AQT

THE ADVANCED QUANTUM TESTBED

2018 - 2023 IMPACT REPORT

BERKELEY LAB

U.S. DEPARTMENT of ENERGY | Office of Science

AQT at a Glance

NOTABLE SCIENTIFIC ACHIEVEMENTS

- Developed an advanced full-stack, whitebox quantum computing platform based on superconducting circuits
- Developed a broad range of multi-qubit processors tailored for science applications with varied topology, gate / readout fidelities > 97% - 99.8%; coherence > 100 μs
- Developed a modular, open source qubit control system (QubiC & QubiC 2.0) with room temperature control electronics and gateware on FPGA and AI/ML capabilities for characterization and calibration
- Transformed fixed-frequency superconducting circuits into modifiable Floquet qubits with programmable Heisenberg interactions
- Demonstrated a hardware-efficient approach for operating multidimensional systems using Raman-assisted interactions and realized highly entangled multi-dimensional states
- Designed a novel 8-qubit QPU (quantum processing unit) Spidernet8 with arbitrary dynamically reconfigurable (up to all-to-all) connectivity
- Boosted qubit coherence with novel cryopacking designed with an industry partner
- Developed qudit operating modes and demonstrated the entanglement of two qutrits with a process fidelity of up to 97.3%, decreasing the infidelity from previous efforts by a factor of around four
- Demonstrated noise tailoring and mitigation with randomized compiling on both multi-qubit and multi-qutrit processors for the first time
- Developed a blueprint for a novel quantum processor based on noise-resilient "fluxonium" qubits
- Demonstrated a novel native three-qubit logic gate (iToffoli) with high-fidelity (98.26%)

USER PROGRAM

2018- 2023

Open proposal calls: **4**

Proposals evaluated: **64**

User types:

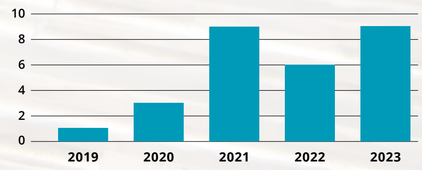
- National Laboratories (41%)
- Universities and Research Organizations (37%)
- Industry (22%)

SCIENTIFIC OUTPUT

2018- 2023

28 High-impact publications, including in:

Nature Physics
Nature Communications
Nature Review Materials
Physical Review X
PRX Quantum

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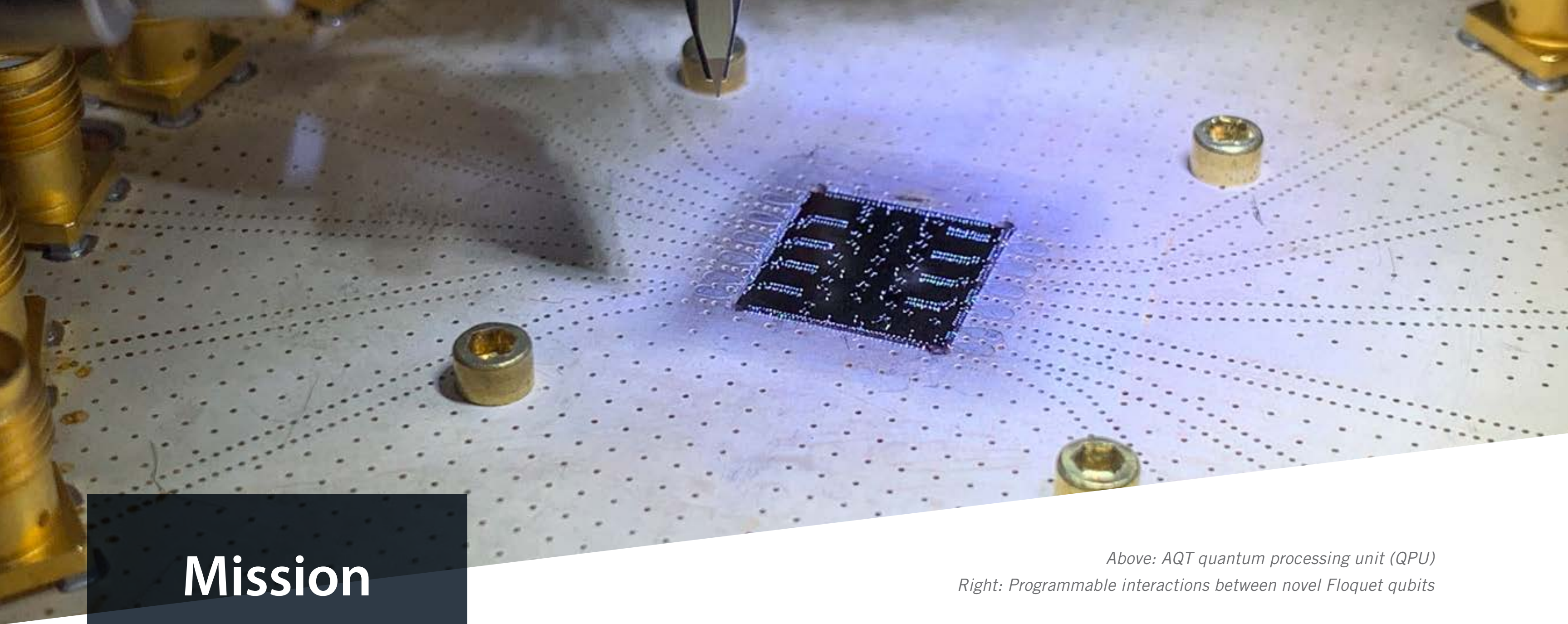


Mission

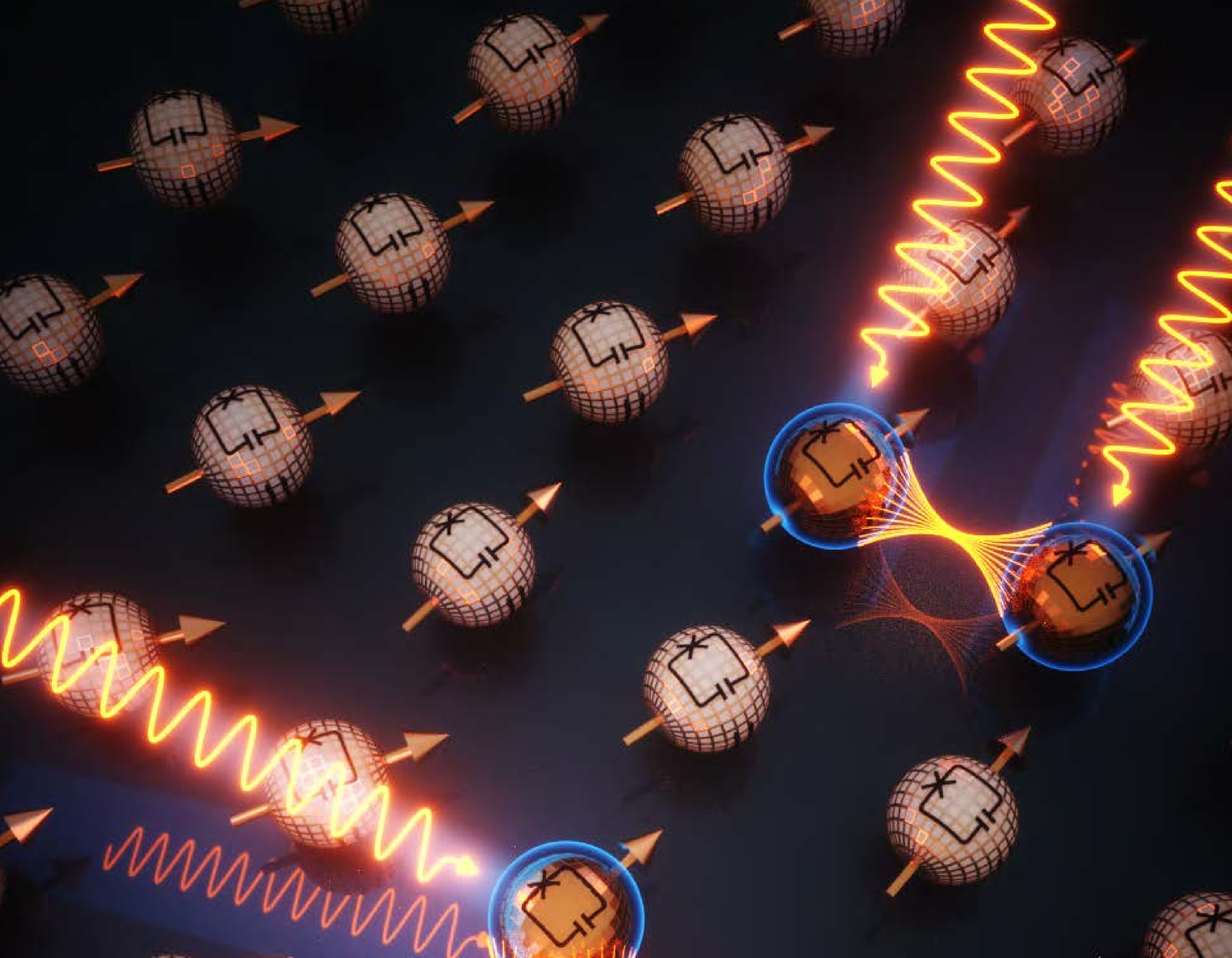
Above: AQT quantum processing unit (QPU)
Right: Programmable interactions between novel Floquet qubits

