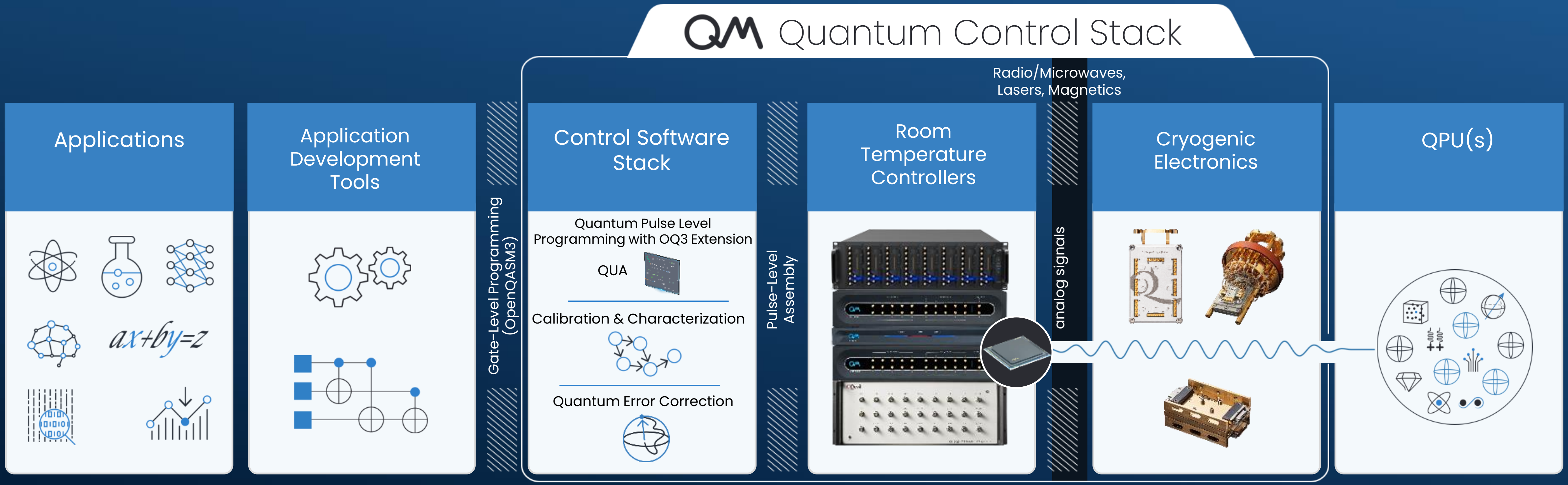
QUANTUM MACHINES

Building the Quantum Control Stack

Elisha Svetitsky
Scientific Business Development Manager

Rogers RLE Forum

9 May 2025



QUANTUM MACHINES

Letter | Published: 20 July 2016

Extending the lifetime of a quantum bit with error correction in superconducting circuits

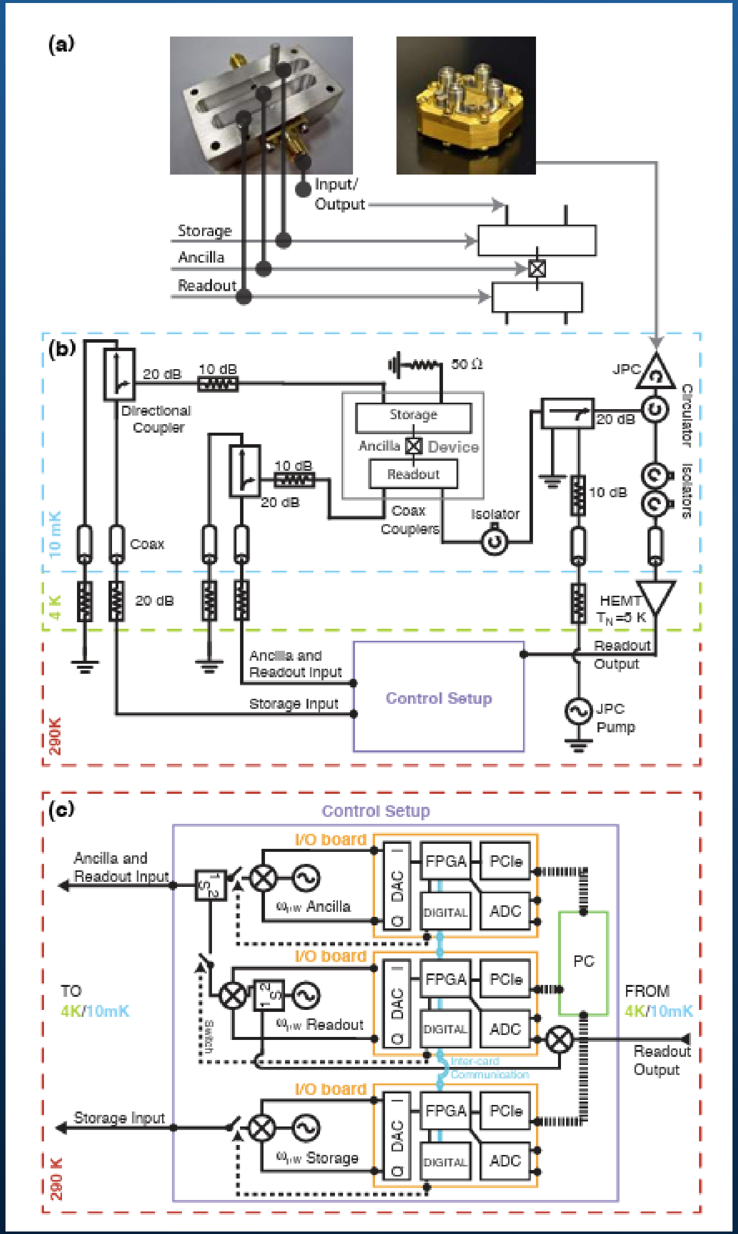
Nissim Ofek, Andrei Petrenko, Reinier Heeres, Philip Reinhold, Zaki Leghtas, Brian Vlastakis, Yehan Liu, Luigi Frunzio, S. M. Girvin, L. Jiang, Mazyar Mirrahimi, M. H. Devoret & R. J. Schoelkopf

