



The QICK: Quantum Instrumentation Control Kit

Sara Sussman, Leandro Stefanazzi
September 17, 2023



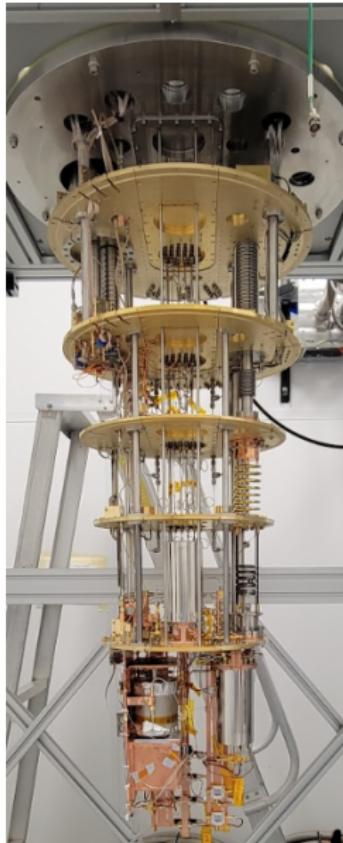
Presentation Outline

- 1 Introduction to Readout and Control
- 2 Description of Firmware and Blocks
- 3 Examples and Demos
- 4 Questions and Links

Outline

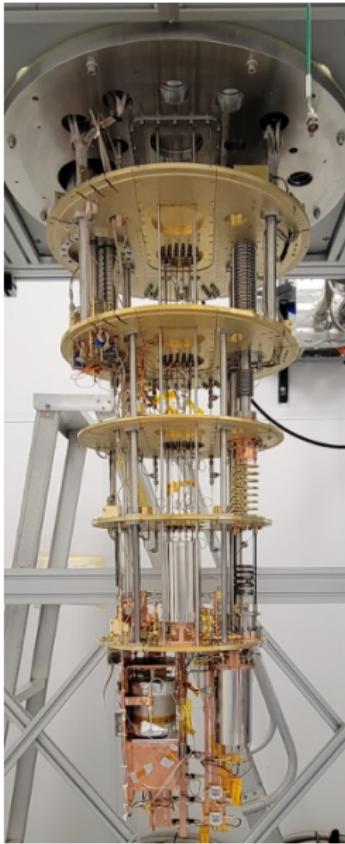
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Superconducting Qubit System



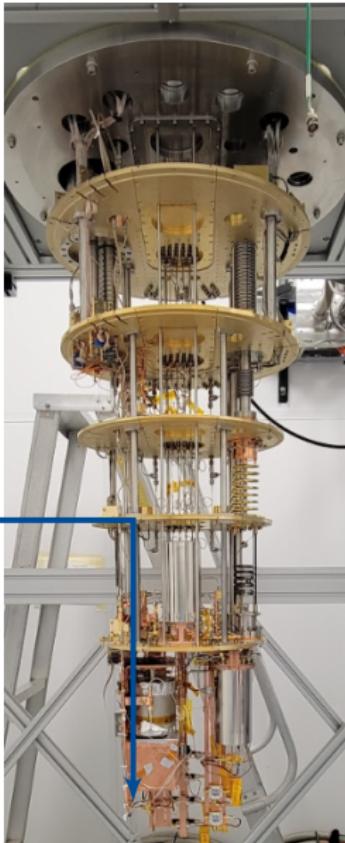
Superconducting Qubit System

Readout and
Control System



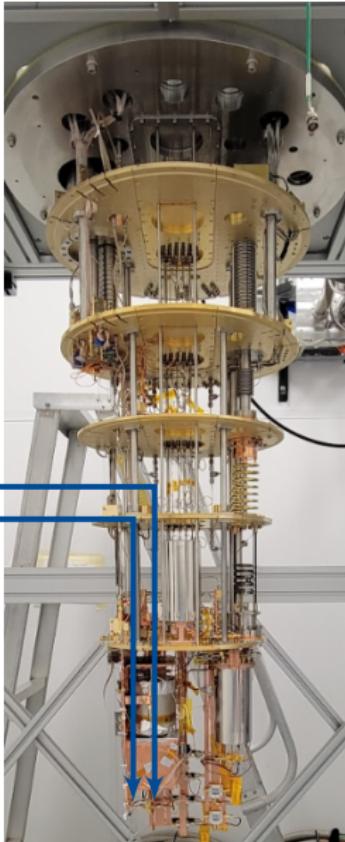
Superconducting Qubit System

Readout and
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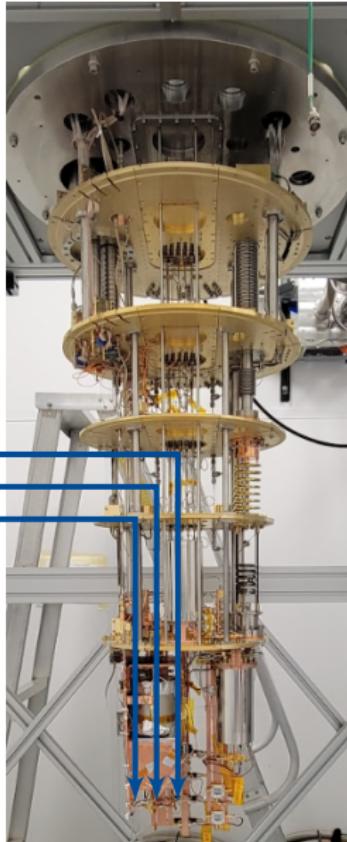
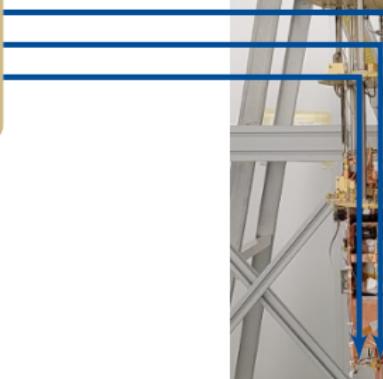
Superconducting Qubit System

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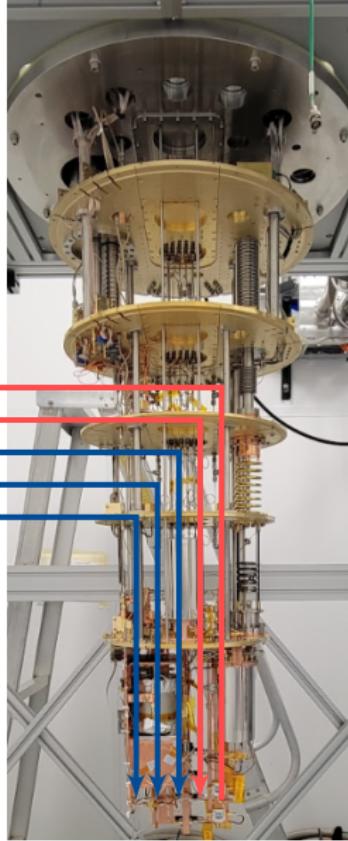
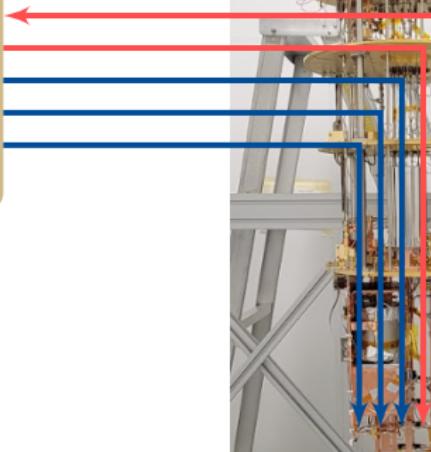
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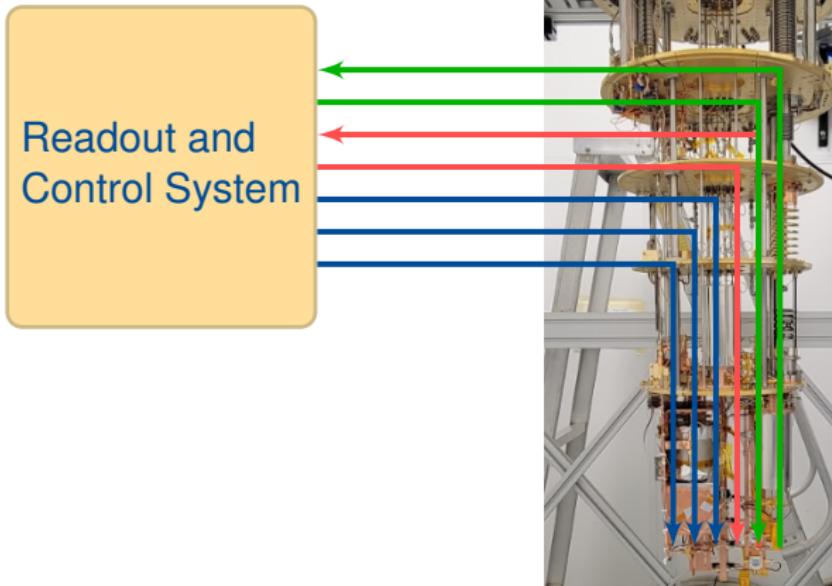


