

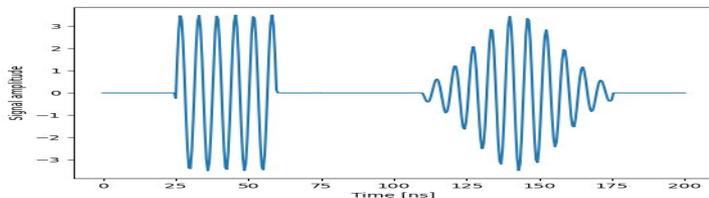
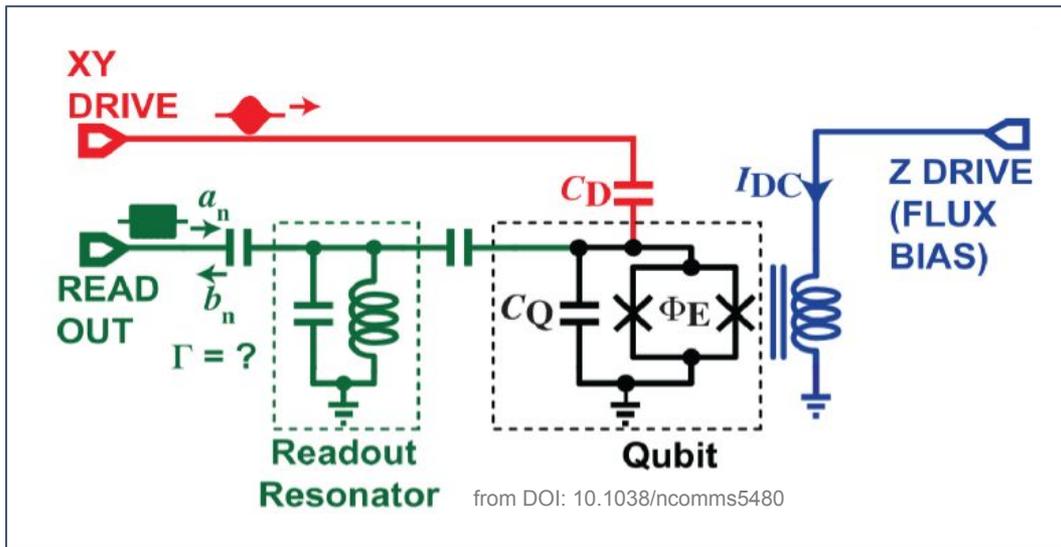
# Development of a Custom Superconducting Qubit Control and Readout System

WP5: Control Hardware and Software  
QUART&T Kick-Off Meeting  
February 21, 2025 | Online

**Rodolfo Carobene**  
University of Milano-Bicocca  
INFN - Milano-Bicocca  
Bicocca Quantum Technologies (BiQuTe) Center

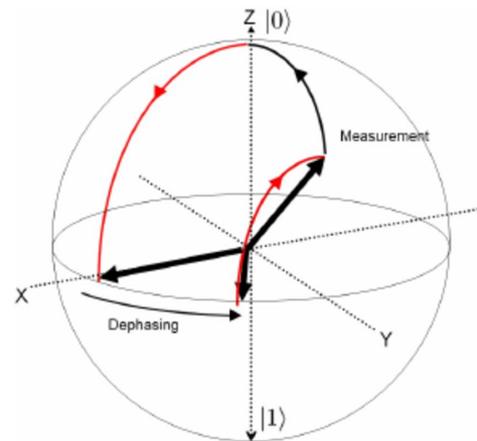


# SINGLE QUBIT CONTROL



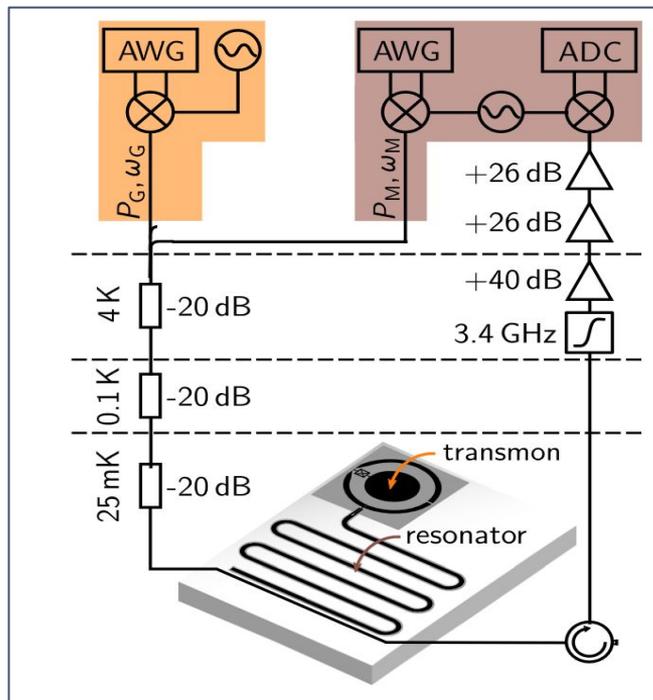
$$\vec{E} = \vec{E}_0 \cos(\omega_d t + \phi_0)$$