Nature **536**, 441–445 (2016) | Cite this article

Yonatan Cohen

Itamar Sivan

Nissim Ofek



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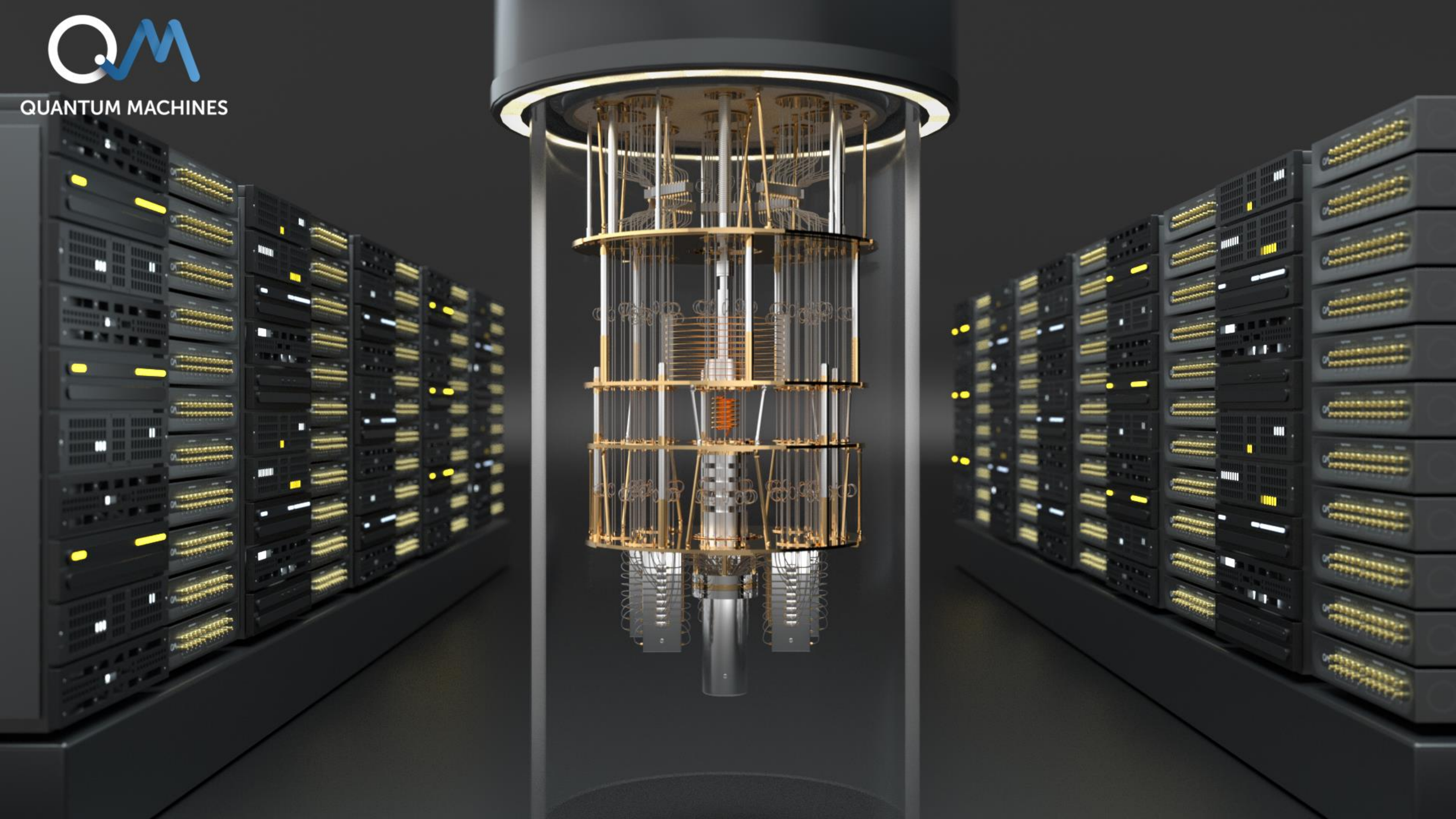

