



Department of Physics  
COLLEGE OF LIBERAL ARTS AND SCIENCES  
UNIVERSITY OF COLORADO DENVER



College of Engineering, Design and Computing  
University of Colorado Denver  
Department of Electrical Engineering

ELEC 4680, ELEC 5680, PHYS 4680, PHYS 5680

## Quantum Computing Technology (Lecture/Laboratory)

Department of Physics  
Department of Electrical Engineering  
University of Colorado Denver

### COURSE SYLLABUS Fall 2024

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Office hours:	By Appointment		
Class Meets:	MWF 9:30 to 10:45 am		
Lecture Location:	NC 1312		
Lab Location:	NC 1009A		

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#### I. Welcome!

In this course, you will have the opportunity to study and practice aspects of multiple technologies essential to the quantum information science and engineering (QISE) discipline, of which quantum computing is but one component. QISE is an emergent field with promise of being as critical to technological advancement as was the semiconductor revolution. The evolution is still in flux, and we will address topics common to all potential implementations as well as those specific to cryogenic and photonic implementations. In your initial readings, you will review the state of the field and those skills of particular relevance to the industry.

#### II. University Course Catalog Description

Students will explore some of the concepts and experimental practices for realizing quantum computers. They will engage in laboratory practice of relevant skills including high-performance analog electronics; optics-based quantum encryption and eraser implementations; RF electronics; *and, lightly, vacuum and cryogenic techniques*\*.

\*Upon introduction of ELEC/PHYS 4681/5681, this final content has been moved to that course.

### III. Course Overview

This course introduces various technologies used in practical implementations of QISE devices. We draw on peer-reviewed literature describing the skills needed in the quantum workforce in selecting course material. Due to the fragile nature of quantum systems, high-performance analog and RF electronics are necessary for qubit measurement and control. In some implementations, optical techniques are used.

The course is delivered in a combination lecture/laboratory format, with emphasis on the hands-on exploration of these techniques. It is team-taught by experts in their respective topical materials, with a single instructor of record who is responsible for assigning the final grade.

Students enrolled in PHYS 5680 and ELEC 5680 will complete additional components of each assignment requiring elevated sophistication and skills, as appropriate for graduate work.

### IV. Course Goals and Learning Objectives

By the end of this course, all students will be able to:

#### *Overview:*

1. Demonstrate an understanding of the current workforce needs in quantum computing technology.

#### *Optical:*

2. Understand various types of optical components and laser safety.
3. Learn to construct and align optical systems using various optical components.
4. Build a quantum eraser system and analyze measured data to understand quantum erasing and interference phenomena.
5. Build a quantum cryptography system and analyze measured data to understand quantum encryption concepts.

#### *Analog:*

6. Select active analog amplifiers based on application requirements.
7. Measure characteristics of high-performance analog circuits.
8. Design analog amplification circuits to meet application requirements.
9. Demonstrate an understanding of parameters used to quantify analog performance.
10. Demonstrate competence in using analog test/measurement equipment to quantify analog performance.

#### *RF:*

11. Develop an understanding of RF signal metrology techniques (frequency domain, power levels, SNR) and equipment (RF signal generator and Signal analyzer)
12. Characterize an RF signal - Signal to Noise Ratio, Power spectral density, Frequency spectral content of a signal.
13. Develop an understanding of RF system characterization (S-parameters, VSWR, return loss) and equipment (VNA)
14. Characterize RF networks such as a filter and an amplifier in terms of the RF parameters

*Capstone:*

15. Select one of the three modules (Analog, Optical, or RF) to design and demonstrate a more advanced experiment for a capstone project as assigned (e.g., design a low-noise, high-bandwidth preamplifier meeting given specifications).

*Additionally, students in PHYS 5680 or ELEC 5680 will:*

- G1. Demonstrate sophistication in each assignment through additional work related to higher-level concepts (e.g., compare measurement to theory qualitatively and quantitatively).