Superconducting Qubit System

Readout and Control System



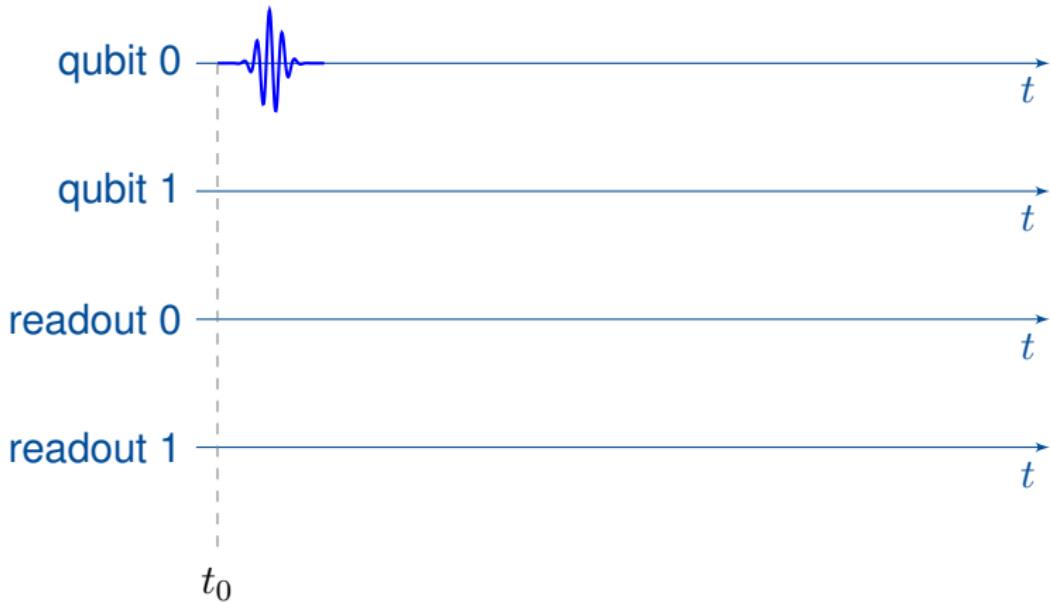
Superconducting Qubit System



Controlling and Reading Qubits

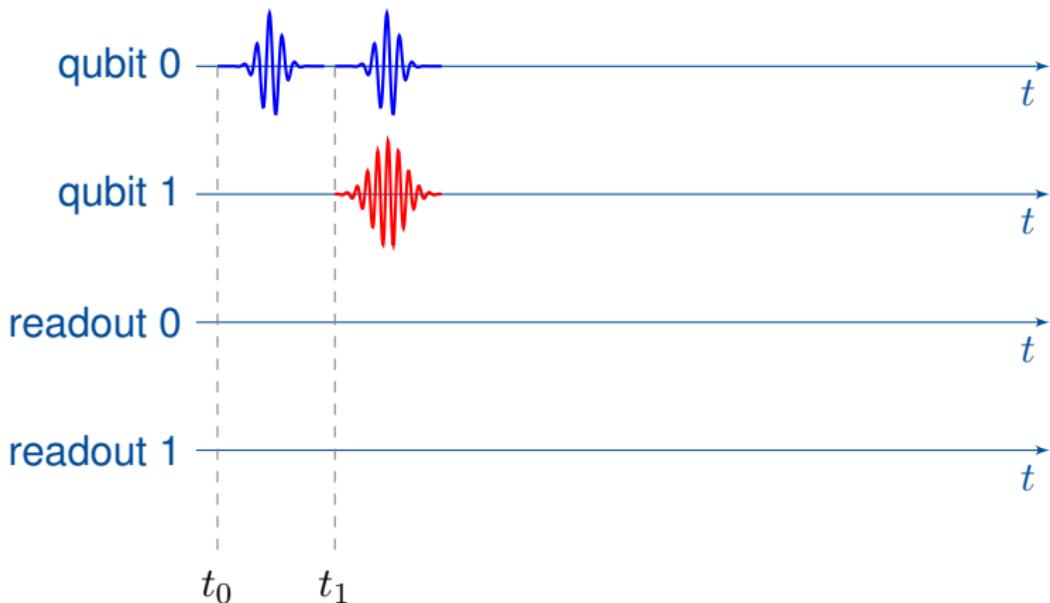


Controlling and Reading Qubits



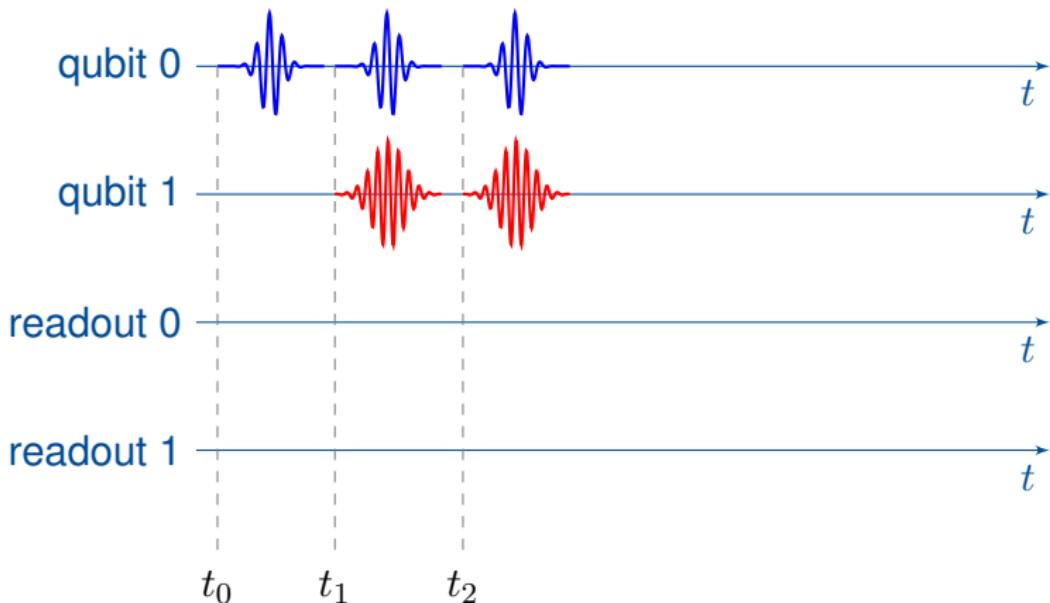
A control pulse is applied to qubit 0 at $t = t_0$.

Controlling and Reading Qubits



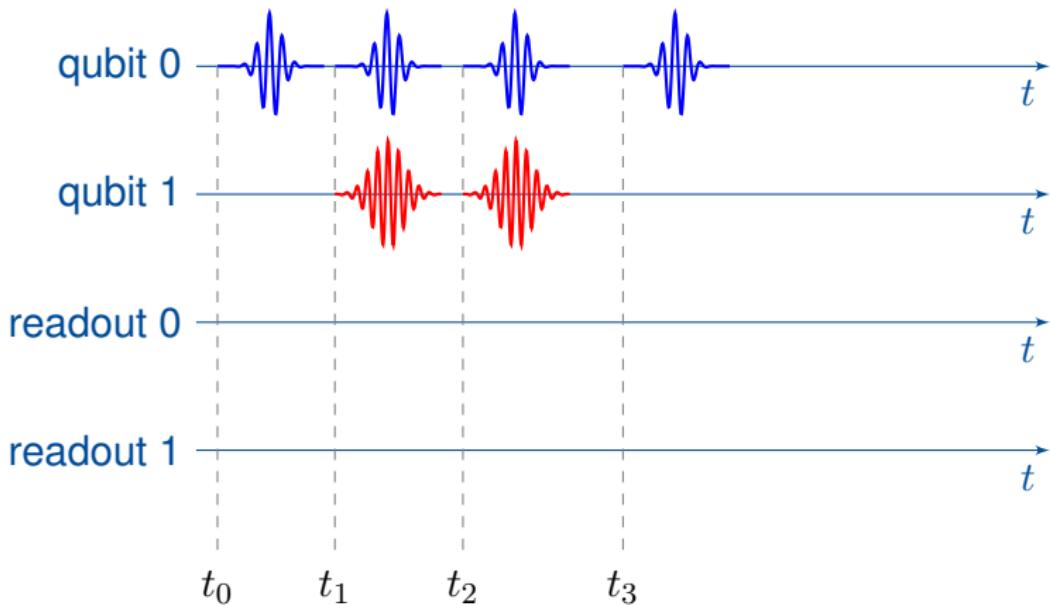
Both qubits are excited at $t = t_1$.

Controlling and Reading Qubits



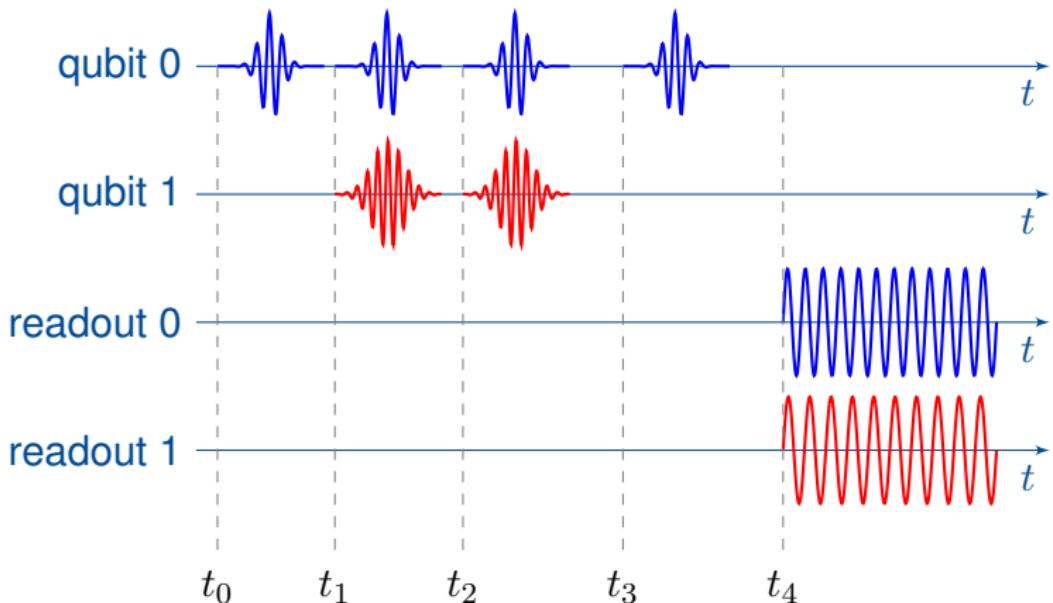
Yet another control pulse for both qubits at $t = t_2$.

Controlling and Reading Qubits



One last touch at $t = t_3$ on qubit 0.

Controlling and Reading Qubits



Readout pulses are sent together at $t = t_4$.

Let's gather some specs

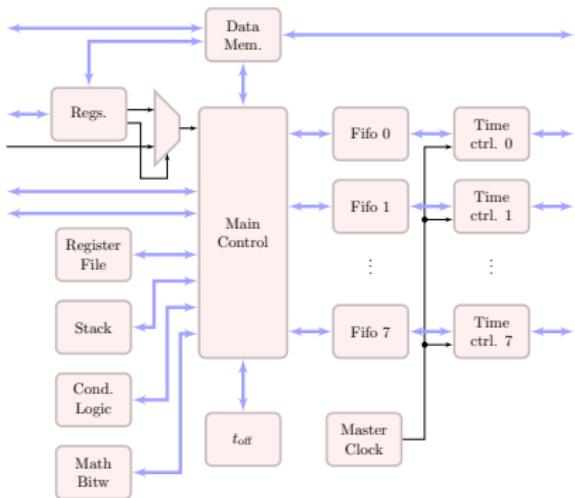
- Frequency range: few GHz up to 10 GHz.
- Phase coherence (more on this to come...)
- Frequency *jumping* capability.
- Pulse duration: from ns to μ s.
- Phase sync across channels.
- Real or Complex envelope.
- Pulse sequence: could be anything.
- The cheaper the better.