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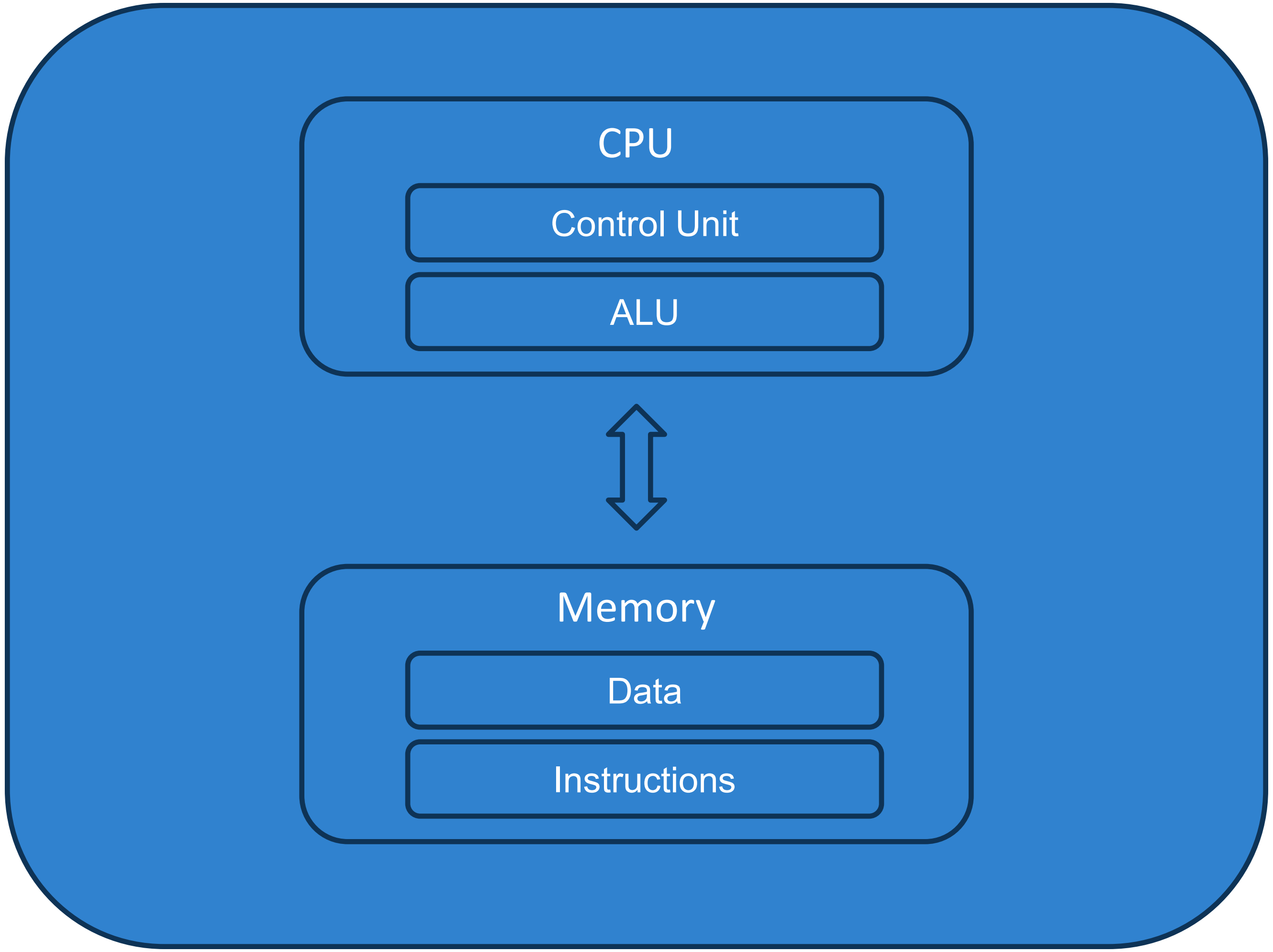
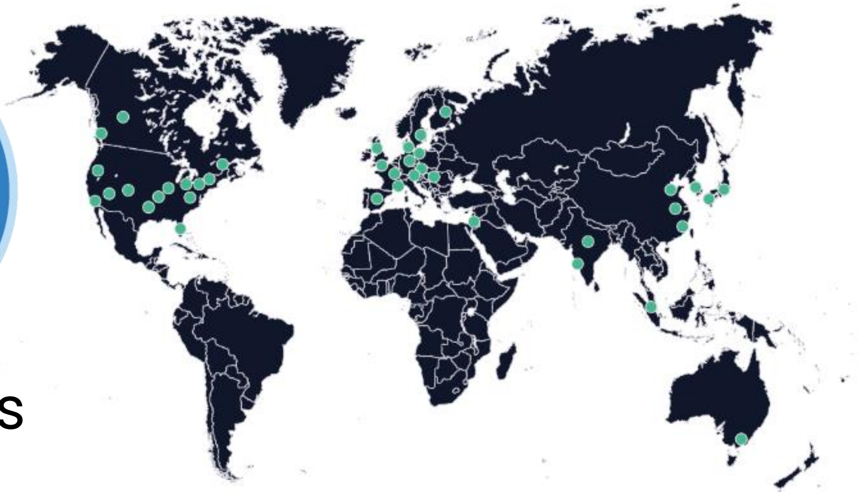


300+

Customers



Corporates, startups, national labs, HPC centers, and academic institutions

Caltech HARVARD UNIVERSITY TUDelft ILLINOIS tifr PASQAL PURDUE
QILIMANJARO HITACHI Inspire the Next PRINCETON UNIVERSITY UNSW ETHzürich DARTMOUTH FAU TII
TUDelft JÜLICH EeroQ 東京大学 THE UNIVERSITY OF TOKYO Lawrence Livermore National Laboratory cea
TECHNION Israel Institute of Technology WEIZMANN INSTITUTE OF SCIENCE IQI ENS JOHNS HOPKINS UNIVERSITY Yale NUS TEXAS UMASS
THE HEBREW UNIVERSITY OF JERUSALEM SORBONNE UNIVERSITÉ MIT KIT NTT USC PSI ÉCOLE POLYTECHNIQUE
HERIOT WATT UNIVERSITY SAMSUNG IST Stanford University diraq RUTGERS UNIVERSITY OF WATERLOO
University of Basel universität innsbruck WISCONSIN Syracuse University Fermilab KRISS THE UNIVERSITY OF CHICAGO

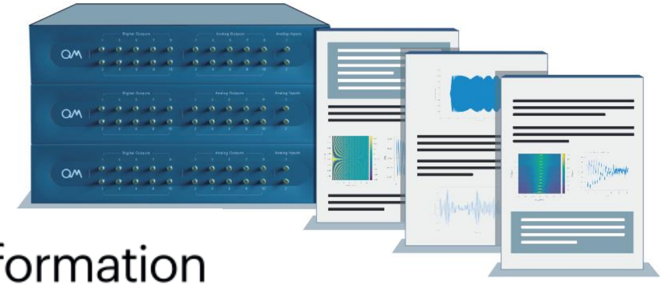
180+

Quantum Physicists & Engineers

Entirely focused on quantum control systems

>60

High-Impact Publications in the Past 12 Months



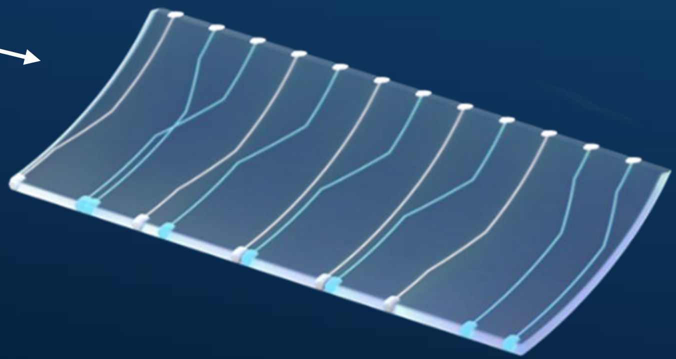
nature physics
nature Science
npj | quantum information