The Advanced Quantum Testbed (AQT) at Lawrence Berkeley National Laboratory (Berkeley Lab) is a state-of-the-art collaborative research laboratory funded by the U.S. Department of Energy Office of Science Advanced Scientific Computing Research program. Founded in 2018, the laboratory offers an advanced superconducting platform for full-stack quantum computing, enabling end-to-end exploration from quantum processor technology to quantum algorithms.

AQT fosters deep research collaborations with external users selected through an open, competitive proposal process, complementing other quantum resources available to the research community. The interactive partnerships with users from academia, National Laboratories, and industry allow for a broad exploration of cutting-edge science with systems engineering that is suitable for scientific applications that rely on gate-based quantum computing.

Testbed users are selected through a peer-reviewed proposal process, gaining full low-level access to AQT hardware and software, including detailed architecture, operation, and performance data. Users participate in the testbed's evolution and share results to maximize the utility of nascent quantum hardware.

Through the research opportunities it offers, AQT is training the next generation of scientists and engineers in quantum computing. The testbed allows early-career scientists to access world-class quantum computing hardware and software systems, establishing a unique environment for active mentoring, open discussion, and networking between stakeholders in the quantum ecosystem.



Team **Leadership**

Irfan Siddiqi, Director

A professor of physics at the University of California, Berkeley (UC Berkeley) and the Giancoli Chair of the Physics Department, Siddiqi is a fellow of the American Physical Society and an elected member of the American Academy of Arts & Sciences. He is also the director of the Quantum Nanoelectronics Laboratory and a faculty scientist in the Quantum Information Science & Technology (QuIST) group within Berkeley Lab's Applied Mathematics and Computational Research Division. Siddiqi also serves as senior advisor to the Quantum Systems Accelerator (QSA), one of five Department of Energy National QIS Research Centers, which he helped launch in 2020.

David I. Santiago, Science and Technical Lead

Santiago is the group leader for QuIST and AQT technical lead. Prior to joining AQT in 2018, Santiago served as a scientific consultant in the Defense Advanced Research Projects Agency and the Intelligence Advanced Research Projects Activity, and participated in the research and development programs producing early technological advances in quantum information devices.

Christopher Spitzer, Quantum Program Manager

Spitzer is the program manager for QuIST and AQT. He was previously the lead for physical sciences and engineering in UC Research Initiatives' grant-making programs and has worked in the U.S. Senate and the Department of State. He received his Ph.D. in physics from the University of Washington and has conducted research in beyond- the-standard-model particle phenomenology.

Kasra Nowrouzi, Head of Hardware

Nowrouzi is a research scientist at AQT, where he oversees the development and deployment of full-stack systems for collaborative quantum computing experiments on superconducting platforms. He received his B.S. in electrical engineering and computer sciences and Ph.D. in applied physics from UC Berkeley. His dissertation work with Professor Roger Falcone included the development of an ultrastable computational x-ray microscope for operando phase-retrieval imaging of nanomaterials for the COSMIC beamline at Berkeley Lab's Advanced Light Source.

Ravi Naik, Head of Measurement

Naik is a research scientist in QuIST and measurement lead at AQT. His current research efforts focus on two-qubit gates in multi-qubit superconducting processors and noise in quantum algorithms. He received his Ph.D. at the University of Chicago for his research on multimode circuit quantum electrodynamics with Professor David Schuster.

Monica Hernandez, Quantum Communications Lead

Monica Hernandez leads the communications efforts for AQT and QSA. As a bilingual science communicator, Monica also produces content in Spanish, which is rare in this fast-growing field. At Berkeley Lab, she's been recognized with several distinctions, including the Director's Award for Exceptional Achievement in Outreach.

Team **Members**

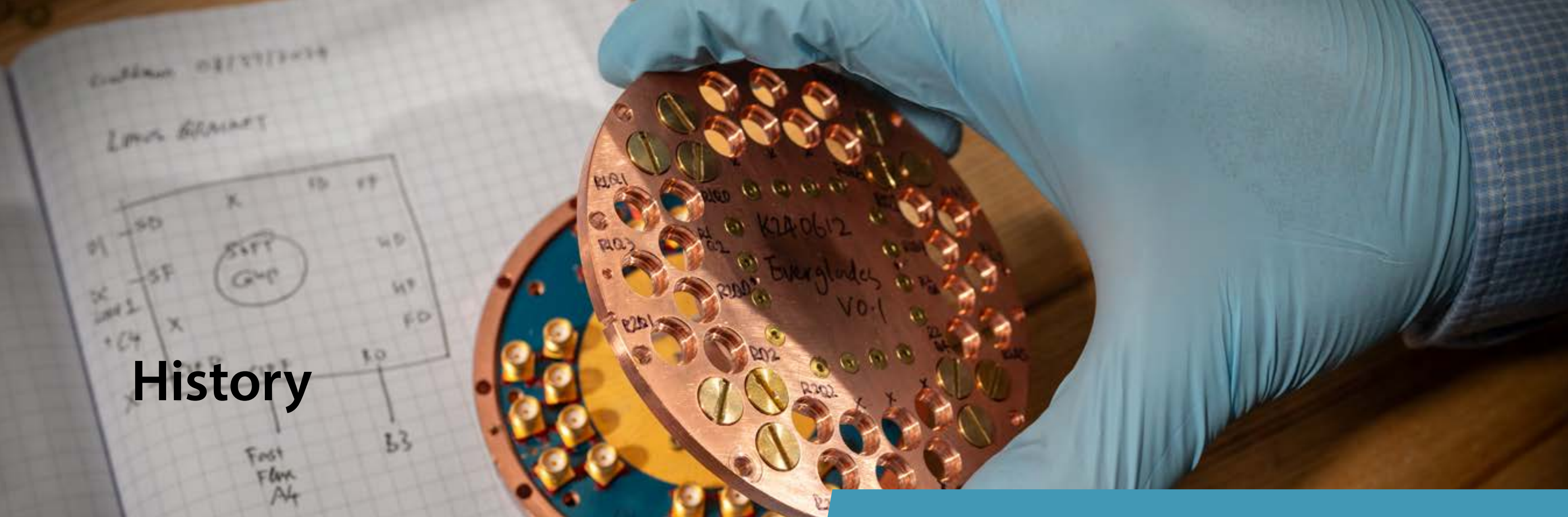
AQT brings together multidisciplinary researchers focused on the design, fabrication, and operation of superconducting quantum processors, as well as the development of the full control stack consisting of classical electronics, firmware, and software to enable the execution of quantum algorithms.

The team includes staff, post-doctoral researchers, graduate students, and undergraduate interns from UC Berkeley's Quantum Nanoelectronics Laboratory and Berkeley Lab. Collaborating scientists at AQT have included researchers from MIT Lincoln Laboratory.

"AQT co-designs innovative quantum computation technologies by assembling a national community of scientists, engineers, and new generations of students. Built from the ground up, AQT supports projects from external teams through access to both the full quantum computing platform and expertise to maximize the platform's potential."

IRFAN SIDDIQI, Director

History



Researcher analyzes a QPU

Since 2018, AQT has built on the research and development at Berkeley Lab and has benefited from DOE's Office of Science investments.

