UNSW SYDNEY Australia's Global University

School of Electrical Engineering and Telecommunications

Term 3, 2019
Course Outline

ELEC4605
Quantum Devices and Computers

COURSE STAFF

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Consultations: You are encouraged to ask questions on the course material, after the lecture class times in the first instance, rather than via email. Lecturer consultation times will be advised during lectures. ALL email enquiries should be made from your student email address with ELEC4605 in the subject line; otherwise they will not be answered.

Keeping Informed: Announcements may be made during classes, via email (to your student email address) and/or via online learning and teaching platforms – in this course, we will use Moodle https://moodle.telt.unsw.edu.au/login/index.php. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

COURSE SUMMARY

Contact Hours

The course consists of 4 hours of lectures (2 x 2 hour), a 3-hour laboratory session each week and a 1-hour tutorial (6 tutorials in total). The laboratories and tutorials begin in week 2.

Lectures	Day	Time	Location
	Tuesday	12pm – 2pm	Science & Engineering B25
	Thursday	9am – 11am	Goldstein G06
Tutorial	Thursday	12pm – 1pm	Science & Engineering B25

Context and Aims

Quantum engineering is concerned with the design and production of devices that exploit the laws of quantum mechanics, unlocking novel functionalities and improved performance. This course will provide an Engineering-oriented and in-depth treatise of the conceptual and practical tools required to model, design and understand natural and engineered quantum systems, such as quantum computers and quantum-enhanced sensors and amplifiers. Particular attention will be given to platforms and algorithms for quantum computation, a technology synonymous with the new quantum revolution.

The course includes a laboratory component that will introduce fundamental quantum effects, ranging from spin resonance to superposition and entanglement. The experiments will demonstrate the tangible applications of these quantum effects, including quantum logic operations, quantum cryptography and quantum state control.

A primary outcome of the course is to train and empower students to become active contributors to the emerging field of quantum technologies, which is undergoing an explosive growth, accompanied by an accelerating demand for highly skilled quantum engineers in the workforce.

In summary, the course aims to:

- Provide students with an overview of the state-of-the-art devices and technologies that exploit Quantum Mechanics to achieve novel or improved functionalities.
- Equip students with the conceptual and practical tools to model, design and understand engineered quantum devices, such as quantum computers and quantum-enhanced sensors and amplifiers.
- Supply students with the skills to design quantum circuits to evaluate basic quantum algorithms.
- Provide students with hands-on experience in assembling quantum experimental apparatus and making fundamental demonstrations of quantum effects in a laboratory setting.
- Empower students to become active contributors to the emerging field of quantum technologies.

Indicative Lecture Schedule

Period	Summary of Lecture Program
Week 1	Revision of key concepts in quantum engineering (matrix mechanics, operators, density matrices)
Week 2	Controlling quantum systems (rotation operators, decoherence, filter-function formalism, Ramsey fringes, Hahn echo, dynamical decoupling, noise spectroscopy and magnetometry)
Week 3	Quantum computation (classical computing, quantum circuit model, one and two-qubit logic gates, conditional unitary operators, universal gates, approximating quantum gates)
Week 4	Quantum algorithms (quantum simulation, quantum Fourier transform, quantum search)
Week 5	The quantum harmonic oscillator (raising and lowering operators, number operator, quantum LC circuit, quantisation of EM fields, vacuum fluctuations) [**assignment 1 due**]
Week 6	Quantum optics (photonic qubits, single and two-qubit gates)
Week 7	Quantum transport and the single-electron transistor (Aharonov-Bohm effect, Coulomb blockade, quantum dots)
Week 8	Superconductivity (Cooper pairs, the Josephson effect, flux quantisation, SQUIDs) [**assignment 2 due**]
Week 9	Superconducting qubits (Charge, transmon and flux qubits)
Week 12	Quantum amplifiers (quantum theory of amplification, mixing, Josephson parametric amplifiers)

