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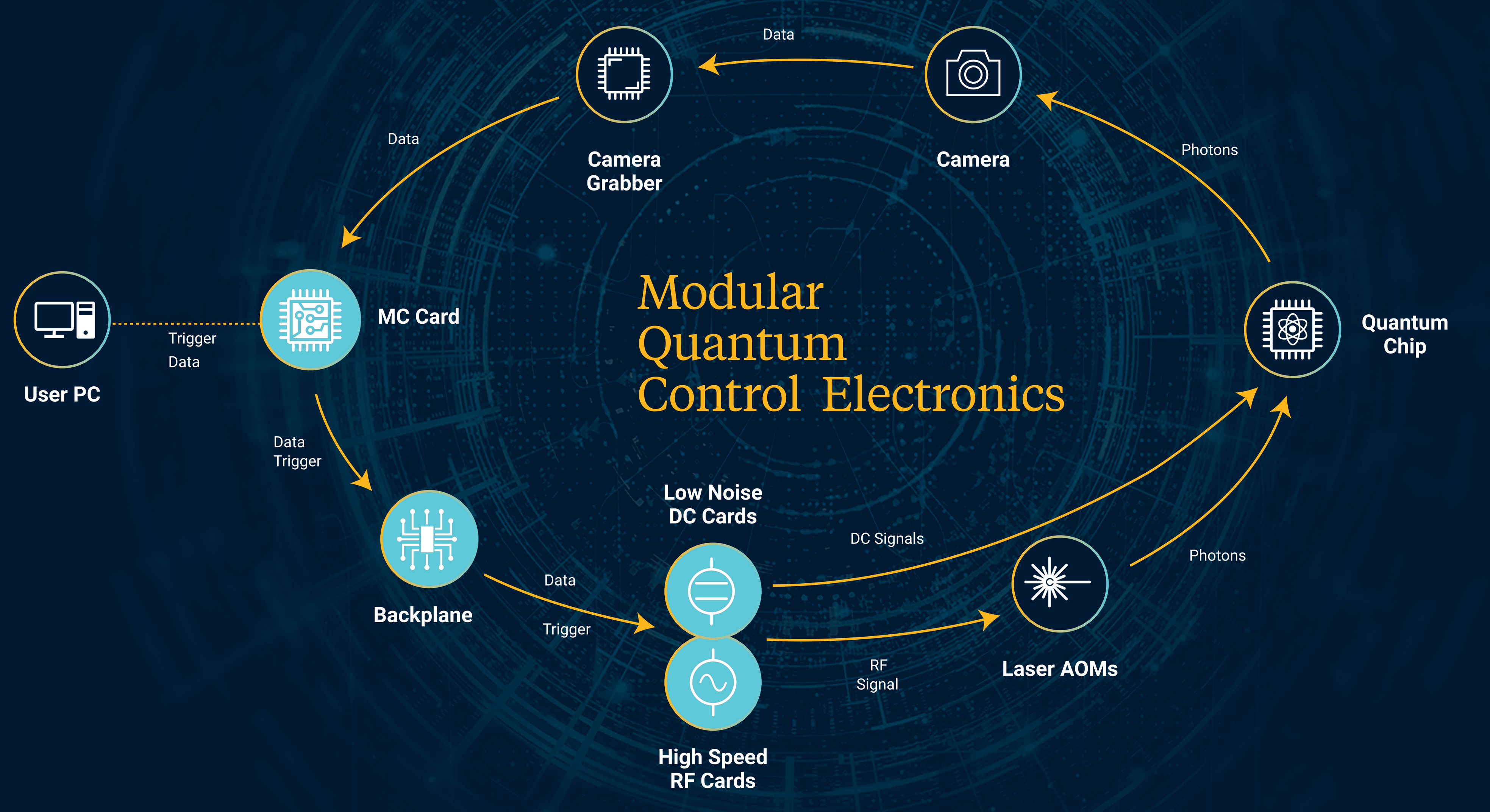
at Akkodis

Modular Quantum Control Electronics

Today's trapped-ion experiments require a large number of precisely controlled signals of various types, such as DC electrode voltages and RF pulses for AOMs. These signals have not only to be precise in the output values but must also be synchronized on sub-microsecond timescales. These requirements are hardly achievable in a monolithic setup.

In the IQuAn project, Akkodis is developing a modular quantum control electronics system which is based on a distributed control logic and thus highly scalable. This system can consist of a selected number of independent DC pulse generators, RF pulse generators, and main-controller cards, building a cascaded control logic of the required size. Well established interfaces like Ethernet and TTL triggers simplify the integration into existing systems.



Modern control electronics for trapped-ion experiments have to be robust and reliably supervised while often running in a hetero geneous environment. In the ATIQ project, Akkodis is addressing this requirement for their modular quantum control electronics system. A seamless integration in the ARTIQ control electronics system and vice versa is been addressed in collaboration with QUARTIQ.

