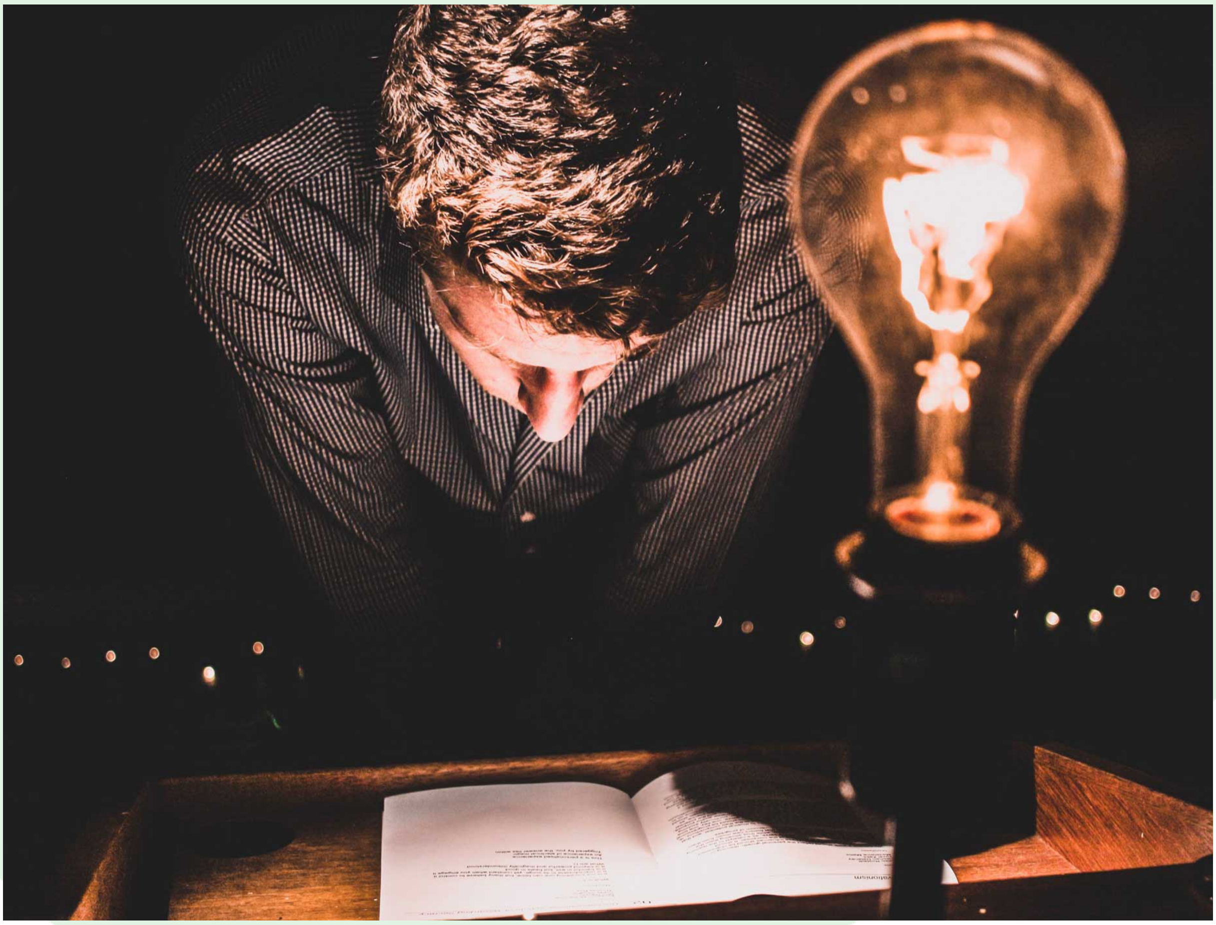
School of Electrical Engineering & Telecommunications

UNSW Engineering

ELEC9782

Special Topics in Electrical Engineering 2

Term 3, 2022



Course Overview

Staff Contact Details

Convenors

Name	Email	Availability	Location	Phone
Dr Hendra Nurdin	h.nurdin@unsw.edu.au		G17 R315	9385 7556