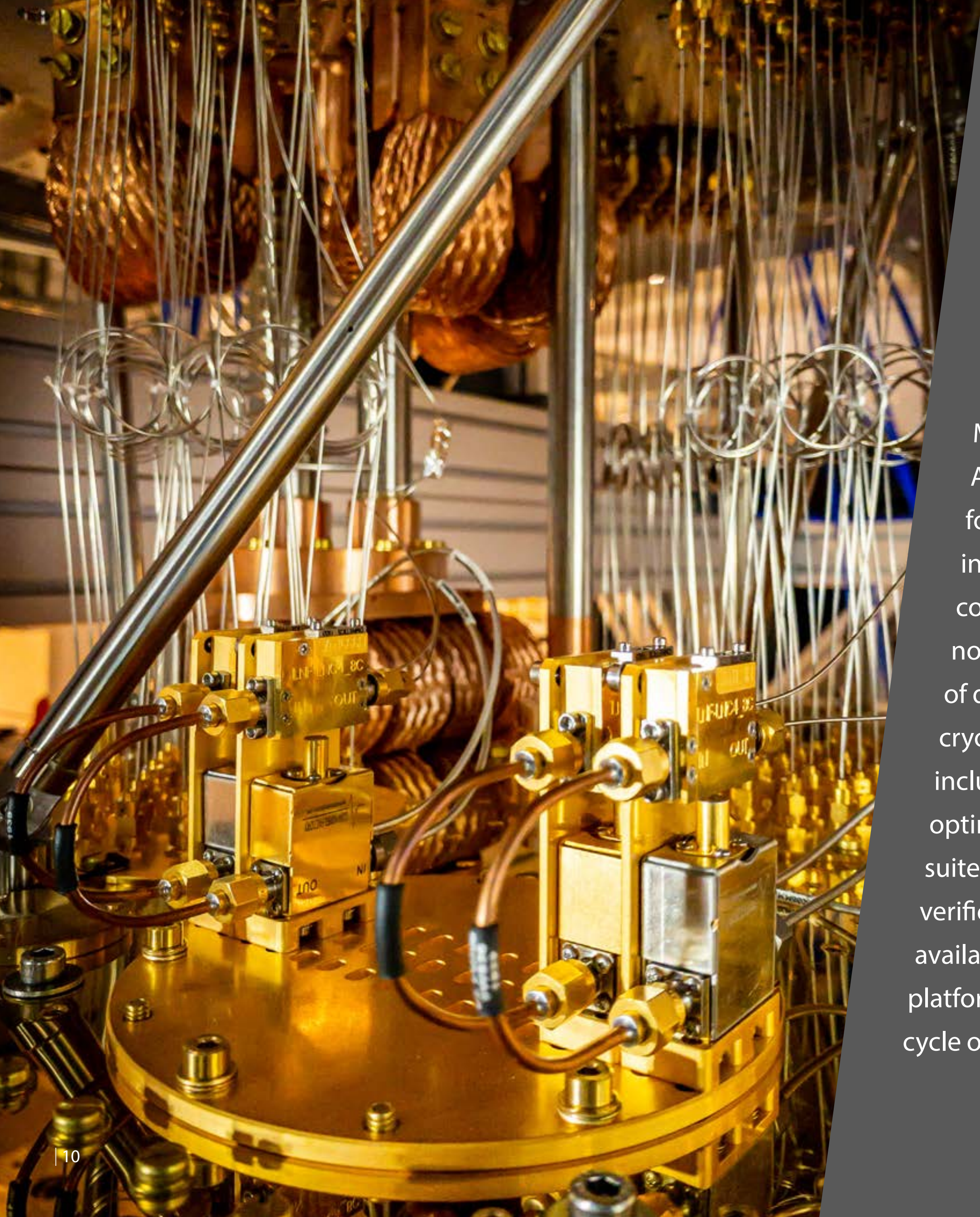
AQT first focused on deploying and integrating state-of-the-art superconducting hardware and developing novel quantum benchmarking techniques. The first phases included verification, validation, noise detection, suppression, and mitigation, including initial science experiments to mimic for example, quantum information scrambling using nonlinear harmonic oscillators as qutrits.

In 2020, AQT opened the testbed for broad user engagement and has received dozens of research proposals from users in academia, National Laboratories, and startups to explore a variety of topics, including algorithms, simulations, characterization, validation, control hardware, firmware, software, and processor architectures. In its initial three years of the user program, AQT performed a variety of demonstrations, including quantum simulation, benchmarking, optimization, quantum chemistry and condensed matter, nuclear physics, and high-energy physics. Protocols and methods developed as a part of one user project often enabled applications in other user projects, resulting in a virtuous cycle that continually advanced the testbed over time.

> "Since 2020, new user institutions are submitting research proposals yearly. We expect scientific output to continue accelerating while nurturing future talent."
>
> **DAVID I. SANTIAGO,** *Technical Lead*

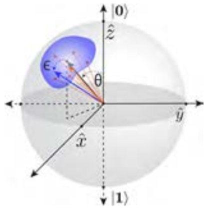
As AQT's user community continues to evolve and grow through annual calls, the next generation of architectures and algorithms are being co-designed, and the rate of high-impact publications steadily increases.

Several internship and undergraduate research programs have also helped dozens of students develop skills in real-world hardware and jumpstart and advance careers in quantum information science.



Architecture

Multidisciplinary teams of researchers at AQT have developed a full-stack platform for collaborative superconducting quantum information processing. This platform comprises the design and fabrication of novel superconducting qubits; architecture of quantum processors; cryopackaging and cryogenics; room-temperature control chain, including hardware, firmware, and software; optimization tools for quantum circuits; and a suite of tools for quantum characterization, verification, and validation. These features are available to all users participating in the platform's development, resulting in a virtuous cycle of valuable partnerships and feedback.



SOFTWARE STACK

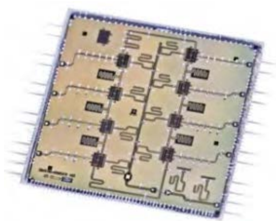
A versatile software stack compatible with a variety of open quantum circuit formats and equipped with a set of evolving tools for algorithmic performance optimization, including efficient compilation techniques and approaches that mitigate error. The stack provides users low-level access and can support non-standard software needs for testbed users.

COMMERCIAL AND IN-HOUSE CUSTOM CONTROLS

The in-house control stack, QubiC and its successor QubiC 2.0, accommodates custom needs of testbed users and provides capabilities unavailable in commercial controls, including for the first time AI/ML on FPGAs (field programmable gate arrays) to perform quantum state discrimination. Close collaboration between users and AQT scientists enables considerably more flexibility than is typically available in commercial quantum computing platforms.

CRYOGENIC PLATFORM

Includes seven cryogenic dilution refrigerators and one adiabatic demagnetization refrigerator. The largest Bluefors dilution fridge at AQT, "Blizzard," is outfitted with 160 RF lines and operates at 10mK. Blizzard was developed in partnership with Berkeley startup Bleximo to include an experimental stage that accommodates modular and extensible sets of experiments and cryopackaging for improved electromagnetic hygiene. The platform provides control and readout for 128 qubits and accommodates multiple quantum processors.



SUPERCONDUCTING QUANTUM PROCESSORS

AQT's processor portfolio includes an array of architectures with varying connectivity and native gate sets. The standard processor for user experiments during the first five years has been an 8-qubit transmon ring with high-coherence qubits (T1 and T2 >100 μs) and high-fidelity gates (99% for two-qubit gates). A novel 8-qubit QPU with arbitrary dynamically reconfigurable (up to all-to-all) connectivity is also available. AQT continues to develop advanced multi-qubit processors that will drive the next generation of scientific applications.

Classical Control Systems for Quantum Computing

A significant achievement leveraging research in accelerator science is a novel FPGA-based control and measurement system - QubiC and its successor QubiC 2.0 - that is modular and open source. QubiC is capable of the efficient upload and execution of experiments with minimal overhead and accommodate users' unique needs. It has demonstrated fast feedback, reset capability, crosstalk compensation, and automated calibration of single- and two-qubit gates. QubiC 2.0 provides in-situ real-time feedback and AI-accelerated quantum state discrimination, being the only freely available control system that utilizes advances in AI/ML on FPGAs for quantum state discrimination.

The extensible and modular room temperature control electronics are modularly based on FPGAs, each offering 16 DACs (digital-to-analog converters) at 8GSPS (giga samples per second), 2 ADCs (analog-to-digital converters) at 2GSPS. The setup includes a DC-capable, flexible analog front-end boards, and multiple FPGAs can be synchronized for control of large processors. The gateware on FPGA enables arbitrary pulse sequence generation and state discrimination on-the-fly.