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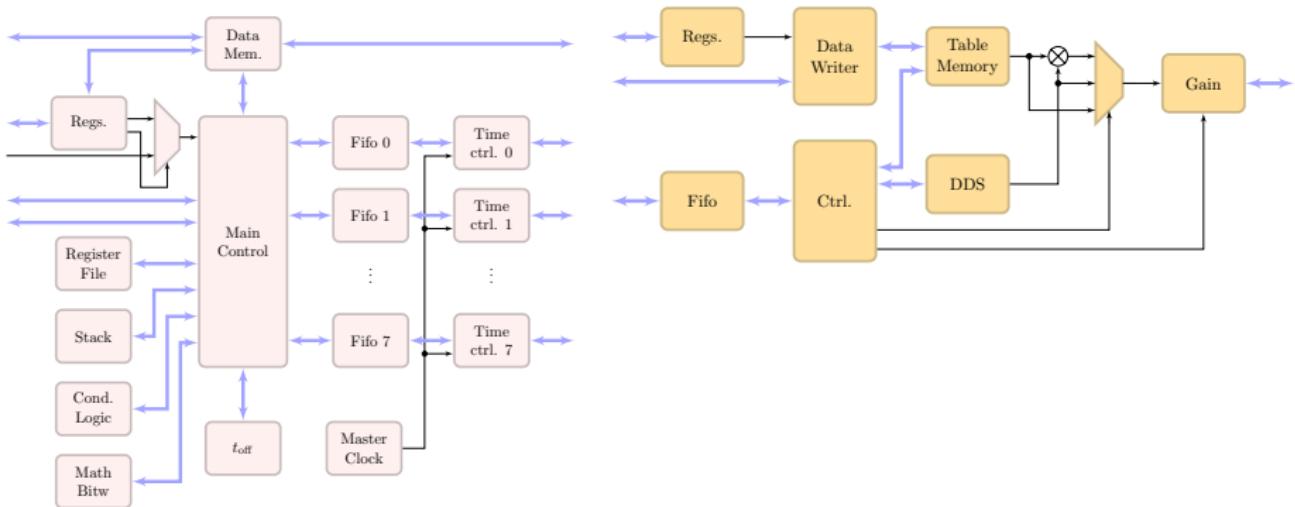
Main blocks of the QICK

- tProcessor: executes the algorithm and controls time.
- Pulse generator: generates the pulses, modulates, etc.
- Readout: gets the samples back and demodulates.



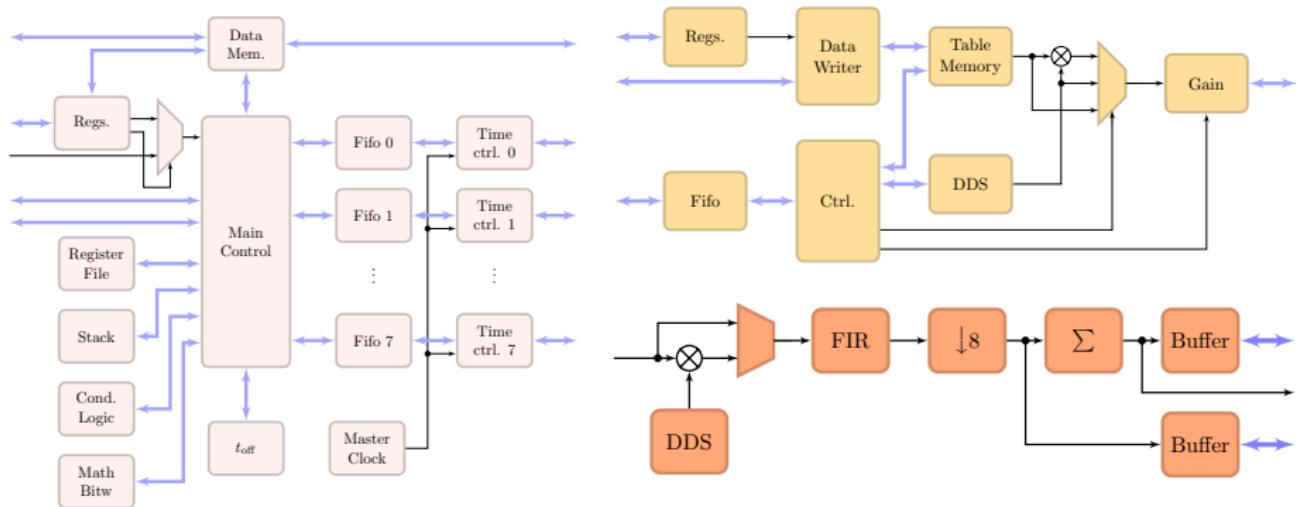
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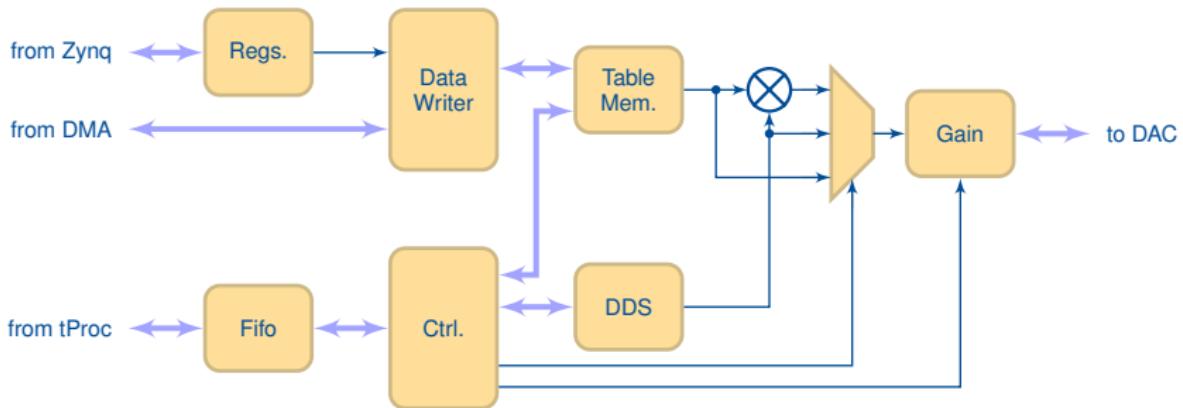
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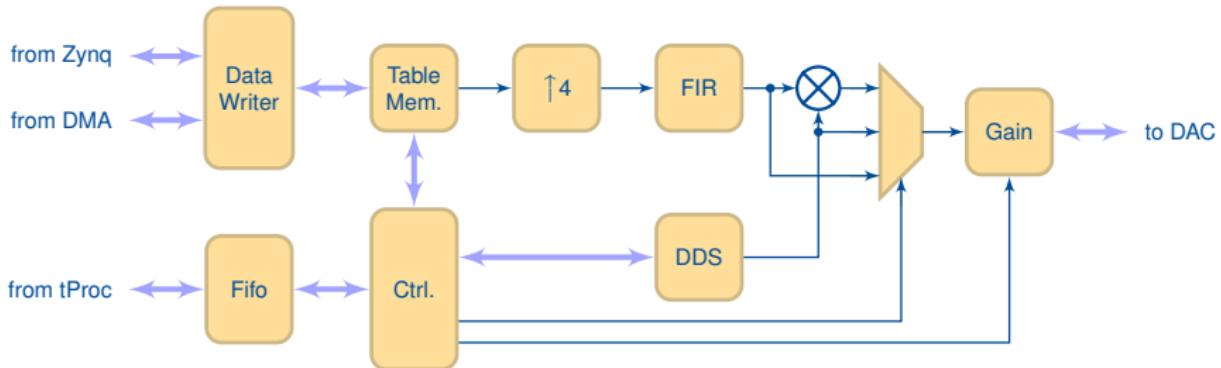
Full Speed Signal Generator

- Full-Speed memory for complex envelope storage.
- Full-Speed Digital Oscillator (DDS) with phase coherency.
- Frequency, Gain, Phase, Length: controlled from tProc.
- Highly parallelized to reach the maximum DAC's speed.



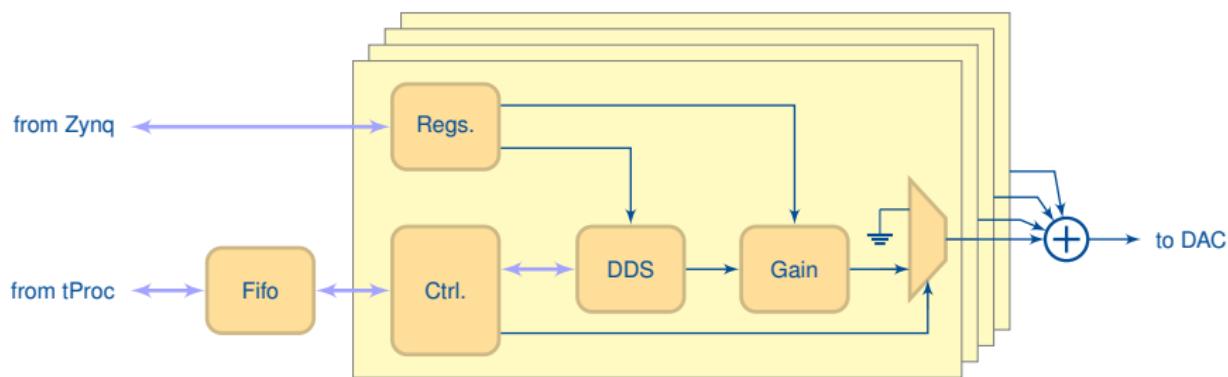
Interpolated Signal Generator

- The envelope memory runs at 1/4 the DDS speed.
- The same amount of memory allows longer pulses.
- The DDS still has phase coherency and is parallel.
- Frequency, Gain, Phase, Length: controlled from tProc.
- Parallelized to reach the required DAC speed.



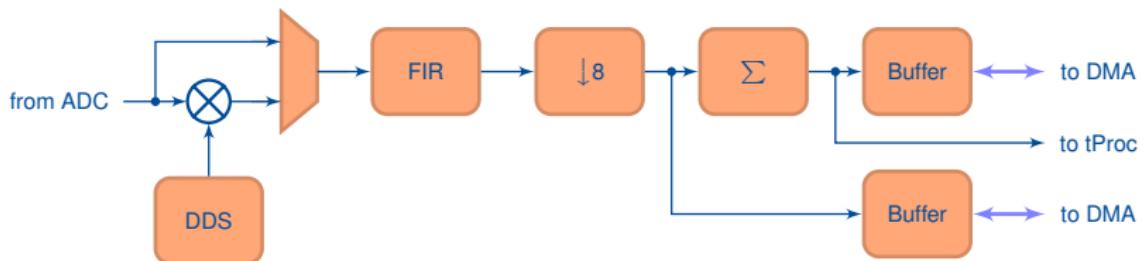
Multiplexed Signal Generator

- Four independent DDS units are included.
- There is no envelope memory to simplify the block.
- Frequency, Phase and Gain can be controlled.
- Independent DDSs can be activated or de-activated.
- Automatic Quantization relying on active outputs.