School Contact Information

Consultations: Lecturer consultation times will be advised during the first lecture. You are welcome to email the tutor or laboratory demonstrator, who can answer your questions on this course and can also provide you with consultation times. ALL email enquiries should be made from your student email address with ELEC/TELExxxx 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.**

Student Support Enquiries

For enrolment and progression enquiries please contact Student Services

Web

Electrical Engineering Homepage

Engineering Student Support Services

Engineering Industrial Training

UNSW Study Abroad and Exchange (for inbound students)

UNSW Future Students

Phone

(+61 2) 9385 8500 – Nucleus Student Hub

(+61 2) 9385 7661 – Engineering Industrial Training

(+61 2) 9385 3179 – UNSW Study Abroad and UNSW Exchange (for inbound students)

Email

Engineering Student Support Services – current student enquiries

- e.g. enrolment, progression, clash requests, course issues or program-related queries

Engineering Industrial Training – Industrial training questions

UNSW Study Abroad – study abroad student enquiries (for inbound students)

UNSW Exchange – student exchange enquiries (for inbound students)

UNSW Future Students – potential student enquiries

- e.g. admissions, fees, programs, credit transfer

Course Details

Units of Credit 6

Summary of the Course

ELEC9782 gives an introduction to control theory for quantum systems. Coverage includes open- loop and closed-loop (feedback) control methods. It reviews relevant concepts from the theory of open quantum systems, quantum measurement theory and stochastic control theory. The course takes a multidisciplinary approach and will draw upon relevant concepts from physics, systems and control, and mathematics and mathematical physics. Close connections between stochastic control for classical Markov processes and measurement quantum feedback control will be highlighted. The course will run over 10 weeks and is aimed at 4th year undergraduate students or postgraduate students already familiar with quantum mechanics, for instance via the courses ELEC3705 and/or ELEC4605, and basic control systems, such as covered in ELEC3114. Materials will be presented at an advanced introductory level, emphasising mastery of basic concepts and methods, supported by illustrations given in the simplest settings to help develop an intuitive understanding. The course will help prepare students for deeper self-study or to take on more advanced courses.

Course Aims

The aims of the course are to:

1. Introduce open-loop optimal control of quantum systems
2. Introduce filtering and stochastic control theory for stochastic dynamical systems
3. Introduce open quantum systems and generalised quantum measurements
4. Introduce measurement quantum feedback control
5. Introduce a unified view of stochastic control and measurement quantum feedback control
6. Develop the ability to simulate open-loop and quantum feedback control in Matlab

Course Learning Outcomes

After successfully completing this course, you should be able to:

Learning Outcome	EA Stage 1 Competencies
1. Demonstrate understanding of open-loop optimal control of quantum systems via gradient ascent	PE1.1, PE1.2, PE2.1, PE2.2, PE3.3, PE3.1, PE3.2
2. Demonstrate understanding of the principles of classical and quantum filtering	PE1.1, PE1.2, PE2.1, PE2.2, PE3.3, PE3.1, PE3.2
3. Demonstrate understanding of open quantum systems and quantum input-output systems	PE1.1, PE1.2, PE2.1, PE2.2, PE3.3, PE3.1, PE3.2
4. Demonstrate understanding of the principles of stochastic control and measurement quantum feedback control	PE1.1, PE1.2, PE2.2, PE3.3, PE3.1, PE3.2
5. Demonstrate the ability to apply open-loop control and measurement quantum feedback control concepts to qubits and linear quantum systems	PE1.1, PE1.2, PE2.1, PE2.2, PE3.3, PE3.1, PE3.2

Learning Outcome	EA Stage 1 Competencies
6. Demonstrate the ability to use Matlab to simulate open-loop and quantum feedback control systems	PE2.1, PE2.2, PE3.1, PE3.3, PE3.2

Teaching Strategies

Delivery Mode

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

- Lectures, which provide you with a focus on the core analytical material in the course, together with qualitative, alternative explanations to aid your understanding;
- Online consultations with the lecturer outside of class hours, according to the scheduled times.