AQT also partnered early on with Zurich Instruments, a leading manufacturer of test and measurement equipment. Zurich Instruments provided cutting-edge instrumentation for AQT's main cryogenic dilution fridge, "Blizzard." AQT staff and Zurich Instrument engineers worked closely to overcome technical challenges as AQT's platform explored the performance limits of the control electronics. These collaborative co-design sessions, in turn, resulted in the solutions and real-time improvements that advanced the nascent devices. As a result of these improvements, AQT successfully performed a variety of experimental demonstrations, including quantum simulation, optimization, quantum chemistry, and research in condensed matter, nuclear physics, and high-energy physics.

Researchers Gang Huang and Yilun Xu led QubiC and QubiC 2.0

"By building QubiC and QubiC 2.0 as a more accessible and affordable system from the ground up, we really know what happens underneath for further integrations and try to scale the design."

GANG HUANG, *Berkeley Lab ATAP Division*

"Since its founding, AQT researchers have worked closely with a host of industrial partners. Our industrial partners have in turn benefited from real-world use and feedback to further develop their solutions."

KASRA NOWROUZI, *Head of Hardware*

2023 User Meeting, Berkeley, CA

Testbed **User Program**

AQT functions as an open platform encouraging research proposals from various teams in academia, industry, and National Laboratories to enable research that supports DOE's science and energy mission. AQT offers easily accessible, deep expertise to refine project ideas for the highest potential impact, often bringing new approaches and carrying them out. User projects at AQT leverage the full stack access to pursue fundamental research directions, which is unavailable on closed quantum computing platforms.

Through 2023, AQT held four open calls for user project proposals, receiving applications nationwide and internationally. This included executing algorithms for scientific computation, benchmarking of NISQ (noisy intermediate-scale quantum) hardware, and co-designing next-generation architectures and algorithms.

Outside of the annual calls, AQT accepts research proposals on a rolling basis for time-sensitive or high-priority projects, serving as a collaborative laboratory for the fast-growing QIS community.

"By revealing the inner controls of quantum hardware, AQT's collaborative approach with users drives innovation throughout the quantum computing stack. We look forward to continuing our research collaboration with AQT, and we will continue to share these results with the scientific community by publishing our findings."

PRANAV GOKHALE, *VP of Quantum Software, Infleqtion*

"Close collaboration with AQT's team is really valuable. We often find that insights from experimental data allow us to improve our methods, and this is an iterative process. An ongoing collaboration with AQT allows us to explore how our methods perform on a real system, improve and perfect them, and then gather huge amounts of data to test the finalized methods. This is much harder to do with publicly accessible devices, with their much more limited access."

TIMOTHY PROCTOR, *Principal investigator, Sandia National Laboratories*

Researcher Larry Chen with a wire bonding device

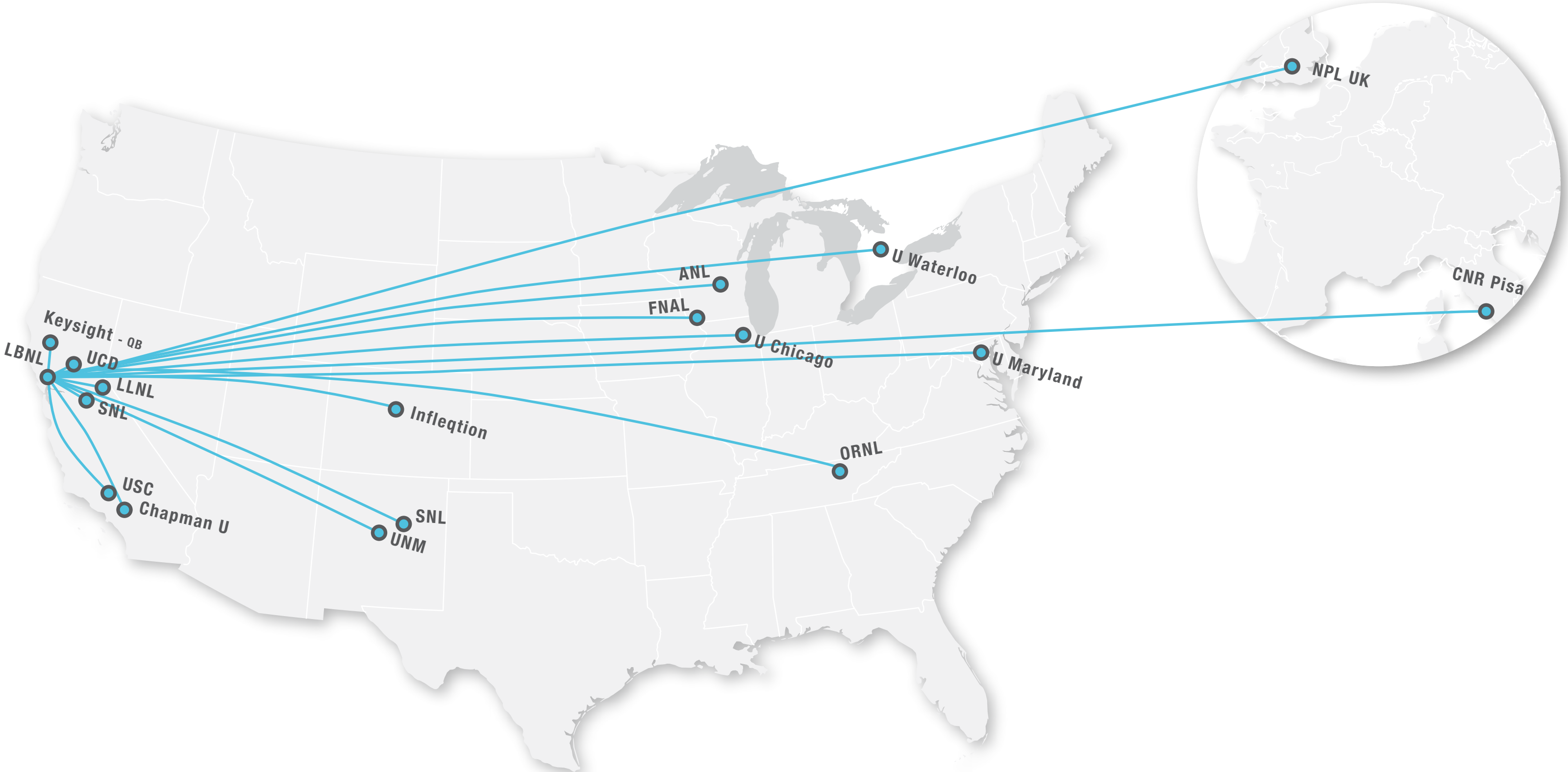
"In the context of a testbed user meeting, we learned about other techniques that we were not aware of. So this user meeting sparked new ideas for our research. At the same time, our research also provides feedback to the hardware specialists."