$$P(t)_1 = \frac{A^2}{\Omega^2} \sin^2\left(\frac{\Omega}{2}t\right)$$

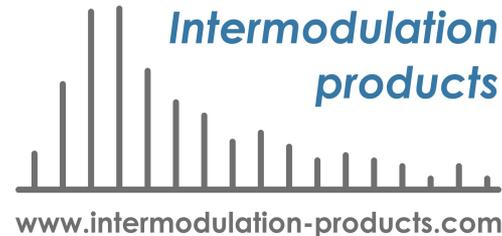




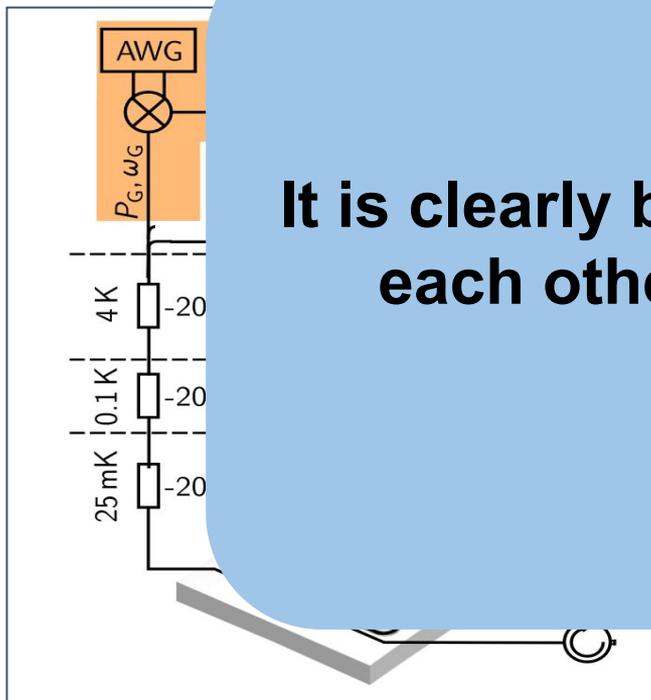
# CONTROL HARDWARE



from DOI: 10.1038/s41534-020-00287-w



# CONTROL HARDWARE



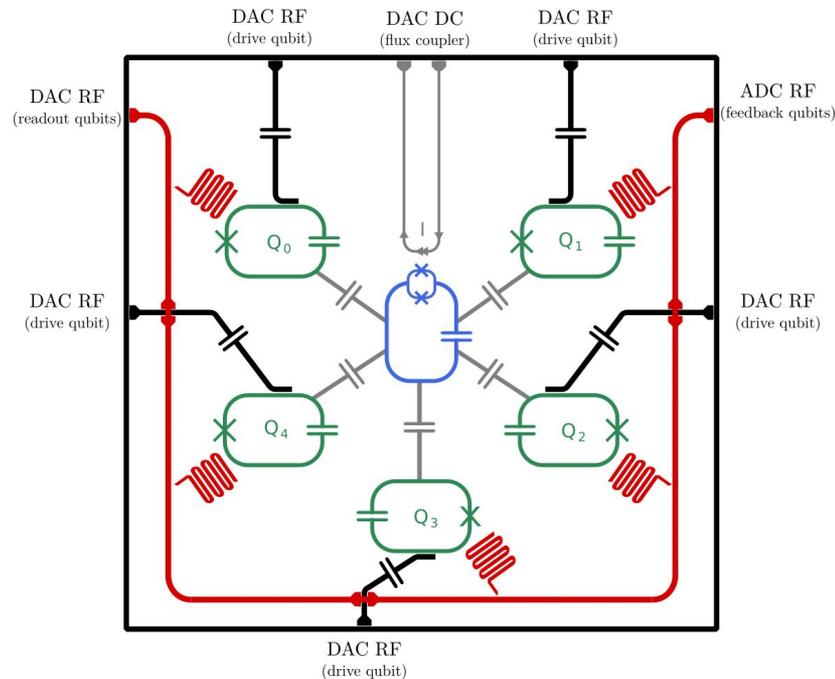
**It is clearly better to coordinate between each others and choose the same solution!**

from DOI: 10.1038/s41534-020-00287-w

[www.intermodulation-products.com](http://www.intermodulation-products.com)