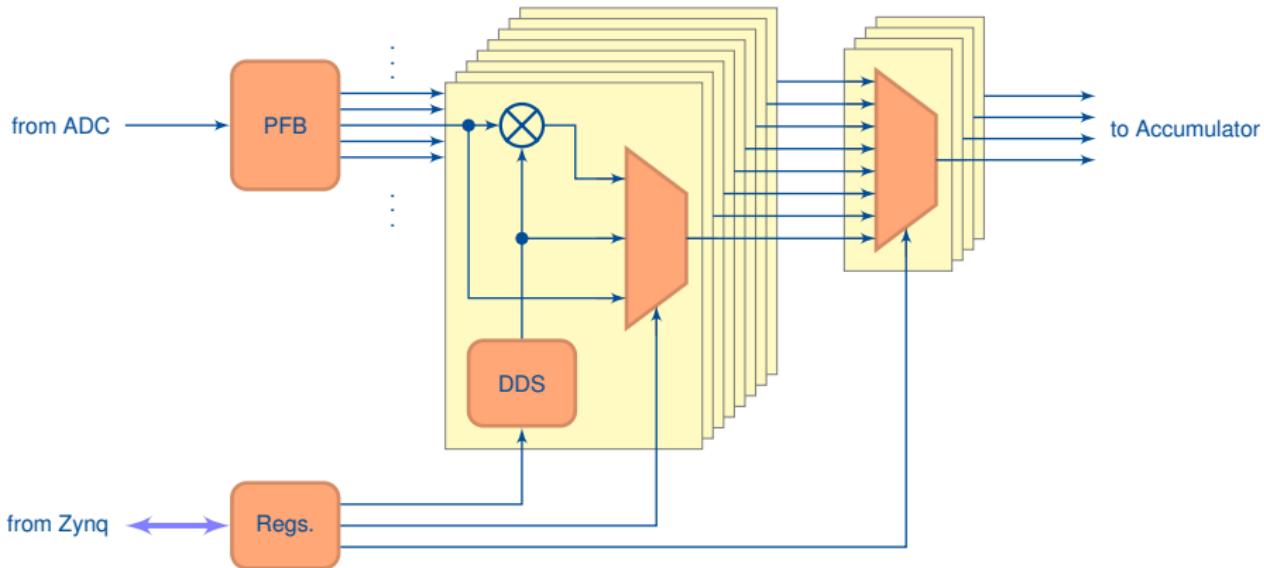
Readout Block

- Input is down-converted with a full-speed DDS.
- Down-conversion output is decimated 8 times.
- Detection is implemented with an accumulator unit.
- Number of accumulated samples is controllable.
- Accumulation process is triggered from the tProc.
- Raw-data is buffered for debugging and calibration.

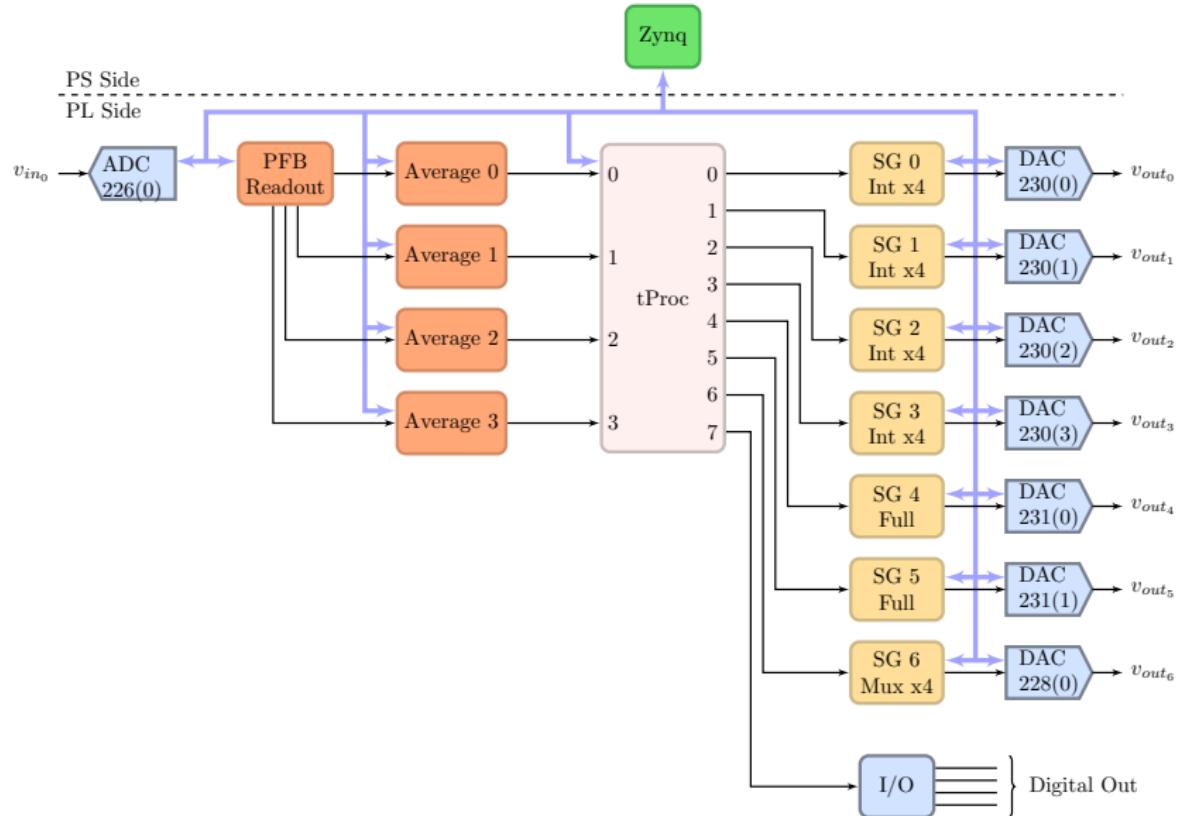


Multiplexed Readout Block

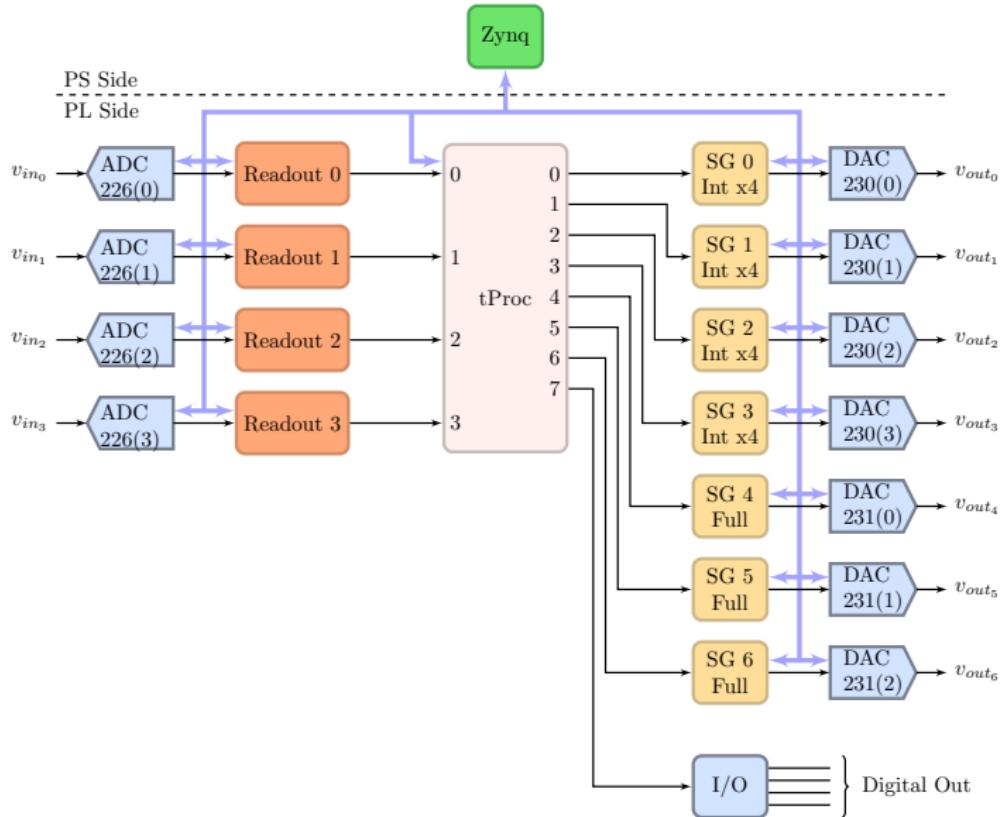
- ADC's spectrum is sliced in 8 channels.
- PFB shifts frequency, filters and decimates by 4.
- There is an extra fine frequency shifting per channel.
- There are 4 all-to-one muxes to select 4 output.