Learning in this course

You are expected to attend all online lectures and attempt assignments and the mid-session exams in order to maximise learning. **There will also be substantial independent reading of selected materials that students will be required to undertake throughout the course.** Reading additional texts beyond the lecture notes and other materials from the course convenor 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 formal classes throughout the course.

Additional Course Information

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 undergraduate course and a 1st year/postgraduate course in the School of Electrical Engineering and Telecommunications.

Pre-requisites and Assumed Knowledge

The pre-requisites for this course are ELEC3705 Fundamentals of Quantum Engineering and ELEC3114 Control Systems, or equivalent courses taken at other institutions. It is also essential that you are familiar with MATH2069, Mathematics 2A, and MATH2099, Mathematics 2B, before this course is attempted (they are already pre-requisites for ELEC3114). Having done ELEC4605 Quantum Devices and Computers and ELEC4631 Continuous-Time Control System Design will also be beneficial for doing this course but are not pre-requisites for the course. Students are expected to be familiar and comfortable with:

- **Basic quantum mechanics:** Wave functions, observables, quantum expectations, Schrödinger equation, Dirac bra-ket notation, quantum measurements, quantum harmonic oscillators (ELEC3705)
- **Probability and statistics:** Sample spaces, probability, random variables and probability distributions, standard discrete and continuous distributions, multivariate distributions, Central

Limit Theorem (MATH2099)

- **Vector calculus:** functions of several variables, multivariable calculus, scalar fields, vector fields, gradients (MATH2069)
- **Linear algebra**: matrices, matrix inversion, matrix determinant, vectors, vector spaces, basis vectors, linearly independence, linear span of vectors, null/kernel spaces, characteristic equations, eigenvalues, eigenvectors, diagonalisation of a matrix, exponentiation of a matrix, Jordan canonical form (MATH2099)
- **Control systems:** Laplace transform, inverse Laplace transform, transfer functions, poles and zeros, state-space modelling, feedback control (ELEC3114)

Assessment

The assessment scheme in this course reflects the intention to assess your learning progress through the semester. Ongoing assessment occurs through the quizzes, the mid-term exam and final exam.

Assessment task	Weight	Due Date	Course Learning Outcomes Assessed
1. Quiz 1	10%	To be announced by the lecturer	1, 2, 5
2. Mid-term exam	25%	In Week 7, to be announced by lecturer	1, 2, 3, 4, 6
3. Quiz 2	10%	To be announced by lecturer	2, 3
4. Final exam	55%	To be announced by lecturer	2, 3, 4, 5, 6

Assessment 1: Quiz 1

Start date: To be announced by the lecturer
Assessment length: 1 week
Due date: To be announced by the lecturer
Deadline for absolute fail: Late quiz submissions will attract a deduction of 25% of the full marks per day that they are late. Submission late by four days or more will receive a mark of zero.
Marks returned: 100

Released in Week 3, covers materials up to and including Week 3. It will consist of analytical exercises.

Assessment criteria

Marks will be assigned according to correctness of the responses. All workings must be included in the submission. Any plagiarism is a serious academic misconduct that will entail a heavy penalty.

Assessment 2: Mid-term exam

Start date: In Week 5, to be announced by lecturer
Due date: In Week 7, to be announced by lecturer
Deadline for absolute fail: Late mid-term exam submissions will attract a deduction of 25% of the full marks per hour block that they are late. No marks will be awarded for submissions when it is late by three hours or more.
Marks returned: 100

The mid-term examination is a take home exam that will test your general understanding of the course material and is designed to give you feedback on your progress through the course. Questions may be drawn from any course material up to the end of Week 5. It will consist of longer analytical questions and Matlab simulations.

Assessment criteria

Marks will be assigned according to correctness of the responses. All workings must be included in the submission. Any plagiarism is a serious academic misconduct that will entail a heavy penalty.