# CONTROL HARDWARE: requirements for QUART&T

- Flexibility for different topologies
- Scalability
- Physical complexity
- Large bandwidth
- High sampling rate
  
- Possibility of generating fast DC pulses
- Possibility of generating stable biases
- Possibility of highly multiplexed readout



# CONTROL HARDWARE: ZCU216



16 DAC (9.85 GSPS)

16 ADC (2.5 GSPS)

4272 DSP slices

930K+ Logic Cells

The ZCU216 is a Gen. 3 RFSoc that can synthesize pulses up to  $\sim 10$  GHz pulses without external upconversion using Direct Digital Synthesis (DDS).

The main positives are the simplicity in the instrumentation (one to rule them all) and the full configurability and flexibility that a FPGA offers.

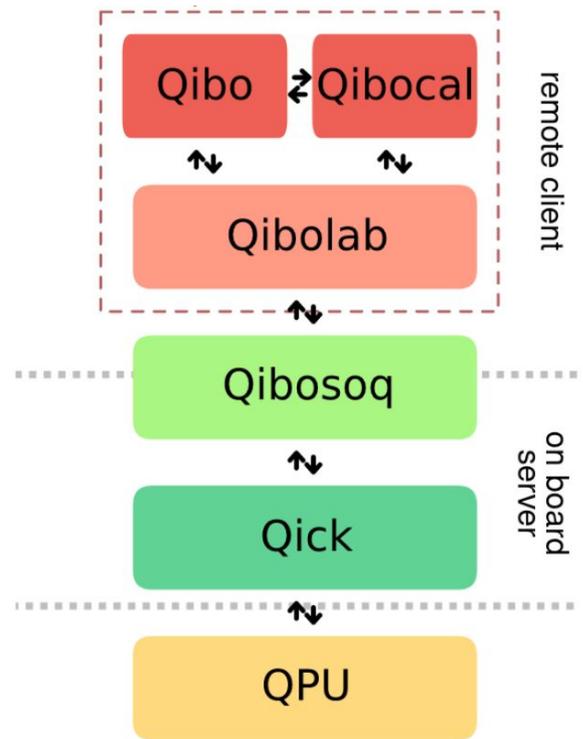
The main negative is that programming a FPGA is not trivial.

# CONTROL FRAMEWORK



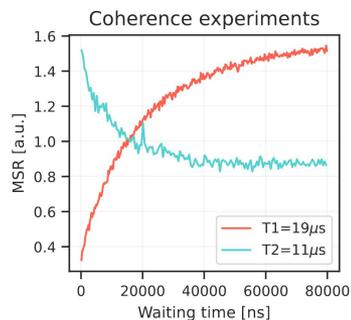
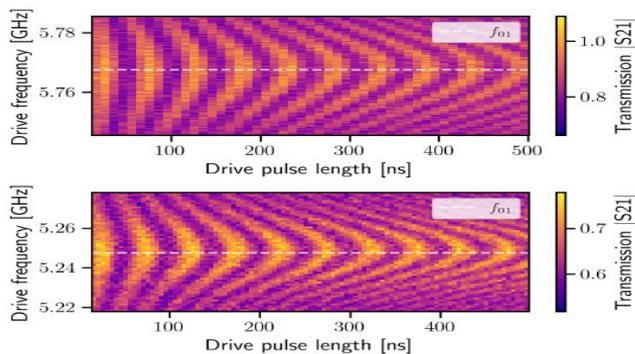
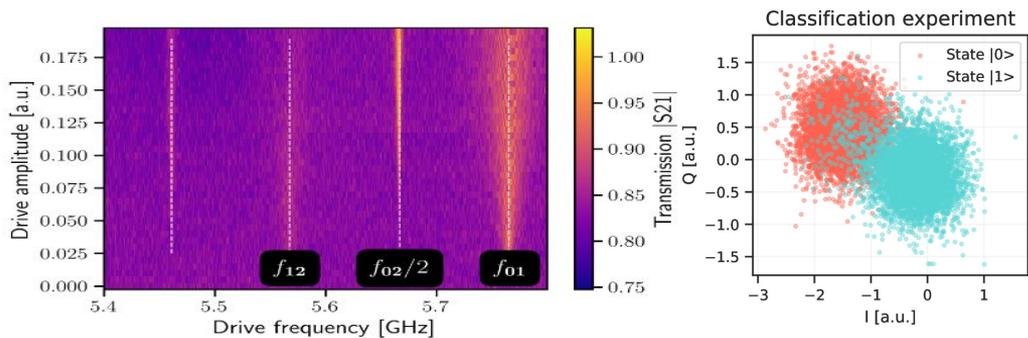
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Qibo ecosystem

