MIQRO: Signals for Quantum Gates, Control, and Automation

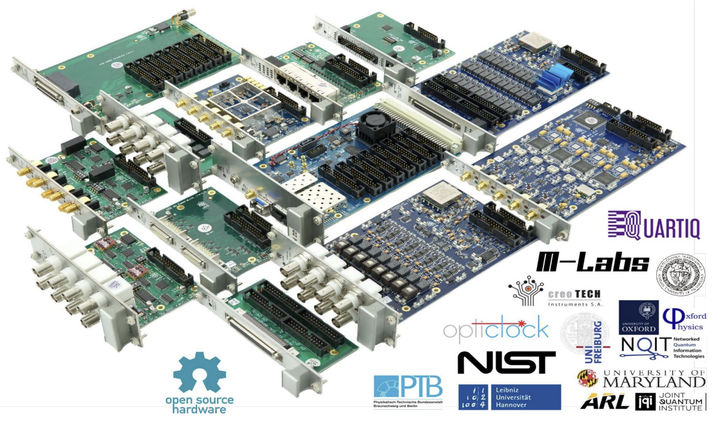
The MIQRO project

The MIQRO project will develop a breakthrough modular quantum computer built from quantum cores using stored atomic ions as quantum bits.

QUARTIQ

- QUARTIQ develops cutting edge control systems for quantum experiments.
- The “Sinara” hardware ecosystem comprises dozens of modules for signal generation, monitoring and processing.
- The “ARTIQ” software framework exposes the hardware functionality in an easy-to-use way using a python-based API [1].
- Tight integration of hardware, gateware, and software ensures precise timing while maintaining the ability for dynamic control flows and easy reprogramming.
- Hundreds of our systems are deployed in research laboratories and with industrial partners around the world.
- Our open source policy empowers our partners to investigate and understand functionality of the devices and enables expansion and customization to their specific needs.

ARTIQ



ARTIQ Logo and “Sinara” Hardware Ecosystem

Challenge

- The MIQRO demonstrator will require precise control over many qubits in a quantum register.
- >100 DC electrodes in the ion register need to be supplied with a high accuracy, low noise voltages.
- The quantum logic in the register is controlled by a global RF field. In order to implement operations on all qubits simultaneously, many tones have to be precisely placed in a wide frequency range covering all qubit frequencies. For highest gate fidelities, gate pulses need to be robust and feature critical temporal and spectral characteristics.
- To optimize computational overhead and flexibility, it is desirable to generate the required control signals dynamically.

Collaborations

Close collaboration with our project partners is necessary to overcome key challenges that span many work packages and partner areas of expertise:

Universität Siegen has developed the “MAGIC” quantum gate protocol used in the project and will host the MIQRO demonstrator.

LUH Hannover will fabricate the ion trap chip and cryogenic platform as well as research optimal DC electrode waveforms for qubit transport across the processor.

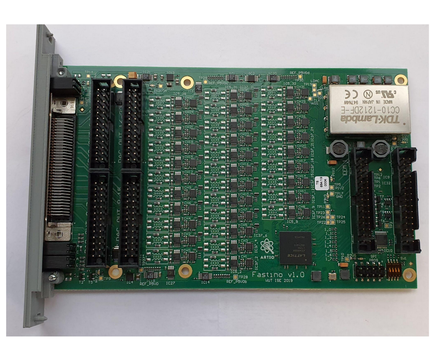
HHU Düsseldorf brings expertise in optimization and characterization in quantum computing and develops the application layer and high level gate compiler architecture.

Work plan

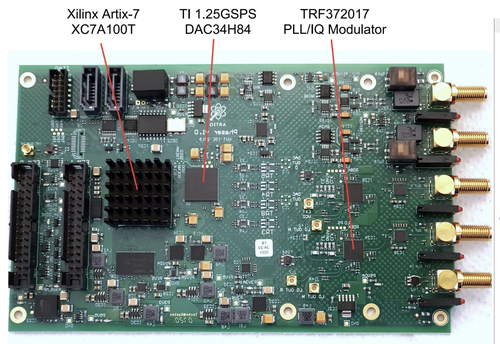
- Current focus on signal sources for DC electrodes and RF fields. Since key processor metrics like qubit coherence time and gate fidelity directly depend on the quality of the signal sources, this groundwork is crucial.
- In-depth research on the processor operating system as well as qubit management will start once first procedures and routines have been identified in collaboration with our partners.
- Finally, application-level algorithms will be explored in order to automatically execute quantum algorithms provided in an abstract representation.

Partner contribution and IP

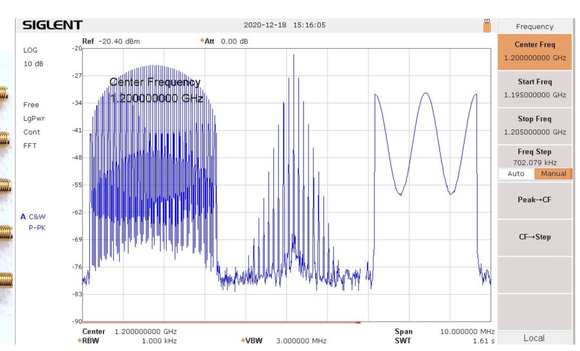
Together with partners from industry and academia, QUARTIQ has developed a variety of voltage sources for ion traps (“Zotino”, “Fastino”), RF sources for laser- and microwave pulses (“Urukul”, “Mirny”, “Phaser”), and a software platform for control of quantum experiments (“ARTIQ”). The substantial know-how from these projects will directly contribute to the MIQRO efforts. Additional experience in high performance signal processing for quantum gate pulse generation was gained within the “Short Time Fourier Transform (STFT) Pulse Generator for Trapped Ion Quantum Gates” thesis [2].