**V. Course Prerequisites**

PHYS 4680: PHYS 3711 (Advanced Laboratory) with a grade of C- or better

PHYS 5680: Permission of Instructor

ELEC 4680: ELEC 3900 (Circuit Design and Fabrication Laboratory)

ELEC 5680: Graduate standing and Permission of Instructor

**VI. Course Credits**

3 SCH

**VII. Required Texts and Materials**

Provided by instructors and published on Canvas

**VIII. Supplementary Texts and Materials**

Provided by instructors and published on Canvas

**IX. Course Schedule** (begins on next page)

## IX. Course Schedule

Date	Topic	Assignments Due*
8/19	Introduction, Quantum technology review	
8/21	Quantum technology review	
8/23	Lab 1: Quantum Eraser I (Lecture/demo)	
8/26	Lab 1: Quantum Eraser I (Lab)	
8/28	Lab 1: Quantum Eraser I (Lab)	Literature review report
8/30	Lab 1: Quantum Eraser II (Lab)	
9/2	Labor Day	
9/4	Lab 1: Quantum Eraser II (Lab)	
9/6	Lab 1: Quantum Eraser II (Lab)	
9/9	Lab 2: Quantum Cryptography I (Lecture/demo)	
9/11	Lab 2: Quantum Cryptography I (Lab)	
9/13	Lab 2: Quantum Cryptography I (Lab)	Lab #1 report
9/16	Lab 2: Quantum Cryptography II (Lab)	
9/18	Lab 2: Quantum Cryptography II (Lab)	
9/20	Lab 2: Quantum Cryptography II (Lab)	
9/23	Lab 3: Analog amplifiers (Lecture/demo)	
9/25	Lab 3: Analog amplifiers (Lab/parameter extraction)	
9/27	Lab 3: Analog amplifiers (Lab)	Lab #2 report
9/30	Lab 3: Gain-bandwidth balancing (Lecture/demo/Lab)	
10/2	Lab 3: Gain-bandwidth balancing (Lab)	
10/4	Lab 3: Gain-bandwidth balancing (Lab)	
10/7	Lab 4: Sensitivity, noise (Lecture/demo/Lab)	
10/9	Lab 4: Sensitivity, noise (Lab)	
10/11	Lab 4: Sensitivity, noise (Lab)	Lab #3 report
10/14	Lab 4: Filtering, S/N (Lecture/demo/Lab)	
10/16	Lab 4: Filtering, S/N (Lab)	
10/18	Lab 4: Filtering, S/N (Lab)	
10/21	Lab 5: RF signal generation & measurement (demo/Lab)	
10/23	Lab 5: RF signal generation & measurement (Lab)	
10/25	Lab 5: RF signal generation & characterization (Lecture)	Lab #4 report
10/28	Lab 5: RF signal characterization (Lab)	
10/30	Lab 5: RF signal characterization (Lab)	
11/1	Lab 6: RF network analyzers (Lecture)	
11/4	Lab 5: RF signal characterization (Lab)	
11/6	Lab 5: RF network analyzers (Lab)	
11/8	Lab 6: RF amplifiers, filters (Lecture)	
11/11	Lab 6: RF network analyzers (Lab)	
11/13	Lab 6: RF amplifiers, filters (Lab)	
11/15	Lab 6: RF amplifiers, filters (Lecture)	Lab #5 report
11/18	Lab 6: RF amplifiers, filters (Lab)	
11/20	Lab 6: RF amplifiers, filters (Lab)	
11/22	Capstone Preparation (Lecture)	
11/25	Fall Break	
11/27	Fall Break	
11/29	Fall Break	
12/2	Capstone work	Lab #6 report†
12/4	Capstone work	
12/6	Capstone work (no RF lab access)	
12/9 or 12/11‡	Capstone Presentations (Finals week)	Capstone presentations & reports†

\*Assignments due at 11:59 PM on the day designated

†Note the close timing of the Lab #6 report and the Capstone Presentations and *plan accordingly!*

‡Scheduled by AHEC; beyond our control. *Keep both days open!*

## EVALUATION

### X. Assignments

There are three types of assignments for this course. The first is a written report demonstrating understanding of the reading material presented in the first week of the semester, due in the second week. The second is a written technical summary, including quantitative data, of six individual laboratory explorations. Each technical summary will also include an introduction demonstrating understanding of the fundamental concepts relevant to that session. Graduate students will have additional components to each assignment relating to Learning Objective G1 above. The third type of assignment is completion of a directed capstone project on the course module of their choosing, culminating in a written technical report and, for the graduate students, a presentation of the results to the entire class in oral format at the end of the term. *Attendance is required of all students for the presentations, whether presenting or not.*

### XI. Other Contributions to Final Grade

Formal assignments are listed above and in the course schedule. In addition to these formal assignments, the final grade will include an attendance record and an instructor assessment of general skill level. The detailed attendance policy is addressed below. Moreover, we recognize that not all knowledge, skills, and abilities will be evident solely through the written reports. Thus, the instructors will assess class participation/skill level throughout, including team communication (equally among students, staff and faculty). Feedback with point values will be given periodically.

