COURSE OFFERED IN THE DOCTORAL SCHOOL

Code of the course	4606-ES-00000BC-0017	Name of the course	Polish	**Informacyjne technologie kwantowe**	
			English	**Information quantum technologies (ITQ)**	
Type of the course	Special courses				
Course coordinator	prof. dr hab. inż. Ryszard Romaniuk				
Implementing unit	WEiTI	Scientific discipline / disciplines*	information and communication technology, automation, electronic, electrical engineering and space technologies		
Level of education	Doctoral studies	Semester	Winter		
Language of the course	English				
Type of assessment:	Graded credit	Number of hours in a semester	30	ECTS credits	2
Minimum number of participants	12	Maximum number of participants	30	Available for students (BSc, MSc)	Yes/~~No~~

Type of classes		Lecture	Auditory classes	Project classes	Laboratory	Seminar
Number of hours	in a week	2	0	0	0	0
	in a semester	30	0	0	0	0

* does not apply to the Researcher's Workshop

1. Prerequisites

Mathematics, physics, basics of electronics, computer science; recommended pre-courses alternatively: physics, photonics, electronic materials, computer architecture, bioelectronics, biomedical apparatus, metrology, image processing, telecommunications, computer engineering;

2. Course objectives

The aim of the course is to show the dynamic development of quantum information technologies, the prospects for the development of some quantum technologies in the country, also at the innovative and commercial level, and the very attractive subject of the implementation of master's theses, especially doctoral dissertations, in the next decade. Information quantum technologies (IQT) are not taught in a compact form as a whole, creating a new area of engineering and technical sciences, including in particular the scientific disciplines of Automation, Electronics and Electrical Engineering (AEE) and Applied Informatics and Telecommunictions (ITT). This area is interdisciplinary and includes the following knowledge with the adjective quantum: principle of operation, technology of functional elements and devices, sensors, clocks, photonics, computer science, computer architecture, complex systems, etc. With the current rapid development of the IQT area, the subject seems to be obligatory for doctoral students in ITT and AEE.

3. Course content (separate for each type of classes)

Lecture

- Information Quantum Technologies. Area of interest and **particular IQT subjects. Differences between classical information and quantum technologies. A brief reminder of quantum physics. Basic concepts of quantum mechanics, the quantum state of a system. Two-level systems. The Heisenberg principle. Quantum non-commutating quantities. Pauli's rule. Wave particle dualism and the** deBroglie wave. Quantum tunneling. Non-classical fields. Interference and superposition of quantum states. Quantum pure and mixed states. Entanglement and quantum nonlocality, Schwarzschild Tunnel and its stability. Relationship of quantum mechanics with IQK.
- Informatic theory of a qubit. Actions on qubits. Single and multi-qubit quantum gates. Quantum algorithms. Publishing workshops with IQT.
- Quantum computing, **open source software community initiatives.** QWorld Initiative. Quantum national QAIF community. Structural quantum programming language QCL. Qiskit platform. Selected quantum algorithms (Bernstein, Deutsch, Kitayev, Simon, Grover, ...).
- Quantum cryptography and cybersecutity. Cryptographic architectures and quantum algorithms. Shor's factorization algorithm. Postquantum cryptography.

• Physical realization of the qubit 1. Atomic optics. Types of qubits - ionic, hyperfine, atomic, spin, vacant, molecular, phase, beam, superconductive, quasi-molecular. Design of ion traps. Miniaturization of quantum elements and devices. Energy optimization. • Physical realization of the qubit 2. Quantum photonics. Non-classical light. Wigner function, Squeezed light, Photon ststistics. Slow light. Lasers for quantum technologies. What does the spectral width of the laser beam 10^{-6} Hz mean and what are the consequences? Stationary and flight qubits. Quantum registers, their implementation and stability. • Quantum computer. Theory. Quantum Turing machine – deterministic and undeterministic. What is really needed to build a good quantum computer? • Quantum computer. Practice. Universal quantum computer. NISQ computer. Parameters of some NISQs machiones, Google / Sycamore, Honeywell, IBM / Hummingbird, D-Wave machines. Quantum Supremacy / Advantage ratio. Performance metric Quantum Volume. Quantum annealer and quantum gate computer. • Quantum photonic computer. Boson sampling algorithm. The problem of photon mastering. Strictly single photon technologies. • Quantum cloud environments. Azure Quantum. Amazon Bracket. IBM Quantum cloud. • Quantum sensors. Quantum NMR measurements. Absolute gravimeters. Navigation without GPS. Measurements below the quantum limit. Quantum Projection Noise Annihilation. How does LIGO work? Multiple entangled NOON states. • Quantum Imaging. Quantum super-resolution imaging. Measurements below the diffraction limit. Quantum structured lighting. Ghost imaging. Quantum microscope. Quantum telescope. • Atomic clocks. Optical comb. What does the instability of the 10^{-20} clock mean and what are the consequences? • Quantum telecommunications. Quantum teleportation of information. Quantum telecommunications channel. Quantum teleportation of local vacuum energy? Quantum informational limit. • ARTIQ and SINARA hardware-programming quantum standardized design environment. Open github / sinara quantum hardware initiatives. ATCA and microTCA standard. The PERG ISE WEiTI Laboratory has an Artiq / Sinara environment and it is possible to organize several demonstration exercises / laboratory shows related to the design of a quantum computer Quantum assisted computational techniques in biophysics and biophotonics. Machine learning and AI for data interpretation. Biology-inspired quantum computational techniques. Hardware and programming environments for the design and construction of quantum apparatus and software: QISKIT, ARTIQ, SINARA.
Project