QUANTUM MACHINES

~~MEMORY-BASED TEST & MEASUREMENT~~
PROCESSOR-BASED QUANTUM CONTROL

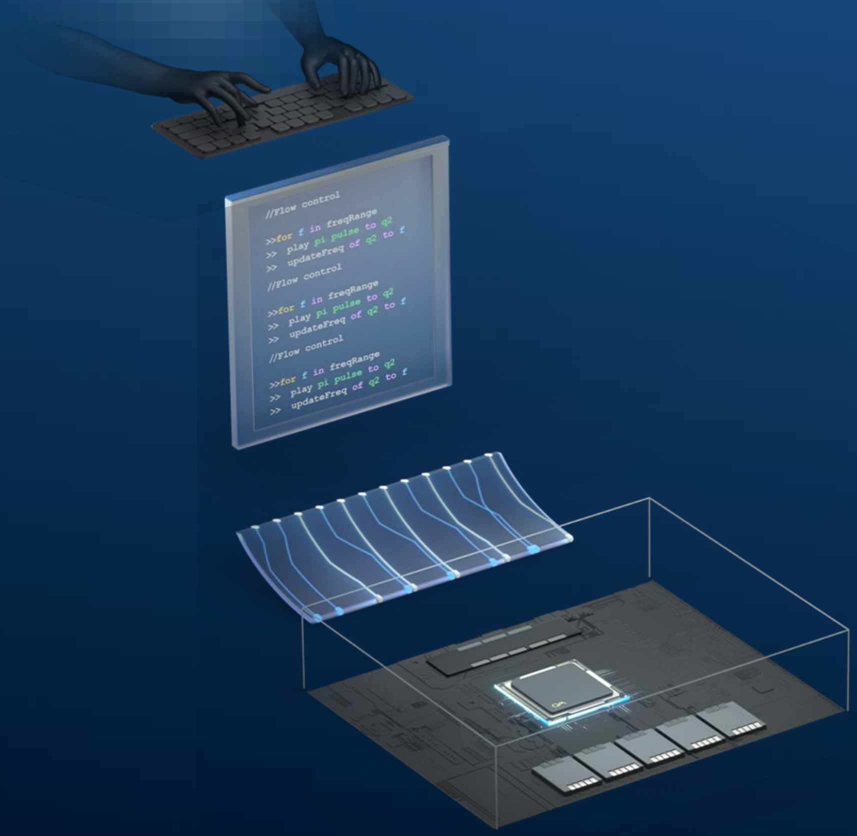
Programming

Compilation



Real-time execution

QUA



Quantum operations: Pulse-level commands

```
play('optimal_pulse', 'qubit_1')
measure('readout', 'resonator', demod.full('cos', I), demod.full('sin', Q))
```

Classical operations: General variables and classical processing

```
assign(a, 5*b+2)
```

Classical variables can be used in quantum operations as pulse parameters

```
play('gaussian'*amp(a), 'qubit_1', duration=b)
```

Classical variables can be fed by measurements

```
assign(a, cos(I))
assign(state, I > 0.012)
```

Control flow

```
if_(state):
        play('pi_pulse', 'qubit_1')
while_(error_synd == 0):
        do_something()
```

Timing control

- Absolute timing (relative to global timestamp)
- Relative timing (sync & async multi-threading)

QUANTUM MACHINES

OPX1000

- ✓ Chassis hosts 8 front-end modules
- ✓ Each module contains own Pulse Processor
- ✓ 2 species of front-end modules, to be combined as needed
- ✓ Highest channel density in the world
- ✓ All-to-all data sharing and feedback

