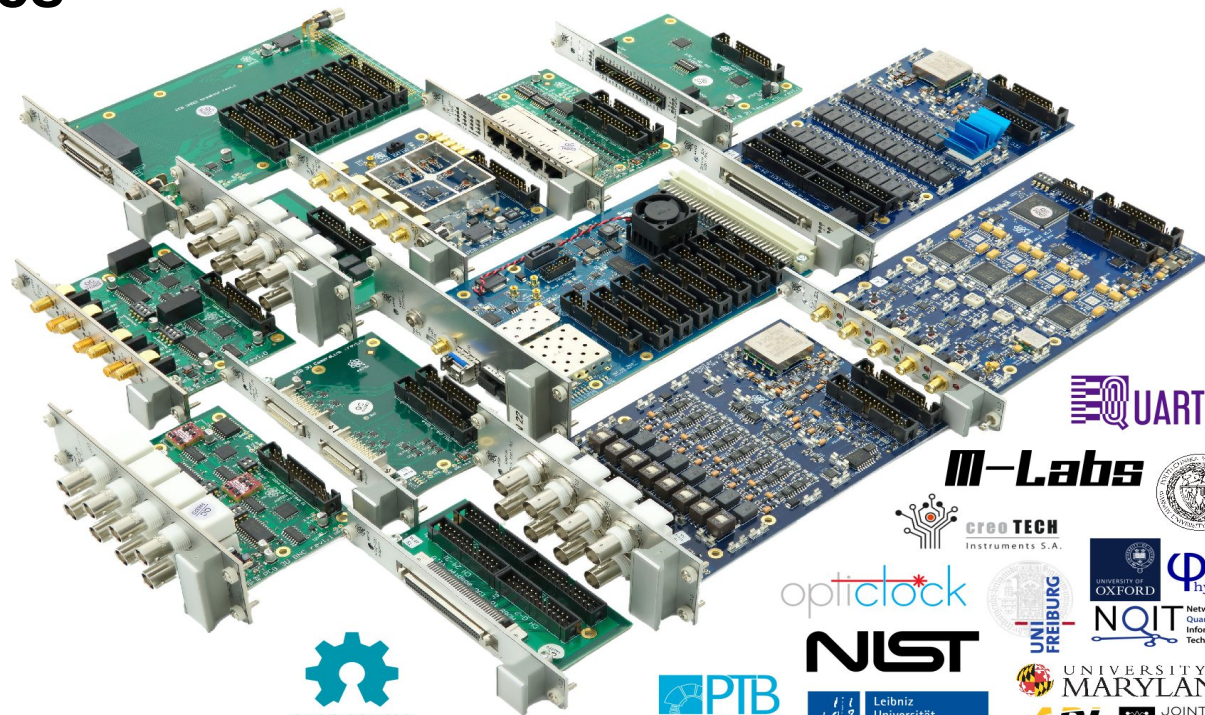


Signal Generation for Trapped Ion Quantum Gates

Norman Krackow
QUARTIQ GmbH



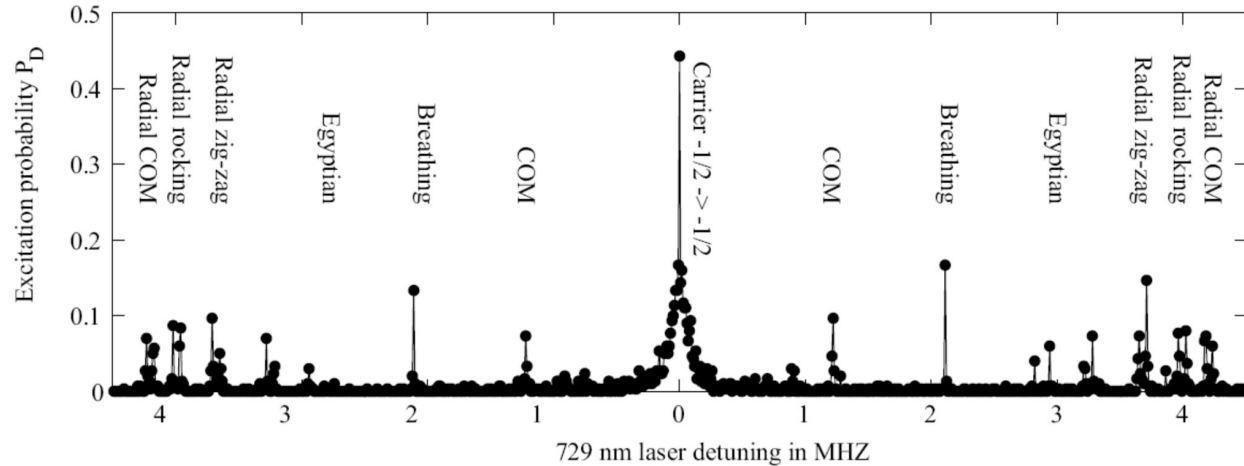
Open tools for open science

Outline

1. **Pulses for Ions**
2. **How do we generate these Signals?**
3. **ARTIQ Architecture**
4. **STFT / MIQRO Pulse Generators**

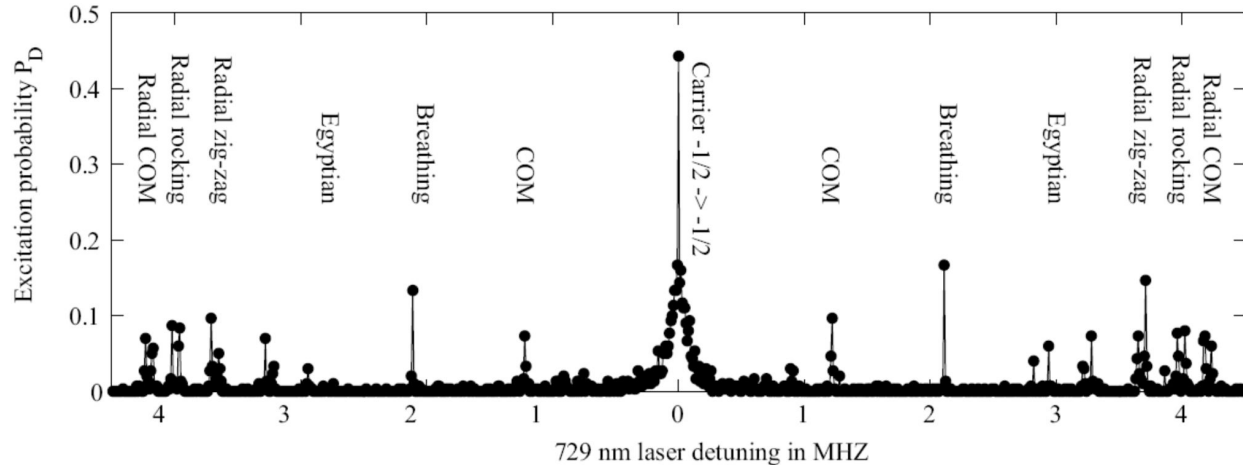
Pulses for Ions

- Interaction with the ion qubits via fields on very specific frequencies.



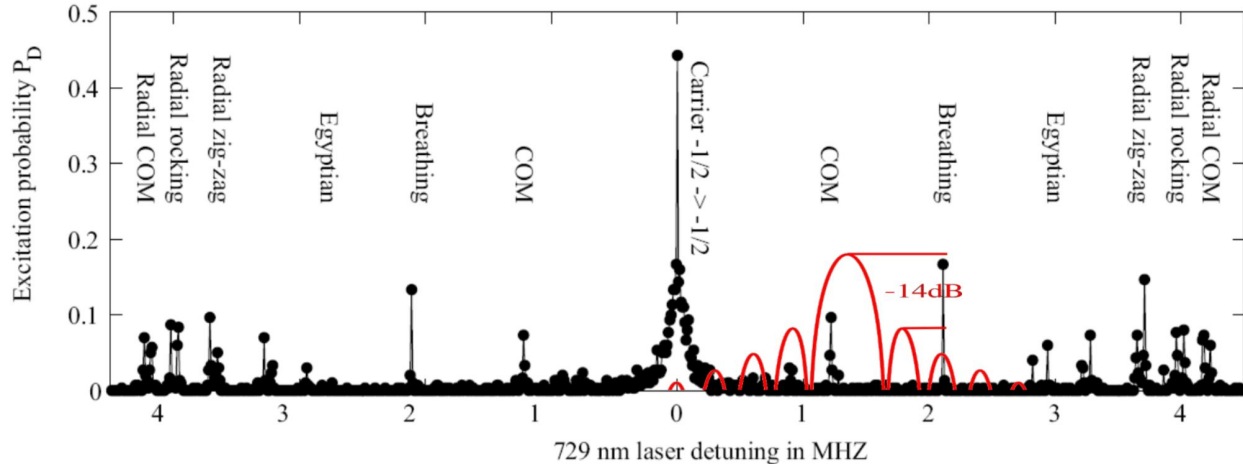
Pulses for Ions

- Interaction with the ion qubits via fields on very specific frequencies.
- Potentially complex waveforms for robust/parallel gates.