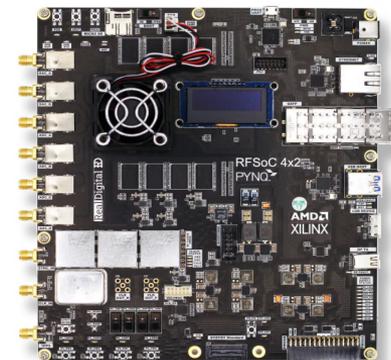


# PAST MEASUREMENTS

ZCU111 (Gen. 1) DAC up to 6 GSPS



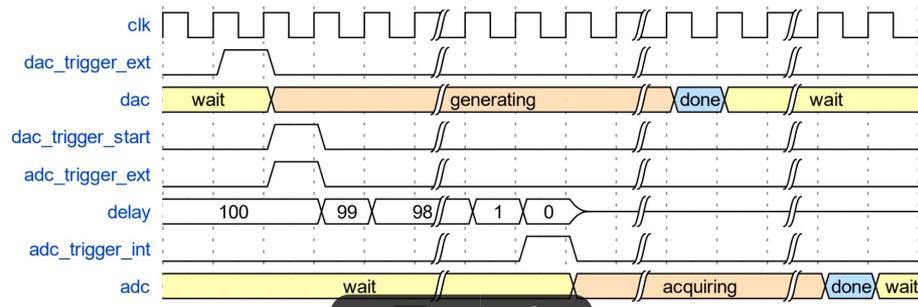
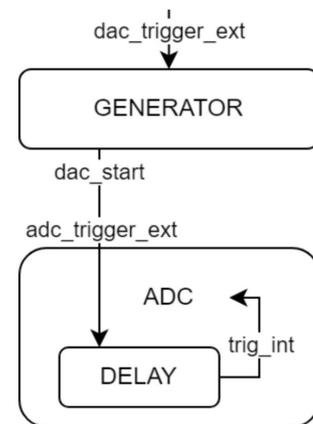
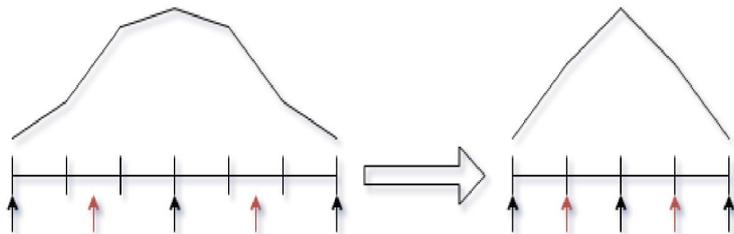
RFSoc4x2 (Gen. 3) channels limited



# FIRMWARE DEVELOPMENT: FIREQ

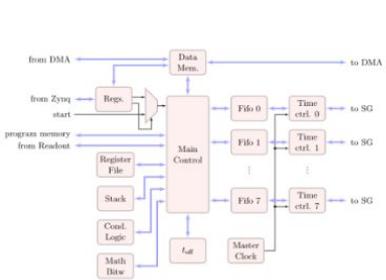
## (FPGA-based Instrumentation for REadout and Qubit control)

- Continuous acquisition using 10 Gb for sensing application
  - possible need of trigger system on the FPGA
- Improve QICK scaling capabilities
  - internal triggering system to launch pulses and measurements
- Real-time sweeps of non trivial pulse-parameters
  - in particular pulse duration sweeps that change samples



# FIRMWARE DEVELOPMENT: FIREQ

- Substitution of QICK tProcessor (max 7 DACs, limited commands...) with general purpose soft processor

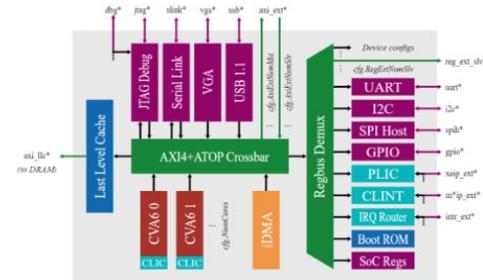


## MicroBlaze:

- Custom "Xilinx" ISA;
- 32 bit processor;
- Hard-core dependant;
- High platform mantainance (Vivado IP);
- Fast implementation;
- High performances on ZynqUltrascale+