SOFIA QUAGLIONI, *Deputy Group Leader, Lawrence Livermore National Laboratory*

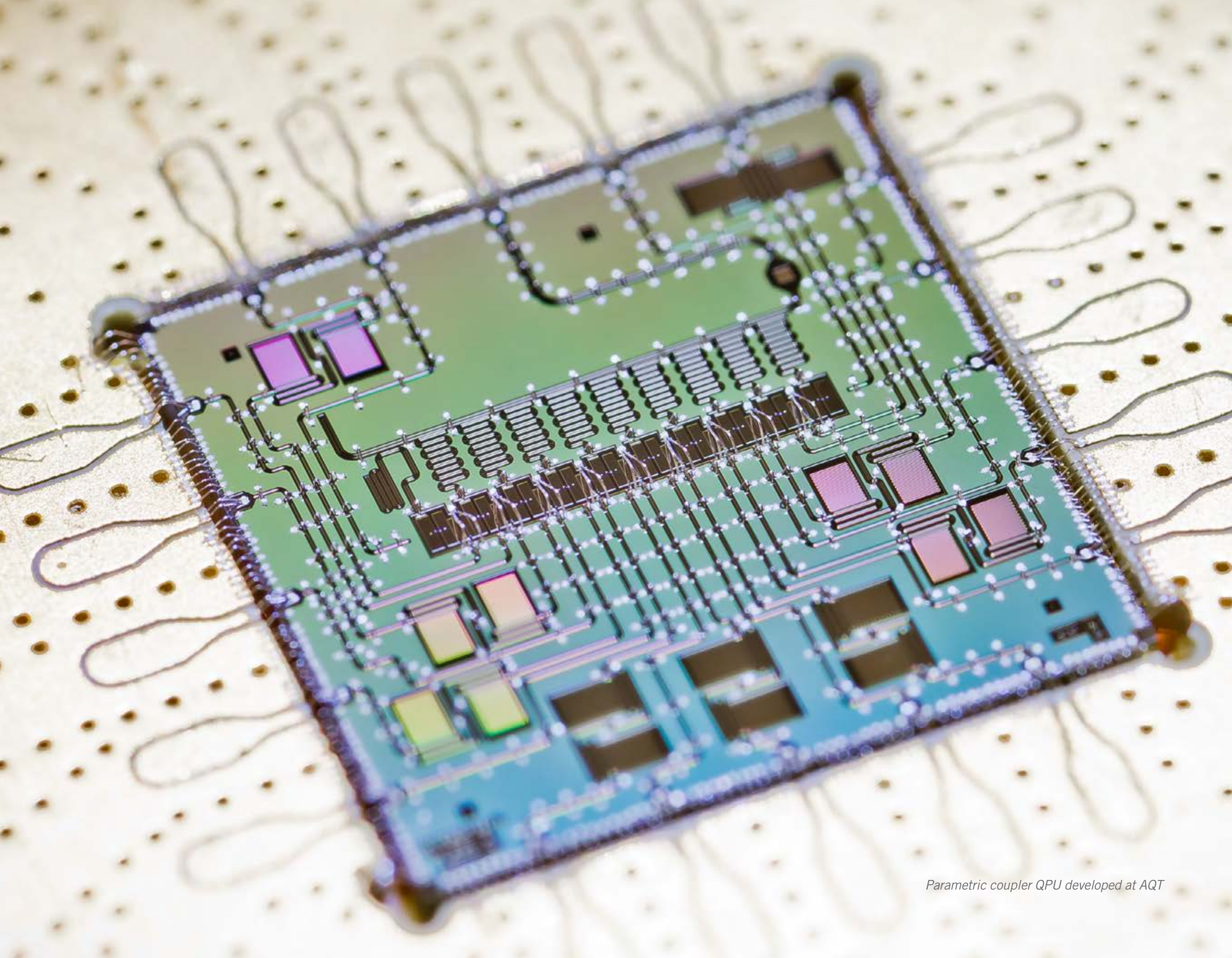
"Through the close collaboration with researchers from AQT, we learned about new cutting-edge experiment ideas early on. This helped us improve our control electronics – also it influenced strongly our recently-launched next generation of Quantum Computing Control Systems."

CLAUDIUS RIEK, *Managing Director, Zurich Instruments*

User **Institutions**



ANL	Argonne National Laboratory (Argonne, IL)	**Infleqtion**	Infleqtion (Boulder, CO)	**ORNL**	Oak Ridge National Laboratory (Oak Ridge, TN)	**U Chicago**	University of Chicago (Chicago, IL)
Chapman U	Chapman University (Orange County, CA)	**Keysight QB**	Keysight QB (Santa Rosa, CA)	**LLNL**	Lawrence Livermore National Laboratory (Livermore, CA)	**U Maryland**	University of Maryland (College Park, MD)
CNR Pisa	National Research Council (Pisa, Italy)	**LBNL**	Lawrence Berkeley National Laboratory (Berkeley, CA)	**SNL**	Sandia National Laboratories (Albuquerque, NM; Livermore, CA)	**U New Mexico**	University of New Mexico (Albuquerque, NM)
FNAL	Fermi National Accelerator Laboratory (Batavia, IL)	**NPL UK**	National Physical Laboratory (London, UK)	**UCD**	UC Davis (Davis, CA)	**U Waterloo**	Waterloo University (Ontario, Canada)



Parametric coupler QPU developed at AQT

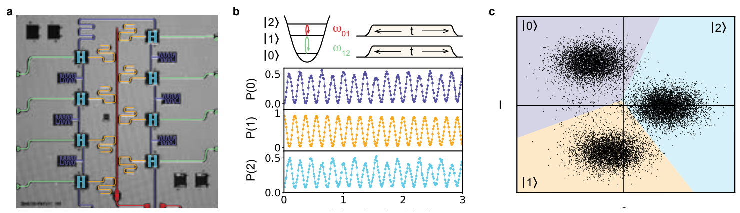
"As part of its mission to bridge fundamental science and quantum algorithms beyond single, academic, proof of concept demonstrations to a broad range of informative and impactful calculations, AQT complements other resources in the quantum ecosystem by providing users access to the latest protocols and devices."

RAVI NAIK, Head of Measurement

Researcher Linus Kim analyzes a QPU

Science **Highlights**

Qutrit Processors for Resource-efficient Quantum Computing and the Scrambling of Quantum Information



Superconducting qutrit processor. (a) Optical micrograph of the five-transmon processor (b) Coherent Rabi dynamics of a single qutrit induced by simultaneous microwave driving at frequencies ω01 and ω12 (c) Example single-shot readout records of an individual qutrit (Credit: M. S. Blok, University of Rochester)

THE SCIENCE

Researchers developed pioneering experimental methods to encode and process quantum information using three-level systems, qutrits. Each qutrit represents three states simultaneously; therefore, qutrit encodings are resource-efficient and may allow for more robust quantum computation. A series of five qutrits were used to successfully probe the scrambling of quantum information, the dynamics of scattering local quantum information across the system, akin to the behavior in black holes.

THE IMPACT

One of the challenges in quantum computing is faithfully manipulating quantum information in larger processors. Quantum algorithms may be deployed more efficiently with qutrit encodings because fewer qutrits and entangling gates are required to execute an algorithm of the same complexity.

SUMMARY

Researchers engineered a novel two-qutrit gate to realize entanglement between qutrits. Transmon circuits were coupled to an integrated Purcell-filter and readout bus via individual linear resonators, enabling multiplexed state measurement. Exchange coupling between nearest-neighbor transmons was mediated by resonators, while microwave drive lines enabled coherent driving of individual qubits. Coherent Rabi dynamics of a single qutrit was induced by simultaneous microwave driving at frequencies ω01 and ω12. Achievable Rabi frequencies were in the range of tens of megahertz, 3 orders of magnitude faster than decoherence timescales. Single-shot readout records of an individual qutrit was generally achievable with fidelities above 0.95. The experiment demonstrated that with the advances in materials, packaging, and control, these excited states are now coherent enough for running quantum algorithms. With this new control, researchers ran a five-qutrit algorithm that probed the scrambling of quantum information between two qutrits while using teleportation to witness the scrambling.

Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory and Physics Department at UC Berkeley and the Perimeter Institute for Theoretical Physics in Canada.

Publications

Blok, Michael S., et al. Quantum Information Scrambling on a Superconducting Qutrit Processor. Physical Review X 11, 021010 (2021).

Media Coverage

Going Beyond Qubits: New Study Demonstrates Key Components for a Qutrit-Based Quantum Computer, Berkeley Lab News, April 2021

Radio Frequency Mixing Modules for Superconducting Qubits

THE SCIENCE

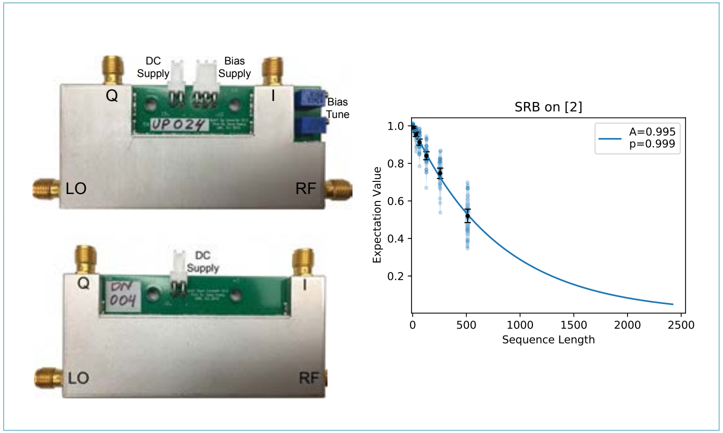
Researchers successfully developed a series of compact low-noise and high-performance RF mixing modules to shift the qubit manipulation and measurement signal frequency between the electronics baseband and the quantum system intrinsic band at room temperature. Their tests proved that using modular design methods reduces the cost and size of traditional RF control systems while still delivering superior or comparable performance levels to those commercially available.

THE IMPACT

Traditional RF control systems use analog circuits to control superconducting qubits, but they can become bulky and overwhelmingly complex, thus serving as a potential point of failure and increasing the costs for hardware control. The low-noise and high-reliability mixing modules address the extensibility challenges of RF analog circuits in terms of physical size, cost, and electrical failure rate.