Pulses for Ions

- Interaction with the ion qubits via fields on very specific frequencies.
- Potentially complex waveforms for robust/parallel gates.
- Extreme requirements on accuracy and spectral confinement.



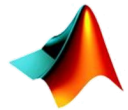
How do we generate these Signals?

Brute Force?

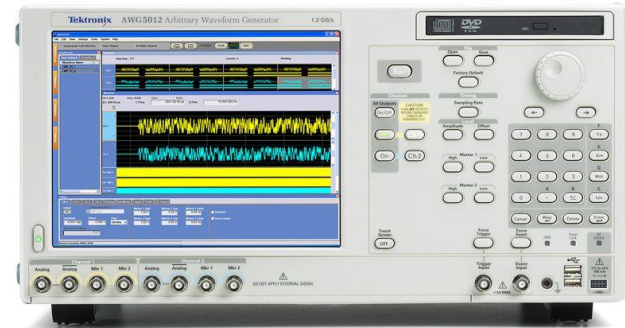
- Easy! Use Matlab/Python and play back datasamples at high rate on a signal generator.



python™

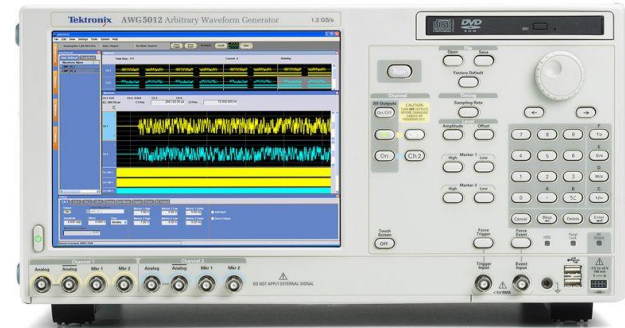


MATLAB



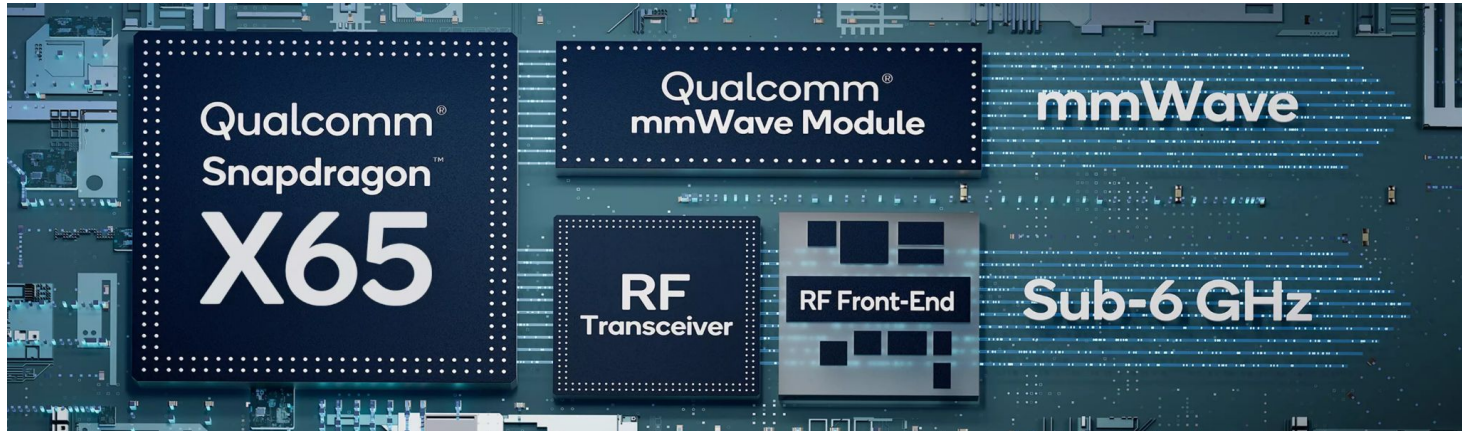
Brute Force?

- Easy! Use Matlab/Python and play back datasamples at high rate on a signal generator.
 - Slow
 - A lot of computation each time a small detail changes
 - Expensive
 - Not scalable
 - No way to use feedback from the experiment



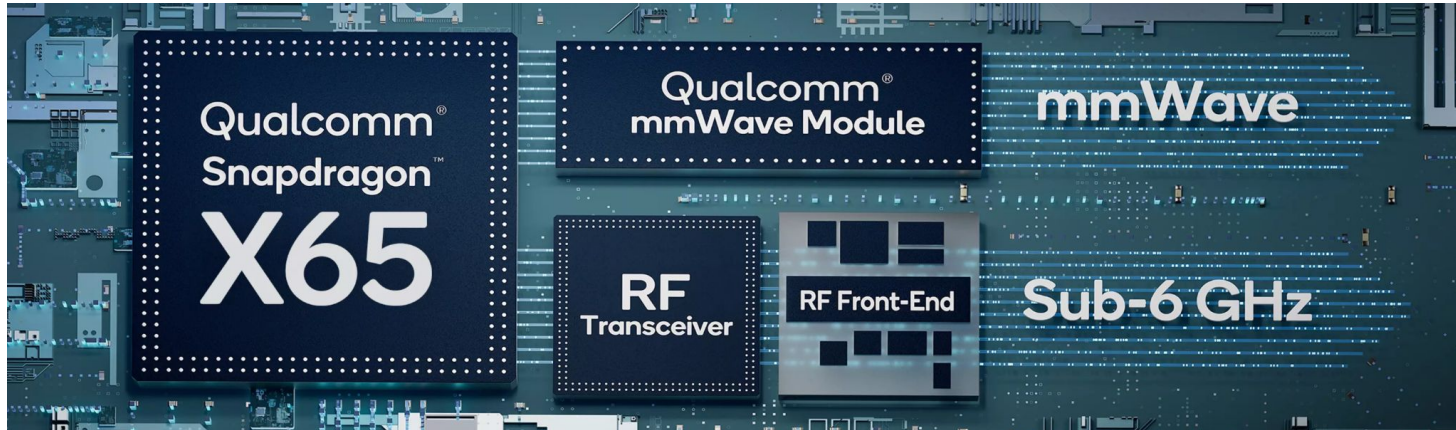
Leverage fully integrated solutions?

- Wait! That's exactly what my phone does!



Leverage fully integrated solutions?

- Wait! That's exactly what my phone does!
 - Only very specific protocols and waveforms
 - No way to reprogram
 - Highly secret
 - Basically magic



So what do we do?

So what do we do?

 **We need to combine parts of both.**

So what do we do?

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- **Programmability**

So what do we do?

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- **Programmability**
- **Dynamic computation**

