Special Topics in EE: FPGA in Quantum Computing with Superconducting Qubits

Last Offered: 2020 Fall (online, at Sabancı University)
Faculty: Faculty of Engineering and Natural Sciences
Subject: Electronics Engineering (EE)
SU Credit: 3
Instructor(s): Kadir Akin aakin@phys.ethz.ch
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Language of Instruction: English
Level of Course: Graduate
Prerequisites: -
Mode of Delivery: Formal lecture, Interactive lecture, Laboratory
Planned Learning Activities: Interactive, Communicative, Task based learning
Time and Place: Thursday 09:40-12:30, Online (A few lab sessions, midterm and final projects would require in place demonstrations)

Abstract

This course provides a comprehensive introduction to FPGA programming and its advanced applications in controlling and measuring superconducting qubits. No prior knowledge in quantum physics or FPGA programming is required.

Content

Hardware description languages, fixed point arithmetic, simulating digital hardware using Vivado, system-on-chip design, programming embedded processor and FPGA, analog to digital converters, digital to analog converters, block RAMs and ROMs, FPGA implementation of digital down conversion module and finite impulse response filter, pipelining, resource sharing, signal processing using MATLAB, IQ demodulation, signal reconstruction, bloch sphere, resonators, control and measurement of superconducting qubits, quantum state identification, qubit decay, Rabi measurement, Ramsey measurement, quantum fidelity, and fidelity optimization.

Objective

Primary educational objective is to learn the FPGA based signal processing for superconducting circuits-based quantum experiments. The course participants will learn the implementation techniques of the modules for fast quantum signal acquisition and processing, the electronics supporting quantum experiments, and FPGA programming. Students will implement quantum signal processing and quantum state detection modules using Xilinx FPGA, Verilog HDL, high speed ADC and DAC. The course utilizes project-based learning approach for encouraging students to engage in their learning process actively. Students will apply their theoretical knowledge in mathematics, signal processing and physics, while implementing advanced architectures using FPGA.

Assessment Methods and Criteria

	Percentage
Weekly Assignments (group work)	20
Midterm Project Report (group work)	20

Midterm Presentation (individual)	20
Final Project Report (group work)	20
Final (Oral Exam) (individual)	20

Weekly Schedule:

Lecture 1: Introduction & Quantum Signal Processing
Lecture 2: Programming Xilinx FPGA
Lecture 3: Introduction to Verilog
Lecture 4: Vivado Simulator and Rabi Measurement
Lecture 5: Using ROM and DAC for Controlling Rabi Measurement
Lecture 6: Using ROM and DAC for Controlling Ramsey Measurement
Lecture 7: IQ Demodulation for the Measurement of Quantum States (using Matlab)
Lecture 8: IQ Demodulation for the Measurement of Quantum States (using FPGA)
Lecture 9: Advantages of Pipelined Circuit
Lecture 10: FIR filter using FPGA
Lecture 11: Fidelity in Quantum Measurement
Lecture 12: Quantum State Identification using FPGA
Lecture 13: State Tomography and Summary

Lab Assignments and Grading:

The course involves three types of lab assignments: *weekly lab assignments, a complete design flow project, final project*.

Three students make a group for the lab assignments. The students are expected to complete *weekly lab assignments* during two hours lab sessions every week. Students will learn the fundamentals of hardware-software co-design and Vivado design flow with *a complete design flow project.* Students will obtain the tasks via a detailed step-by-step guide in these two types of projects. These projects do not require reporting but would act as attendance.

The students must present their creativity in the *Final Project* and provide midterm and final reports. Students will have time from the start to the end of the semester to complete the *Final Project*.

In the midterm exam, students will present one of the selected papers about using FPGA in quantum computing.

The final exam will be oral and will be based on lecture notes and the final project.