SUMMARY

Many tests were carried out on conventional control systems, component by component, to understand the impact on the quantum system. Using modular design methods, researchers integrated low-noise components on a small physical size and designed electromagnetic interference shielding to eliminate undesired perturbance. The performance of each sub-module and the assembly were thoroughly inspected, characterized, and validated through a loopback bench test and system integration test with superconducting quantum processors.



(a) RF mixing module (up converter) (b) RF mixing module (down converter) (c) Measurements of the single-qubit process infidelity of $9.3(3)\times10^{-4}$ by randomized benchmarking with RF mixing modules (Credit: G. Huang & Y. Xu, Berkeley Lab)

Collaboration

This work included the collaboration of Berkeley Lab's Computing Sciences Division.

Publications

Xu, Y., et al. Radio frequency mixing modules for superconducting qubit room temperature control systems. Review of Scientific Instruments, 92(7), 075108 (2021).

Media Coverage

New modules shrink and improve controls on current quantum computers, Scilight 2021, July 2021

How a novel radio frequency control system enhances quantum computers, Phys.org News, November 2021

QubiC: Open Source FPGA-based Control and Measurement System

THE SCIENCE

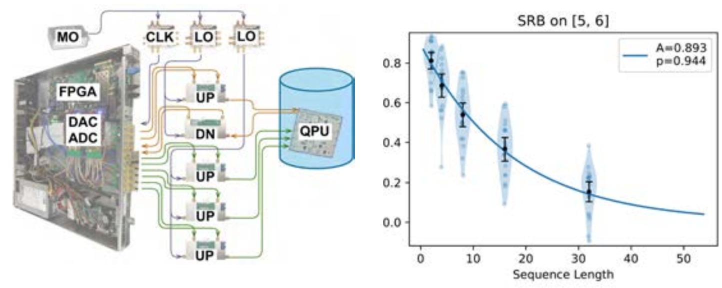
Researchers developed QubiC (and its successor QubiC 2.0) as an open-source, FPGA-based full-stack RF control and measurement system for superconducting quantum information processors inspired by the controls for particle accelerators and the growing need for affordability and modularity. Qubic 2.0 incorporates a novel, extensible AI-accelerated qubit control system empowering mid-circuit measurements and feed-forward capabilities for quantum applications.

THE IMPACT

The cost, size, and complexity of control and measurement hardware increase with a growing number of qubits. QubiC enables the execution of a broader class of computation experiments and the co-design implementation at each level in the next-generation system. QubiC is also compatible with commercial and custom-designed electronics, so testbed users from various national laboratories, startups, and companies can deploy their projects using QubiC's customizable interface.

SUMMARY

QubiC integrates an FPGA (field-programmable gate array) based RF (radio frequency) control system, which modulates the signals at room temperature to manipulate and measure the superconducting qubits cooled down to cryogenic temperatures. QubiC's Python-based software and gateware implement the protocols to characterize and benchmark the quantum chips, optimize one- and two-qubit gate algorithms, and mitigate errors. A multi-layer neural network has been designed and deployed to ensure accurate in-situ state discrimination. AI-accelerated quantum readout processing has been implemented on an RFSoC platform (AMD ZCU216). QubiC and QubiC 2.0 executes quantum algorithms with promising synchronicity and speed, delivering results similar to those of commercially available systems at significantly less cost.



(a) QubiC prototype system employs a heterodyne approach to generate and detect RF signals (b) Randomized benchmarking is used to measure the two-qubit process fidelity of 0.948±0.004. (Credit: G. Huang & Y. Xu, Berkeley Lab)

Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory at UC Berkeley and Berkeley Lab's Computing Sciences Division.

Publications

Xu, Y., et al. "QubiC: An Open-Source FPGA-Based Control and Measurement System for Superconducting Quantum Information Processors." **IEEE Transactions on Quantum Engineering, vol. 2, pp. 1-11, 2021, Art no. 6003811**.

Y. Xu, et al. "QubiC 2.0: An Extensible Open-Source Qubit Control System Capable of Mid-Circuit Measurement and Feed-Forward." **arXiv:2309.10333, (2023)**.

Media Coverage

Open sourced control hardware for quantum computers, Phys.org News, February 2022

Automatic Qubit Characterization and Gate Optimization with QubiC

THE SCIENCE

Researchers developed a concise and automatic calibration protocol to characterize qubits and optimize gates using QubiC on a superconducting quantum information processor.

THE IMPACT

Unlike conventional calibration methods, which require intricate and lengthy measurements to fine-tune qubits and gates, the QubiC automatic calibration protocol excels in efficiently characterizing qubits, optimizing gates, and delivering high-fidelity results. This streamlined process saves time and offers an easily scalable solution for large-scale quantum systems.

SUMMARY

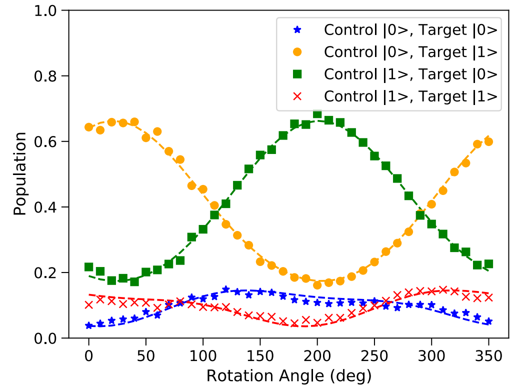
Researchers proposed multi-dimensional loss-based optimization for single-qubit gates and a full XY-plane measurement method for the two-qubit CNOT gate calibration. The automatic qubit characterization and gate optimization protocols are validated by performing randomized benchmarking sequences on a superconducting quantum information processor.

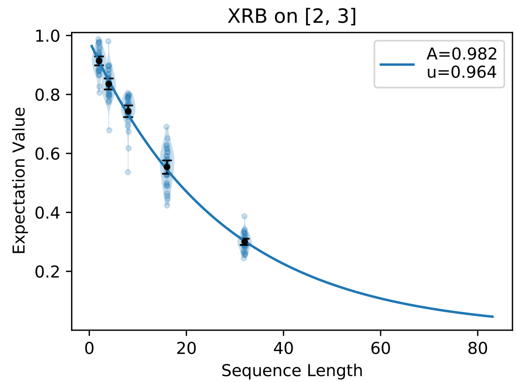
Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory at UC Berkeley.

Publications

Xu, Y., et al. "Automatic qubit characterization and gate optimization with QubiC." ACM Transactions on Quantum Computing 4.1 (2022): 1-12.





Caption: (a) Full XY-plane measurement and fitting results (b) Protocol validated by performing randomized benchmarking sequences (Credit: Yilun Xu, Gang Huang, Berkeley Lab)

Novel Quantum Processor Architecture with High-Performing Qubits

THE SCIENCE

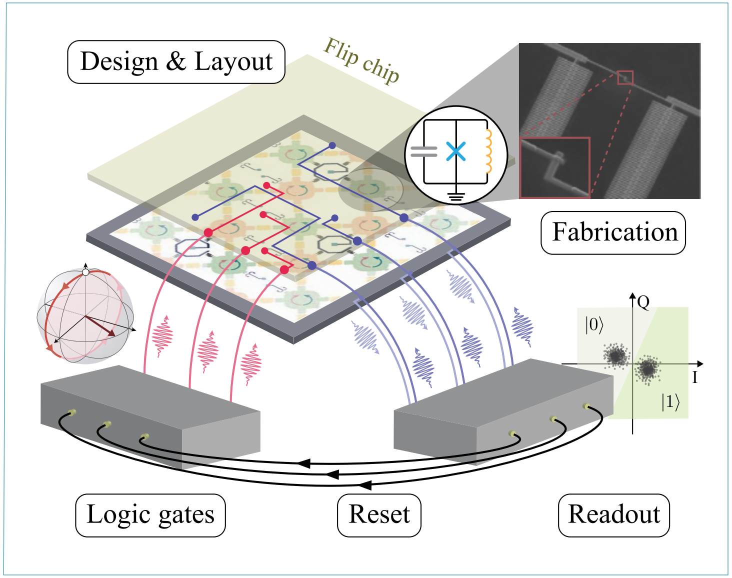
The next generation of programmable quantum devices will require processors built around superior qubits. Researchers developed a blueprint for a novel quantum information processor based on fluxonium qubits. A fluxonium qubit is an artificial atom that outperforms the most widely used superconducting qubits - transmons - in quantum computing due to its highly controllable properties.