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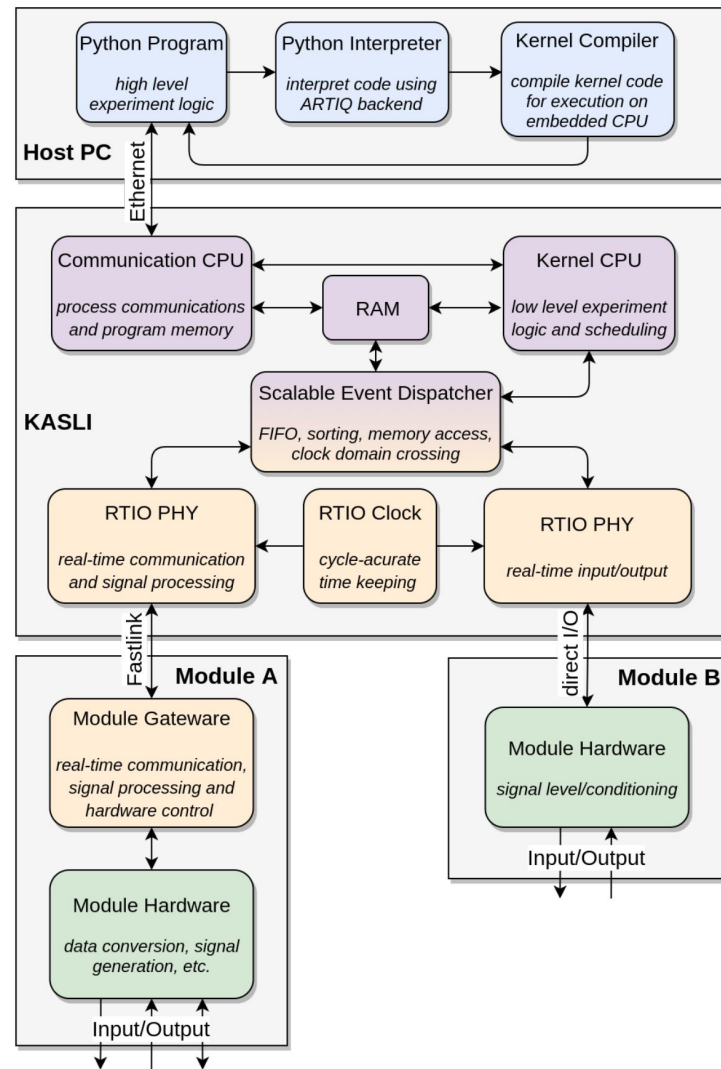
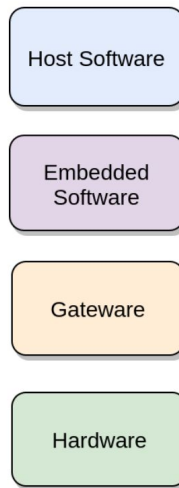
- **Programmability**
- **Dynamic computation**
- **Custom architecture**

So what do we do?

 **We need to combine parts of both.**

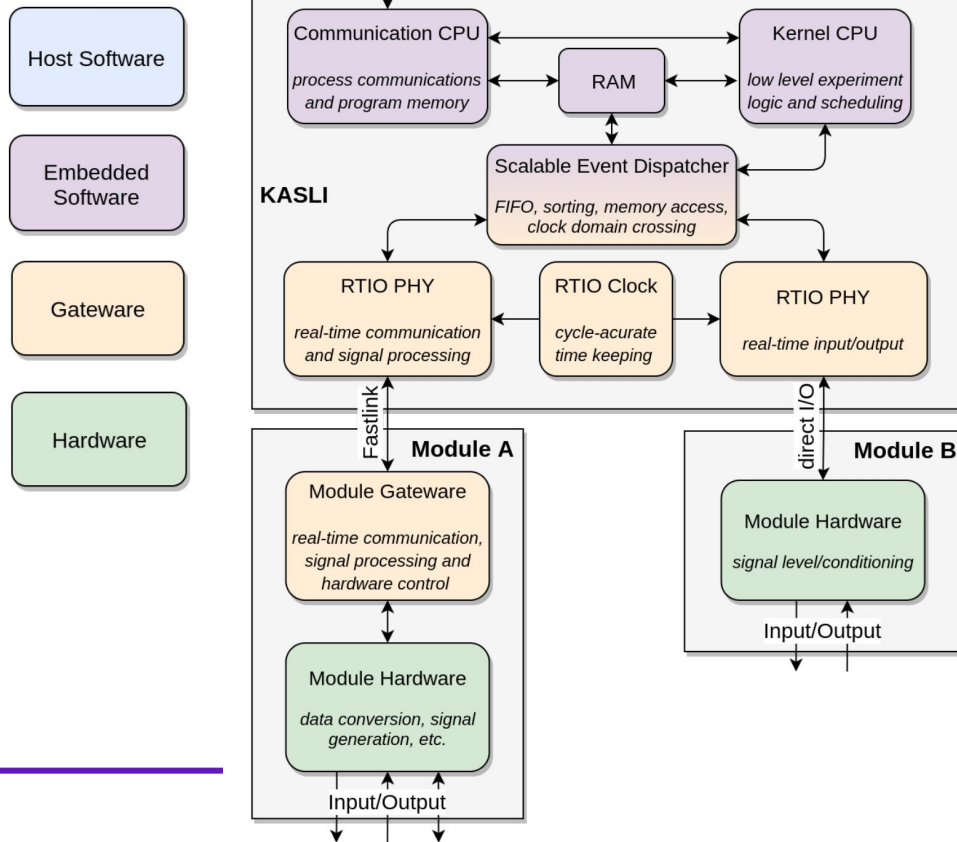
- **Programmability**
- **Dynamic computation**
- **Custom architecture**
- **Infrastructure to expose the functionality to the user**

ARTIQ System Overview



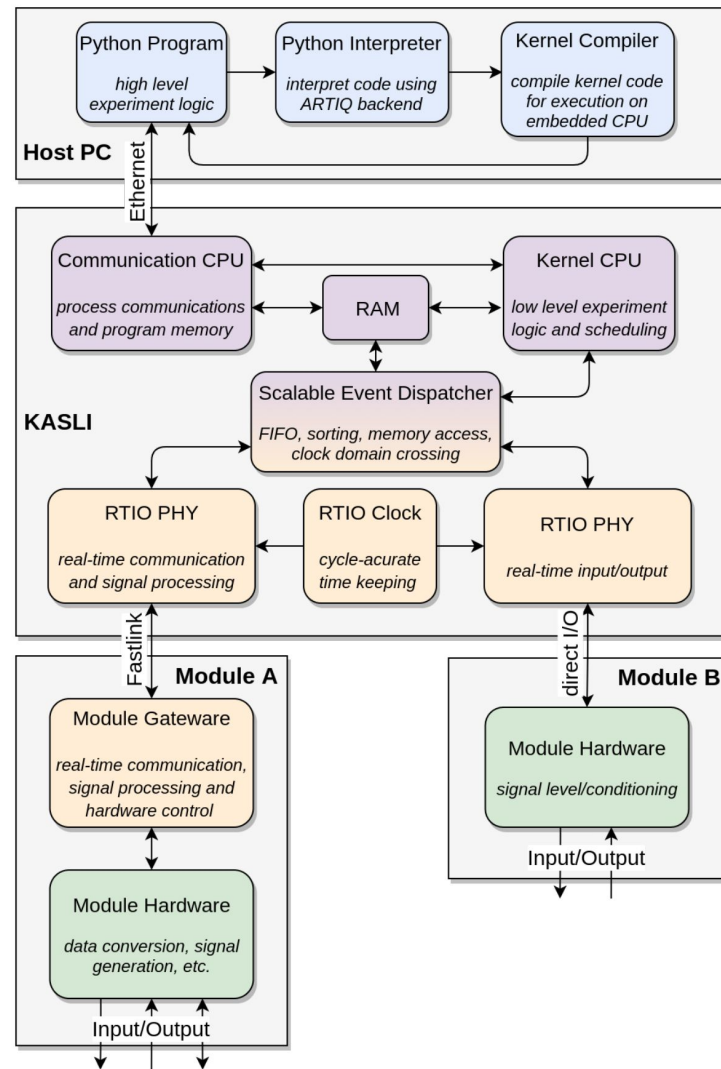
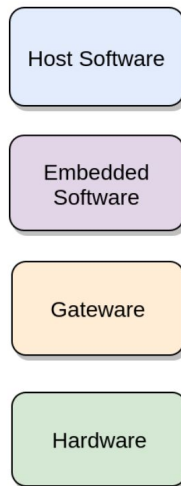
ARTIQ System Overview

- High level Python code is written by the user.