This enables CCD image capture and processing entirely within our embedded electronics system. The selected inter-faces are assessed to be also suitable for other hardware providers. Integration of monitoring and diagnostic possibilities in each card supports a constant super-vision of the system which increases the robustness during long-term operations. The in-system monitoring during sequence execution enables tasks like auto-calibration and sequence compiler optimization.

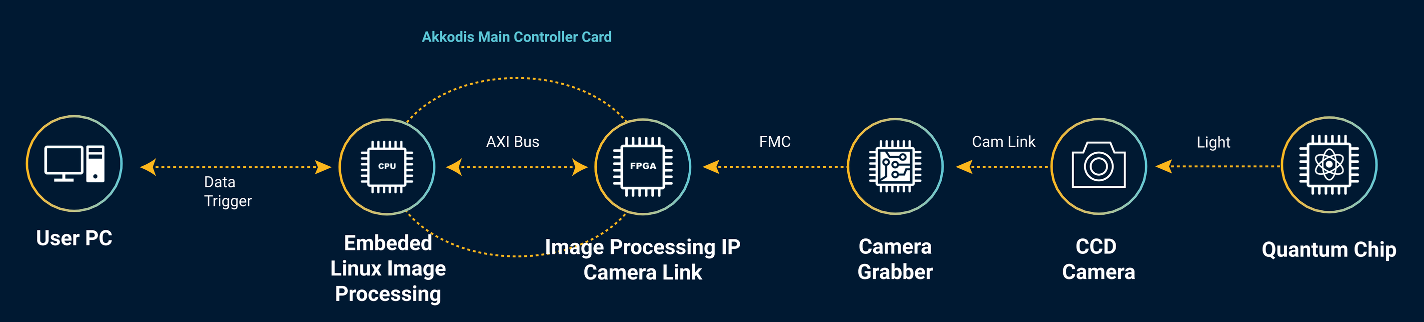
DC Pulse Generation

For IQuAn, we have developed a second generation analog signal generator card which combines an embedded control and processing unit with 32 parallel, highly flexible arbitrary waveform generators, low-noise DACs, and amplifiers. This design combines the experimentally validated output stage of the first generation with the scalability and modularity of the second generation system. This allows simple adjustment of the control setup to the needs of the ion trap while keeping fast and accurate control of the electrode voltages, enabling operations like shuttling or swapping of ions during an experimental sequence.

- Build around system-on-chip (SoC), flexible AWGs and low-noise DACs
- High dynamic range: +50 to −50 V output voltages
- High accuracy: 16 bit amplitude sampling, ±20 mV output noise
- High agility: 20 ns command sampling, rise & fall in 200 ns to 1 µs, jitter < 1 µs
- High parallelization: 32 separate output channels per card

CCD Image Processing

For ATIQ, we are developing a flexible, real-time-capable framework for CCD camera image proces-sing and measurement analysis on embedded electronic systems. Image processing tasks can be distributed between FPGA for optimal timing or Embedded Linux for advanced processing as well as user-friendly development. This framework allows to implement fully parallelized qubit readout, advanced calibration routines, and multi-qubit sequence branching.



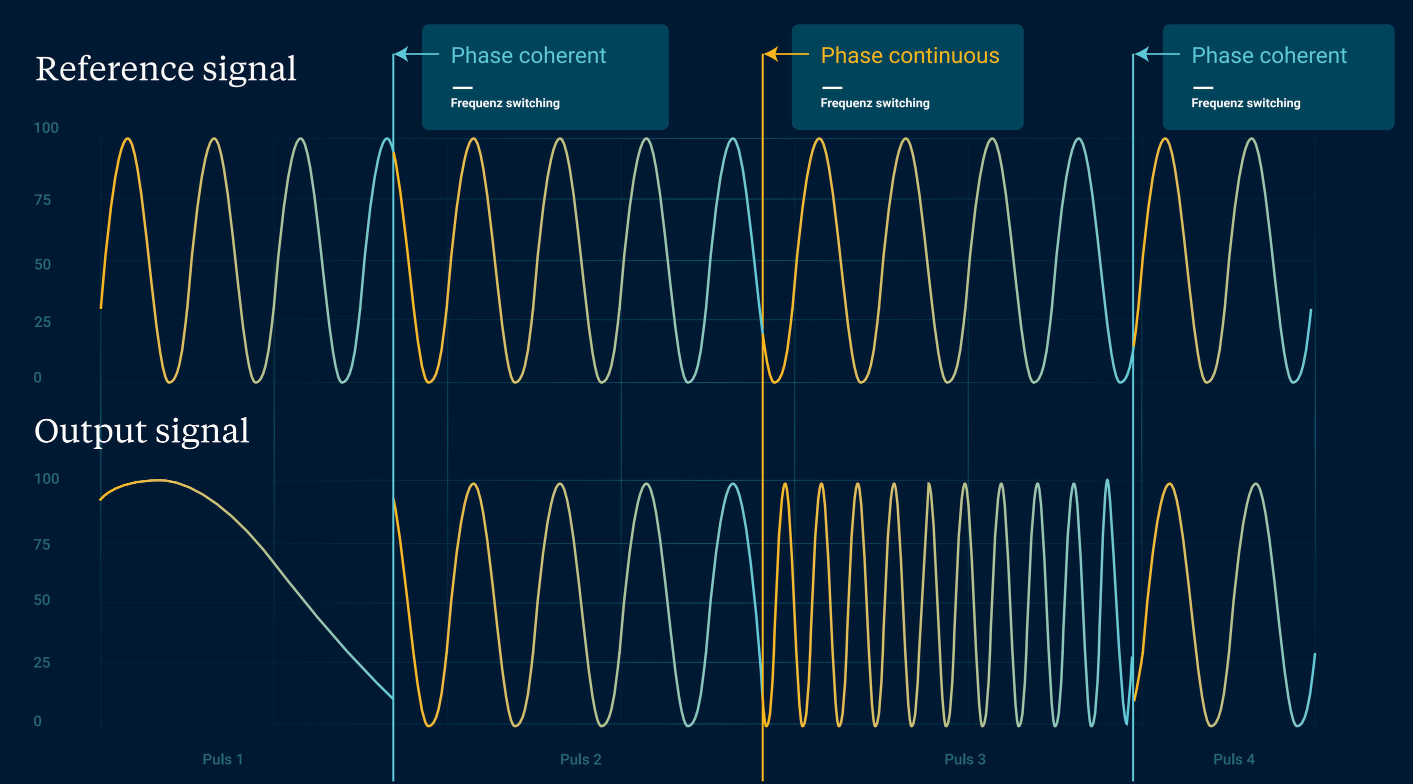
- Tailor-made image processing IP cores for real-time processing of CCD images on FPGA
- Implemented timing-optimized OpenCV library for advanced image processing routines and user-friendly development in Embedded Linux (C, Python)
- Effective drivers for image and meta-data transmission between FPGA and Embedded Linux
- Measurements on images such as ion identification, ROI definition, and qubit classification

