COURSE DESCRIPTION CARD - SYLLABUS

Course name
Microwaves in Quantum Computers [S1MiKC1E>MwKK]

Course

Field of study
Microelectronics and Digital Communication

Year/Semester
3/5

Area of study (specialization)
–

Profile of study
general academic

Level of study
first-cycle

Course offered in
English

Form of study
full-time

Requirements
elective

Number of hours

Lecture
15

Laboratory classes
30

Other
0

Tutorials
0

Projects/seminars
0

Number of credit points

3,00

Coordinators

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Lecturers

Prerequisites

Students enrolling in this course should have a fundamental knowledge of basic electronics, electrical circuit theory, transmission lines, radio wave propagation, and quantum mechanics (specifically phenomena utilized in quantum computing). They should also be proficient in decibel calculus and electrical metrology (including voltage, current, and resistance measurements, oscilloscope operation, and estimation of measurement uncertainty). Furthermore, students are expected to be familiar with the Smith chart, possess the ability to calculate simple DC and AC electrical circuits, be skilled in retrieving information from specified sources, and be prepared to collaborate in a team.

Course objective

The objective of this course is to prepare students to understand the fundamentals and specifics of microwave engineering, including the design, principles of operation, and parameter measurement of active and passive microwave circuit components utilized in quantum computers (superconducting, ion- based, and spin-based). Furthermore, the course aims to familiarize students with measurement methods and instruments typical of microwave technology, such as network analyzers and spectrum analyzers.

Course-related learning outcomes

Knowledge:
Upon completion of the course, the student will possess detailed knowledge of the phenomena, devices, and measurement methods used in the microwave circuits of quantum computers.

Skills:
Upon completion of the course, the student:
1. is familiar with the specific characteristics of microwave circuits that distinguish them from classical electrical circuits;
2. is able to analyze phenomena occurring in the microwave circuits of quantum computers and can interpret scattering matrix parameters (S-parameters) as well as the technical documentation of microwave components;
3. can design, implement, and conduct measurements of signal paths and microwave components, making conscious use of measurement apparatus in a microwave laboratory (including test report preparation in accordance with the PN-EN ISO/IEC 17025 standard);
4. understands the impact of transmission lines and other microwave components on the performance and operation of quantum computers;
5. can retrieve and analyze information from literature, databases, and other sources in both Polish and English;
6. is able to effectively organize individual and team work and collaborate within a group, taking responsibility for joint tasks (including planning the measurement process and recording the results);
7. can apply occupational health and safety (OHS) regulations and principles.

Social competences:
Upon completion of the course, the student:
1. recognizes the limitations of their own knowledge and skills and understands the necessity of lifelong learning and continuous professional development;
2. understands the significance of RF and microwave techniques for the advancement of modern quantum technologies;
3. is able to work effectively in a laboratory team and communicate with representatives of other disciplines, including physics, electronics, and computer science;
4. takes responsibility for designed electronic systems and is aware of the potential hazards to individuals or society resulting from their misuse or negligent design and operation.

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

1. knowledge acquired at lectures is verified during the final written and/or oral exam (duration of the written part 60-90 minutes; descriptive answer to 3-5 questions, the pass threshold of 50% points (grade 3.0) , the list of exam questions is available to students on the E-kursy platform)
2. the knowledge and skills acquired in laboratory exercises are verified on the basis of the evaluations of the reports from laboratory exercises.

Programme content

Lectures
1. Microwaves in the EM spectrum and their characteristics; lumped and distributed parameter circuits; decibel calculus; EM wave propagation in waveguides; TE and TM modes; wave parameters of transmission lines; RF laminates; striplines and microstrips; coplanar waveguide (CPW); microwave circuit components in microstrip technology; resonators; standing waves; VSWR (Voltage Standing Wave Ratio); RL (Return Loss); impedance matching of circuits (4 h).
2. Voltages, currents, and impedances in microwave systems; definition of the S (scattering) matrix; physical significance of S-parameters; Vector Network Analyzer (VNA); measurements of S-parameters and impedance; design and operating principles of a spectrum analyzer; microwave diodes and transistors; temperature effects on material parameters; noise in electronic systems (5 h).
3. Block diagram of a quantum computer; quantum mechanics and its impact on the specifics of quantum computing; Bloch sphere; quantum gates; quantum state control of qubits; qubit readout; microwave amplifiers with HEMT (High-Electron-Mobility Transistor) transistors; I/Q modulation and demodulation; significance of phase for qubit states; phase noise of generators; design and operation of Phase-Locked Loops (PLL); parameters of qubit control pulses; near-field antennas (6 h).

Course topics

Laboratory
Preparatory part for practical exercises (solving numerical problems):
1. Health and Safety (H&S) when working with 230 V electricity and in electromagnetic fields.
2. Matching circuits (Smith chart).
3. Calculation of scattering matrix parameters (S-parameters).
4. Decibel calculus and measurement uncertainty estimation.
Practical part:
1. Measurement of scattering matrix parameters of filters and amplifiers.
2. Measurements of selected microwave components implemented in microstrip technology.
3. Wave propagation in waveguides.
4. Spectrum analyzer.
5. Network analyzer.

Teaching methods

1. Traditional (informational) lecture: multimedia presentations supplemented by examples provided on the board and educational videos.
2. Laboratory classes: solving measurement-related problems in the experimental section, conducting practical exercises in groups (2-4 people) based on written instructions, experimental demonstrations, and educational videos.

Bibliography

Basic:
1. Szóstka J., Mikrofale. Układy i systemy, Wyd. Komunikacji i Łączności, Warszawa, 2006.
2. Szóstka J., Fale i anteny, Wyd. Komunikacji i Łączności, Warszawa, 2006.
3. Szóstka J., Miernictwo radiokomunikacyjne, Wyd. Politechniki Poznańskiej, Poznań, 2021.
4. Salari A., Microwaves Techniques in Superconducting Quantum Computers, Artech House, 2024.

Additional:
1. Young P., Electronic Communication Techniques, Bell & Howell Company, 2003.
2. Bahl I., Bhartia P., Microwave Solid State Circuit Design, John Wiley&Sons, 2003.
3. Pozar D.M., Microwave Engineering, John Wiley & Sons, 2011.
4. Baranowski J., Nosal Z., Układy elektroniczne, cz. I i II, WNT, Warszawa 1993.

Breakdown of average student's workload

	Hours	ECTS
Total workload	75	3,00
Classes requiring direct contact with the teacher	45	2,00
Student's own work (literature studies, preparation for laboratory classes/ tutorials, preparation for tests/exam, project preparation)	30	1,00