Controlling qubits using RFSoC FPGAs

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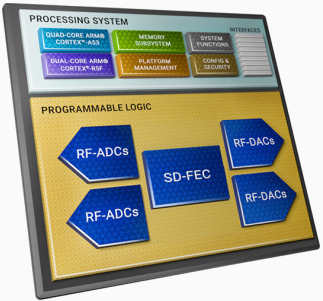
Incontro INFN su schede RFSoC 16/04/2024

Università degli Studi di Milano-Bicocca



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BIQUTE

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Qub-IT

Outline:

1. RFSoC: Radio Frequency System on chip
2. Which projects are out there?
3. What did we do? Qibosoq
4. Next steps

RFSoC: Radio Frequency System on chip

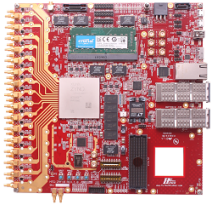
What is a RFSoC?

RFSoC is a device that integrates RF/analog, digital signal processing (DSP), and programmable logic (FPGA) on a single chip. It combines high-speed data converters, RF transceivers, multi-core processors, and programmable logic fabric. RFSoCs offer significant advantages in terms of reduced power consumption and improved system performance compared to traditional multi-chip RF systems.

Which boards are available?

Xilinx ZCU111 (Gen. 1) [8]

Xilinx RFSoC4x2, -208, -216 (Gen. 3) [7, 9]



HiTech Globals FPGAs [3]

Altera FPGAs [4]

Which projects are out there?

Different projects, same boards

QICK

- Developed in 2021 by FNAL [5, 2]
- Open-source
- Widely used

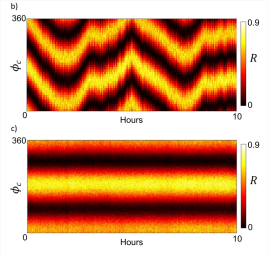
Presto

- Developed in 2022 by Intermodulation Products [6]
- Proprietary
- Used by Chalmers

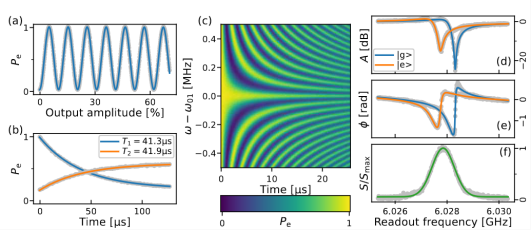
Qubic 2.0

- Developed in 2023 by Berkley [10]
- Open-source (?)

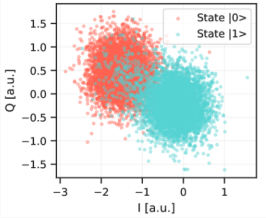
Positive reseults achieved by various groups



Longtime phase stability [2]



Characterization with Presto [6]

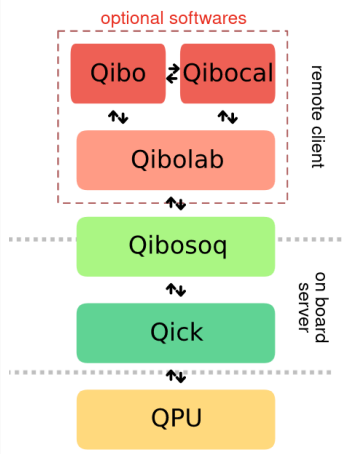


Characterization with Qibosoq [1]

What did we do? Qibosoq

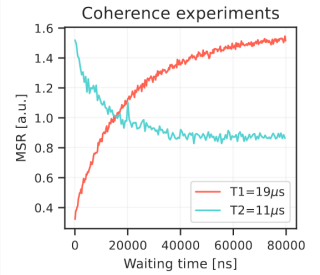
Qibosoq: a bridge between Qibo and QICK

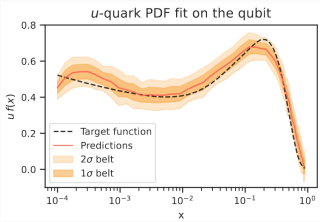
- Allows to deploy Qibolab, Qibocal and Qibo on QICK-controlled RFSoCs
  - Qibolab: coordination with other instruments and setups with multiple qubits
  - Qibocal: experiments already written for qubit calibrations
  - Qibo: deployment of algorithms or circuits
- Adds on top of QICK: abstracting from low-level technicalities