### XII. Basis for Final Grade

Assignments due dates are listed above in the course schedule. Apart from the capstone presentation, each assignment will be evaluated by the instructor assigning it. The capstone report and presentation will be graded by both instructors. Laboratory reports will be in the format of a technical report from an engineer/physicist staff to their supervisor, summarizing the results of the laboratory experiments and background knowledge gained from the lecture components.

Assessment	Points Possible (undergrad)	Points Possible (graduate)
Literature review report	18 (10%)	24 (10%)
Laboratory reports (6 x 15/20)	90 (50%)	120 (50%)
Capstone project	18 (10%)	24 (10%)
Attendance (complicated; see text)	36 (20%)	48 (20%)
Instructor evaluation (6 x 4.5/6)	18 (10%)	24 (10%)
Total	180	240

Grading will be based on the scale below, based on percent of final grade. Not that it includes the use of +/- grading. In exceptional cases, the instructor of record may, at their discretion, apply a curve to raise the final letter grades. A curve will never be applied to lower the final letter grades.

Scale (%)	
94-100	A
90-93.99	A-
87-89.99	B+
84-86.99	B
80-83.99	B-
77-79.99	C+
74-76.99	C
70-73.99	C-
67-69.99	D+
64-66.99	D
60-63.99	D-
0 – 59.99	F

### XIII. Grade Dissemination

You can access your scores at any time within the Canvas gradebook. Graded electronic submissions will be returned via the Canvas course shell. Student grade information can be found at: <https://www.ucdenver.edu/registrar/student-resources/grades>

*Note: Canvas is unreliable in calculation of grading schemes as intricate as those for this course. Thus, you should not rely on Canvas' calculation of percentages. The lead instructor (Huber) keeps a record of all grades according to the policies in this syllabus and that record takes priority over what might be displayed in Canvas.*

## COURSE PROCEDURES

### XIV. Course Policies: Grades

**Attendance Policy:** Attendance will be required for all classes and attendance will be taken. The policy on excused and unexcused absences is linked below. Be considerate to your lab partners; your absences affect their learning experience, too.

There are 42 scheduled course meetings, not counting the first two lectures and finals week. The attendance policy does not apply to the first two class meetings, and a separate attendance policy will apply during finals week. There will be 1 attendance point per scheduled meeting; arriving late or departing early (by more than 10 minutes) will result in a 0.4-point deduction. Full absence results in a 1-point deduction. Attendance will be tracked with daily sign-in sheets. No points will be deducted for excused absences (with documentation as required by the specific excuse); each student is allowed two unexcused absences and two late arrivals/early departures without penalty. Due to the complicated structure of the joint sections and resulting grading, the total possible attendance points of 42 will be scaled by 36/42 for undergrads and by 48/42 for grads so that in either case the total possible attendance points equate to 20% of the final grade.

*UC Denver Student Attendance and Absences Policy:*

<https://www.ucdenver.edu/docs/librariesprovider284/default-document-library/7000-student-affairs/7030---student-attendance-and-absences.pdf>

**Emergencies:** If at any point during the semester you have an emergency that interferes with your active participation in this course, please let us know as soon as possible. If you let us know of difficulties prior to a due date, we can often find a solution to satisfy all concerned. Dealing with an issue after a due date is very difficult; this is especially true for group assignments and those occurring during Finals Week.

**Late Arrivals:** Please come to class on time. If you are running late, please send an email to the current instructor to let them know your status.

**Religious Observances:** Students must notify the instructor in advance if they intend to miss a class to observe a holy day of their religious faith.

**Late Work Policy:** Late work is accepted only by prior arrangement with the instructor or in documented cases of emergencies beyond the individual student's control (sickness, accidents).

**Regrading:** Requests for regrading of assignments must be in writing and must specify exactly why and where additional credit is warranted. No requests for regrading will be accepted more than 48 hours after an assignment is returned.

**Extra Credit Policy:** There are no opportunities for extra credit.

**Rewrite/Resubmit Policy:** There are no opportunities for rewriting or resubmitting assignments.

**Group Work Policy:** Everyone must take part in projects and laboratory assignments assigned as groups. All members of a group will receive the same score on the Team Reports, and will receive independent, individual scores on the Individual Reports and, if appropriate, Graduate Reports. Groups will be assigned for each experimental assignment; groups cannot be altered or switched without approval of the instructor.