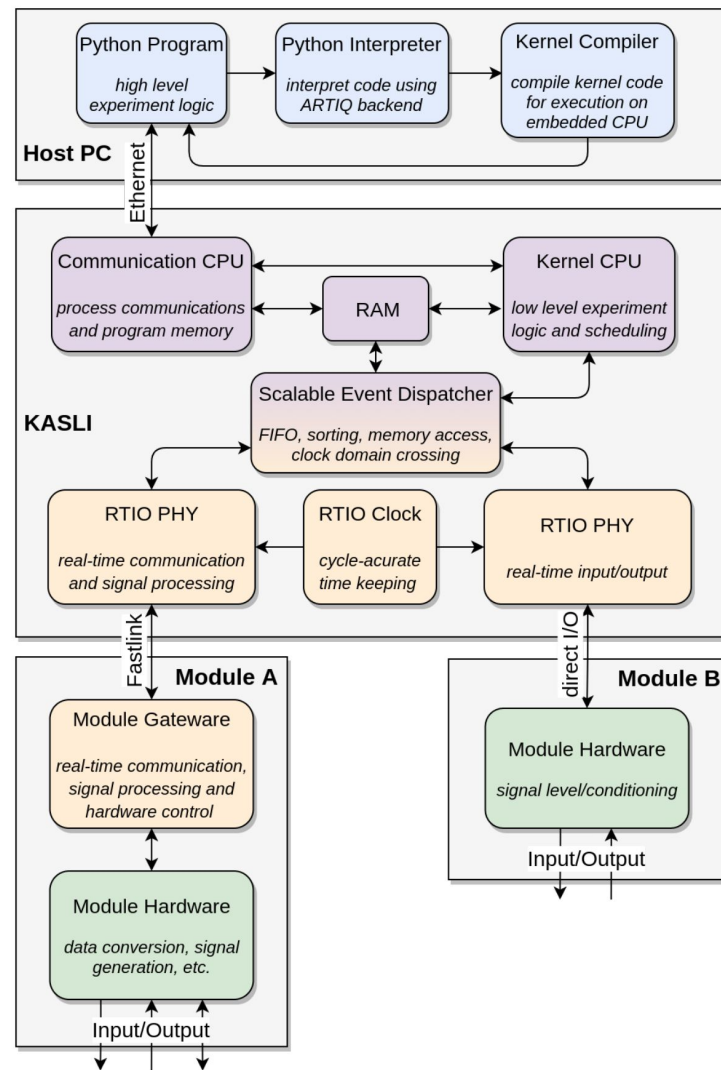
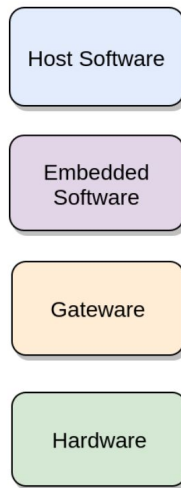
ARTIQ System Overview

- High level Python code is written by the user.
- *Kernel* code is dynamically compiled and executed on the embedded Kasli CPU.



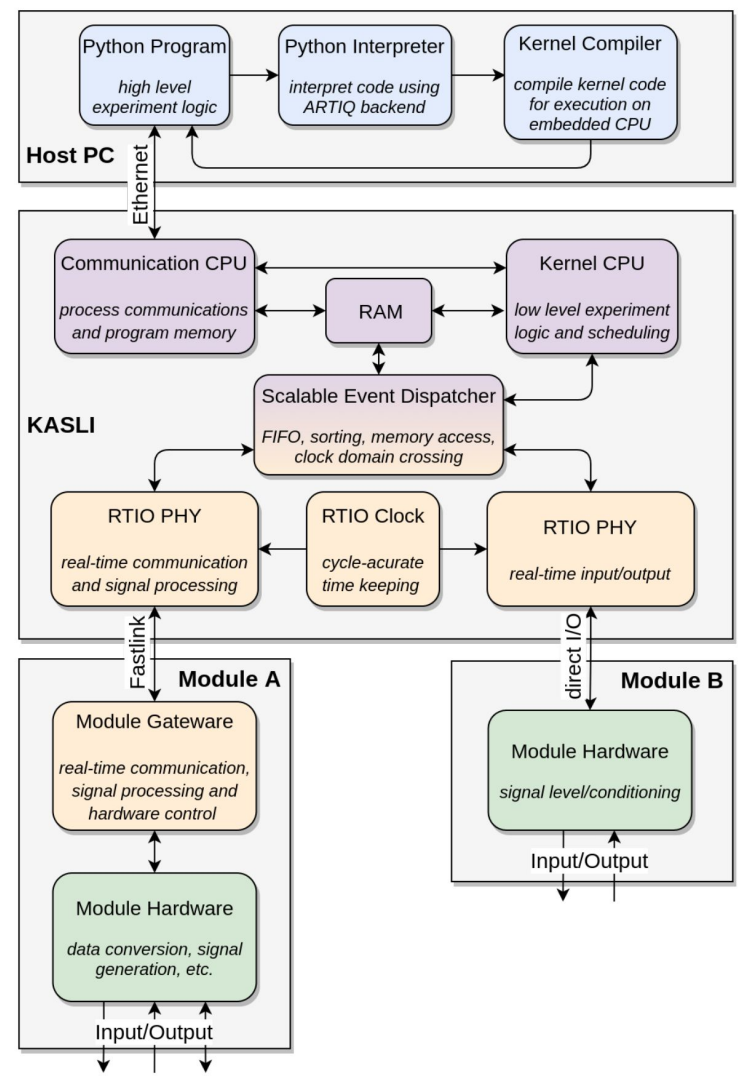
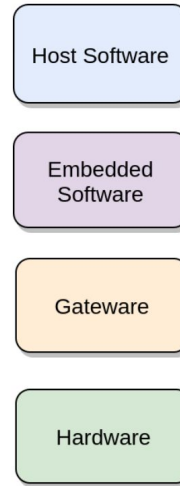
ARTIQ System Overview

- High level Python code is written by the user.
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- *Kernel* code can schedule realtime events in the RTIO system.



ARTIQ System Overview

- High level Python code is written by the user.
- *Kernel* code is dynamically compiled and executed on the embedded Kasli CPU.
- *Kernel* code can schedule realtime events in the RTIO system.
- Realtime events interact with Sinara hardware.