THE IMPACT

The architectural blueprint pioneered a systematic study of fluxonium qubits that can be engineered to have high fidelity, which is vital for fabricating high-performance quantum devices. Furthermore, researchers focused on the scalability and adaptability of the processor's main components to improve the performance of quantum circuits, while offering practical suggestions to adapt and build the cutting-edge hardware for superconducting devices.

SUMMARY

The fluxonium circuit presented in the research is composed of three elements: a capacitor, a Josephson Junction, and a superinductor, which helps suppress magnetic flux noise – a typical source of unwanted interference that affects superconducting qubits and causes decoherence. Researchers simulated two types of programmable logic gates in the quantum device based on fluxonium qubits to validate the performance of the proposed blueprint. Researchers hope that continued research and development on fluxonium and superconducting qubit alternatives will bring about the next generation of devices for quantum information processing.



Technical illustration of a high-performance quantum processor architecture based on fluxonium qubits. (Credit: Long Nguyen, Berkeley Lab)

Collaboration

This work included the collaboration of Berkeley Lab's Materials Science Division, Yale University, and industry partner Bleximo.

Publications

Nguyen, L.B., et al. Blueprint for a High-Performance Fluxonium Quantum Processor. PRX Quantum 3, 037001 (2022).

Media Coverage

Innovating Quantum Computers with Fluxonium Processors, Berkeley Lab News, April 2023

Two-Qutrit Entangling Gates are Generated with High Fidelity

THE SCIENCE

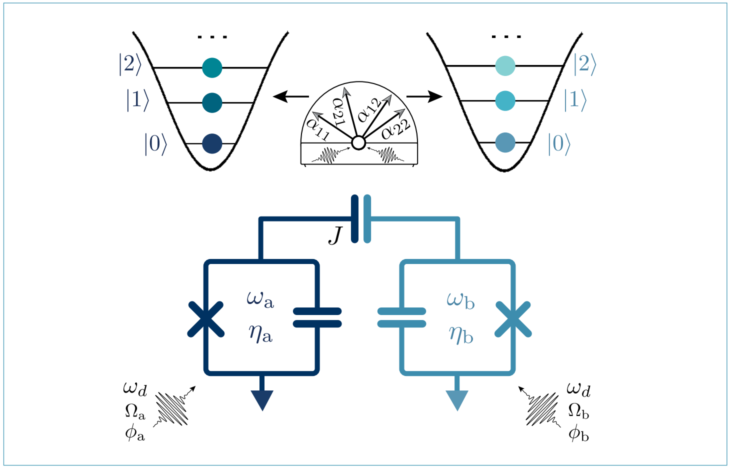
Quantum information processors that operate with three-level quantum systems – qutrits – offer significant potential advantages for quantum processing over their binary counterparts – qubits. Qutrits provide larger and more connected computational spaces due to the quantum mechanical properties of superposition and entanglement. However, characterizing and understanding qutrits is complex. To fully leverage a qutrit processor's power, it's necessary to execute operations with high control of individual qutrits and entangle neighboring qutrits with high fidelity and flexible control. Researchers successfully generated two-qutrit entangling gates on a superconducting quantum processor with gate fidelities significantly higher than in previously reported works.

THE IMPACT

The qutrit experimental development paves the way to a deeper understanding of ternary logic that can encode more information in quantum processors than qubits. Furthermore, it contributed to the fast-growing field of quantum information science as researchers introduced an interaction for qutrits with a high degree of control which had not been studied before.

SUMMARY

The team leading the experimental demonstration implemented a faster, flexible, and tunable microwave-activated entanglement between two transmon qutrits with fixed frequency and fixed coupling. This new approach to qutrit entanglement generated two universal two-qutrit gates, the controlled-Z gate (CZ) and the controlled-Z inverse gate (CZ+). For the first time in the study of qutrits, researchers also applied and generalized another established protocol – cross-entropy benchmarking – for characterizing gate noise and determining the fidelity of gate operations.



Microwave-activated two-qutrit entangling gates at fixed frequency and coupling (Credit: Noah Goss, Berkeley Lab)

Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory at UC Berkeley, Berkeley Lab's Computing Sciences and Material Sciences Divisions, and Keysight Technologies.

Publications

Goss, N., et al. High-fidelity qutrit entangling gates for superconducting circuits. **Nature Communications 13, 7481 (2022)**.

Media Coverage

Toward ternary quantum information processing: Success generating two-qutrit entangling gates with high fidelity, *Phys.org News, July 2023*

Éxito reportado en la generación de operaciones cuánticas entrelazadas de dos cutrits con alta fidelidad, *Berkeley Lab News , July 2023*

High-Fidelity Three-Qubit Native iToffoli Gate

THE SCIENCE

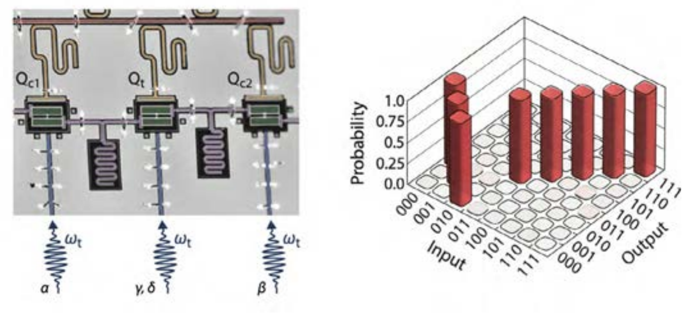
Researchers conducted the first experimental demonstration of a novel three-qubit high-fidelity iToffoli native gate in a superconducting quantum information processor and in a single step. The team demonstrated a very high fidelity operation of the gate at 98.26%.

THE IMPACT

Noisy intermediate-scale quantum processors typically support one- or two-qubit native gates, the types of gates that can be implemented directly by hardware. More complex gates are implemented by breaking them up into sequences of native gates. The team's demonstration adds a novel and robust native three-qubit iToffoli gate for universal quantum computing. Furthermore, researchers showed that the gates schematic on superconducting quantum processors could produce additional three-qubit gates, which provide more efficient gate synthesis—the process of breaking up quantum gates into shorter ones to improve circuit running times.

SUMMARY

The Toffoli or the controlled-controlled-NOT (CCNOT) is a key logical gate in classical computing because it is universal, so it can build all logic circuits to compute any desired binary operation. Furthermore, it is reversible, which allows the determination and recovery of the binary inputs (bits) from the outputs, so no information is lost. To create an easy-to-implement three-qubit gate for the experiment, AQT designed an iToffoli gate instead of a conventional Toffoli gate by applying simultaneous microwave pulses fixed at the same frequency to three superconducting qubits in a linear chain.



Experimental schematic of the high-fidelity iToffoli gate (Credit: Yosep Kim, Berkeley Lab)

Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory at UC Berkeley and Berkeley Lab's Computing Sciences Division.

Publications

Kim, Y., et al. High-fidelity three-qubit iToffoli gate for fixed-frequency superconducting qubits. Nat. Phys. 18, 783–788 (2022).

Media Coverage

Breakthrough in quantum universal gate sets: A high-fidelity iToffoli gate, Phys.org News, May 2022

Scalable Quantum Computing via Randomized Compiling

THE SCIENCE

Future large-scale quantum computations will inevitably encounter complex sources of errors. However, errors in quantum circuits can be simplified by randomizing the gates in an algorithm so that the final computation remains the same. This randomization changes systematic errors into probabilistic (i.e., stochastic) errors, which scale more favorably with system size, enabling more scalable quantum technologies.

THE IMPACT

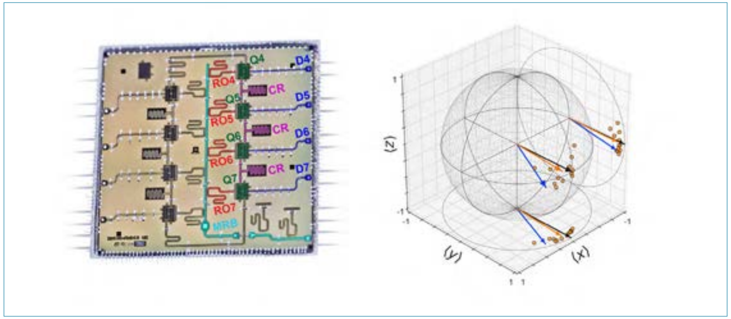
Probabilistic errors in quantum computations are favorable over other error types because they can be efficiently characterized and mitigated. Error mitigation methods based on probabilistic error cancellation are only possible on a large scale if the errors are purely stochastic. Performing readout correction on many qubits is more efficient if errors in readout are fundamentally probabilistic. Error thresholds for quantum error correcting codes are calculated using probabilistic errors due to their simplicity and ease of simulation. These advantages make randomized compiling vital for quantum computing beyond NISQ.

