' motivation by incentivizing deeper engagement. This bonus encourages active classroom participation and fosters consistent engagement by deterring last-minute cramming.

Grading Policy
The following is given as an example only.

Percent	Grade	Grade Points
93.4 - 100	A	4.00
90.0 - 93.3	A-	3.67
86.7 - 89.9	B+	3.33
83.4 - 86.6	B	3.00
80.0 - 83.3	B-	2.67
76.7 - 79.9	C+	2.33
73.4 - 76.6	C	2.00
70.0 - 73.3	C-	1.67
66.7 - 69.9	D+	1.33
63.4 - 66.6	D	1.00
60.0 - 63.3	D-	0.67
0 - 59.9	E	0.00

More information on UF grading policy may be found at:
UF Graduate Catalog
Grades and Grading Policies

Students Requiring Accommodations
Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting https://disability.ufl.edu/students/get-started/. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

Course Evaluation
Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

In-Class Recording
Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in

connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A "class lecture" is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To "publish" means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

University Honesty Policy

UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://sccr.dso.ufl.edu/process/student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment

The Herbert Wertheim College of Engineering values varied perspectives and lived experiences within our community and is committed to supporting the University's core values, including the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of race, creed, color, religion, age, disability, sex, sexual orientation, gender identity and expression, marital status, national origin, political opinions or affiliations, genetic information, and veteran status.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

- Your academic advisor or Graduate Program Coordinator
- HWCOE Human Resources, 352-392-0904, student-support-hr@eng.ufl.edu
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Student Privacy

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

Campus Resources:

Health and Wellness

U Matter, We Care:
Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

Counseling and Wellness Center: https://counseling.ufl.edu, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Sexual Discrimination, Harassment, Assault, or Violence
If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

Sexual Assault Recovery Services (SARS)
Student Health Care Center, 392-1161.

University Police Department at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

Academic Resources

E-learning technical suppor*t*, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.

Career Connections Center, Reitz Union, 392-1601. Career assistance and counseling; https://career.ufl.edu.

Library Support, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.

Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

Writing Studio, 302 Tigert Hall, 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

Student Complaints Campus*:* https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/;https://care.dso.ufl.edu.

On-Line Students Complaints*: https://distance.ufl.edu/getting-help/; https://distance.ufl.edu/state-authorization-status/#student-complaint.*