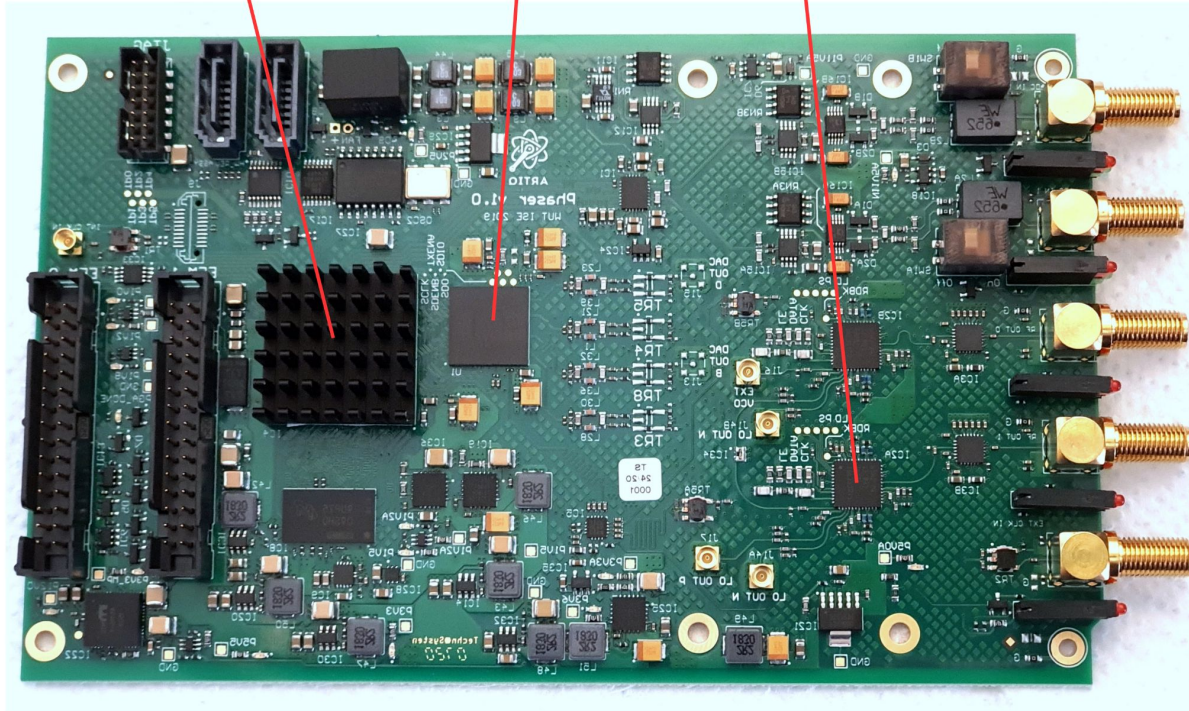


The “Phaser” Dynamic Signal Generator

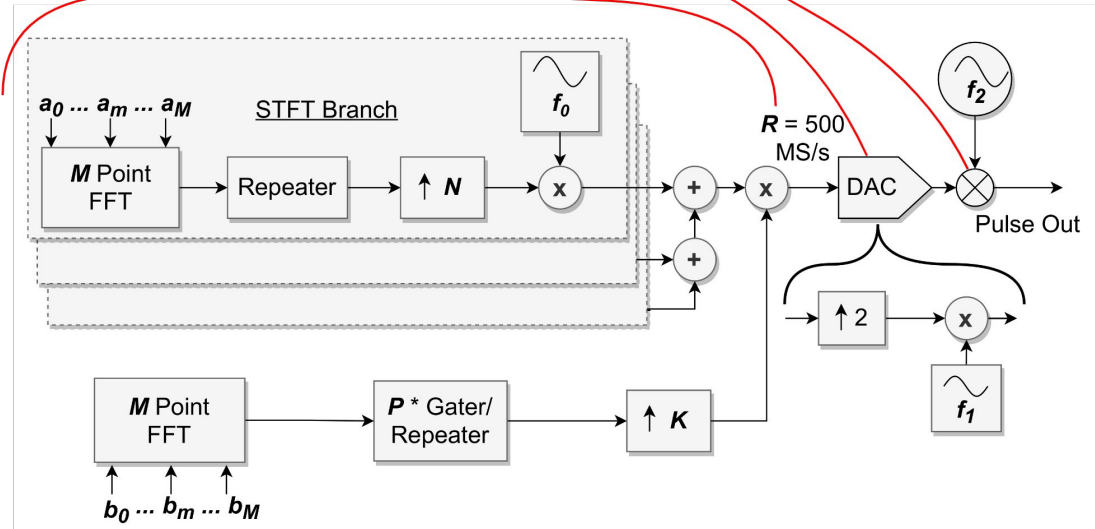
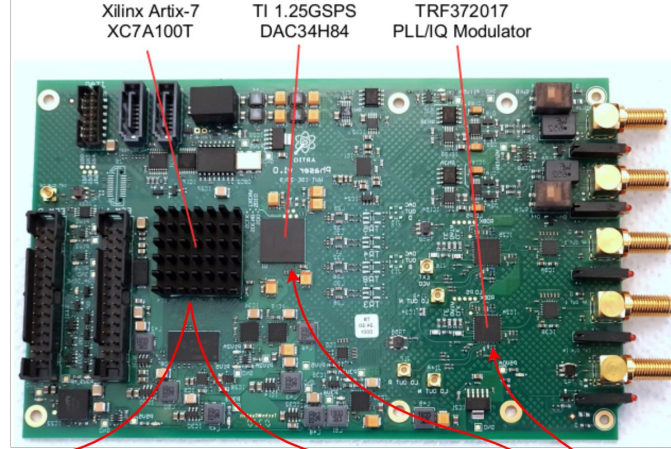
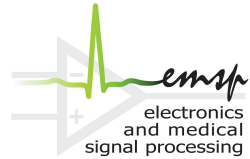
Xilinx Artix-7
XC7A100T

TI 1.25GSPS
DAC34H84

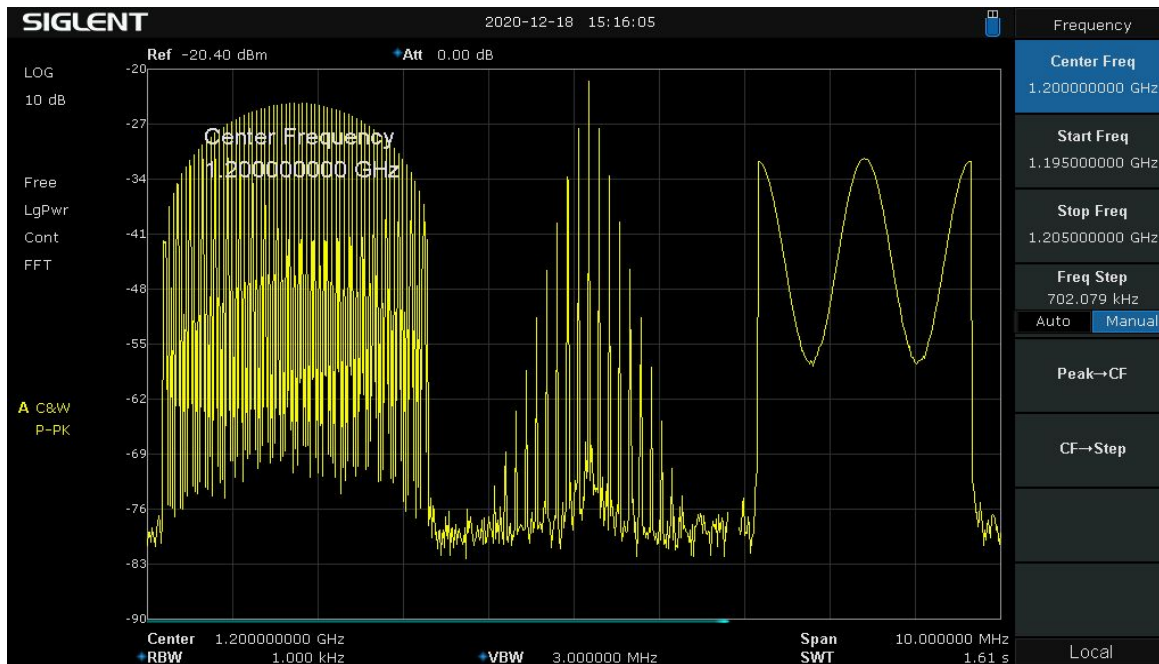
TRF372017
PLL/IQ Modulator



STFT Pulse Generator Architecture



STFT Pulse Generator Output Spectrum

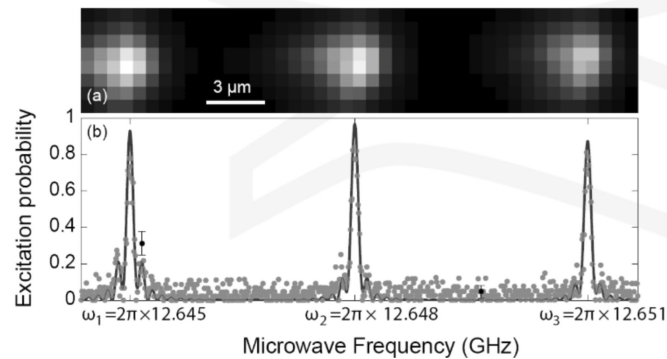
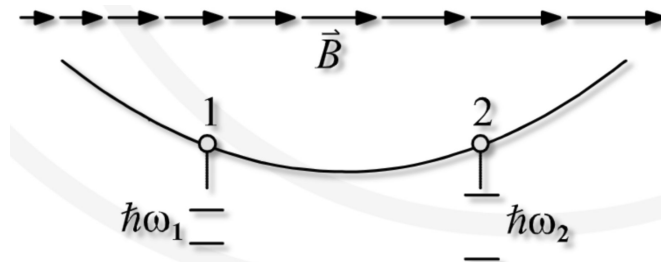


MIQRO qubit interaction

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arXiv:1112.5302, arXiv:0905.0118

MIQRO qubit interaction

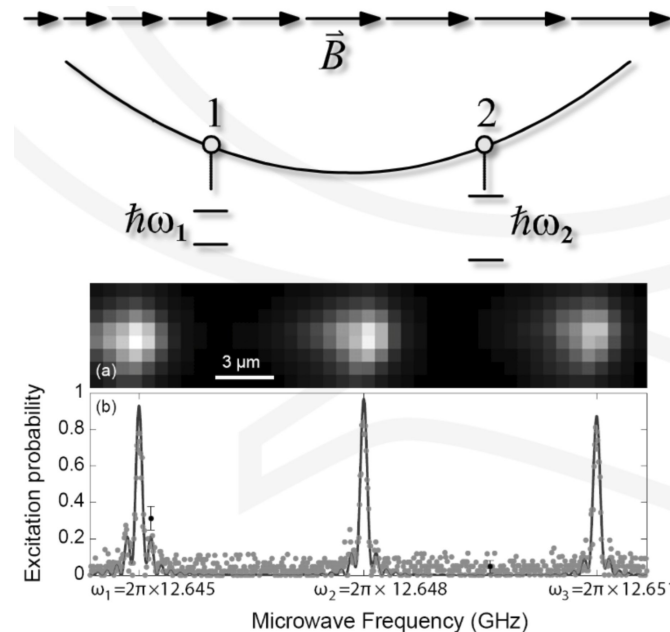


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- Qubit control using a global microwave field.