SPU

16-core PPU/FEM

QUA-compatible

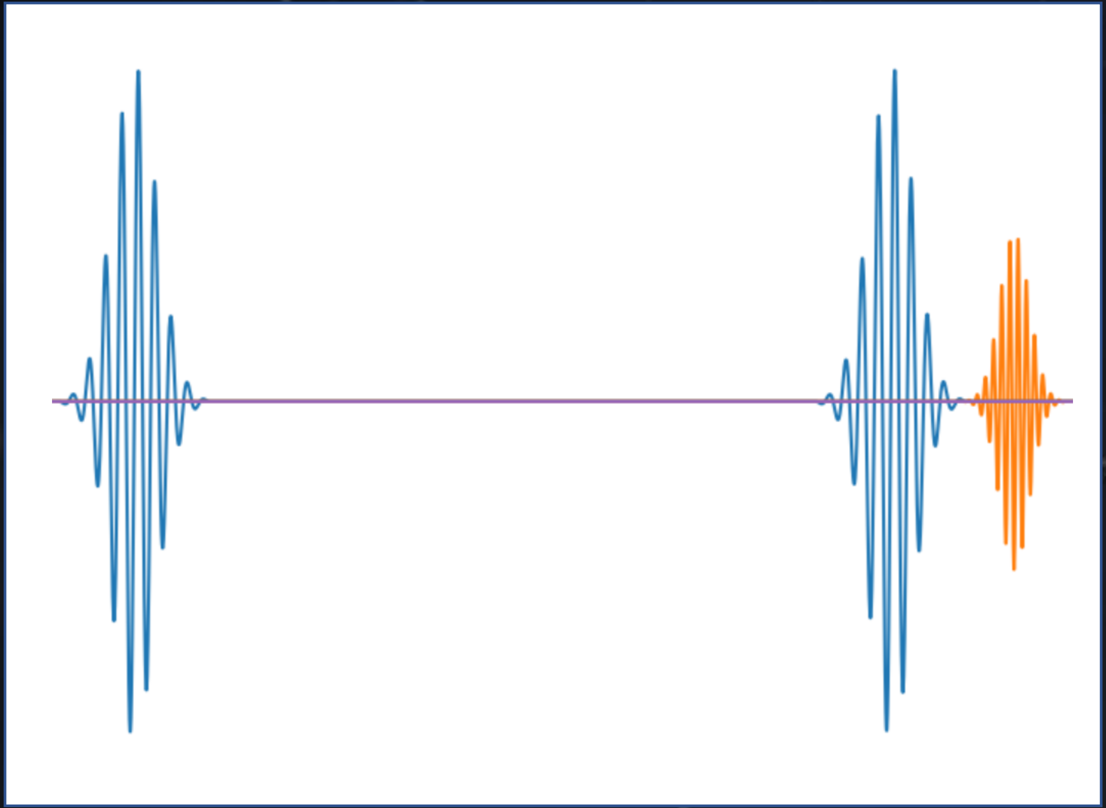
Low-Frequency FEM

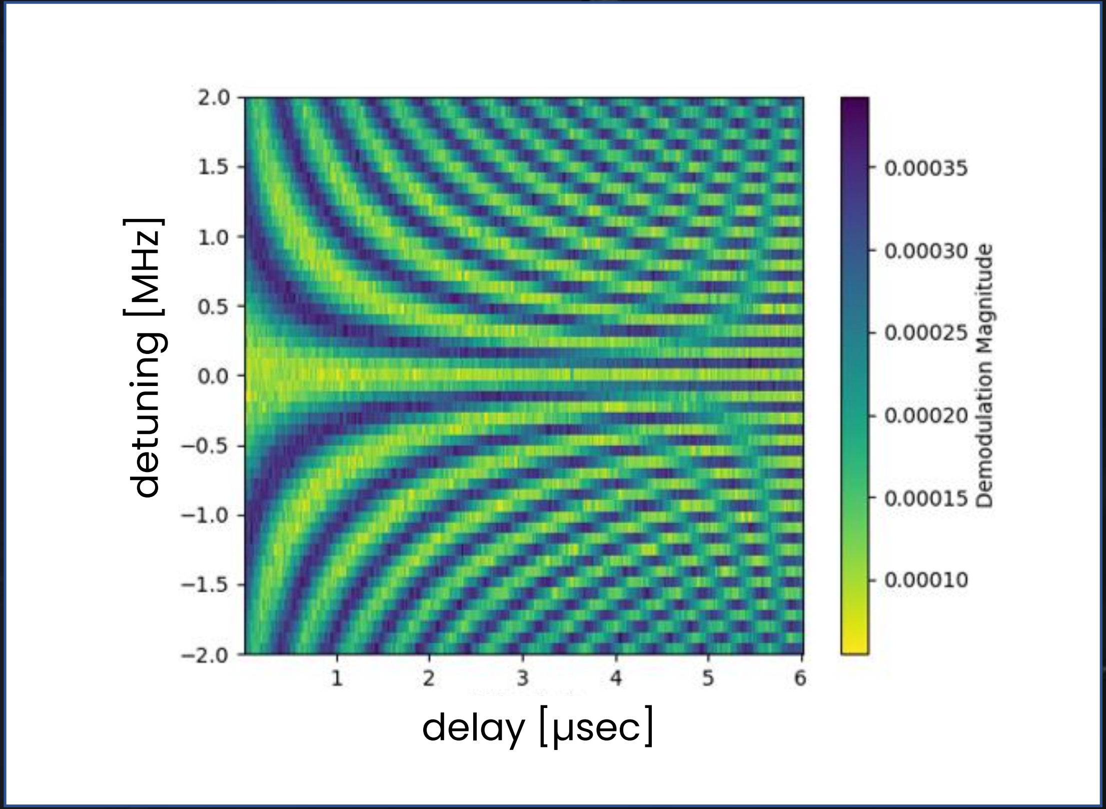
- ✓ 8 analog outputs @ 2 GSa/s | 16 bit resolution | DC-750 MHz
- ✓ 2 analog inputs @ 2 GSa/s | 12 bit resolution | DC-750 MHz
- ✓ 16-core Pulse Processing Unit (PPU)
- ✓ Includes all real-time capabilities of OPX+
- ✓ State-of-the-art analog specifications

Microwave FEM

- ✓ 8 analog outputs @ 2 GSa/s | 16 bit resolution | 0.05-10.5 GHz Direct Digital Synthesis!
- ✓ 2 analog inputs @ 2 GSa/s | 12 bit resolution | 1.8-10.5 GHz OR DC-1.8 GHz
- ✓ 16-core Pulse Processing Unit (PPU)
- ✓ Includes all real-time capabilities of OPX+
- ✓ State-of-the-art analog specifications

