Faculty of Engineering
School of Electrical Engineering and Telecommunications

ELEC 9705
Quantum Devices

Session 2, 2008
Course Introduction
1. COURSE PERSONNEL

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Guest lectures by research specialists may be delivered during the session.

2. COURSE INFORMATION

- The course is worth 6 Units of Credit.
- The lectures are normally scheduled on Tuesdays, in Red Centre M032, 18:00 – 21:00. Occasional changes in the schedule may be necessary at times, and will be discussed with the students to ensure that everyone is able to attend all lectures.
- There will be no laboratories or tutorials.
- The course is available in the following programs: Master of Engineering Science; PhD in Electrical Engineering; Bachelor of Engineering (4th Year Elective substitution).

3. AIMS AND SCOPE

The progress of nanotechnology has started to allow the fabrication of devices whose dynamics no longer obeys the laws of classical physics. Such devices behave according to Quantum Mechanics, which opens the possibility to exploit entanglement and quantum superpositions to perform otherwise cumbersome or impossible tasks. These include the efficient solution of hard computational problems, or the secure teleportation of information.

This course on Quantum Devices aims to provide a deep but accessible introduction to the properties of nano-engineered devices that are designed to be the building blocks of future quantum information and communication systems. Such devices allow to observe and manipulate individual electron charges, measure their spin state, and couple them to quantized electromagnetic fields. Some of these devices also represent the ultimate detectors of electric and magnetic signals, with sensitivity limited by the fundamental quantum mechanical uncertainty. The relevance of Quantum Mechanics in advanced electronic devices will be illustrated by discussing in details several practical examples:

- **Single-electron transistor** - the most sensitive electrometer, capable of detecting the displacement of a single electron charge in its vicinity;
- **Quantum point contact** - an electrical conductor with cross-section comparable to the electronic wavelength;
- **Superconducting Quantum Interference Device** - the most sensitive magnetometer, able to detect a fraction of a magnetic flux quantum;
- **Charge, phase, and flux qubits** - micron-size electrical circuits that can be prepared in a macroscopic quantum superposition of different states;
- **Quantum dots** - also known as ‘‘artificial atoms’’: nanostructures that confine a small number of electrons and allow the preparation and observation of their charge and spin states.
4. LEARNING OUTCOMES

At the end of the course, the students are expected to be familiar with the basic concepts of Quantum Mechanics, and be able to recognize its relevance for the technological progress in electronic devices. They should be able to appreciate the radically new range of device functionality that is made available to the engineer by the control of quantum systems. Also, the course will ideally prepare the students to participate in advanced post-graduate research projects, or work in specialized industries with high involvement in research and development.

5. TEACHING METHOD

The lecturers will deliver either white-board or projected PowerPoint lectures. Lecture notes and additional reading material will be progressively made available on the course WebCT website, but they are no substitute for accurate notes taken by the students during the lectures. This is because it is probable and desirable that many questions will arise during the lectures, and the outcomes of such discussions are hard to capture in lecture notes prepared in advance. It is therefore essential that students attend every lecture. The material covered by the course is rather unusual and it would be difficult for the students to assemble this knowledge by reading scattered references. The lecturers will also give informal assignments to stimulate the assimilation of new concepts and get feedback on the students’ progress.

6. REFERENCES

No textbook is formally set for this course. Recommended readings include:


Further specialized reading material will be made available on the course WebCT website.

5. ASSESSMENT

The assessment in this subject will be entirely based on the final exam. The informal assignments given during the course will be used by the lecturers to stimulate the students and get feedback on the pace of their learning process. This assessment method makes plagiarism essentially inapplicable - the informal assignments are not marked and do not contribute to the final score. However, it is crucial that the students work individually on the assignments, since they are tailored to help them deepening their understanding of the subject. Copying or paraphrasing other people’s work to compile a better looking assignment is a self-defeating strategy, which will reduce the chances of success at the final exam. More information on plagiarism, and the related University policy, is available on the Learning Centre website: [http://www.lc.unsw.edu.au/plagiarism](http://www.lc.unsw.edu.au/plagiarism)
6. THE COURSE WEBSITE

The WebCT Vista portal will be the primary point of contact, for administrative matters, with the student. Any important announcements will be placed on the ‘Announcements’ page, which the student is obliged to check regularly. Lecture notes, assignments and other course materials will also be made available for download from WebCT.