Example System 1



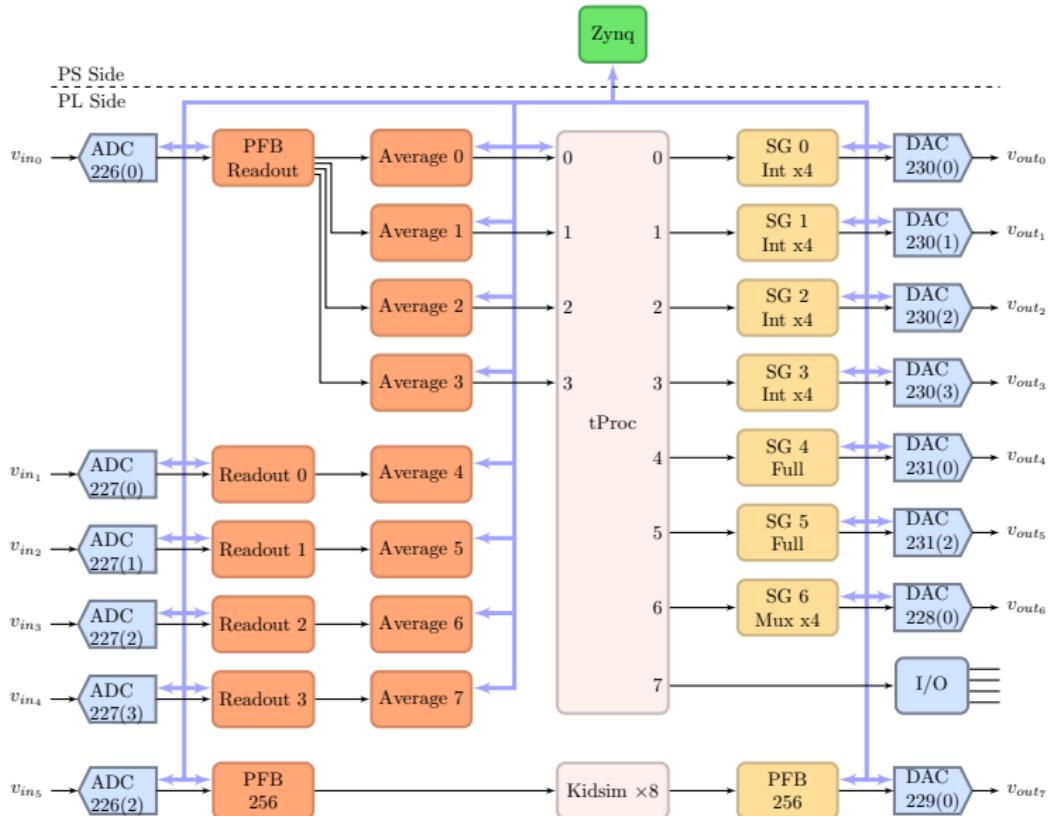
Example System 2



Outline

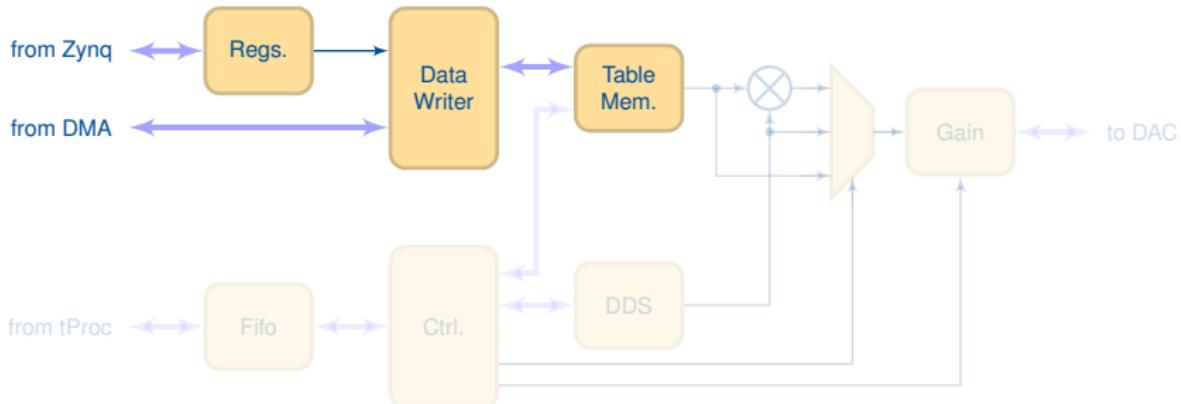
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QICK Training Firmware



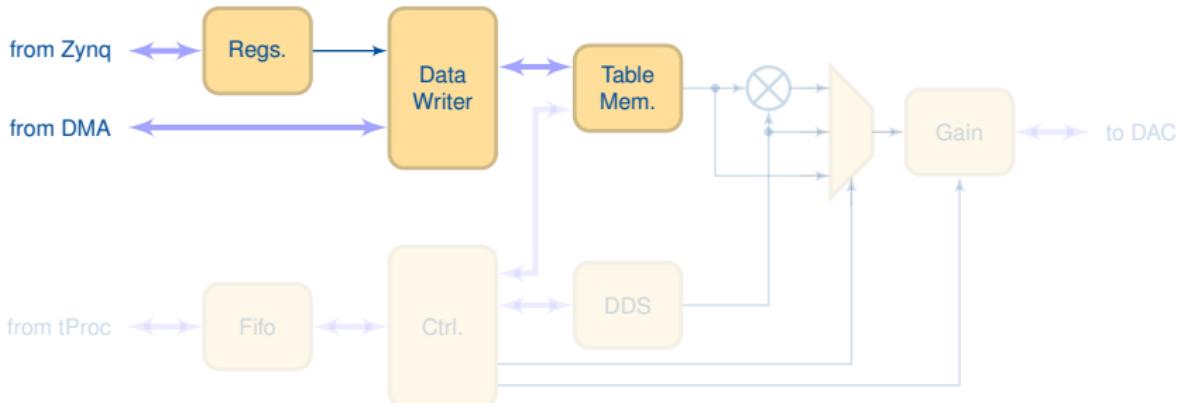
Signal Generator

- Envelopes are pre-loaded in the Table Memory.
- Multiple envelopes can be pre-loaded for later use.
- The internal queue (FIFO) can hold few waveforms.
- Envelope, DDS or Mixed output can be selected.
- When a waveform is pushed, it's played right away.



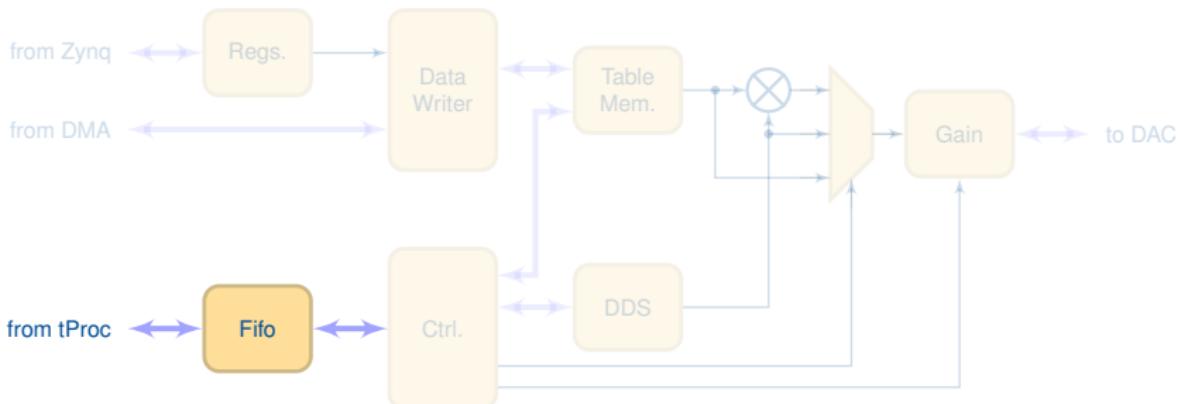
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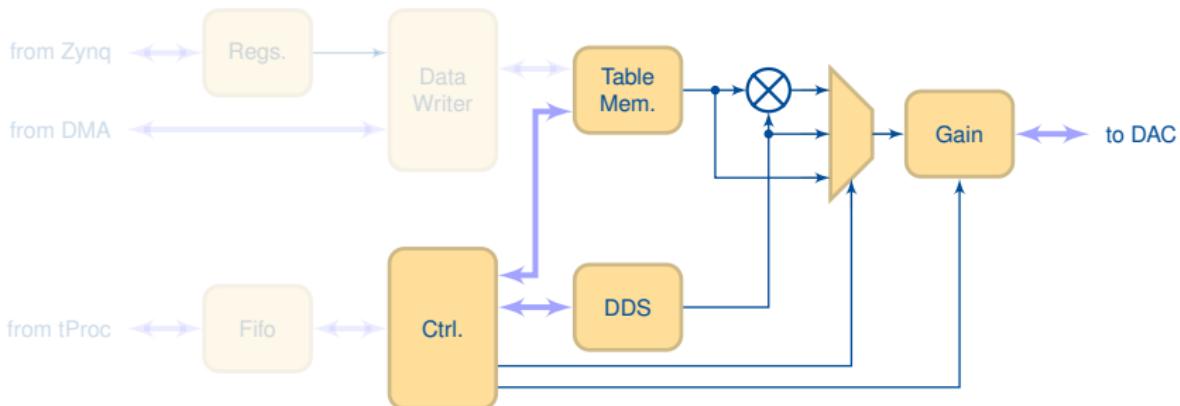
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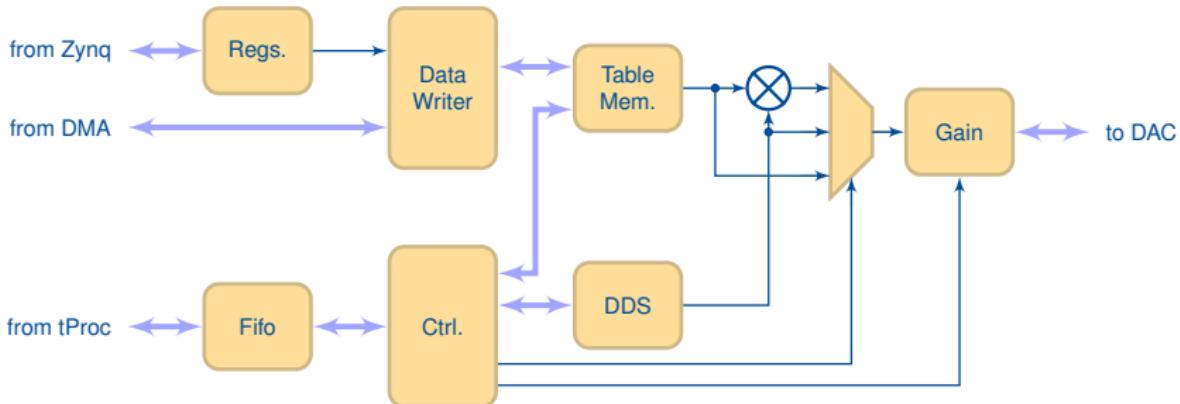
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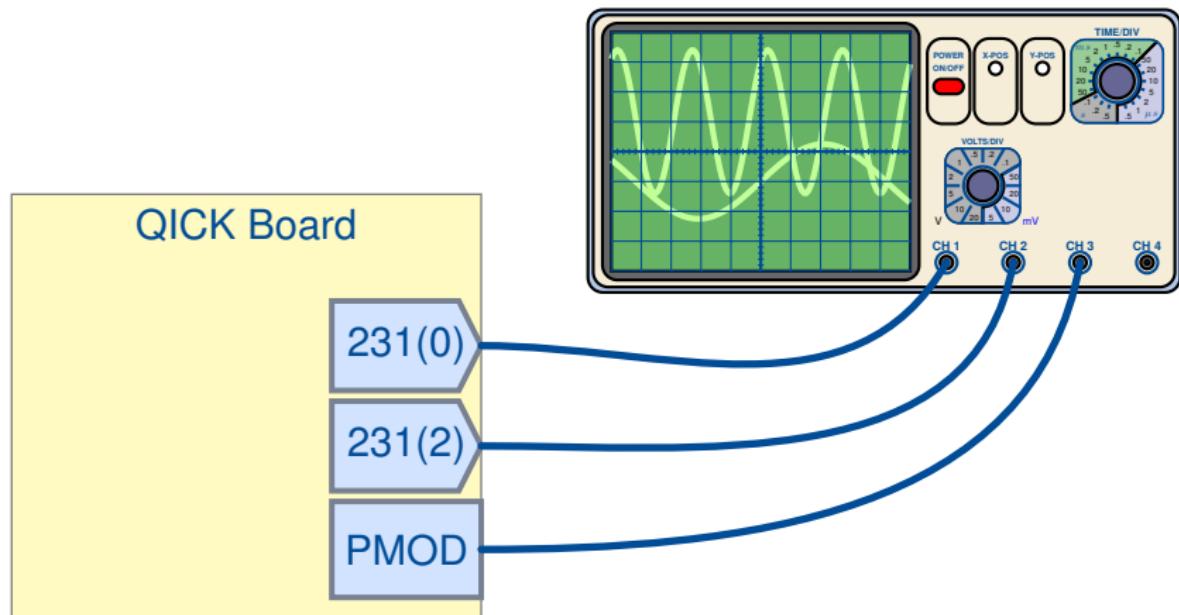