**Grades of Incomplete:** Per current university policy, incomplete grades are given only in situations where unexpected emergencies prevent a student from completing the course; students have up to one year (three semesters, counting summer) to complete course requirements. Your instructor is the final authority on whether you qualify for an incomplete. Incomplete work must be finished within the time allowed or the "I" will automatically be recorded as an "F" on your transcript.

## **XV. Course Policies: Technology and Media**

**Email:** Email will be considered official communication for the course in addition to Canvas; all such communication will be through university email addresses. Email will be checked daily and infrequently on weekends. You may expect a reply in at most 24 hours; typically, we will respond sooner.

**Canvas:** Canvas will be used for posting and accepting assignments and for posting grades. The Canvas shell is presently a work in progress and will be finalized shortly; please be patient. Assignments will be given in class in the interim.

## **XVI. Course Policies: Student Expectations**

Our commitment is to create a climate for learning characterized by respect for each other and the contributions each person makes to class. I ask that you make a similar commitment.

### **The Student and Community Counseling Center (located in Tivoli 454)**

The University supports students who are feeling overwhelmed or experiencing life stressors that interfere with academic or personal success through the Student and Community Counseling Center services. It is located in Tivoli 454 and provides cost-free and confidential mental health services to help students manage personal challenges that impact emotional or academic wellbeing. You can learn more at the Center at <http://www.ucdenver.edu/life/services/counseling-center> or by calling 303-556-4372.

### **Campus Assessment, Response & Evaluation (CARE)**

The University of Colorado Denver has created the Campus Assessment, Response & Evaluation (CARE) Team to address the health and safety needs of students as well as the campus community. If you have immediate concern about the behavior or safety of a student at CU Denver, help by making a referral to the CARE Team. The CARE team's purpose is to promote a safe productive learning, living and working environment by addressing the needs of students, faculty, and staff. If you or a classmate are in need of help, please submit a concern at <http://www.ucdenver.edu/life/services/CARE/Pages/default.aspx> or call 303- 352-3579.

**Professionalism:** Mobile devices must be silenced during all classroom and lab meetings. Those not heeding this rule will be asked to leave the classroom/lab immediately so as to not disrupt the learning environment.

**Electronic Cigarettes (e-cigarettes):** The use of e-cigarettes is distracting in the classroom environment not only to the instructor but to other students. The use of e- cigarettes during all classroom activity is prohibited. Any student who does not comply with this rule will be asked to leave the classroom immediately so as to not disrupt the learning environment. Pursuant to the Auraria Campus Smoking Policy, the use of e- cigarettes indoors and within twenty-five (25) feet of any entrance is strictly prohibited.

<https://www.ucdenver.edu/docs/librariesprovider284/default-document-library/3000-general-admission/3059---smoke-free-and-tobacco-free-environment.pdf>



**Auraria Library:** Library services for University of Colorado Denver are provided by the Auraria Library. Their resources are available to you and include research databases and collections and librarian expertise. <https://library.auraria.edu/services/askus>

**Writing Center:** The Writing Center is available to all students, whether undergraduate or graduate, to aid in written professional and technical communications. <https://clas.ucdenver.edu/writing-center/>

**XVII. DISABILITY ACCESS:**

The University of Colorado Denver is committed to providing reasonable accommodation and access to programs and services to persons with disabilities. Students with disabilities who want academic accommodations must register with Disability Resources and Services (DRS) in Academic Building 1, #2116, Phone: 303-315-3510, Fax: 303-315-3515. We will be happy to provide approved accommodations, once provided with a copy of DRS's letter. Note: DRS requires students to provide current and adequate documentation of their disabilities. Once a student has registered with DRS, DRS will review the documentation and assess the student's request for academic accommodations in light of the documentation. DRS will then provide the student with a letter indicating which academic accommodations have been approved.

**XVIII. Academic Honesty/Student Code of Conduct:**

Students are expected to know, understand, and comply with the ethical standards of the university, including rules against plagiarism, cheating, fabrication and falsification, multiple submissions, misuse of academic materials, and complicity in academic dishonesty. For suggestions on ways to avoid academic dishonesty, please see the Academic Integrity link:

<https://www.ucdenver.edu/student/wellness/student-conduct/academic-integrity>

Plagiarism is the use of another person's ideas or words or data without acknowledgement. The incorporation of another person's work into yours requires appropriate identification and acknowledgement. Examples of plagiarism when the source is not noted include: word-for-word copying of another person's ideas or words; the "mosaic" (interspersing your own words here and there while, in essence, copying another's work); the paraphrase (the rewriting of another's work, while still using their basic ideas or theories); fabrication (inventing or counterfeiting sources); submission of another's work as your own; and neglecting quotation marks when including direct quotes, even on material that is otherwise acknowledge.

