



AQT at Berkeley Lab

## AQT Capabilities

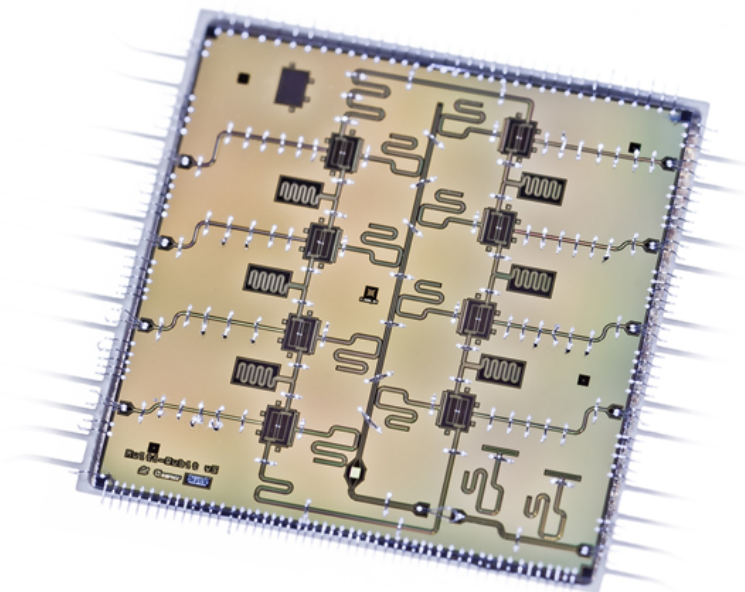
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This information about the Advanced Quantum Testbed (AQT) at Lawrence Berkeley National Laboratory (Berkeley Lab) is current as of **August 2022**. Please check our website for ongoing updates. If you have any further questions, contact us via email: [aqt@lbl.gov](mailto:aqt@lbl.gov).

### Baseline AQT QPUs:

The current QPU available to AQT users is the 8-qubit ring design chip. The specifications and typical parameters for this QPU are:

- Eight transmon qubits in ring, with nearest neighbor connectivity
- Resonance frequency range: 5.2-5.8 GHz
- Typical anharmonicity: 250 MHz
- Multiplexed readout with traveling-wave parametric amplification (TWPA)
- Readout fidelities: >97%
- Coherence times:  $T_1 \sim 100 \mu\text{s}$ ,  $T_2^{\text{echo}} \sim 100 \mu\text{s}$  (with fluctuations)



For detailed information, read: [Kreikebaum, J. M., et al. "Improving wafer-scale Josephson junction resistance variation in superconducting quantum coherent circuits." Superconductor Science and Technology 33.6 \(2020\): 06LT02](#)



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Available for the following cycle is a linearly-connected nine-transmon sample, where the qubits are instead flux-tunable. This processor was developed and fabricated at MIT-Lincoln Laboratories. Specifications:

- Nine transmon qubits, nearest-neighbor connectivity
- Qubit frequencies ranging from 3.3 to 4.8 GHz
- 600-800 MHz tunability for each qubit
- Anharmonicities: 200-210 MHz
- Multiplexed readout
- Coherence times:  $T_1 \sim 10\text{-}60 \mu\text{s}$ ,  $T_2^{\text{echo}} \sim 10\text{-}60 \mu\text{s}$

In the future, the AQT will provide access to Spidernet-8, a novel 8-qubit QPU with arbitrary dynamically reconfigurable (up to all-to-all) qubit-qubit connectivity. Additionally, this QPU will provide support for bosonic encoding with interfacing to transmon qubits. The QPU contains the following elements:

1. Eight Tunable Transmon Qubits
  - a. Nominal Frequency Tunable Range: 4.65.1 GHz-5.97 GHz
  - b. Nominal Anharmonicities: 230-270 MHz
  - c. **Expected** Coherence Times:  $T_1 \sim \leq 10\text{-}15 \mu\text{s}$ ,  $T_2^{\text{echo}} \sim \leq 16\text{-}13 \mu\text{s}$
  - d. Readout frequencies: 7.6-8.0 GHz
2. Coupling resonator A Linear Microwave Resonator Coupled to All Transmons
  - a. Nominal Frequency (8th mode): 5.614 GHz
  - b. Nominal Coupling to resonator drive:  $\sim 2$  kHz
  - c. Parametric coupling rate 1-7 MHz
  - d. Quality Factor:  $10^4\text{-}10^5$