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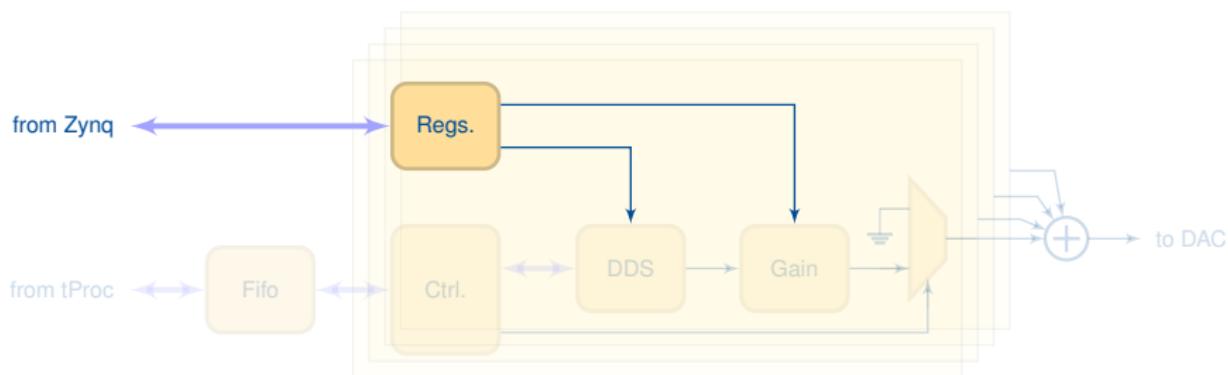


Connections for demo_00 and demo_01



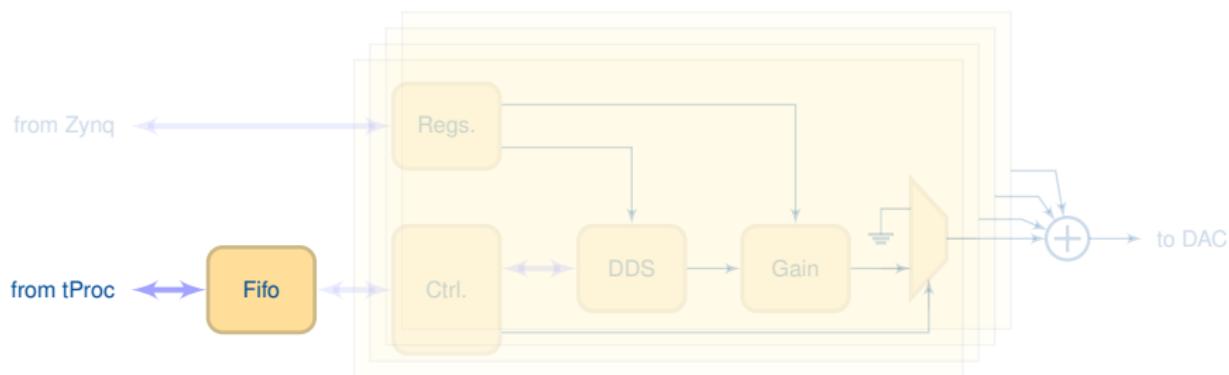
Multiplexed Signal Generator

- Frequency and Gain are configured with registers.
- The internal Queue can store a few waveforms to play.
- The tProc controls the length of the pulse and mask.
- The four instances are independent from each other.



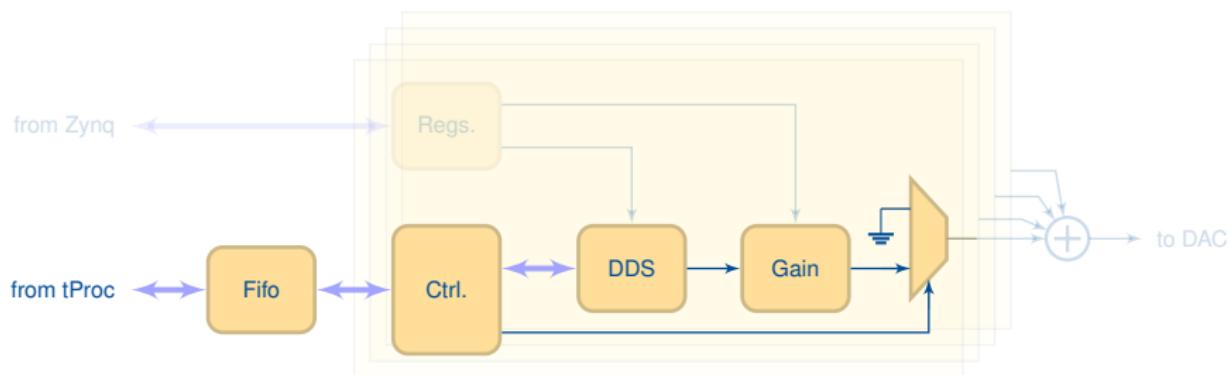
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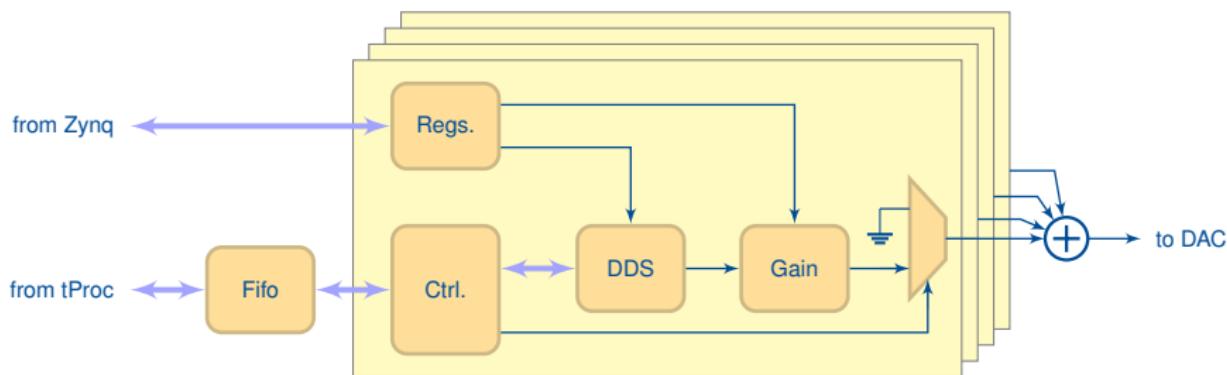
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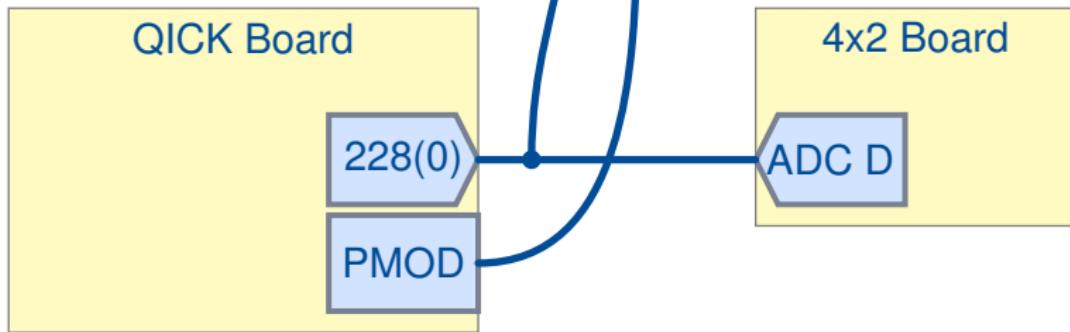
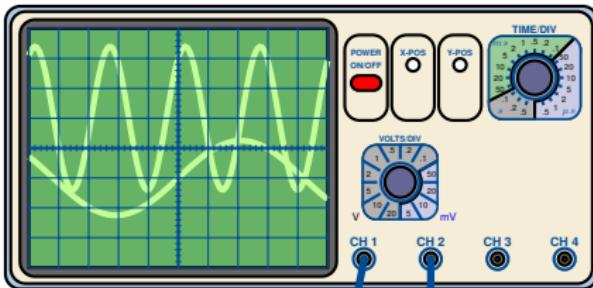


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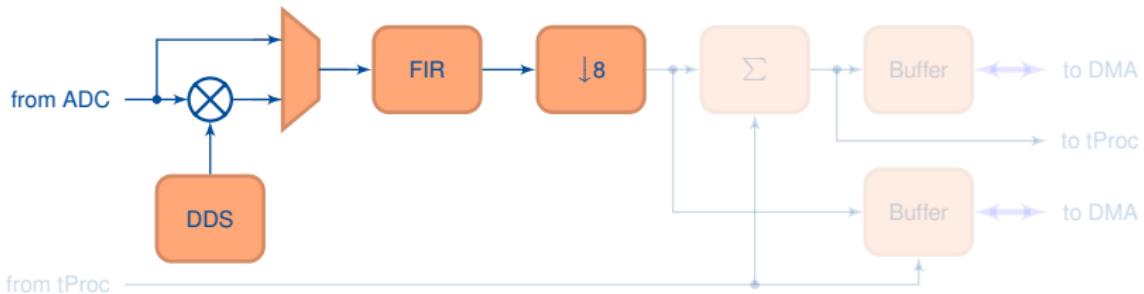


Connections for demo_02



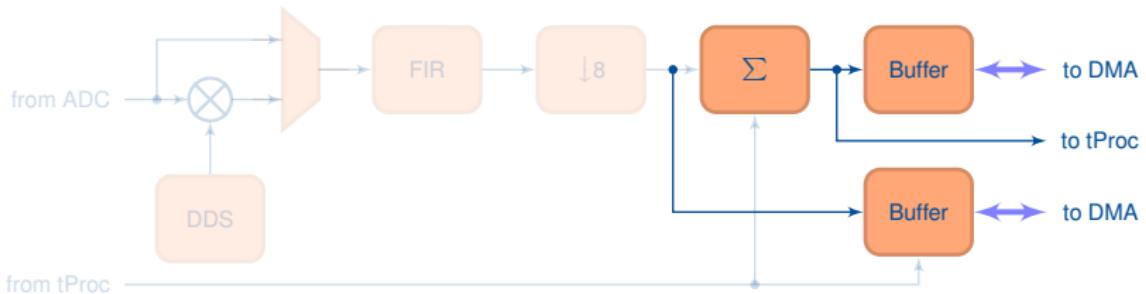
Readout Block

- Input is down-converted and decimated 8 times.
- Detection is implemented with an accumulator unit.
- Number of accumulated samples is controllable.
- Accumulation process is triggered from the tProc.
- Raw-data is buffered for debugging and calibration.



