PHYS 550 Topics in Condensed Matter Physics: Quantum Devices I

Number of units: 1.5
Prerequisite:
Attendance of the QSciTech-QuantumBC-CMC virtual workshop on superconducting circuit and qubits is mandatory.
https://www.cmc.ca/virtual-workshop-build-your-own-superconducting-quantum-device/

Because workshop attendance is mandatory, this course is available to first-year and second-year graduate students who start in January or May, but those who start in September (and miss the workshop) will have to wait until year 2 to take the course.

Course dates: July to December (this includes the workshop)

Overview
Building quantum computers is a great challenge and involves concepts and technology that have similarities and differences with those in conventional "classical" computers. It involves cryogenic electronics and in the currently most advanced approach it relies on superconducting circuits that display quantum effects. The topic of this course is superconducting quantum devices and circuits for quantum computation.

This is a 1.5-unit course broken up in two mandatory parts.
Part 1: The first part of the course, ***which is mandatory***, is a workshop in July where students learn the theory of how the devices behave, how to analyze superconducting devices and circuits, and how to design devices and circuits that are compatible with foundry-based fabrication.

PART 2: The second part of the course, ***which is mandatory***, is a course project carried out from September to November, where the deliverable is a midterm report and final report on the design, analysis, and fabrication of superconducting circuits for quantum computing.

Part 1 (2022): June 20 to July 8: Attendance of the QScitech-QuantumBC-CMC virtual workshop on superconducting circuit and qubits is mandatory.
https://www.cmc.ca/virtual-workshop-build-your-own-superconducting-quantum-device/

Part 2 (2022)**:** September to November.

Learning objectives
The learning objectives for the course are:
1. Be able to use models to predict the performance and behaviour of superconducting devices and circuits.
2. Be able to design a superconducting circuit using software such as LEdit, and to predict its properties using Ansys HFSS, Q3D, etc.
3. Be able to compare foundry processes to see their impact on the performance of devices.

4. Translate the physical design into a foundry compatible process for submission to fabrication.

Evaluation is based on a project presentation and two reports. The first report is on the analysis and device design. The second report is a final design report.

Overview

Lecture format: A total of fifteen (15) 90-minute lectures during the summer workshop “superconducting circuits and qubits” delivered by worldwide experts in the field from academia (UBC, UVic, Sherbrooke) and industry (D-Wave and IBM).

Office hour format: From September to November, the course will offer weekly one-hour meetings, where students discuss their progress towards course goals with the instructor. Other experts may be asked to attend some of the office hours in order to help with device design.

Lecture contents:

1. Theory of applied superconductivity: Penetration depth, Josephson effect, RF and DC SQUIDS.
2. Theory of superconducting devices as quantized circuits: canonical quantization, the Josephson Junction as a nonlinear device.
3. Theory of circuit extraction and distributed circuit design: transmission lines, resonators, and filters.
4. Foundry manufacturing process and Process Design Kit Tutorial + L-edit basics.
5. Theory of two-level quantum systems, harmonic oscillators, circuit elements, quantizing circuits.
6. Design tutorial: coplanar waveguide resonator and lumped element resonators for qubit readout.
7. Experimental measurement tutorial: cryogenics, low-frequency measurement, signal-to-noise ratio, 1/f noise.
8. Q3D and parameter extraction.
9. Design tutorial: Qubit layout : Xmon coupled to resonator
10. material loss measurements using microwave resonator
11. Design tutorial: Xmon qubit coupled to a resonator.
12. Design and simulation Tutorial: Lumped element resonator.
13. Theory: readout of superconducting circuits, superconducting analog to digital converters.
14. Design tutorial: RF-SQUID qubit and readout circuitry.
15. Amplifiers and signal amplification in superconducting circuits.

Course evaluation/assessment

Course timing:

- <u>Deliverable:</u> Project proposal: 5 minute student presentation – September 28.
- <u>Deliverable:</u> Project design report R1 – October 16.

- Deliverable: .gds file – October 15 (CMC deadline).
- Deliverable: Final design report R2 – November 1.

Details of reports

The project design report (R1) and final design report (R2) have the following sections and are 4 pages and 8 pages, respectively, in 2-column format:

- R1: Introduction: What is the problem, how has it been tackled before, what are the remaining problems?
- R1: Proposed design: What you plan to design and why? Figures and schematics of the proposed design.
- R1: Methodology: tools you plan to use to predict device and circuit behaviour.
- R1: Results: Output of the methodology once applied to your design.
- R1/R2: Fabrication details: description of the fabricated design.
- R1/R2: Test plan: how you anticipate testing the circuit.
- R1/R2: Appendix: overall chip layout.

Grading system

- 10% Project proposal.
- 50% Project design report.
- 40% Final design report.