UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Applied Quantum Technologies

2526-1-F1703Q004

Aims

Quantum Technologies exploit the ability to control quantum phenomena in matter to create sensors with otherwise unreachable sensitivities and computing systems capable of solving otherwise inaccessible problems. This is the second quantum revolution that is underway in recent years and at the base of which there are quantum devices - qubits - realized by exploiting different platforms.

In this course the student will acquire the key skills necessary to understand the mechanisms by which qubits can be used as elements of a computer or as sensors. In particular, we will focus on superconducting qubits, which are now the core of the most advanced quantum computers, and the technologies related to their use.

The skills students acquire will provide a solid foundation for understanding more complex quantum devices, including those based on other platforms, and their applications.

Contents

- qubits practical implementations
- superconducting qubits
- operate with qubits
- qubits as sensors
- application examples
- other type of qubits and examples of their application

Detailed program

- Quantum systems for quantum technologies: qubits
- Superconductivity
  - Phenomenology
  - Josephson effects
  - Josephson junctions
  - RF and DC SQUIDS
  - Macroscopic Quantum Effects with Josephson junctions
- Superconducting qubits
  - Quantization of superconducting circuits
  - Circuit QED
- Two-level quantum systems dynamics
  - Density matrix dynamics
  - Open systems
  - Two-level quantum system coherent control
- Quantum measurement
  - Quantum Non Demolition measurements
  - Amplification and noise
  - Noise and decoherence
- Coupled qubits and entanglement
- Parametric amplifiers
- Other platforms examples
- Quantum sensing with qubits

Prerequisites

A course in Quantum Mechanics at the bachelor's degree level in physics (the basic concepts required will be recalled)

Teaching form

21 2-hour lectures conducted in person and in *delivery* mode (6 cfu).

Textbook and teaching resource

Two texts providing the basic concepts might be:

- "Quantum Engineering - Theory and Design of Quantum Coherent Structures", A.M. Zagoskin, Cambridge University Press, 2011
- “Quantum measurement “, Vladimir B. Braginsky, Farid Ya Khalili, Kip S. Thorne, Cambridge University Press, 1992

More specific textbooks will be suggested during the course.

Furthermore, review articles will be referenced during the course according to the topics covered in class. A preliminary list includes:

- “Quantum sensing”, C. L. Degen, F. Reinhard, and P. Cappellaro. Rev. Mod. Phys. 89, 035002; https://doi.org/10.1103/RevModPhys.89.035002
- “A quantum engineer's guide to superconducting qubits”, P. Krantz, M. Kjaergaard, F. Yan, T. P. Orlando, S. Gustavsson, and W. D. Oliver. Applied Physics Reviews 6, 021318 (2019); https://doi.org/10.1063/1.5089550
- “Introduction to Experimental Quantum Measurement with Superconducting Qubits”, Mahdi Naghiloo, PhD 2019, Murch Lab, Washington University in St. Louis; arXiv:1904.09291

Semester

1st semester

Assessment method

Oral examination on the topics presented during the course. The exam is conducted in English.
The colloquium begins with the discussion of a scientific article chosen by the student.

The exam aims to assess the student's ability to independently read and understand a scientific article in the field of experimental quantum science and technology by applying the principles and concepts learned in class.

The ability to expand one's knowledge by consulting the extensive bibliography proposed in class and through the seminars offered during the course will also be assessed, as well as the ability to present and argue through the presentation of the chosen article.

Exam grade 18-30/30
No intermediate test is planned.

Office hours

On appointment by email

Sustainable Development Goals

INDUSTRY, INNOVATION AND INFRASTRUCTURE