Course guide
2301117 - QBAP - Qubit Applications

Last modified: 17/06/2023

Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 739 - TSC - Department of Signal Theory and Communications.

Degree: MASTER'S DEGREE IN PHOTONICS (Syllabus 2013). (Optional subject).

Academic year: 2023 **ECTS Credits:** 3.0 **Languages:** English

LECTURER

Coordinating lecturer: Juan P. Torres, professor at Signal Theory and Communications (TSC) Department, Universitat Politecnica de Catalunya (UCP), and Group Leader of Quantum Engineering of Light group at ICFO-Institute of Photonic Sciences

Others: Juan P. Torres, professor at Signal Theory and Communications (TSC) Department, Universitat Politecnica de Catalunya (UCP), and Group Leader of Quantum Engineering of Light group at ICFO-Institute of Photonic Sciences

PRIOR SKILLS

Basic knowledge of algebra and quantum physics

REQUIREMENTS

No requisites

TEACHING METHODOLOGY

- Lectures
- Resolution of exercises in the classroom

LEARNING OBJECTIVES OF THE SUBJECT

Quantum theory is not only a great achievement of human thinking, but almost since its beginning, also a source of new technologies that eventually affect the daily life of people everywhere. The laser, the transistor, atomic clocks and Positron Emission Tomography (PET) are examples of this, just to name a few.
In the last few decades, a surge of new ideas that make use of quantum thinking and concepts coming from information theory are finding its way towards applications (Quantum Information). The concept of qubit summarizes precisely the peculiarity of quantum thinking about information. Some call this stage in the development of quantum theory a second revolution (see Alain Aspect, John Bell and the second quantum revolution, prologue for a new edition of the book Speakable and unexplicable in quantum mechanics, Cambridge University Press, 2004). This surge of applications has been made possible by an extraordinary improvement in our capacity to generate, manipulate and detect with precision a large family of quantum state of atoms and photons.
Many of these applications are still in its infancy, and what level of development and society impact they will reach is uncertain. Notwithstanding, nowadays important technology companies that base its business on information have divisions devoted to quantum science, especially quantum computing: IBM (https://research.ibm.com/quantum-computing), Google (https://quantumai.google/), Microsoft (https://www.microsoft.com/en-us/quantum/). The European Union has a program to booster the development of quantum applications (Quantum Technologies Flagship, 2018-2028).
In this course we aim at unveiling what fundamental quantum concepts make special a quantum application, and provide an advantage to it over alternative approaches. The goal is to isolate the specific features that make quantum a quantum application. We will do this by considering relevant, specific, but simple, examples. The detailed analysis of these examples will ease the exploration of the quantumness of the applications studied. We will consider quantum applications with high expectations nowadays in three areas of technology: quantum communications (secure communications), quantum imaging and sensing (imaging and sensing with enhanced sensitivity) and quantum computing.

STUDY LOAD

Type	Hours	Percentage
Hours large group	24,0	32.00
Self study	51,0	68.00

Total learning time: 75 h

CONTENTS

1. Introduction (2 hours)

Description:
1.1 Quantum thinking with an information flavour: Quantum information.
1.2 Generation, manipulation and detection of quantum states of atoms and photons (quantum engineering).
1.3 A panorama of quantum applications: communications, sensing and imaging, computing and simulations.

Full-or-part-time: 2h
Theory classes: 2h

2. Secure Communications (6 hours)

Description:
2.1 The quantum concepts: Distinguishability of quantum states and no-cloning of quantum information.
2.2 Perfect secrecy is possible: the one-time pad protocol and the question of key distribution.
2.3 Security through quantum indistinguishability: Bennet-Brassard quantum key distribution protocol (BB84).
2.4 Security through quantum entanglement: Ekert quantum key distribution protocol (EK91).
2.5 Perspective of applications: technical hurdles to be overcome.

Full-or-part-time: 6h
Theory classes: 6h

3. Quantum imaging and sensing (8 hours)

Description:
3.1 The quantum concept: exotic quantum states with peculiar properties.
3.2 Quantum Fisher information and the quantum Cramer-Rao bound (quantum estimation theory). Optimum measurement.
3.3 Examples: NOON states, the Hong-Ou-Mandel effect, atomic Ramsey interferometer, photonic SU (1,1) interferometer.
3.4 Mimicking (part) of the quantum world: quantum inspired protocols for imaging and sensing.

Full-or-part-time: 8h
Theory classes: 8h

4. Quantum Computing (8 hours)

Description:
4.1 The quantum concept: principle of superposition (everything that can happen will happen). Quantum gates.
4.2 Examples: Deutsch–Jozsa algorithm, boson sampling and Shor algorithm.
4.3 Technical hurdles towards success: decoherence

Full-or-part-time: 8h
Theory classes: 8h

GRADING SYSTEM

1) One or two short written exams (40%)
2) Homework assessments, individual or in groups (60%)

BIBLIOGRAPHY

Complementary:

- Susskind, Leonard ; Friedman, Art. Quantum Mechanics: The theoretical minimum. New York: Basic Books, 2014. ISBN 9780465036677.
- Gisin; N. Quantum chance: nonlocality, teleportation and other quantum marvels [on line]. Cham: Springer International Publishing, 2014 [Consultation: 04/07/2023]. Available on: https://ebookcentral.proquest.com/lib/upcatalunya-ebooks/detail.action?docID=1782235. ISBN 9783319054735.
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- Haroche, S.; Raimond, J.-M. Exploring the quantum: atoms, cavities and photons. Oxford: Oxford University Press, 2006. ISBN 0198509146.
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