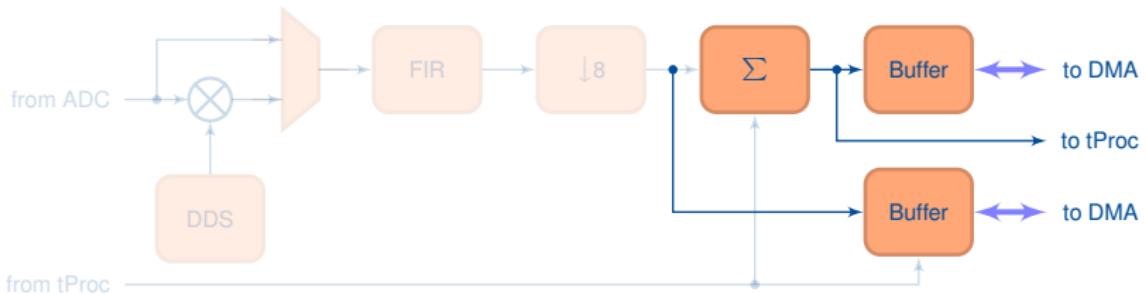
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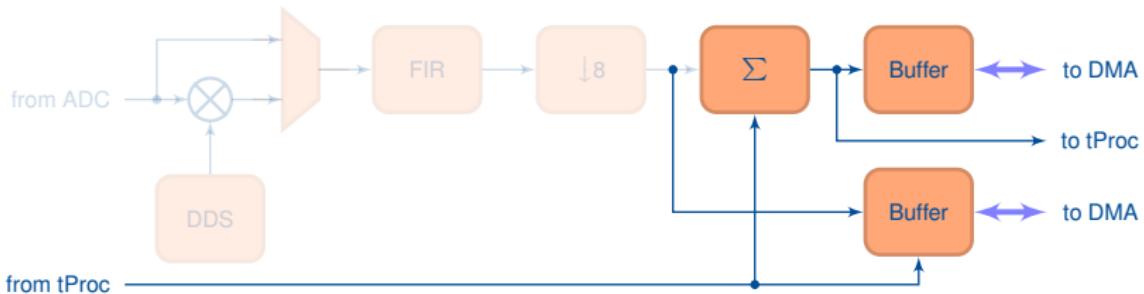
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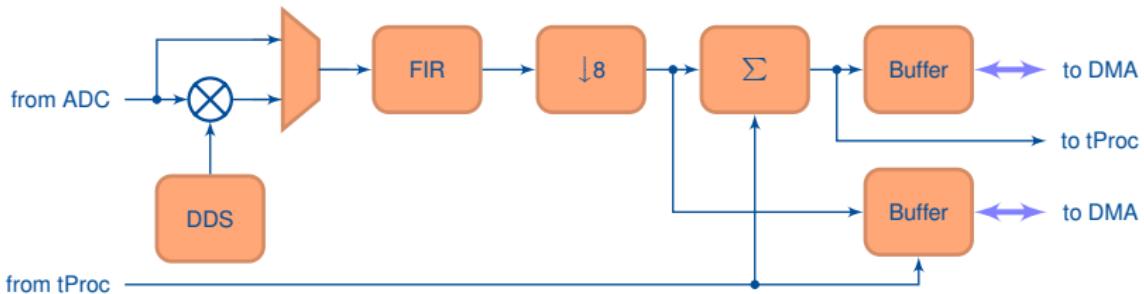
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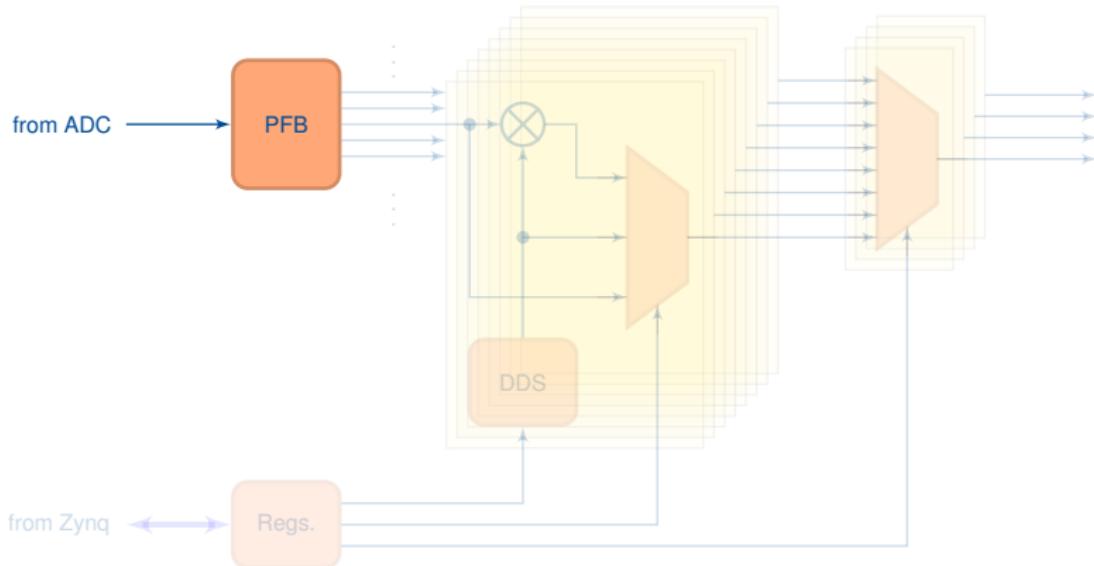
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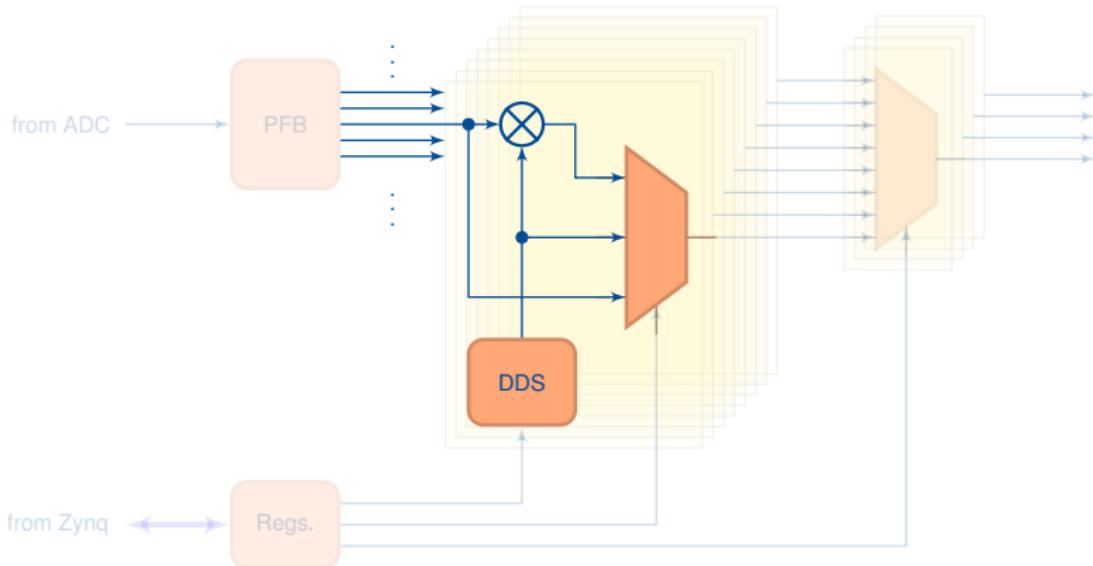
Multiplexed Readout Block

- PFB slices ADC's spectrum in eight channels.
- There is an extra fine frequency shifting per channel.
- Four all-to-one muxes select four output.
- Outputs feed the standard averager/detection block.



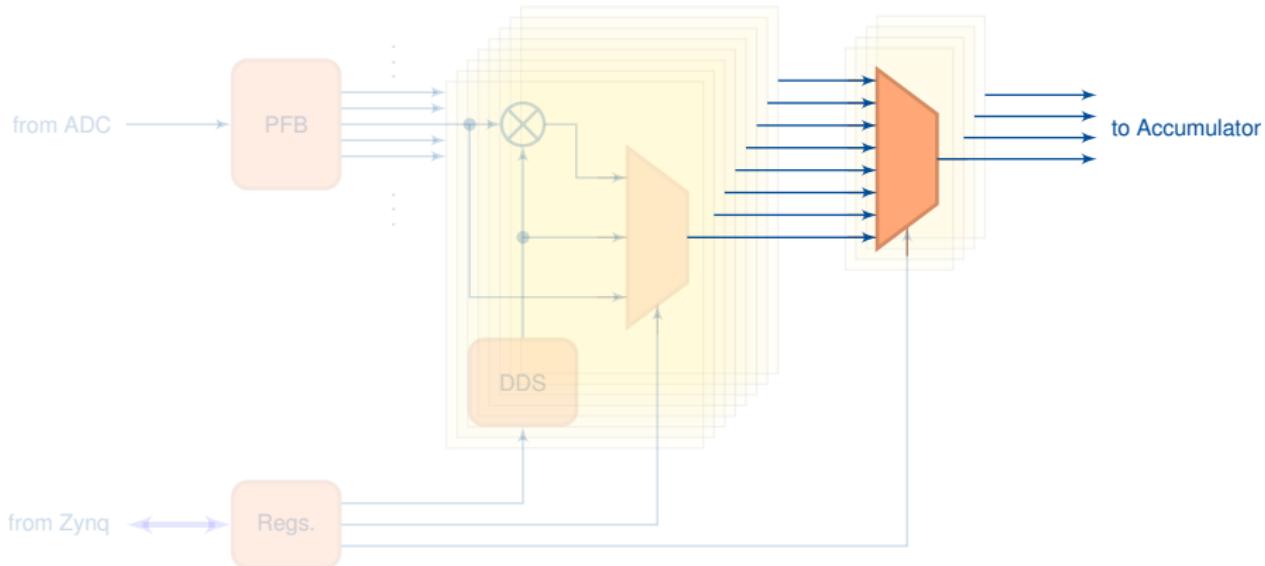
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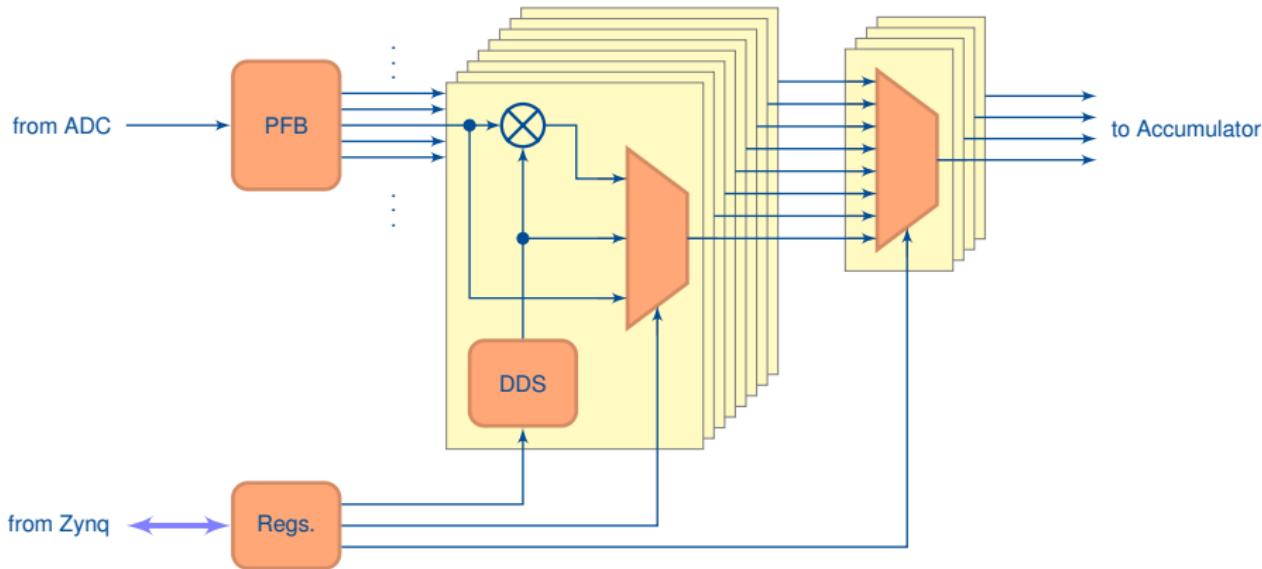
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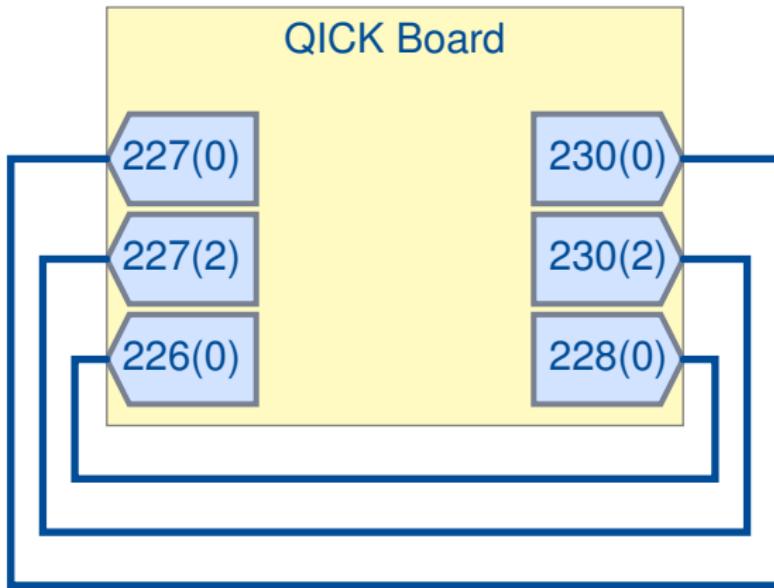