RF Pulse Generation

A first generation radio frequency generator card which combines an embedded control and processing unit with eight parallel, high frequency, tunable arbitrary waveform generators, high-speed DACs, and amplifiers has been developed for IQuAn. The hardware design is finished, first perfor-mance measurements have been taken on evaluation boards and prototypes will be produced in 2024.

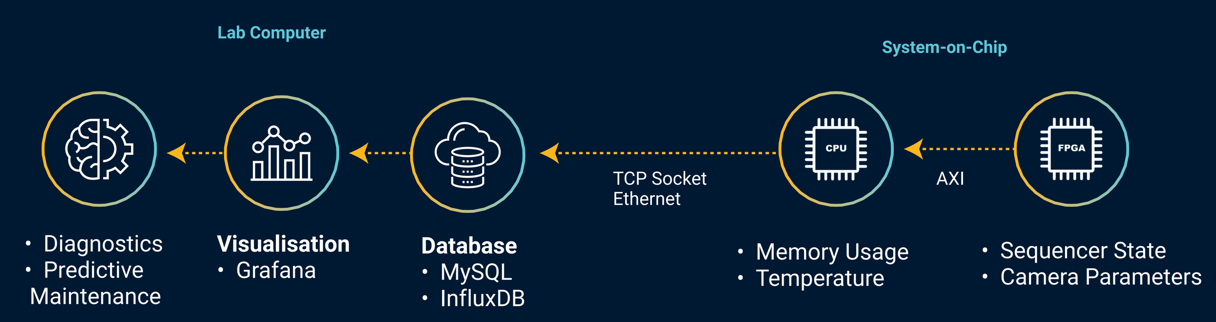
- Build around system-on-chip (SoC), widely tunable AWGs, and high-speed DACs
- Wide frequency range: 20 mHz to 200 MHz waves
- Phase-coherent and phase-continuous frequency switching
- High accuracy: 800 MSps data sampling rate, 16 bit amplitude sampling
- High agility: 5 ns command sampling, jitter < 1 µs
- Parallelization: 8 separate output channels per card

FPGA design simulation showing the swichting behaviour between phase-coherent and phase-con-tinuous outputs.



Monitoring and Diagnostics

An architecture for monitoring and diagnostics to ensure optimal performance and reliability for hardware and software elements encompassing SoCs and embedded electronics is developed by us for ATIQ. A streamlined framework that facilitates seamless data acquisition and visualization at the user end, offering an insightful perspective on system health. The use of well established industrial standards enables the integration in various lab environments with well defined interfaces.



- Flexibility through continuous, real-time monitoring or request-based data retrieval
- Suitable for integration within a modular setup of multiple devices
- Seamless data acquisition through TCP socket and efficient data management systems such as MySQL and InfluxDB
- Harnessing tools like Grafana for dynamic data analysis and visualization
- Enables diagnostics tests and predictive maintenance

Operational Control

Our modular electronics system can be operated with or without main-controller card as every card is equipped with a fully operational Embedded Linux and FPGA control system. This grants our users the freedom to adjust the control logic to the architecture that fits best into their lab environment. While multiple synchronization interfaces like trigger distribution, Ethernet, CAN, and a real-time bus provide the necessary connectivity to run the system fully synchronized.

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