## X-HEEP:

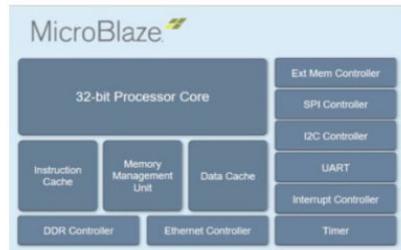
- RISC-V ISA;
- 32 bit processor;
- Hard-core dependant;
- High platform mantainance (maintainers also in the VLSI Lab);
- Easy implementation;
- Highly customizable;



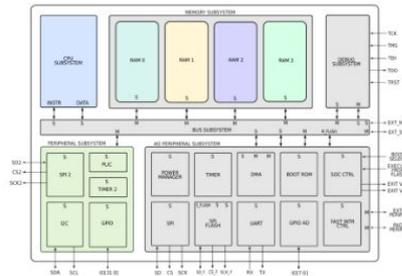
## tProcessor:

- Custom "tProc" ISA;
- 32 bit processor;
- Developed by Fermi Insiteute;
- Hard-core dependant;
- Low platform mantainance (~2 year for a new version);

Current Implementation



Thesis Goal



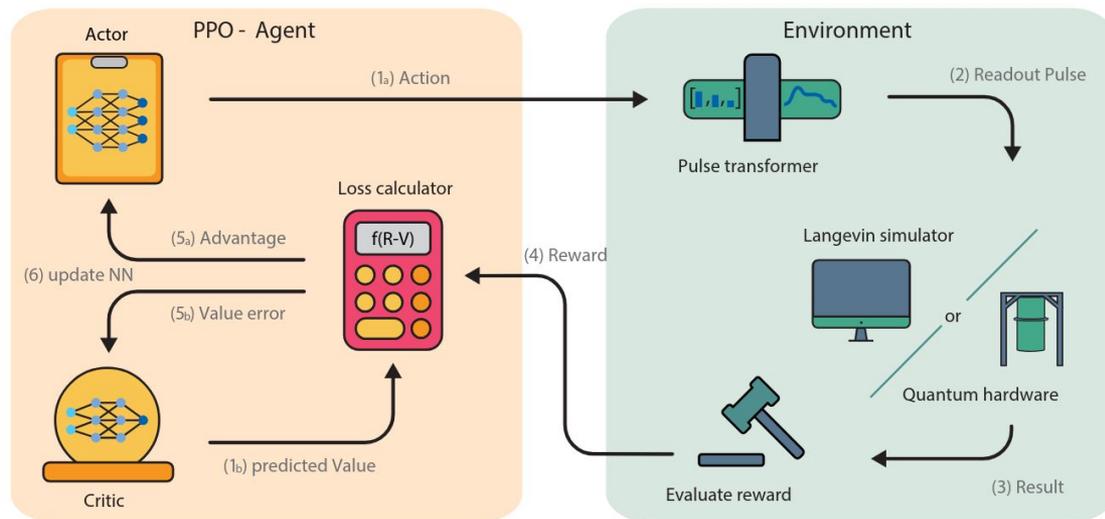
Short-term Goal

## PULP Cheshire:

- RISC-V ISA;
- 64 bit processor;
- Linux capable;
- High performance (multi-core) processor;
- Easy porting from X-HEEP to Cheshire;
- High-performance processor;

# SOFTWARE DEVELOPMENT

- Better exposure of RFSoc features
  - change of the sampling rates to move DDS spurious tones
  - control of on-chip filters and digital Local Oscillator for readout datapath
- Integration with Optimal Control systems or/and RL pulse control
- Update to tProcessor v2
- Test and debugging



# HARDWARE DEVELOPMENT

- Design of complete open-source enclosure for safety and moving towards a more complete laboratory instrument
- Design of a specific auxiliary board tailored to our needs (the standard one has baluns on the output, filtering DC, and other non-bypassable filters)



# COLLABORATION

## Unimib group

Rodolfo Carobene, Pietro Campana, Marco Gobbo, Danilo Labranca, Roberto Moretti, Luca Origo, Sara Gamba, Alessandro Cattaneo, Hervè Corti, Matteo Borghesi, Marco Faverzani, Elena Ferri, Angelo Nucciotti, Andrea Giachero

## LNF group

Matteo Beretta, Pietro Albicocco, Claudio Gatti

## PoliTo group

Deborah Volpe, Christian Conti, Andrea De Simone, Giuseppe La Capra, Fabrizio Riente

## UNIMI group

Alessandro Candido, Stefano Carrazza



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