FAST CALIBRATIONS



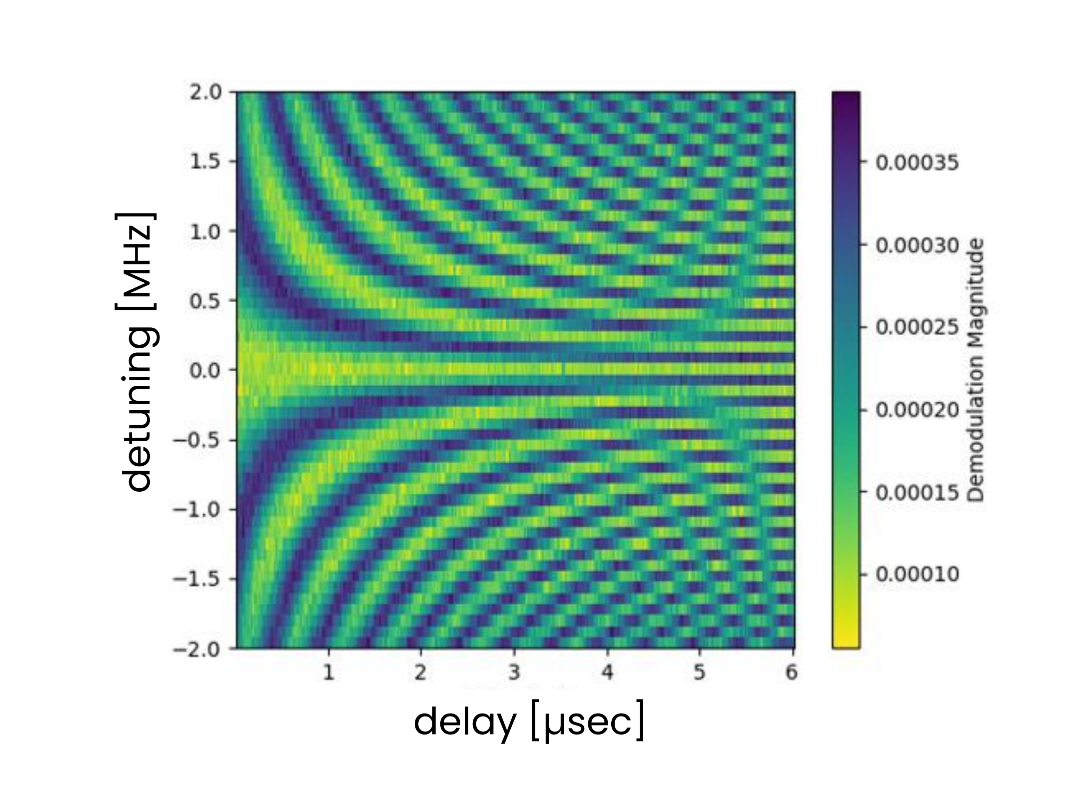


QUANTUM MACHINES

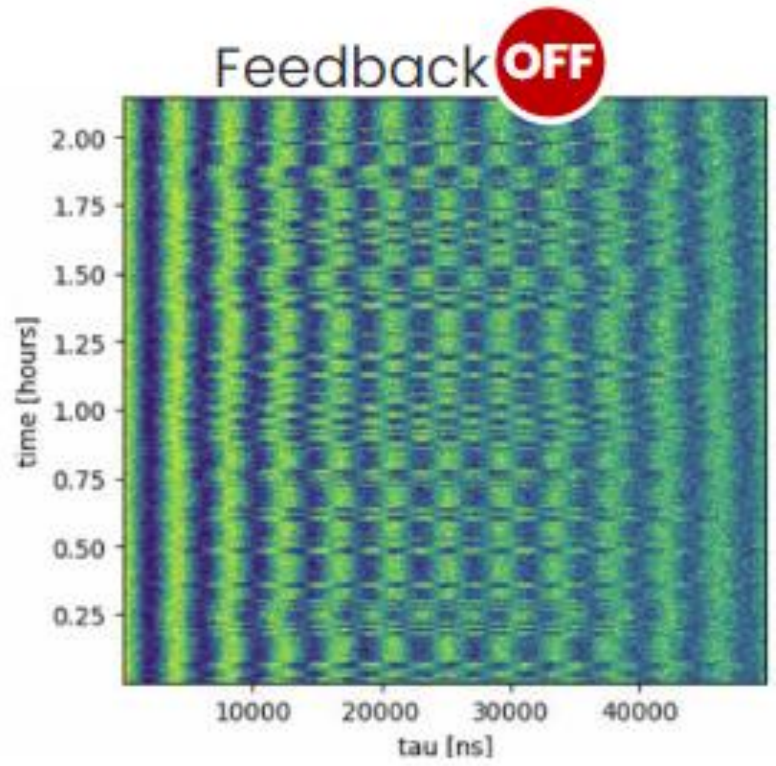
FAST CALIBRATIONS

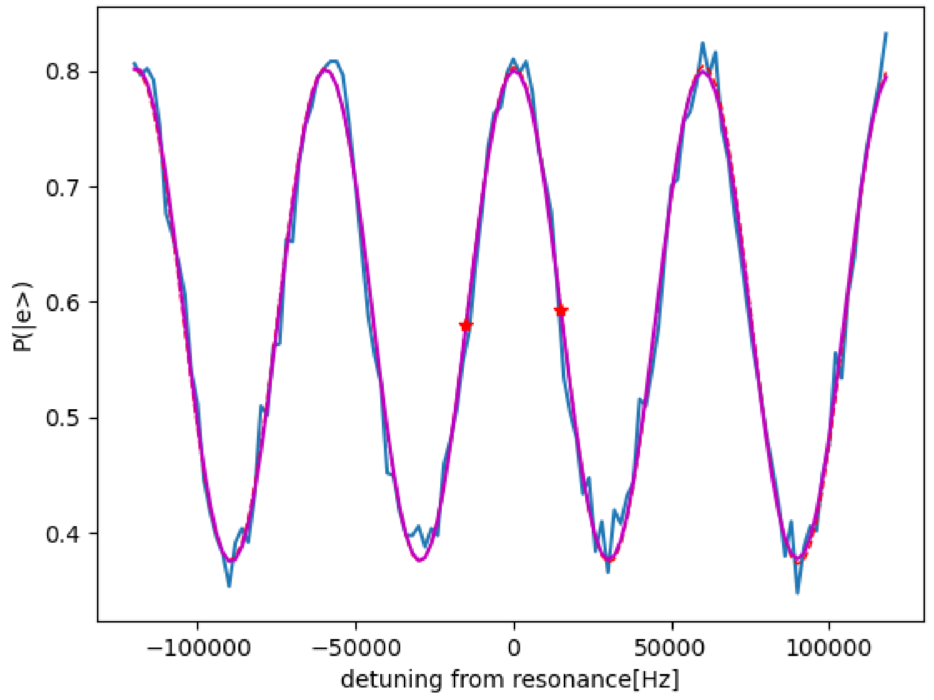
```
with for_(n, 0, n < N_avg, n + 1):   ← AVERAGING
    with for_(t, t_i, t < t_f, t + dt):
        with for_(f, f_i, f < f_f, f + df):
            update_frequency('qubit', f)
            play('pi_half', 'qubit')
            wait(t)
            play('pi_half', 'qubit')
            align('qubit', 'resonator')
            measure('readout', 'resonator', None,
                    demod.full('cos', I), demod.full('sin', Q))
            save(I > threshold, results)
ACTIVE RESET → play('pi', 'qubit', condition=I > threshold)

with stream_processing():
    results.buffer(t_length, f_length).average().save('results')
```

