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QICK

QICK: Quantum Instrumentation Control Kit

Workshop objectives

Gustavo Cancelo (Fermilab) for the QICK group.

QICK workshop

- **This workshop: over 135 participants from over 30 universities, 10 companies, 15 foreign institutions, and DOE program managers.**

INFN, LNF	Quantinuum
Amazon Web Services	Quantum Machines
AMD	Rigetti Computing
Argonne National Laboratory	SQMS
California Institute of Technology	Stanford University
DOE	t0 technology
Fermilab	Technology Innovation Institute (UAE)
Groupe DFI, Paris, France	U. Chicago, Schuster lab
IBM Systems	U. Nortwestern (Fermilab)
IIT-SQMS	UIC Chicago
Infleqtion (formerly ColdQuanta)	UIUC
INFN Ferrara	UMass Amherst
INFN Milano	United Arab Emirates
Institute of Physics, Academia Sinica	University of Chicago, Awschalom lab
Instituto Tecnológico de Aragón, Spain	University of Chicago, Bernien lab
Massachusetts Institute of Technology	University of Chicago, Cleland lab
Milano-Bicocca	University of Illinois at Urbana-Champaign
NASA-JPL	University of Massachusetts
Northwestern University	University of Pittsburgh
Oak Ridge National Laboratory	University of Texas at Austin
Ohio State University	University of Wisconsin - Madison
Princeton University	wistron, Taiwan
Purdue University	Yale University
Instituto Tecnológico de Aragón, Spain	Zurich instruments

QICK founding team

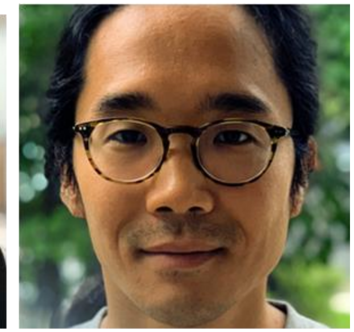
Neal Wilcer (FNAL)

Ken Treptow (FNAL)

Leo Stefanazzi (FNAL)

Shefali Saxena ~~(QuantiSED at ANL)~~

Sho Uemura(FNAL)



Sara Sussman (U. Princeton)

Andrew Houck Lab (Princeton)

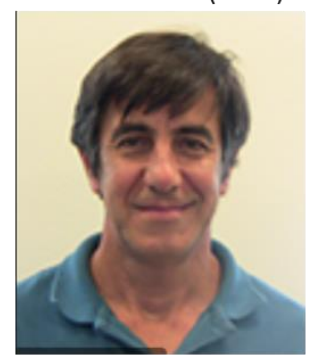
Chris Stoughton (FNAL)

David Schuster ~~(U.Chicago)~~

David Schuster (Stanford)

Martin Di Federico (FNAL)

Gustavo Cancelo(FNAL)



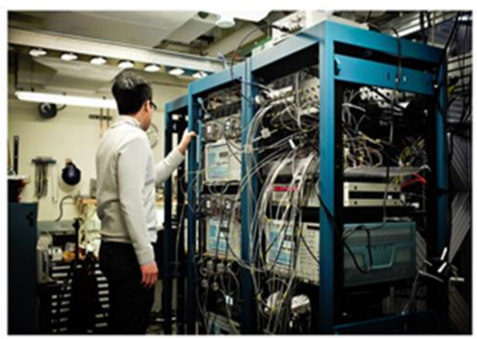
Open-source Quantum Instrumentation Control Kit (QICK)

- Started funded by DOE-QuantiSED.
- Transition to DOE-QSC at the creation of NQISRC.
- Founding members: D. Schuster (U.Chicago, now Stanford) and Andrew Houck (Princeton) labs. Sara Sussman (Princeton)
- More collaborations were added along the way (SQMS, Pitt., other U.Chicago labs, etc.)

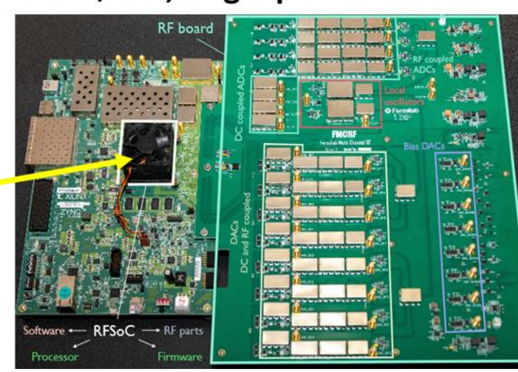
- This workshop: over 135 participants from over 30 universities, 10 companies, 15 foreign institutions, and DOE program managers.