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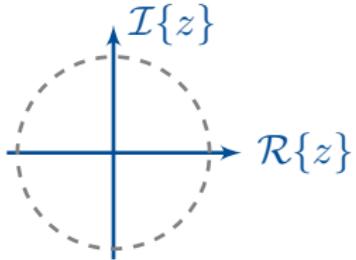
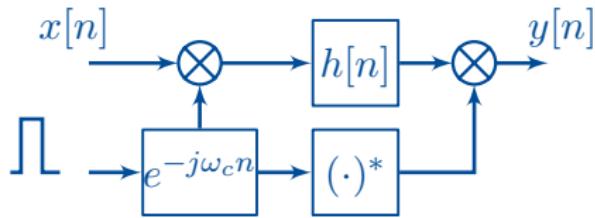
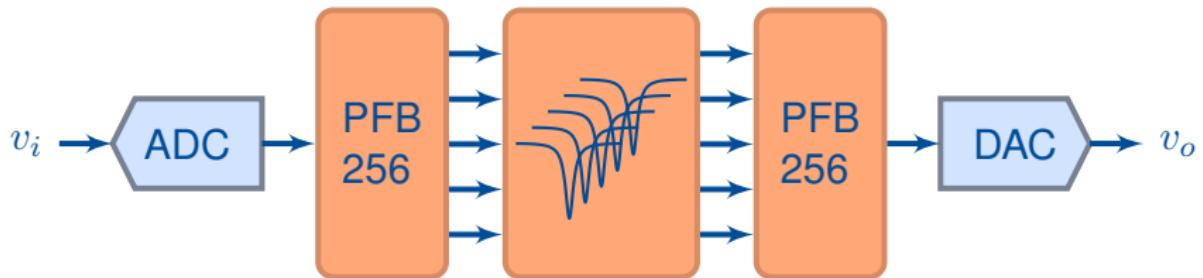
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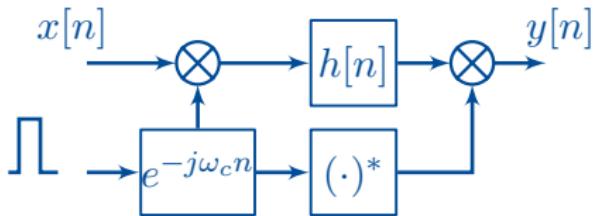
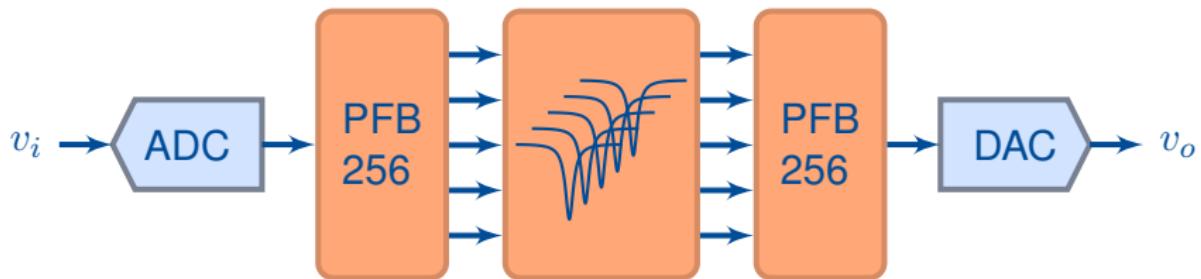
Connections for demo_03



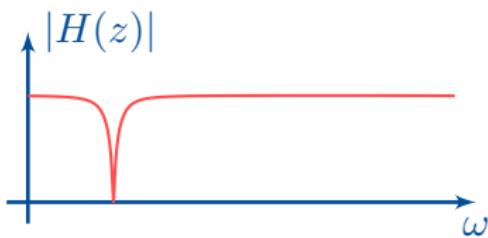
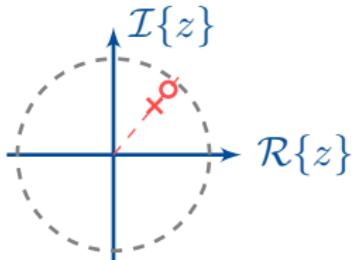
Resonator and Qubit Emulator



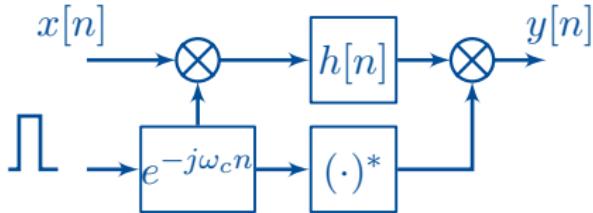
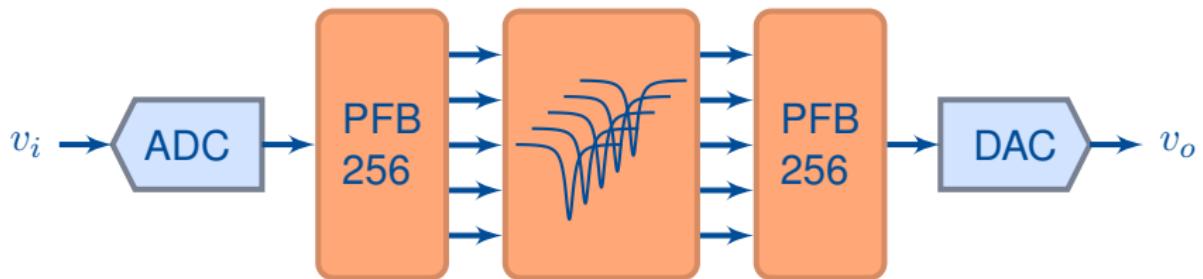
Resonator and Qubit Emulator



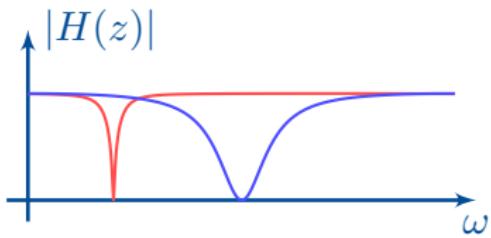
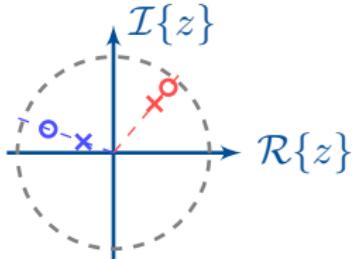
Resonator frequency and Q factor can be adjusted.



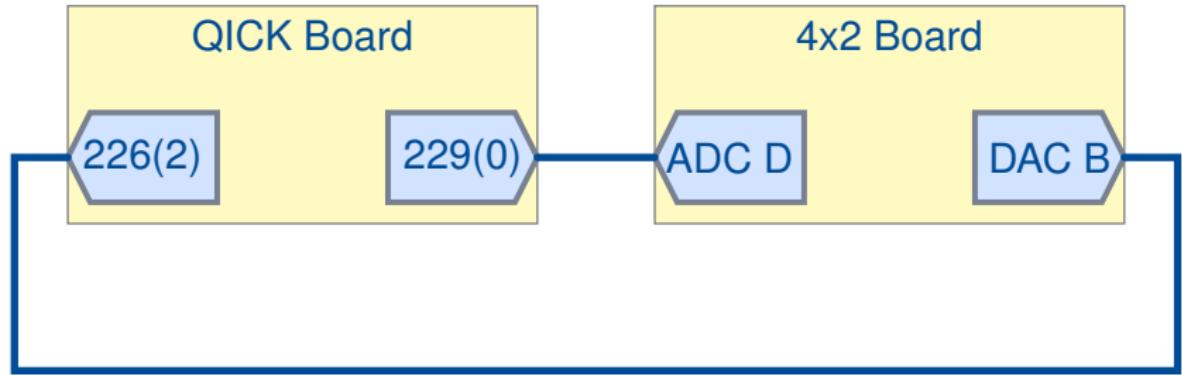
Resonator and Qubit Emulator



Resonator frequency and Q factor can be adjusted.



Connections for demo_04



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Thanks for your attention!

Questions?



Project files and examples:

<https://github.com/openquantumhardware/qick.git>

https://github.com/openquantumhardware/QCE2023_public.git