PULSE GENERATION

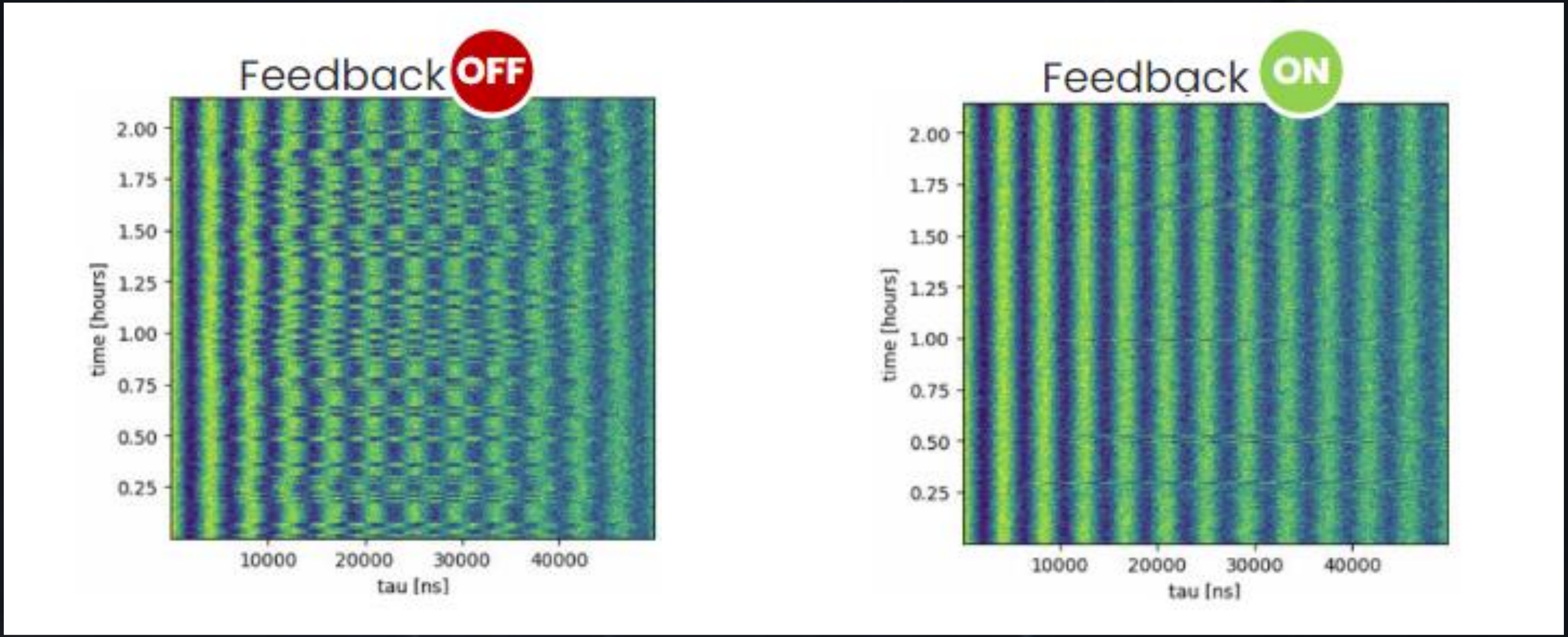


EMBEDDED CALIBRATIONS





EMBEDDED CALIBRATIONS



BAYESIAN ESTIMATION

nature communications

Article

https://doi.org/10.1038/s41467-024-45857-0

Real-time two-axis control of a spin qubit

Received: 22 August 2023

Accepted: 5 February 2024

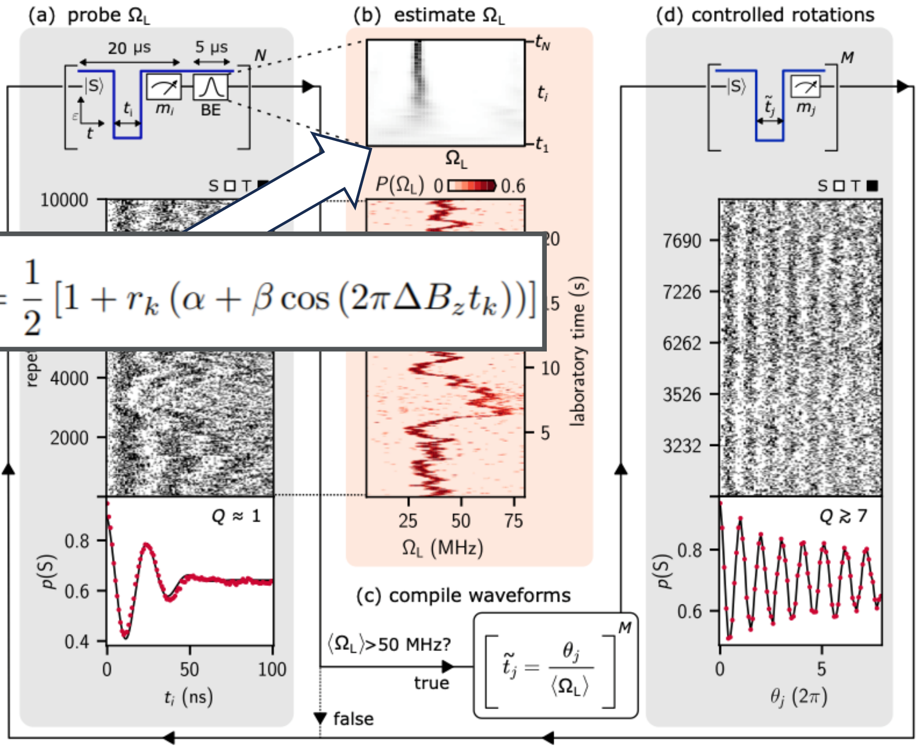
Published online: 23 February 2024

Check for updates

Fabrizio Berritta[1], Torbjørn Rasmussen[1], Jan A. Krzywda[2], Joost van der Heijden[3], Federico Fedele[1], Saeed Fallahi[4,5], Geoffrey C. Gardner[5], Michael J. Manfra[4,5,6,7], Evert van Nieu… Jeroen Danon[8], Anasua Chatterjee[1] & Ferdinand Kuemmet…

Optimal control of qubits requires the ability to adapt continuously to their ever-changing environment. We demonstrate a real-time control protocol for a two-electron singlet-triplet qubit with two fluctuating Hamiltonian parameters. Our approach leverages single-shot readout classification and dynamic waveform generation, allowing full Hamiltonian estimation to dynamically stabilize and optimize the qubit performance. Powered by a field-programmable gate array (FPGA), the quantum control electronics estimates the Overhauser field gradient between the two electrons in real time, enabling controlled Overhauser-driven spin rotations and thus bypassing the need for micromagnets or nuclear polarization protocols. It also estimates the exchange interaction between the two electrons and adjusts their detuning, resulting in extended coherence of Hadamard rotations when correcting for fluctuations of both qubit axes. Our study highlights the role of feedback in enhancing the performance and stability of quantum devices affected by quasistatic noise.

$$P(m_k|\Delta B_z) = \frac{1}{2}\left[1 + r_k\left(\alpha + \beta\cos\left(2\pi\Delta B_z t_k\right)\right)\right]$$