4. Learning outcomes			
	Learning outcomes description	Reference to the learning outcomes of the WUT DS	Learning outcomes verification methods*
Knowledge			
K01	Has knowledge of: the basics of relativistic and quantum physics, local and non-local quantum phenomena used to build technical devices.	SD_W2, SD_W3,	exam, presentation evaluation; assessment of activity during classes;
K02	Has ordered, theoretically founded knowledge in the field of design and rules of using quantum technical devices, such as computers, sensors and measuring devices, and complex systems, including telecommunications.	SD_W2, SD_W3,	exam, presentation evaluation; assessment of activity during classes;
K03	Is able to assess where the potential of IQT techniques can be used in the conducted own research.	SD_W1, SD_W2, SD_W3,	exam, presentation evaluation; assessment of activity during classes; homework;
Skills			

S01	Student can use the known methods and theoretical and technical models to analyze the basic issues in the area of quantum information technologies and apply the basic methods of designing quantum technical devices.	SD_U1, SD_U2, SD_U8,	exam, presentation evaluation; assessment of activity during classes;
S02	Is able to use the learned principles and methods of quantum information technologies and appropriate design tools to solve basic tasks in the field of quantum computing, quantum metrology, and the basics of quantum telecommunications.	SD_U1, SD_U2, SD_U8,	exam, presentation evaluation; assessment of activity during classes;
S03	Is able to obtain information from literature, databases and other sources, can integrate the obtained information, interpret it, as well as draw conclusions and formulate and justify opinions. Can work effectively in a virtual design environment. Can prepare an outline of a publication on the role of ITQ in own research.	SD_U1, SD_U2, SD_U8,	exam, presentation evaluation; assessment of activity during classes; homework;
Social competences			
SC01	Understands the need for lifelong learning; can inspire and organize the learning process of other people.	SD_K1, SD_K2,	exam, presentation evaluation; assessment of activity during classes;
SC02	Can interact and work in a group, assuming various roles in it. Understands the role and importance of scientific and technical publications as documentation of valuable results of own work.	SD_K1, SD_K2,	exam, presentation evaluation; assessment of activity during classes; homework;

*Allowed learning outcomes verification methods: exam; oral exam; written test; oral test; project evaluation; report evaluation; presentation evaluation; active participation during classes; homework; tests

5. Assessment criteria

Activity during classes; Substantive quality of the preparation of an individual academic seminar; Participation in publication workshops and preparation of a team article; ;

6. Literature

<u>Basic bibliography (examples)):</u>

[1] T. Fortier and E. Baumann (2019). 20 years of developments in optical frequency comb technology and applications. Commun Phys, Vol. 2, Issue 153, pp. 1-15.
[2] J.Tom, et al (Dec. 2020), Exploring the role of high-purity laser light in quantum technology, Photonics Spectra.
[3] T. Ladd et al. (2010). Quantum computers. Nature, Vol. 464, Issue 45, pp. 45-53.
[4] X. S.L.Bayliss et al. (2020), Optically addressable molecular spins for quantum information processing, arXiv 2004.07998.
[5] X. G.Wolfowicz, et al (2020), Vanadium spin qubits as telecom quantum emitters in silicon carbide, arXiv 1908.09817.
[6] Z.Ma, et al. (Dec.2020), Ultrabright quantum photon sources on chip, PRL 125, 263602.
[7] H-S.Zhong, et al. (2020), Quantum computational advantage using photons, Science 370(6523), 1460-1463,
[8] D.P.DiVincezno (2000), The physical implementation of quantum computation, arxiv:quant-ph/02077.
[9] G.B.Lemos, et al. (Jan.2014), Quantum imaging using undetected photons, Nature.
[10] http://scienceinpoland.pap.pl/en/news/news%2C33740%2Ctwo-polish-scientists-eu-quantumtechnologies-advisory-board.html
[11] https://github.com/sinara-hw/meta/wiki/Team

[12] https://sinara-hw.github.io/
[13] https://m-labs.hk/experiment-control/artiq/
[14] https://github.com/sinara-hw/meta/wiki/Status
[15] C.J.Ballance, et al (2016), High-fidelity quantum logic gates using trapped-ion hyperfine qubits, PRL 117, 060504.
Supplementary bibliography:
[1] Cycle of research and technical papers authored by the lecturer in IJET PAN Quarterly Journal and Electronics Monthly during 2021-2022

7. PhD student's workload necessary to achieve the learning outcomes**		
No.	Description	Number of hours
1	Hours of scheduled instruction given by the academic teacher in the classroom	30
2	Hours of consultations with the academic teacher, exams, tests, etc.	10
3	Amount of time devoted to the preparation for classes, preparation of presentations, reports, projects, homework	20
4	Amount of time devoted to the preparation for exams, test, assessments	10
	Total number of hours	**70**
	ECTS credits	**2**

** 1 ECTS = 25-30 hours of the PhD students work (2 ECTS = 60 hours; 4 ECTS = 110 hours, etc.)