Indicative Laboratory Schedule

Period	Summary of Laboratory Program
Week 2	Spins: Introduction to experiment (lock-in detection, data acquisition, optics)
Week 3	Spins: ESR spectrum, Zeeman splitting, Rabi oscillations
Week 4	Spins: Coherence (T_2) time, two-axis control, dynamical decoupling
Week 5	**Spins: Lab report due and oral assessment**
Week 6	Optics: Measuring single photons and generating bi-photons
Week 7	Optics: Quantum states and indistinguishability of photons
Week 8	Optics: Entangled photons
Week 9	**Optics: Lab report due and oral assessment**

Assessment

Laboratory	25%
Assignments	25%
Final Exam (2 hours)	50%

The final exam will be in written form and will ask the students to answer questions about concepts, principles, and devices introduced during the course.

COURSE DETAILS

Credits

This is a 6 UoC course and the expected workload is 15 hours per week throughout the 10-week term.

Relationship to Other Courses

This is a 4th year elective course in the School of Electrical Engineering and Telecommunications.

Pre-requisites and Assumed Knowledge

The pre-requisite for this course is ELEC3705, or an equivalent combination of mathematics and physics courses. Please contact the lecturers if you are unsure whether you have the required background knowledge.

Following Courses

There are no courses that directly follow from this course. However, students interested in this stream might want to consider TELE9757, Quantum Communications.

Learning outcomes

After successful completion of this course, you should be able to:

1. Apply control techniques (e.g. spin resonance) to manipulate a quantum state and extend its coherence lifetime.
2. Develop code to simulate the response of a quantum system to arbitrary control sequences.
3. Argue the relative merits of the different physical platforms for quantum computation.
4. Construct quantum algorithms using primitive quantum logic gates.
5. Assemble advanced quantum experiments and use them to make fundamental demonstrations in spin resonance and quantum computation (e.g. quantum control, entanglement, logic gates).
6. Show a broad understanding of the quantum-enhanced techniques and devices used in quantum sensing and amplification.

This course is designed to provide the above learning outcomes which arise from targeted graduate capabilities listed in ***Appendix A***. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate capabilities (listed in ***Appendix B***). This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in ***Appendix C***.

TEACHING STRATEGIES

Delivery Mode

The teaching in this course aims at establishing a good fundamental understanding of the areas covered using:

- Lectures: Face-to-face lectures will be used to present students with core material essential for an understanding of quantum devices and computation.
- Laboratory: A weekly three-hour laboratory session will provide students with experience in assembling quantum experimental apparatus and making demonstrations of fundamental quantum effects, such as superposition and entanglement.

- Tutorials: A weekly one-hour tutorial (6 in total) will be used to solve tutorial problems assigned in the lectures.

Learning in this course

You are expected to attend all lectures, tutorials, labs, and the final exam in order to maximise learning. You must prepare well for your laboratory classes and your lab work will be assessed. In addition to the lecture notes/video, you should read relevant sections of the recommended text. Reading additional texts will further enhance your learning experience. Group learning is also encouraged. UNSW *assumes* that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

Tutorial classes

You should attempt all of your problem sheet questions in advance of attending the tutorial classes. The importance of adequate preparation prior to each tutorial cannot be overemphasized, as the effectiveness and usefulness of the tutorial depends to a large extent on this preparation. Group learning is encouraged. Answers for these questions will be discussed during the tutorial and the tutor will cover the more complex questions in the tutorial class. In addition, during the tutorial, 1-2 new questions that are not in your notes may be provided by the tutor, for you to try in class. These questions and solutions may not be made available on the web, so it is worthwhile for you to attend your tutorial classes to gain maximum benefit from this course.

Laboratory program

The laboratory schedule is deliberately designed to provide practical, hands-on exposure to the concepts conveyed in lectures soon after they are covered in class. You are required to attend laboratory from Week 2 to Week 9. Laboratory attendance WILL be kept, and you MUST attend at least 80% of labs.