“Fastino” voltage source



“Phaser”RF signal generator

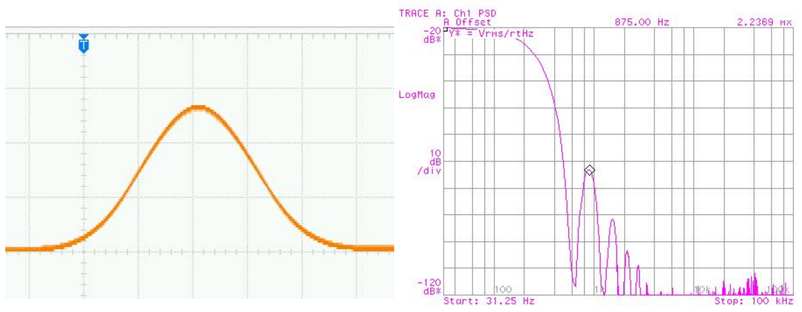


“STFT” pulse generator output spectrum

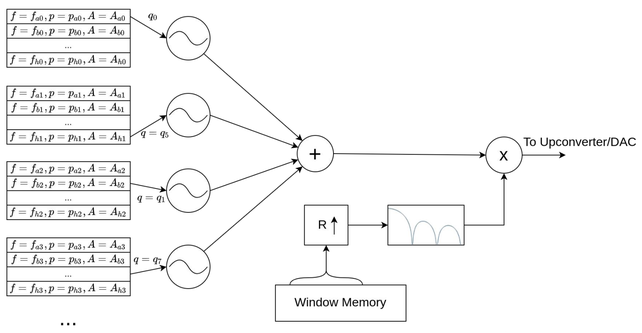
Approach

Building on our work on the open source ARTIQ/Sinara Soft- and Hardware system, QUARTIQ will research novel approaches for signal generation and qubit control by the operating system (OS) in order to meet the project objectives. Key metrics include: **size, weight, power, cost, channel density, data rate.**

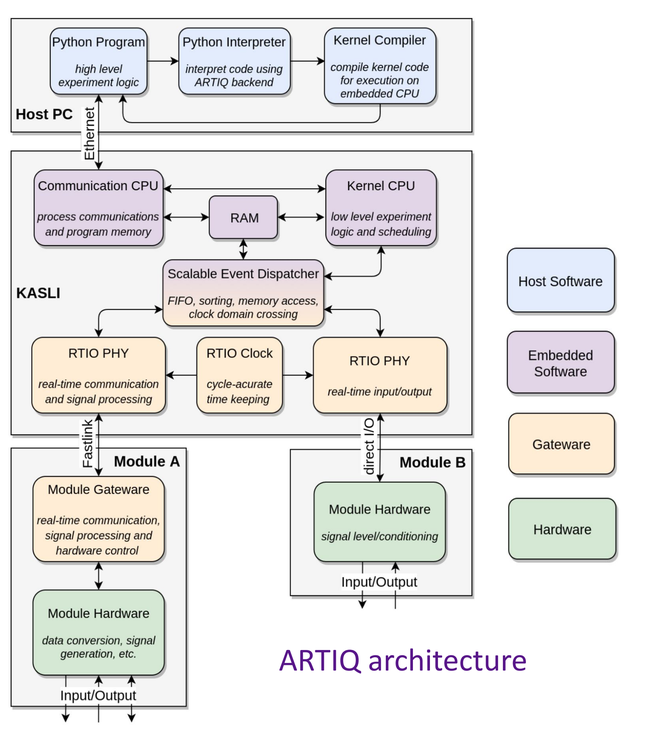
- A custom gateware cascaded integrator comb (CIC) interpolation scheme is under development for the DC electrode voltages sources that can feed the channel outputs at a optimal data rate while requiring few trajectory samples by the OS and ensuring smooth output waveforms.
- An advanced many-tone pulse generator based on high performance DSP cores will drive the quantum logic in the processor. Optimized data flow and gate-pulse representation enable the OS to dynamically emit millions of pulses per second with dozens of tones per pulse.
- Ultra-compact pulse instruction set design allows for efficient real-time mapping between qubit operations and hardware pulses without any software overhead.



CIC interpolator output waveform and spectrum



MIQRO gate pulse generation scheme



ARTIQ architecture

Outlook

- Scaling up to more registers and qubits will require additional efforts into integration and signal processing. The techniques, schemes and IP currently being developed by QUARTIQ and our partners in the MIQRO collaboration are crucial for expanding the demonstrator to a practical-size quantum computer based on trapped ions.
- The signal sources are not limited to the specific MIQRO application but can be further customized to fit future project needs or incorporated into stand-alone products.
- The qubit management and high-level algorithms for processor operation can be applied to other hardware platforms and potentially licensed to operators of fully integrated systems.

References

1. Bourdeauducq, Sébastien et al. (2016). ARTIQ 1.0. Zenodo. 10.5281/zenodo.51303
2. Norman Krackow, Short Time Fourier Transform Pulse Generator for Trapped Ion Quantum Gates. MSc thesis, Technische Universität Berlin, 2021, https://quartiq.de/talks/thesis_nkrackow.pdf

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