Contribution ID: **63** Type: **Poster contribution**

Open-source control of quantum devices via RFSoC FPGAs

Tuesday, 7 May 2024 17:30 (1h 30m)

Abstract

The control of superconducting qubits demands advanced instruments and software capable of handling rapid pulses with arbitrary waveforms across microwave frequencies. Traditionally, achieving such precision involved up and down-conversion techniques, merging lower-frequency pulses with higher-frequency tones. This approach often requires multiple instruments per qubit, presenting scalability challenges for larger chip designs. Several companies have therefore engineered their own hardware solutions, selling all essential components into single boxes with FPGAs for coordinating the instruments. Despite their apparent convenience, these off-the-shelf products lack flexibility and are often cost-prohibitive for research laboratories.

In recent years, Radio Frequency System on Chip (RFSoC) FPGAs have emerged as robust alternatives to conventional up/down-conversion schemes. These RFSoC boards are highly customizable, making them versatile tools for both general-purpose and quantum applications. Notably, RFSoC boards allow for direct pulse synthesis within the gigahertz range, which is where resonance and qubit frequencies typically are. The use of RFSoC boards also provides a huge simplification of the experimental setup: indeed, a single board can be the sole instrument required to control multiple qubits.
For Quantum Control, the research community achieved open firmware through the QICK (Quantum Instrumentation Control Kit) project by FNAL (Fermi National Accelerator Laboratory.) Presently, QICK provides firmware for various RFSoC boards manufactured by Xilinx, allowing control of up to 7 qubits with a single instrument.

Over the past year, we have developed an open-source software named Qibosoq to augment the functionalities of QICK. Qibosoq integrates the FPGA platforms supported by QICK into the Qibo framework, an open-source project that provides fast simulation tools for quantum circuits, as well as various tools for controlling and calibrating self-owned qubits. In particular, one of the components of Qibo is Qibolab, which aims to provide researchers a common frontend to control custom quantum processing units independently from the lab setup and the controller instrument. At the moment, various commercial instruments are supported, as well as all the QICK-supported RFSoC boards, through Qibosoq.
Through the Qibo integration, it is straightforward to launch both pulse-based experiments and circuit-based algorithms on self-owned qubits.

Extensive testing of Qibosoq across all three RFSoC boards supported by QICK has yielded promising results, effectively characterizing both flux-tunable and non-tunable qubits with fidelities competitive against those obtained through commercial instruments. Moreover, Qibosoq has been successfully employed in a Quantum Machine Learning demonstration.

Acknowledgements

This work is supported by Qub-IT, a project funded by the Italian Institute of Nuclear Physics (INFN) within the Technological and Interdisciplinary Research Commission (CSN5), and PNRR MUR projects PE0000023-NQSTI and CN00000013-ICSC.
This work was supported by the Technology Innovation Institute (TII) of Abu Dhabi.

Abstract category

Other

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Session Classification: Poster session