Laboratory Exemption

There is no laboratory exemption for this course. Regardless of whether equivalent labs have been completed in previous courses, all students enrolled in this course must take the labs. If, for medical reasons, (note that a valid medical certificate must be provided) you are unable to attend a lab, you will need to apply for a catch-up lab during another lab time, as agreed by the laboratory coordinator.

ASSESSMENT

The assessment scheme in this course reflects the intention to assess your learning progress through the semester.

Laboratory Exam

Two in-class laboratory oral tests will be given, in weeks 5 and 9, at the end of each experiment topic (spins and optics). There, you will be expected to answer questions about the experiments you have been working on within the topic. You will also be required to submit a laboratory report summarizing your experimental results for each topic, due at the end of your laboratory sessions in weeks 7 and 12. The oral test and lab report for each experiment will contribute a combined 12.5% to your final course grade.

Assignments

Two take-home assignments will be given, with submission deadlines in weeks 5 and 8 (5pm, Friday). Each assignment is worth 12.5% of your final grade.

Assignment submission will be handled through the Moodle portal. You will be expected to upload pdf files that summarize your answers to all the questions, plus every Matlab file you have used to arrive at the solutions. *Late reports will attract a penalty of 10% per day* (including weekends).

Final Exam

The exam in this course is a standard closed-book 2 hour written examination. University approved calculators are allowed. The examination tests analytical and critical thinking and general understanding of the course material in a controlled fashion. Questions may be drawn from any aspect of the course (including laboratory), unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses. *Please note that you must pass the final exam in order to pass the course.*

Relationship of Assessment Methods to Learning Outcomes

	Learning outcomes					
Assessment	**1**	**2**	**3**	**4**	**5**	**6**
Laboratory assessments	✓	✓	-	-	✓	-
Assignments	✓	✓	-	✓	-	-
Final exam	-	-	✓	✓	-	✓

COURSE RESOURCES

Textbooks

Prescribed textbook

- Michael A. Nielsen & Isaac L. Chuang. *Quantum Computation and Quantum Information.* Edn. 10 (Cambridge University Press, 2010).

Reference books

- Claude Cohen-Tannoudji, Bernard Diu & Frank Lalo. *Quantum Mechanics*. Edn. 1 Vol. 1 (Wiley, 1991).
- Supriyo Datta. *Quantum Transport: Atom to Transistor*. Edn. 2 (Cambridge University Press, 2005).
- Charles Kittel. *Solid State Physics*. Edn. 8 (Wiley, 2005).
- Grosso and Pastori Parravicini. *Solid State Physics*. (Academic Press, 2000).
- David A. B. Miller. *Quantum mechanics for scientists and engineers*. Edn. 1 (Cambridge University Press, 2008).

On-line resources

Moodle

As a part of the teaching component, Moodle will be used to disseminate teaching materials, host forums and occasionally quizzes. Assessment marks will also be made available via Moodle: https://moodle.telt.unsw.edu.au/login/index.php.

Mailing list

Announcements concerning course information will be given in the lectures and/or on Moodle and/or via email (which will be sent to your student email address).

OTHER MATTERS

Dates to note

Important Dates available at: https://student.unsw.edu.au/dates

Academic Honesty and Plagiarism

Plagiarism is the unacknowledged use of other people's work, including the copying of assignment works and laboratory results from other students. Plagiarism is considered a form of academic misconduct, and the University has very strict rules that include some severe penalties. For UNSW policies, penalties and information to help you avoid plagiarism, see https://student.unsw.edu.au/plagiarism. To find out if you understand plagiarism correctly, try this short quiz: https://student.unsw.edu.au/plagiarism-quiz.

Student Responsibilities and Conduct

Students are expected to be familiar with and adhere to all UNSW policies (see https://student.unsw.edu.au/guide), and particular attention is drawn to the following:

Workload

It is expected that you will spend at least **ten to twelve hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both face-to-face classes and *independent, self-directed study*. In periods where you need to need to complete assignments or prepare for examinations, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

General Conduct and Behaviour

Consideration and respect for the needs of your fellow students and teaching staff is an expectation. Conduct which unduly disrupts or interferes with a class is not acceptable and students may be asked to leave the class.