Those unfamiliar with WebCT should consult the following website, which contains instructions and other resources for students:
http://support.vista.elearning.unsw.edu.au/content/default.cfm?ss=0

7. COURSE SCHEDULE (TENTATIVE)

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Lecturer</th>
<th>Topic</th>
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<tbody>
<tr>
<td>1</td>
<td>No lecture: tentatively rescheduled on Fri 8/08</td>
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<tr>
<td>2</td>
<td>Tue 5/08</td>
<td>Morello</td>
<td><strong>Introduction to Quantum Mechanics:</strong> The postulates of Quantum Mechanics; Hamiltonian operators, Schrödinger equation; Spin operators, Pauli matrices</td>
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<td></td>
<td>Fri 8/08</td>
<td>Morello</td>
<td><strong>Two-level systems – qubits:</strong> Bloch sphere, rotations and projections; Coupling to resonant excitations, Rabi oscillations; Double-well potential, tunneling, mapping to Bloch sphere</td>
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<td>3</td>
<td>No lecture this week: make-up lecture on week 6 after consulting the students</td>
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<td>4</td>
<td>Tue 19/08</td>
<td>Guest</td>
<td><strong>Nanofabrication and experimental techniques:</strong> Scanning probe techniques; Nano-lithography; Low temperature techniques</td>
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<td>5</td>
<td>Tue 26/08</td>
<td>Morello</td>
<td><strong>Decoherence:</strong> Density matrix, tracing over environment; Noise, spectral densities; Relaxation and dephasing</td>
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<td>6</td>
<td>Tue 2/09</td>
<td>Morello</td>
<td><strong>Coupled qubits - logic gates:</strong> Exchange interaction, singlet-triplet states; Physical implementation of Controlled-NOT gates; Entanglement</td>
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<td>TBA (make-up of week 3)</td>
<td>Dzurak</td>
<td><strong>Quantum Dots I:</strong> Coulomb blockade and single electron tunnelling; The quantum point contact (QPC); Few electron quantum dots</td>
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<td>7</td>
<td>Tue 9/09</td>
<td>Dzurak</td>
<td><strong>Quantum Dots II:</strong> Spin to charge conversion; 2 electron dot: single and triplet states; double dots and spin blockade</td>
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<td>8</td>
<td>Tue 16/09</td>
<td>Morello</td>
<td><strong>Basics of superconductivity:</strong> Cooper pairs, condensation, order parameter; Energy spectrum, superconducting gap; Josephson effects</td>
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<td>9</td>
<td>Tue 23/09</td>
<td>Morello</td>
<td><strong>Superconducting Quantum Devices:</strong> Superconducting Quantum Interference Devices; Macroscopic quantum tunneling, phase qubits, flux qubits; Coupling phase and flux qubits</td>
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<td>Mid-session break</td>
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<td>10</td>
<td>Tue 7/10</td>
<td>Morello</td>
<td><strong>Single Charge Devices:</strong> The single-electron transistor; The RF-SET and its applications; Cooper-pair box: reduction to a two-level system and effective spin on the Bloch sphere</td>
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|   | Tue 14/10 | Morello | **The Cooper-pair box**  
|   |           |         | Spectroscopy and rotations on the Bloch sphere; Decoherence; Coupled qubits |
| 12 | Tue 21/10 | Morello | **Circuit Quantum Electrodynamics:**  
|   |           |         | Qubit plus resonator model - quantizing the electromagnetic field; Vacuum Rabi oscillations, dispersive measurements; Future directions |

**Notes:**
- There will be no lecture on Week 1. The first lecture will be on Tuesday 5 August, and a make-up lecture is tentatively scheduled for Friday 8 August. If this is inconvenient for some students, notify the lecturer during the first lecture.
- There will be no lecture on Week 3. A make-up lecture for this is tentatively scheduled on week 6, at a time and date convenient for the students.