arXiv:1112.5302, arXiv:0905.0118

MIQRO qubit interaction

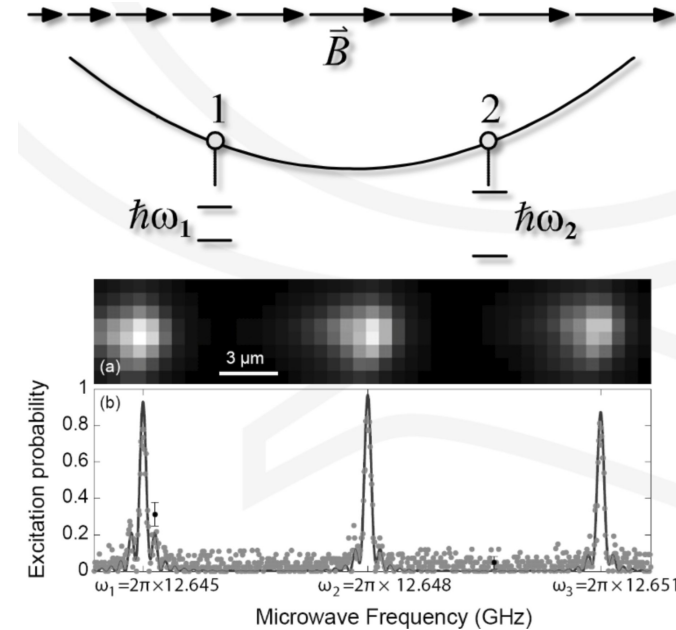


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- Qubit control using a global microwave field.
- Static magnetic gradient
 - different qubit frequencies
 - easy addressing in frequency space



arXiv:1112.5302, arXiv:0905.0118

MIQRO qubit interaction

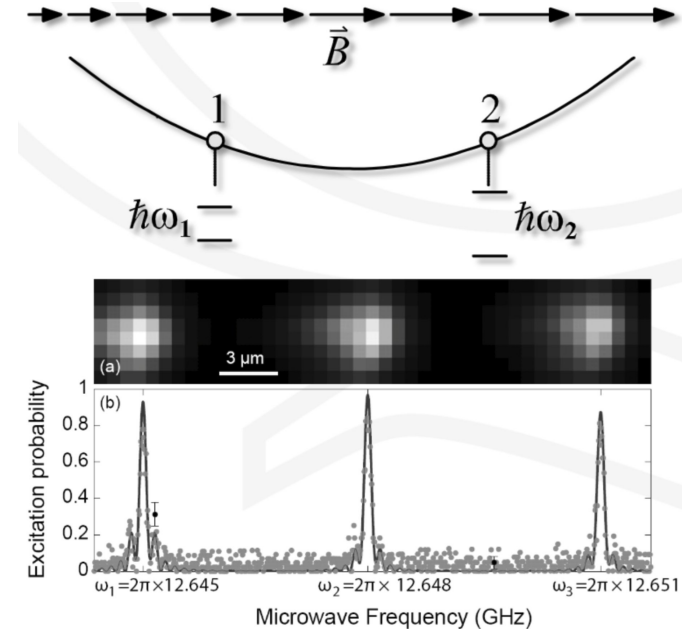


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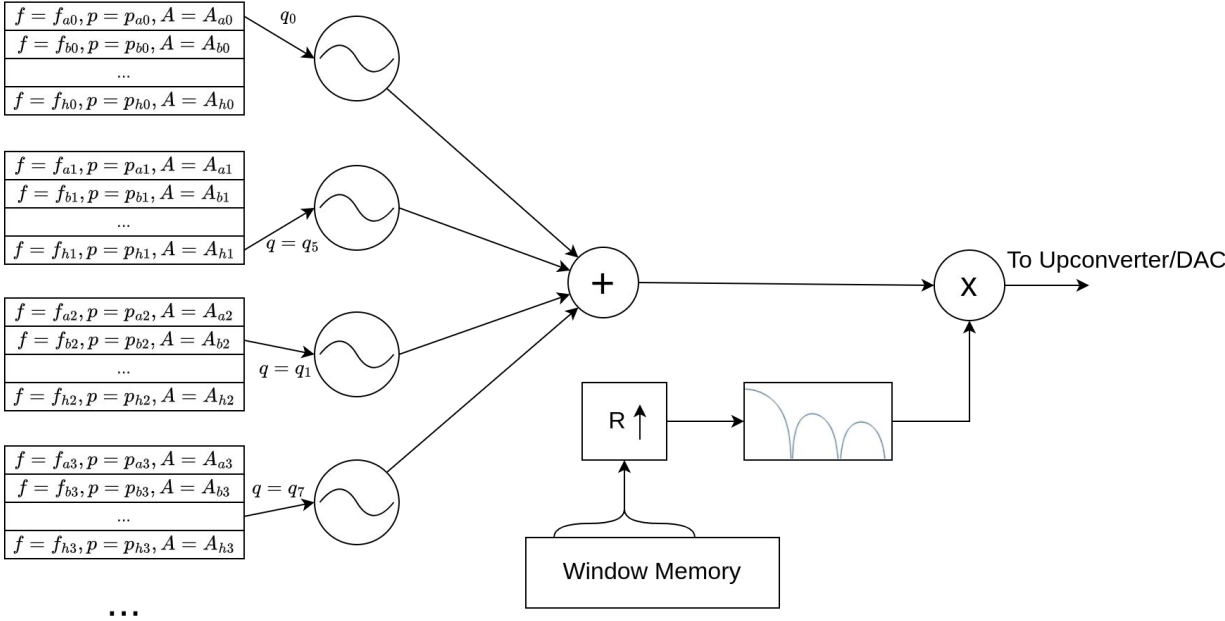
Federal Ministry
of Education
and Research

- Qubit control using a global microwave field.
- Static magnetic gradient
→ different qubit frequencies
→ easy addressing in frequency space
- Magnetic Gradient Induced Coupling (MAGIC)
entangling gates.