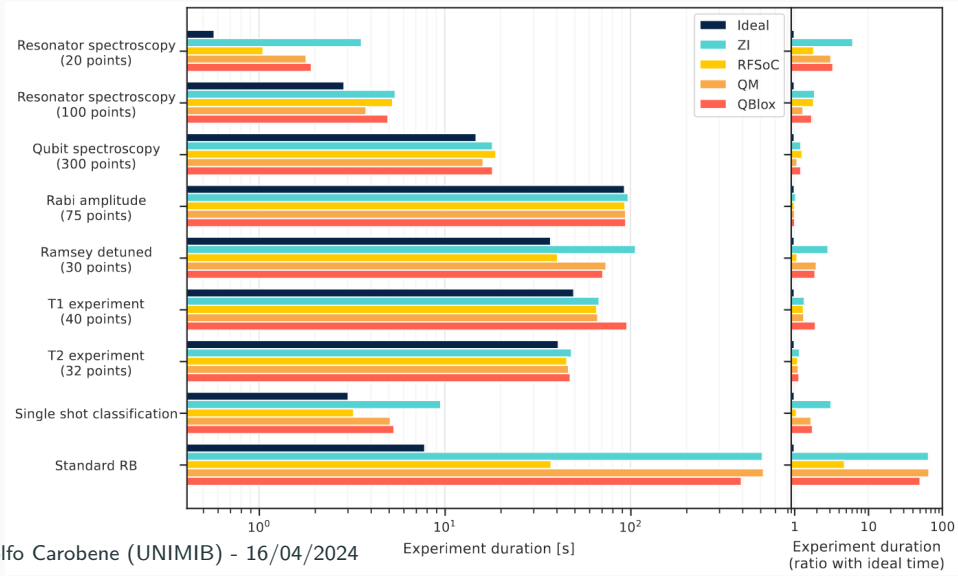
Measurements at TII

- Various qubits characterized (with 3D cavity, 2D resonators, multiplexed readout, flux-tunable, fixed-frequency)
- Results comparable to the ones of commercial instruments (QBlox, Quantum Machines, Zurich Instruments)
- Single gates with 99% fidelity and assignment fidelity of 96%.
- Two-qubit gate achieved (althought not properly calibrated)
- Now extending support to HiTech Global boards



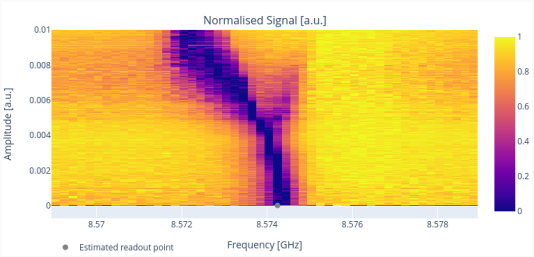


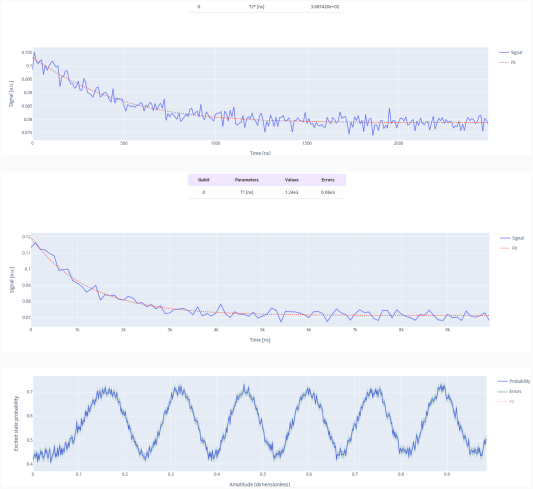
Cross-platform benchmarks



Measurements at UNIMIB

Measurements started on Monday (16/04)





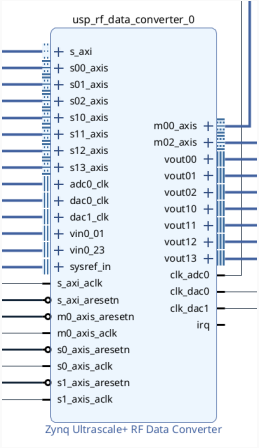
Next steps

General improvements

- Custom boxes for RFSoC4x2 and ZCU111
- Qibosoq is still evolving! Now that we are using it at UNIMIB labs, some improvements are coming to mind
- Qibocal experiment repository is growing continuosly. Latests experiments added: CHSH test, qutrit classification, cross-talk matrix
- QICK is working on new version of the timed-processor. This should lead to the possibility of syncronizing multiple boards and controlling more qubits with the same board

Firmware customization

- It is risky to fully depend from a single group (QICK)
- Writing blocks for specific applications could be useful for more applications
- It is possible to use RFSoC boards to “substitute” more instruments in a lab $->$ RFSoC are cost efficient!
- QICK is not optimal, it is possible to code something much faster and more efficient



References

[1] Rodolfo Carobene et al. **Qibosoq: an open-source framework for quantum circuit RFSoC programming.** 2023. URL: https://arxiv.org/abs/2310.05851.

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[4] Intel. **Agilex™ 9 SoC FPGA Direct RF-Series.** www.intel.com/content/www/us/en/products/details/fpga/agilex/9/direct-rf-series.html.

[5] Leandro Stefanazzi et al. **"The QICK (Quantum Instrumentation Control Kit): Readout and control for qubits and detectors".** In: *Review of Scientific Instruments* 93.4 (Apr. 2022). ISSN: 1089-7623. DOI: 10.1063/5.0076249. URL: http://dx.doi.org/10.1063/5.0076249.

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[7] Xilinx. **RFSoC 4x2 Kit.** www.amd.com/en/corporate/university-program/aup-boards/rfsoc4x2.html.

[8] Xilinx. **Zynq UltraScale+ RFSoC ZCU111 Evaluation Kit.** www.xilinx.com/products/boards-and-kits/zcu111.html.

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[10] Yilun Xu et al. **QubiC 2.0: An Extensible Open-Source Qubit Control System Capable of Mid-Circuit Measurement and Feed-Forward.** 2023. URL: https://arxiv.org/abs/2309.10333.