Assessment 3: Quiz 2

Start date: To be announced by lecturer
Assessment length: 1 week
Due date: To be announced by lecturer
Marks returned: 100

Released in Week 8. Covers materials in Weeks 7 and 8

Assessment criteria

Late quiz submissions will attract a deduction of 25% of the full marks per day that they are late. Submission late by four days or more will receive a mark of zero.

Assessment 4: Final exam

Start date: After Week 10, to be announced by lecturer
Submission notes: Submission will be via Moodle
Due date: To be announced by lecturer
Deadline for absolute fail: Late final exam submissions will attract a deduction of 25% of the full marks per hour block that they are late. No marks will be awarded for submissions when it is late by three hours or more.
Marks returned: 100

The final exam for this course will be a take home exam with a duration and submission time that will be advised in Week 10. The examination tests analytical and critical thinking and general understanding of the course material. Questions may be drawn from any aspect of the course and will involve simulation in Matlab. Marks will be assigned according to the correctness of the responses.

Assessment criteria

Marks will be assigned according to correctness of the responses. All workings and codes must be included in the submission. Any plagiarism is a serious academic misconduct that will entail a heavy penalty.

Attendance Requirements

Students are strongly encouraged to attend all classes and review lecture recordings.

Course Schedule

There will be lectures in Weeks 1 to 5 and from Weeks 7 to 10. There will be no lectures during the flexibility week in Week 6. There are no tutorials or labs in the course.

[View class timetable]

Timetable

Date	Type	Content
Week 1: 12 September - 16 September	Lecture	Introduction to the course and quantum control systems
	Lecture	Review of basic quantum mechanics Hilbert spaces, wave functions, Schrödinger equation, Heisenberg picture, interaction picture, quantum expectations, composite quantum systems, qubits, Dyson series, time-ordered exponentials, density operators, Bloch sphere
Week 2: 19 September - 23 September	Lecture	Open-loop optimal control of quantum systems Open-loop optimal quantum control by gradient ascent, applications
Week 3: 26 September - 30 September	Lecture	Modern probability theory and stochastic processes Probability spaces, random variables, expectations and conditional expectations, jointly Gaussian random variables, stochastic processes, Markov processes, white noise, Wiener process (Brownian motion)
	Lecture	Modern probability theory and stochastic processes (continued)
	Assessment	Quiz 1 released
Week 4: 3 October - 7 October	Lecture	Filtering theory and stochastic control Ito's formula, stochastic differential equations,

		flitering theory, Kalman filter, optimal stochastic control, linear quadratic Gaussian (LQG) control
	Lecture	Filtering theory and stochastic control (continued)
	Assessment	Quiz 1 due
Week 5: 10 October - 14 October	Lecture	Open quantum systems Completely positive maps, quantum operations, Kraus representation, decoherence
	Lecture	Quantum measurements Projective measurements, projection-valued measures, positive operator-valued measures, sequential measurements, quantum non-demolition (QND) measurements, quantum conditional expectations
	Assessment	Mid-term exam released
Week 7: 24 October - 28 October	Lecture	Quantum measurements (continued)
	Lecture	Continuous-variable systems and free travelling quantum fields Quantum harmonic oscillators, quantum Gaussian states of multi-mode oscillators, free travelling quantum fields, quantum Gaussian states of free travelling fields
	Assessment	Midterm exam due
Week 8: 31 October - 4 November	Lecture	Quantum input-output systems Quantum white noise, quantum stochastic differential equations, quantum Markov models, Lindblad master equation, linear quantum systems, physical examples
	Lecture	Quantum filtering and feedback control

		Quantum filtering, quantum Kalman filter, measurement quantum feedback control, quantum LQG control, applications
	Assessment	Quiz 2 released
Week 9: 7 November - 11 November	Lecture	Quantum filtering and feedback control (continued)
	Assessment	Quiz 2 due
Week 10: 14 November - 18 November	Lecture	Quantum filtering and feedback control (continued)
	Lecture	Review lecture

Resources

Prescribed Resources

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).