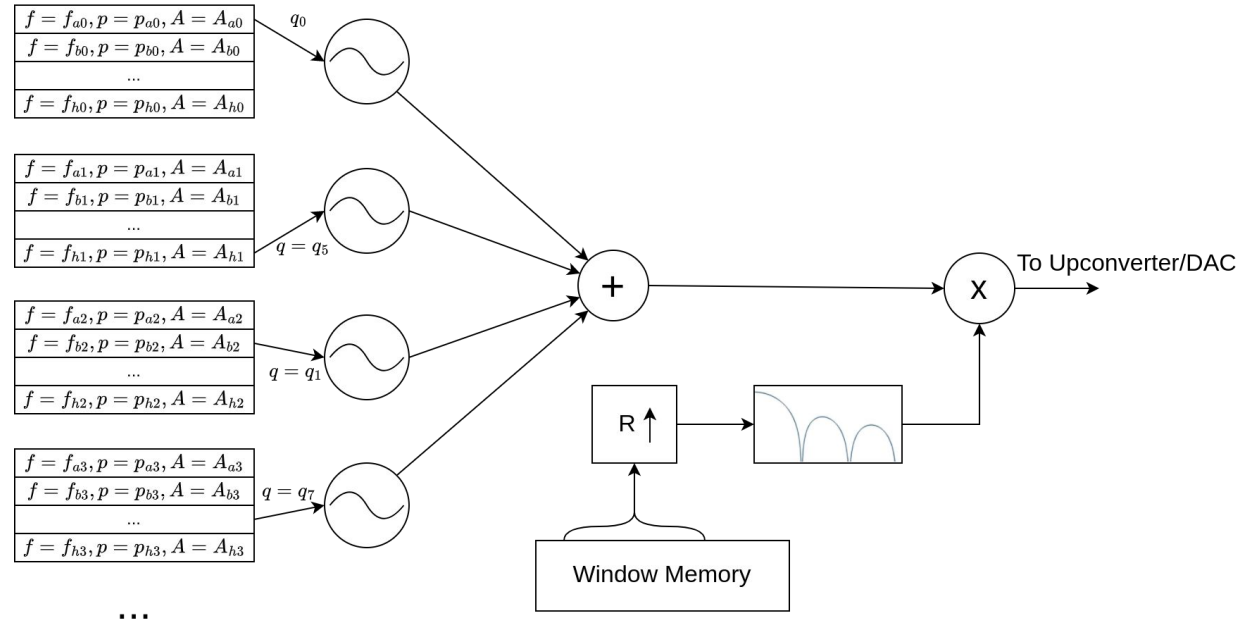
arXiv:1112.5302, arXiv:0905.0118

MIQRO Pulse Generator Architecture



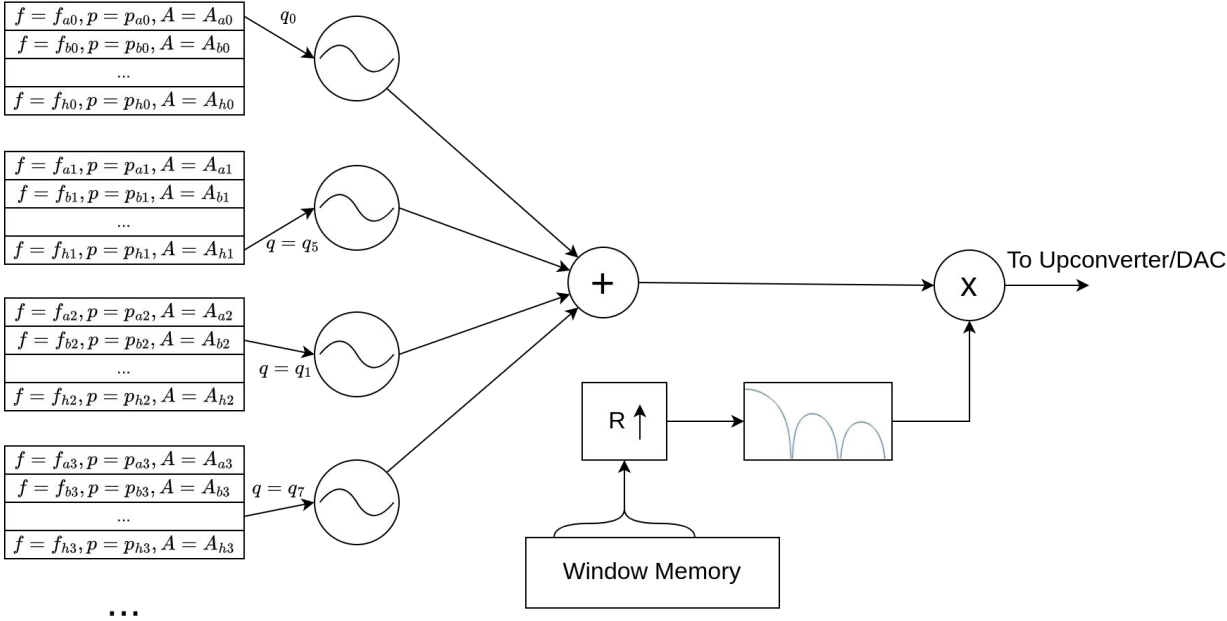
MIQRO Pulse Generator Architecture

- 16 digital oscillators



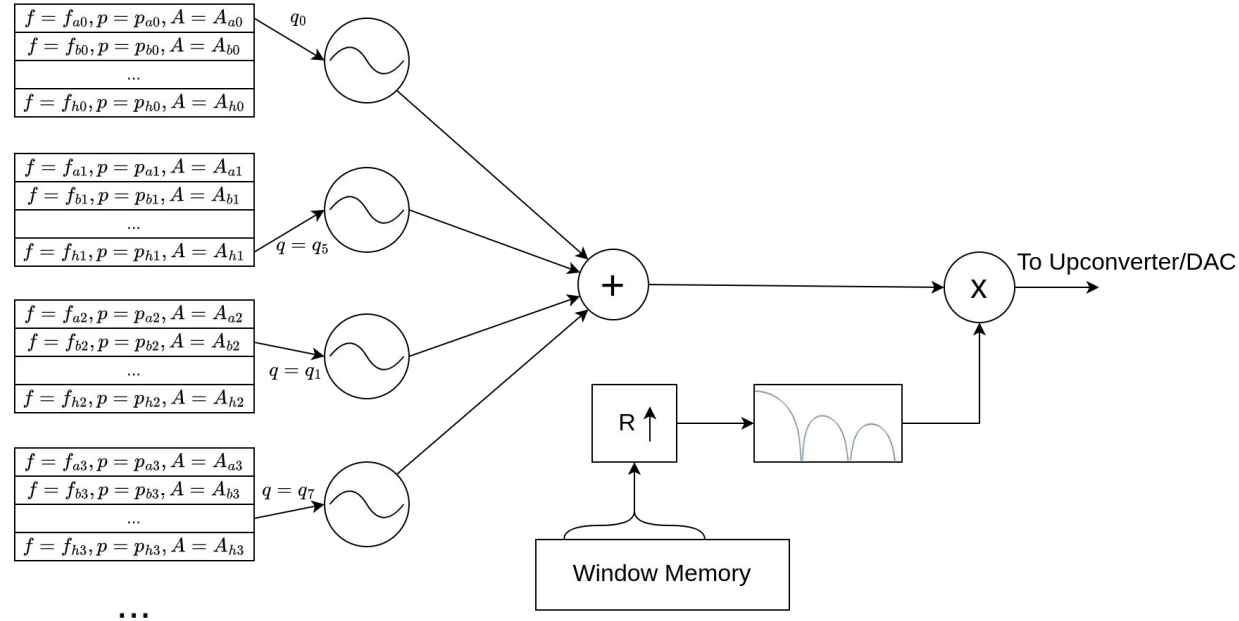
MIQRO Pulse Generator Architecture

- 16 digital oscillators
- 32 profiles



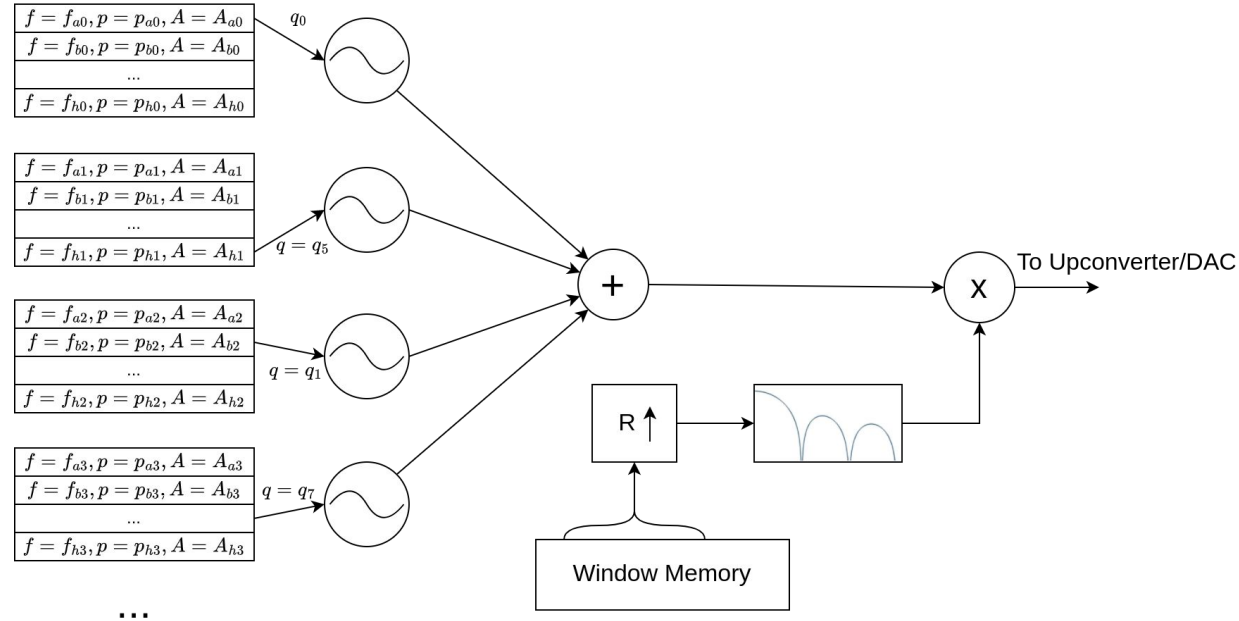
MIQRO Pulse Generator Architecture

- 16 digital oscillators
- 32 profiles
- Phase tracking between pulses



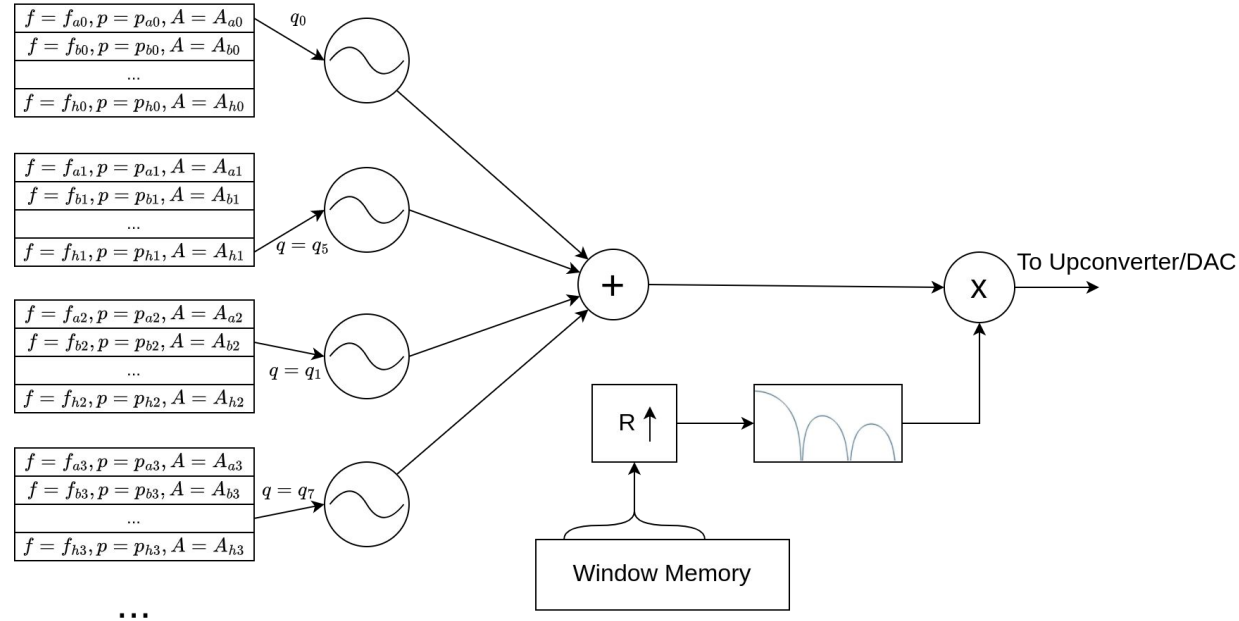
MIQRO Pulse Generator Architecture

- 16 digital oscillators
- 32 profiles
- Phase tracking between pulses
- Pulse shaper

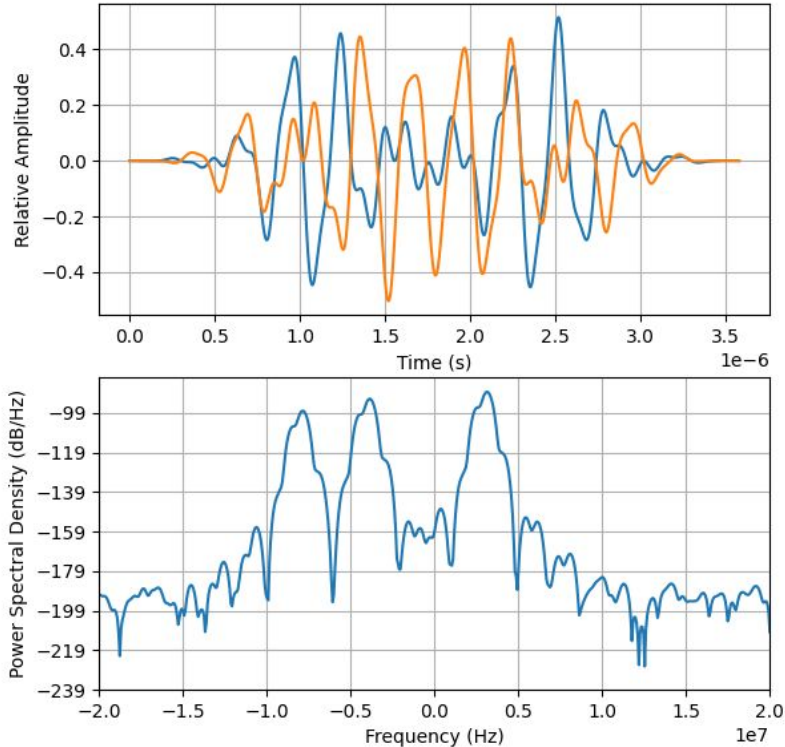