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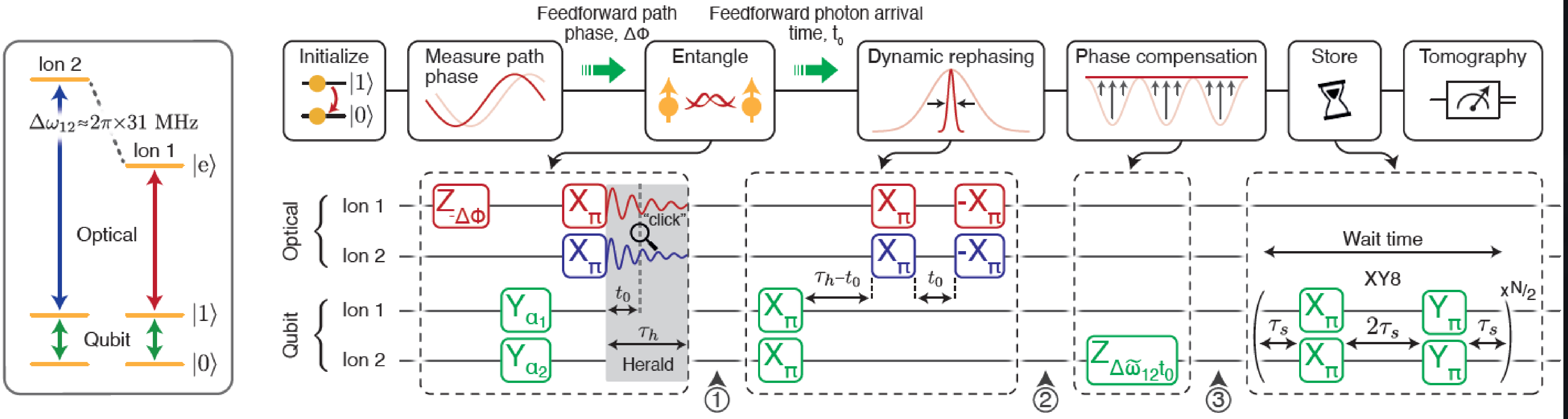
SCALABLE MULTIPARTITE ENTANGLEMENT

Article | Published: 26 February 2025

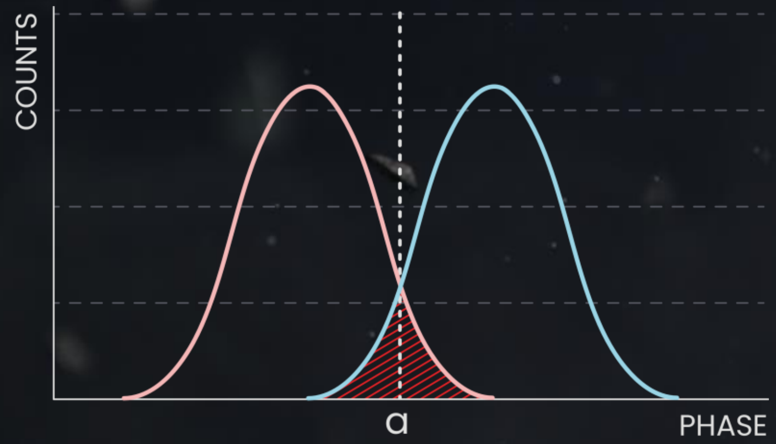
Multiplexed entanglement of multi-emitter quantum network nodes

A. Ruskuc, C.-J. Wu, E. Green, S. L. N. Hermans, W. Pajak, J. Choi & A. Faraon

Nature **639**, 54–59 (2025) | Cite this article

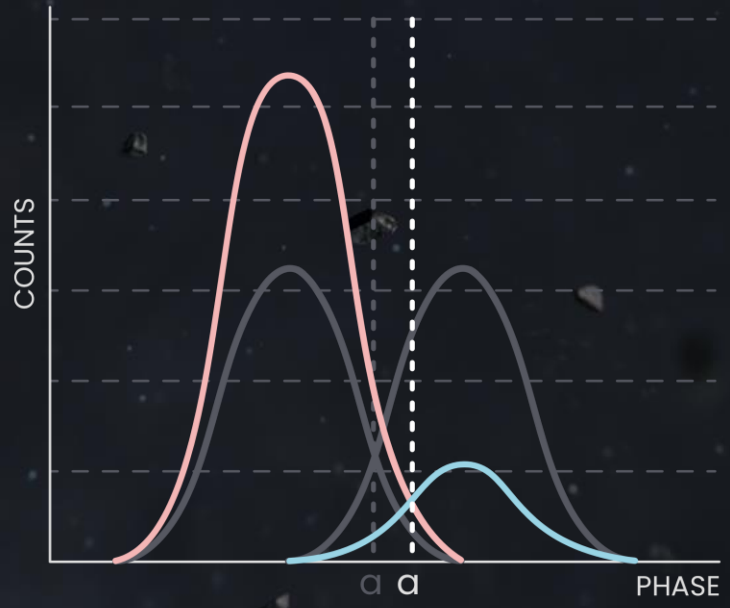


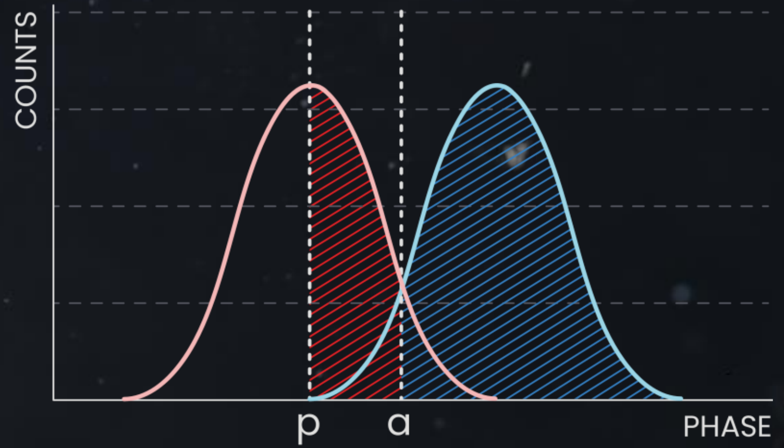
SCALABLE QPU INITIALIZATION



Conditional reset pulse with 120 ns latency

Dynamic threshold adapting to qubit history





Double-threshold, repeat-until-success

QUANTUM MACHINES

Requirements for quantum control at scale

- Synchronization across 1000s of channels
- Global data broadcasting
- Distributed control/processing
- Scalable programming
- High channel density
- Low heat dissipation
- Economics of scale
- HPC integration

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