## Available Gates:

Single-qubit gates:

- Calibrated X90 and virtual Z gates for universal control
- Isolated error rates  $\sim 5 \times 10^{-4}$ , measured by randomized benchmarking (RB)
- Simultaneous error rates  $1\text{-}2 \times 10^{-3}$  per qubit, measured by RB

Cross-resonance gates:

- Nearest-neighbor microwave gates between fixed-frequency qubits
- Typical gate times between 100 to 200 ns
- Controlled-NOT (CNOT) gate error rates ranging from 1% to 4%, measured via interleaved randomized benchmarking (IRB) and cycle benchmarking (CB)

Controlled-phase gates ([arXiv:2105.05384](https://arxiv.org/abs/2105.05384)):

- Novel nearest-neighbor microwave gates between fixed-frequency qubits
- Typical gate times of 200 ns



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- CZ error rates: 0.5 – 1% as measured with interleaved RB and CB

#### Parametric flux-modulation gates

- Created by modulating the frequency of the qubits
- Fermionic simulation (fSim) gate: combination of controlled phase (CZ) and iSWAP
- Gates faster than 100 ns
- CZ error rates below 4%

## Control Hardware:

The standard control hardware available to AQT users consists of Zurich Instruments devices. [HDAWG](#) units (High Definition Arbitrary Wave Generator) are used for qubit control, operating at 2.4 GSPS with a bandwidth of 750MHz. For qubit readout, we use [UHFQA](#) units (Ultra High Frequency Quantum Analyzer), operating at 1.8 GSPS with a bandwidth of 600MHz. Triggering and synchronicity among multiple devices is orchestrated through a [PQSC](#) (Programmable Quantum System Controller). This setup enables state-detection on-the-fly, enabling fast reset and fast feedback to less than a microsecond point-to-point.

In addition, the AQT team is developing an in-house control solution, dubbed QubiC (for Qubit Control), to accommodate custom control needs and lower-level access control to the hardware than can be provided by proprietary commercial hardware. The current QubiC design consists of AQT-developed HDAWGs, with optical fiber synchronizations expected to be available soon, as well as customized hardware for control of the upcoming Spidernet-8 processor described above. If you have needs or interests in the categories of, but not exclusively: developing better synchronization solutions for superconducting (SC) qubit systems; specialized electronics designed for your project or more efficient control of SC processors; access to control hardware as close as possible to the qubit level (i.e. pulse level) which cannot be accommodated using the standard Zurich Instruments devices or other proprietary commercial solutions, please contact the AQT team to discuss QubiC access, development, and use. AQT is open to partnering on projects in co-developing, customizing, and optimizing control hardware solutions that might require too much specialization or flexibility for commercial vendors.



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## Programming Stack:

To support QubiC, AQT has developed an early-stage programming stack whose development is ongoing. AQT can accept circuits from widely-used software illustrated at the top of the graph on the right. AQT can work with users to provide access with non-standard software, if required for a project. AQT can also provide access initiated at any starting point in the programming stack, if the circuit is produced in the OpenQasm format, as well as alternate types of access since AQT is developing an in-house instruction set architecture (ISA). From OpenQasm, circuits will be optimized using `t|ket>` and transpiled into sequences compatible with QTROL, the AQT's control software, using AQT's Qasm2qtrl transpiler. QTROL then interfaces with the control hardware to run the experiment. AQT is open to developing specialized software at the QTROL level for nonstandard user software needs. Access to the programming stack can also be provided or developed for users interested in pursuing their own circuit optimization solutions. AQT is open to partnering on projects with users who are interested in co-developing and optimizing the programming stack.