MIQRO Pulse Generator Architecture

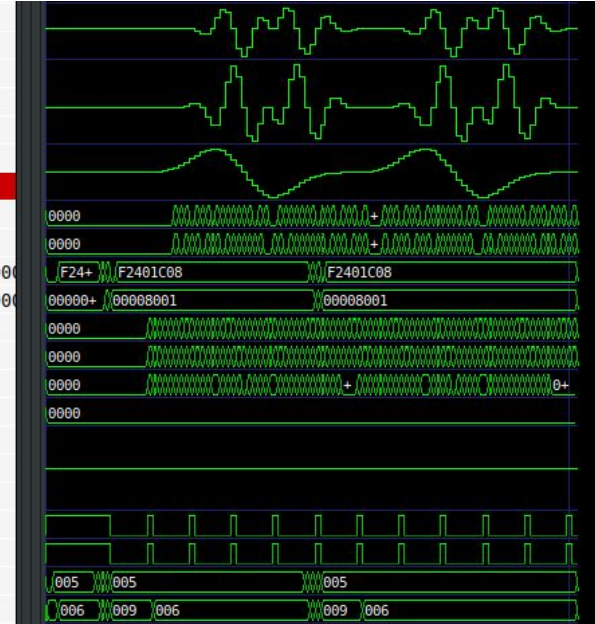
- 16 digital oscillators
- 32 profiles
- Phase tracking between pulses
- Pulse shaper
- Compact pulse parametrization



MIQRO Pulse Generator Simulations

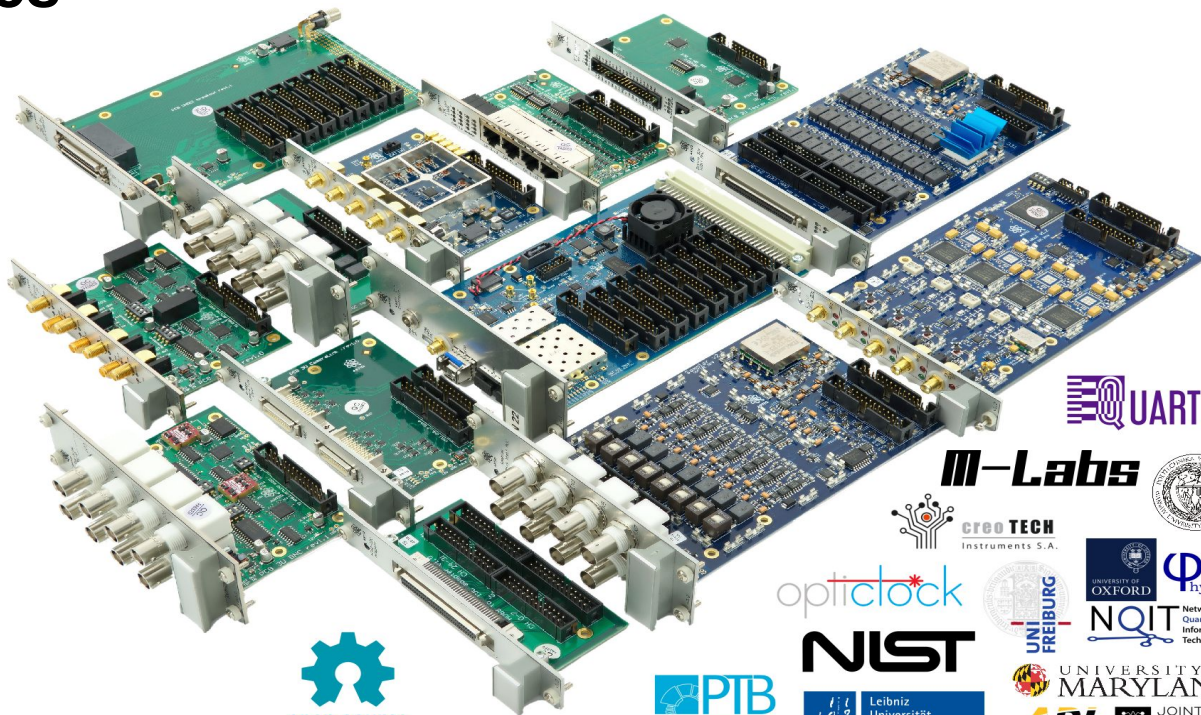


```
p_i[15:0]=0
p_q[15:0]=0
b_i[15:0]=0
p_i[15:0]=0000
p_q[15:0]=0000
buf_x_payload_data[31:0]=00000000
buf_y_payload_data[31:0]=00000000
a_i[15:0]=0000
a_q[15:0]=0000
b_i[15:0]=0000
b_q[15:0]=0000
cic_i_cic_x_ack=0
cic_i_cic_x_ack=0
window_adr[9:0]=000
window_current[9:0]=000
```



Signal Generation for Trapped Ion Quantum Gates

Norman Krackow
QUARTIQ GmbH



Open tools for open science