- What makes QICK attractive?
  - Cost (~$1K/qubit)
  - Functionality
  - Versatility
  - Scalability

Replaces ~$1M, full rack, off-the-shelf

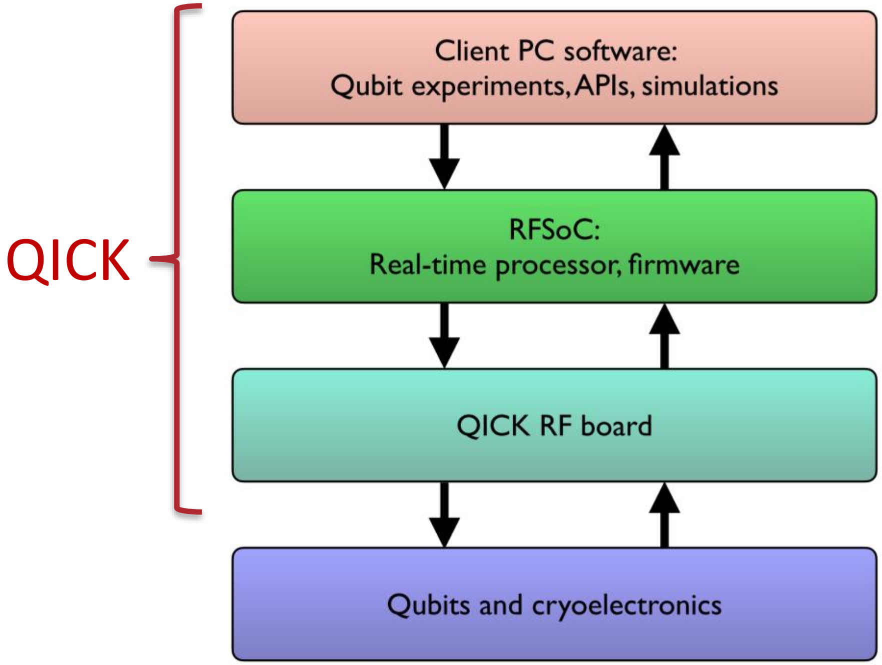


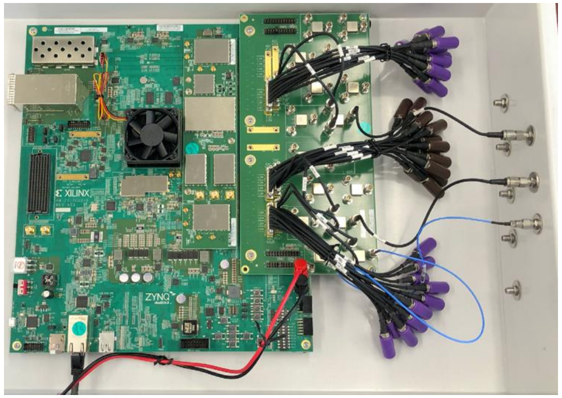
with $20K, single pair of boards

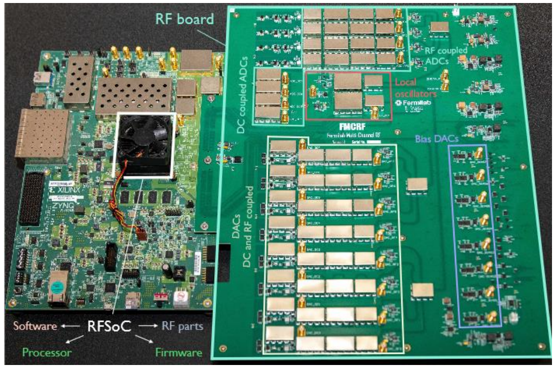


RFSoc
FPGA

QICK in a nutshell: Hardware + firmware + software







- **Hardware:**
  - **AMD-Xilinx RFSoC FPGA based: 2, 8 and 16 channel platforms supported.**
  - **Custom RF up to 16 channel 10 GHz (outputs, inputs), 8 output bias.**
- **Firmware and software runs on FPGA:**
  - **Using logic and on-board processors (more on Leo Stefanazzi's talk).**
- **APIs to high level quantum software on PCs.**

Opportunities for collaboration in all three areas. (A workshop objective).