Lecture notes

Some lecture notes will be supplied and posted on Moodle.

Recommended Resources

Further texts and references

Part of the course will be drawn from and use contents from some of the following references. They are in general useful as references for the course

1. M. Nielsen and I. Chuang, Quantum Information and Computation, 10th anniversary edition, Cambridge University Press, 2010
2. H. M. Wiseman and G. J. Milburn, Quantum Measurement and Control, Cambridge University Press, 2010.
3. H. I. Nurdin and N. Yamamoto, Linear Dynamical Quantum Systems: Analysis, Synthesis and Control, Springer, 2017
4. A. Bagchi, Optimal Control of Stochastic Systems, Pearson, 1994

Besides this, some materials will be based upon papers that will be posted on Moodle.

Course Evaluation and Development

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, the course contents have been modified and rearranged as reflected in the revised course schedule.

Laboratory Workshop Information

This course contains no labs.

Academic Honesty and Plagiarism

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.

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.

Academic Information

COVID19 - Important Health Related Notice

Your health and the health of those in your class is critically important. You must stay at home if you are sick or have been advised to self-isolate by NSW health or government authorities. Current alerts and a list of hotspots can be found here. **You will not be penalised for missing a face-to-face activity due to illness or a requirement to self-isolate**. We will work with you to ensure continuity of learning during your isolation and have plans in place for you to catch up on any content or learning activities you may miss. Where this might not be possible, an application for fee remission may be discussed.

If you are required to self-isolate and/or need emotional or financial support, please contact the Nucleus: Student Hub. If you are unable to complete an assessment, or attend a class with an attendance or participation requirement, please let your teacher know and apply for special consideration through the Special Consideration portal. To advise the University of a positive COVID-19 test result or if you suspect you have COVID-19 and are being tested, please fill in this form.

UNSW requires all staff and students to follow NSW Health advice. Any failure to act in accordance with that advice may amount to a breach of the Student Code of Conduct. Please refer to the Safe Return to Campus guide for students for more information on safe practices.

Dates to note

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

Student Responsibilities and Conduct

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

Workload

It is expected that you will spend at least **15 hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both formal classes and *independent, self-directed study*. In periods where you 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.

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 can apply for special consideration when illness or other circumstances beyond your control interfere with an assessment performance. If you need to submit an application for special consideration for an exam or assessment, you must submit the application **prior to the start** of the exam or before the assessment is submitted, except where illness or misadventure prevent you from doing so. Be aware of the “fit to sit/submit” rule which means that if you sit an exam or submit an assignment, you are declaring yourself well enough to do so and cannot later apply for Special Consideration. For more information and how to apply, see https://student.unsw.edu.au/special-consideration.

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

Disclaimer

This Course Outline sets out description of classes at the date the Course Outline is published. The nature of classes may change during the Term after the Course Outline is published. Moodle should be consulted for the up-to-date class descriptions. If there is any inconsistency in the description of activities between the University timetable and the Course Outline (as updated in Moodle), the description in the Course Outline/Moodle applies.

Image Credit

Synergies in Sound 2016

CRICOS

CRICOS Provider Code: 00098G

Acknowledgement of Country

We acknowledge the Bedegal people who are the traditional custodians of the lands on which UNSW Kensington campus is located.

Appendix: Engineers Australia (EA) Professional Engineer Competency Standard

Program Intended Learning Outcomes	
Knowledge and skill base	
PE1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline	✓
PE1.2 Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline	✓
PE1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline	
PE1.4 Discernment of knowledge development and research directions within the engineering discipline	
PE1.5 Knowledge of engineering design practice and contextual factors impacting the engineering discipline	
PE1.6 Understanding of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline	
Engineering application ability	
PE2.1 Application of established engineering methods to complex engineering 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	
Professional and personal attributes	
PE3.1 Ethical conduct and professional accountability	✓
PE3.2 Effective oral and written communication in 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	