Work Health and Safety

UNSW policy requires each person to work safely and responsibly, in order to avoid personal injury and to protect the safety of others.

Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. You should seek assistance early if you suffer illness or misadventure which affects your course progress. All applications for special consideration must be **lodged online through myUNSW within 3 working days of the assessment**, not to course or school staff. For more detail, consult https://student.unsw.edu.au/special-consideration.

Continual Course Improvement

This course is under constant revision in order to improve the learning outcomes for all students. Please forward any feedback (positive or negative) on the course to the course convener or via the online student survey myExperience. You can also provide feedback to ELSOC who will raise your concerns at student focus group meetings. As a result of previous feedback obtained for this course and in our efforts to provide a rich and meaningful learning experience, we have continued to evaluate and modify our delivery and assessment methods.

Administrative Matters

On issues and procedures regarding such matters as special needs, equity and diversity, occupational health and safety, enrolment, rights, and general expectations of students, please refer to the School and UNSW policies:
https://student.unsw.edu.au/guide
https://www.engineering.unsw.edu.au/electrical-engineering/resources

APPENDICES

Appendix A: Targeted Graduate Capabilities

Electrical Engineering and Telecommunications programs are designed to address the following targeted capabilities which were developed by the school in conjunction with the requirements of professional and industry bodies:

- The ability to apply knowledge of basic science and fundamental technologies;
- The skills to communicate effectively, not only with engineers but also with the wider community;
- The capability to undertake challenging analysis and design problems and find optimal solutions;
- Expertise in decomposing a problem into its constituent parts, and in defining the scope of each part;
- A working knowledge of how to locate required information and use information resources to their maximum advantage;
- Proficiency in developing and implementing project plans, investigating alternative solutions, and critically evaluating differing strategies;

- An understanding of the social, cultural and global responsibilities of the professional engineer;
- The ability to work effectively as an individual or in a team;
- An understanding of professional and ethical responsibilities;
- The ability to engage in lifelong independent and reflective learning.

Appendix B: UNSW Graduate Capabilities

The course delivery methods and course content directly or indirectly addresses a number of core UNSW graduate capabilities, as follows:

- Developing scholars who have a deep understanding of their discipline, through lectures and solution of analytical problems in tutorials and assessed by assignments and written examinations.
- Developing rigorous analysis, critique, and reflection, and ability to apply knowledge and skills to solving problems. These will be achieved by the laboratory experiments and interactive checkpoint assessments and lab exams during the labs.
- Developing capable independent and collaborative enquiry, through a series of tutorials spanning the duration of the course.
- Developing digital and information literacy and lifelong learning skills through assignment work.

Appendix C: Engineers Australia (EA) Professional Engineer Competency Standard

	Program Intended Learning Outcomes	
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	✓
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	✓
	PE1.3 In-depth understanding of specialist bodies of knowledge	✓
	PE1.4 Discernment of knowledge development and research directions	✓
	PE1.5 Knowledge of engineering design practice	
	PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice	
PE2: Engineering Application Ability	PE2.1 Application of established engineering methods to complex problem solving	✓
	PE2.2 Fluent application of engineering techniques, tools and resources	✓
	PE2.3 Application of systematic engineering synthesis and design processes	
	PE2.4 Application of systematic approaches to the conduct and management of engineering projects	
PE3: Professional and Personal Attributes	PE3.1 Ethical conduct and professional accountability	✓
	PE3.2 Effective oral and written communication (professional and lay domains)	✓
	PE3.3 Creative, innovative and pro-active demeanour	✓
	PE3.4 Professional use and management of information	✓
	PE3.5 Orderly management of self, and professional conduct	✓
	PE3.6 Effective team membership and team leadership	