QICK functionality

- We think of QICK as an integral part of a QIS system.
- QIS control includes quantum computing, quantum networking and quantum sensing applications.
  - There is a large overlap with superconducting detectors (e.g. MKIDs, BREAD broadband antenna) for astrophysics. DM, DE, CMB.
- The open-source concept has allowed us to work with institutions in close relationship.
- QICK hardware, firmware and software have been growing in parallel with QIS experiments.
  - Solving problems raised by experimenters.
  - In general, we find out that solving a problem in one experiment, solves the same problem for other experiments. Or makes other experimenters realize that they would benefit from that solution.
- Yet to be proven by data in papers: We have reasons to believe that controls has an impact in achieving better experiments.
  - Experimenters realize that they can do things that they have not considered before.
    - For example, the RF phase synchronization of multi outputs and inputs for all experiment runs may impact performance.
    - 500K point FFT every 60us and day long averaging for BREAD allowed a science run.

Workshop objective: define new functionality requirements for controls.

QICK versatility

- Although QICK started as a control kit for superconducting qubits, experimenters at different labs started to use it for other types of qubits (AMO, trapped ions, etc.)
  - Since QICK is an open system, some labs have modified the firmware and software.
  - The QICK team started receiving requests for help to add more features to the system.
  - Some control functions overlap with what is needed for gravitational wave interferometry (e.g. GQuest talk by Lee McCuller, Caltech).
- In parallel QICK migrated to quantum sensing and quantum networking.
  - We have some new results using QICK to generate sub 100ps pulses on multiple channels to trigger photon generation and we have used inputs to accurately time stamp photons detected by SNSDPDs (talks by Cristian Peña (FNAL), Matt Shaw (NASA-JPL).
- We have three sessions and 6 talks on these topics today.

Workshop objective: define new functionality requirements for controls.
Look for overlaps that may facilitate their use in other applications.
Define collaborative efforts.

QICK software and integration

- **At the lower level we have QICK quantum programs running on the RFSoC PS (Stefanazzi's talk)**
  - **4 core ARM running linux and PYNQ.**
  - **The low-level software is optimized for speed.**
  - **A tProc implemented in RFSoC logic manages the channel queues and guaranties that the quantum program runs on time.**
- **At a higher level, AWS (Amazon) and QICK team developed an application to place QICK on the AWS cloud (Jeff Heckey talk, Amazon).**
  - **That will allow remote users to have access to a QICK system (learning and educational).**
- **Next steps: software effort needs to grow**
  - **Integrate QICK as a backend for open-source software such as Qiskit, Bracket, OpenQasm. (Thomas Alexander, IBM talk)**
  - **Integrate or develop quantum (qubit) simulators.**

Workshop objective: Define collaborative efforts.
Great opportunity to integrate collaborations with companies.

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QICK scalability, calibration, testbeds.

- **How scalable is QICK?**
  - We have tested the hardware synchronization of QICK boards. We are working on tProc sync across boards.
  - Fermilab and DOE labs are experts in building big control and readout systems.
  - We can explore that limit. Academia does not yet have testbeds with ~ or > 100 of qubits, but they may in the near future.
  - Companies do and have defined roadmaps for scaling up.
- **Calibrations are key:**
  - This work is typically done by experimenters using their test facilities.
  - They feedback new requirements for controls, we iterate.
  - University groups have more experiments than fridge availability, long delays.
- **Can we add new test beds and fridges?**
  - Opportunity for DOE labs and companies to help academia?
  - Integrate that coordinated with control systems.

Workshop objective: Define collaborative efforts.
Great opportunity to integrate collaborations with companies.

In summary

- Open control systems are attractive (I'd say needed) for the next step up in QIS.
  - Low Cost (~$1K/qubit).
  - Functionality.
  - Versatility.
  - Scalability.

- QICK has achieved quite a bit, let's say that has shown a path, but now requires a different model.
  - Grow collaborations with DOE labs, universities and industry.
  - Diversify funding.
  - Generate consensus.
  - Find a new architectural model.
  - Encourage communication between QICK users.
  - We need to grow the QICK team and encourage collaborators to grow their effort in controls so not all the work is done by the QICK core team.

Workshop objective: Explore possibilities.
It will be a gradual approach.
Please talk to the QICK team.

Thanks a lot for attending the workshop.

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