Cheating involves the possession, communication, or use of information, materials, notes, study aids, or other devices and rubrics not specifically authorized by the course instructor in any academic exercise, or unauthorized communication with any other person during an academic exercise. Examples of cheating include: copying from another's work or receiving unauthorized assistance from another; using a calculator, computer, or the internet when its use has been precluded; collaborating with another or others without the consent of the instructor; submitting another's work as one's own.

Fabrication involves inventing or counterfeiting information—creating results not properly obtained through study or laboratory experiment. Falsification involves deliberate alteration or changing of results to suit one's needs in an experiment or academic exercise.

Multiple submission involves submitting academic work in a current course when academic credit for the work was previously earned in another course, when such submission is made without the current course instructor's authorization.

Misuse of academic materials includes: theft/destruction of library or reference materials or computer programs; theft/destruction of another student's notes or materials; unauthorized possession of another student's notes or materials; theft/destruction of examinations, papers, or assignments; unauthorized assistance in locating/using sources of information when forbidden or not authorized by the instructor; unauthorized possession, disposition, or use of examinations or answer keys; unauthorized alteration, forgery, fabrication, or falsification of academic records; unauthorized sale or purchase of examinations, papers, or assignments.

UC Denver has a license agreement with a service that helps detect plagiarism by comparing student papers with their database and Internet sources. Students who take this course agree that all required papers may be submitted to this service. While students retain copyright of their original course work, papers submitted to this service may become part of their reference database for the purposes of detecting plagiarism.

Complicity in academic dishonesty involves knowingly contributing to or cooperating with another's act(s) of academic dishonesty, including failing to disclose observed acts.

**XIX. Policy on Generative Artificial Intelligence**

Any student work in this course that is written, developed, or created with or by generative artificial intelligence (e.g., ChatGPT) outside of permitted uses listed in the course syllabus, is considered unauthorized assistance under the University's Academic Integrity policy. Student use of this technology does not support this course's learning goals and outcomes. Specifically, it can mask poor understanding of core concepts and reduce independent proficiency at the practical skills being developed in this course. Restrictions on use of generative AI is universal (this includes not only writing, but also creation of electronics schematics). Reports or papers may be subject to oral follow-up at any time for any reason. If either instructor has reasonable evidence that a student has used AI in an unauthorized way, it is the student's responsibility to prove otherwise (e.g., documentation of draft versions). The instructors will determine penalties for violations on a case-by-case basis, which may result in a student failing an assignment, failing the course, or being reported to the CU Denver Office of Student Conduct. **Exceptions:** Use of the Writing Center is allowed and encouraged (if time); use of grammar- and/or spell-checkers (e.g., Grammarly) is allowed.

**XX. Nondiscrimination and Sexual Misconduct**

The University of Colorado Denver is committed to maintaining a positive learning, working and living environment. University policy and Title IX prohibit discrimination on the basis of race, color, national origin, sex, age, disability, pregnancy, creed, religion, sexual orientation, veteran status, gender identity, gender expression, political philosophy or political affiliation in admission and access to, and treatment and employment in, its educational programs and activities.

University policy prohibits sexual misconduct, including harassment, domestic and dating violence, sexual assault, stalking, or related retaliation. If you have experienced some sort of sexual misconduct or discrimination, please visit the Office of Equity/Title IX web site

(<https://www1.ucdenver.edu/offices/equity>) to understand the resources available to you or contact the Office of Equity/Title IX Coordinator (303-315-2567).

**XXI. Important Dates to Remember/Academic Calendar**

For the full list, see: <https://www.ucdenver.edu/student/student-calendars/academic/fall>

**XXII. Syllabus Updates**

It is expected that there will be minimal need for updates or modifications to the syllabus, required only in the case of “discovered” conflicts or ambiguities that require clarification or to reflect unforeseen situations that may arise beyond anyone’s control. Announcements about updates, of any kind, to the syllabus will be made in class and posted to Canvas and will take precedence over this version. You are responsible for checking Canvas regularly for such changes and for any other course announcements.