SUMMARY

Randomized compiling is a valuable tool for transforming all error types in quantum circuits into probabilistic errors. Researchers demonstrate randomized compiling and its benefits to quantum algorithms, quantum error mitigation, quantum measurement, and benchmarking gates. Future work will focus on how these various applications of randomized compiling can be utilized to make quantum computations more efficient at large scales.

Collaboration

This work included collaboration between UC Berkeley, Berkeley Lab, and Quantum Benchmark (acquired by Keysight Technologies).



Experimental demonstration of error mitigation through randomized compiling. Left: Eight-qubit superconducting quantum processor. Right: Quantum state tomography of a single qubit with (orange) and without (blue) randomized compiling compared to the ideal (black) state. (Credit: Akel Hashim, Berkeley Lab)

Publications

Hashim, A., et al. Randomized Compiling for Scalable Quantum Computing on a Noisy Superconducting Quantum Processor. Phys. Rev. X 11, 041039 (2021).

Ferracin, S., et al. Efficiently improving the performance of noisy quantum computers. arXiv:2201.10672 (2022).

Ville, J.-L., et al. Leveraging randomized compiling for the quantum imaginary-time-evolution algorithm. Phys. Rev. Research 4, 033140 (2022).

Hashim, A., et al. Benchmarking quantum logic operations relative to thresholds for fault tolerance. npj Quantum Inf. 9, 109 (2023).

Hashim, A., et al. Quasi-Probabilistic Readout Correction of Mid-Circuit Measurements for Adaptive Feedback via Measurement Randomized Compiling. arXiv:2312.14139 (2023).

Media Coverage

Crucial Leap in Error Mitigation for Quantum Computers, Phys.org, December 2021

Software-optimized Fermionic SWAP Networks

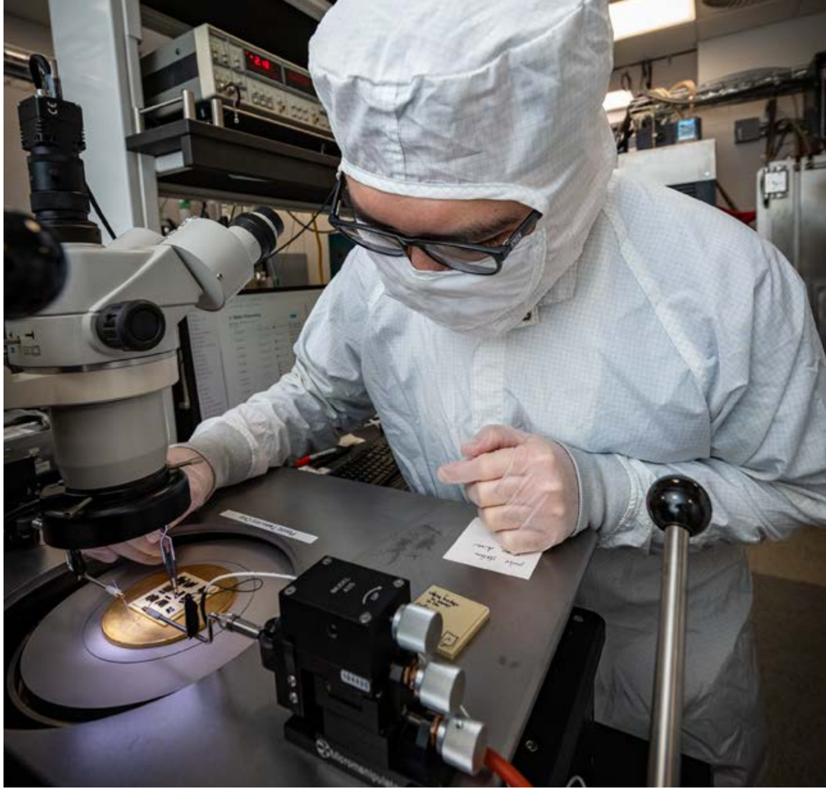
THE SCIENCE

Researchers demonstrated how to optimize the execution of the ZZ SWAP network protocol, important to quantum computing. The team also introduced a new technique for quantum error mitigation that will improve the network protocol's implementation in quantum processors. As part of the experiment, the team also introduced a novel technique called Equivalent Circuit Averaging (ECA), which randomized the various parameters of the SWAP networks to generate many logically equivalent circuits. ECA randomizes the decomposition of quantum circuits, mitigating the impact of systematic coherent errors — one of the most severe errors in quantum computers and widely studied at AQT. These experimental optimizations resulted in an improvement of up to 88% in the performance accuracy of QAOA. Researchers are looking to continue to explore and refine the methods in this work and apply them to other applications.

THE IMPACT

Quantum processors typically have limited qubit connectivity, where each qubit interacts with only a few neighbors. Furthermore, each qubit's information can only exist for so long before noise and errors cause decoherence, limiting the runtime and fidelity of quantum algorithms. When designing and executing a quantum circuit, researchers must optimize the translation of the circuit of abstract (logical) gates to physical instructions based on the native hardware gates available in a given quantum processor. Efficient circuit decompositions minimize the operating time because they can consider the number of gates and operations natively supported by the hardware to perform the desired logical operations.

SWAP gates — which swap information between qubits — are often introduced in quantum circuits to facilitate interactions between information in non-adjacent qubits. If a quantum device only allows gates between adjacent qubits, swaps are used to move information from one qubit to another non-adjacent qubit.



Researcher Long Nguyen at a probe station

In noisy intermediate-scale quantum (NISQ) hardware, introducing swap gates can require a large experimental overhead. The swap gate must often be decomposed into native gates, such as controlled-NOT gates. Therefore, when designing quantum circuits with limited qubit connectivity, it is important to use a smart compiler that can search for, decompose, and cancel redundant quantum gates to improve the runtime of a quantum algorithm or application.

SUMMARY

The research partnership used Super.tech's SuperstaQ software enabling scientists to finely tailor their applications and automate the compilations of circuits for AQT's superconducting hardware, particularly for a native high-fidelity controlled-S gate, which is not available on most hardware systems. This smart compiling approach with four transmon qubits allows the SWAP networks to be decomposed more efficiently than standard decomposition methods.

A network of ZZ SWAP gates requires only minimal linear connectivity between qubits without additional couplings, so it offers practical advantages for the efficient execution of quantum algorithms such as the Quantum Approximate Optimization Algorithm (QAOA). QAOA approximates solutions to combinatorial optimization problems — finding the optimal answer by giving a set of criteria. The Maximum-Cut problem, which can be used to arrange hubs on a transport grid system, is an example of a famous combinatorial optimization problem that can be potentially solved faster with QAOA using quantum circuits.

Collaboration

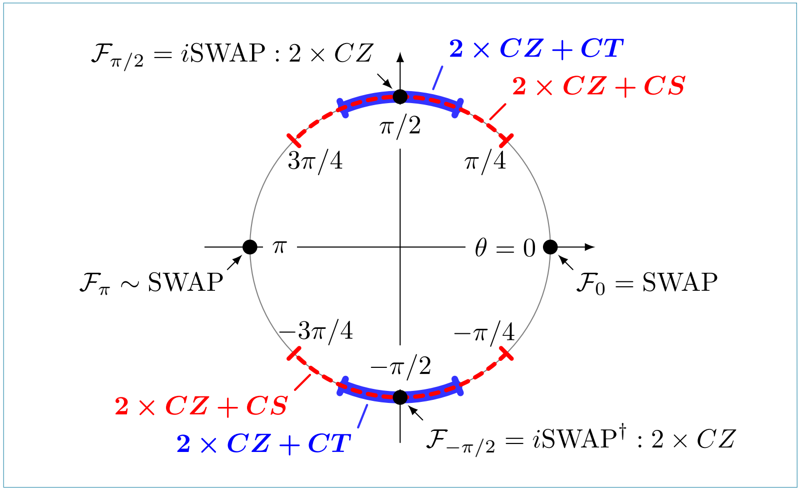
This work included the collaboration of UC Berkeley, Berkeley Lab's Computing and Material Sciences Divisions, Super.tech (acquired by Infleqtion), and the University of Chicago.

Publications

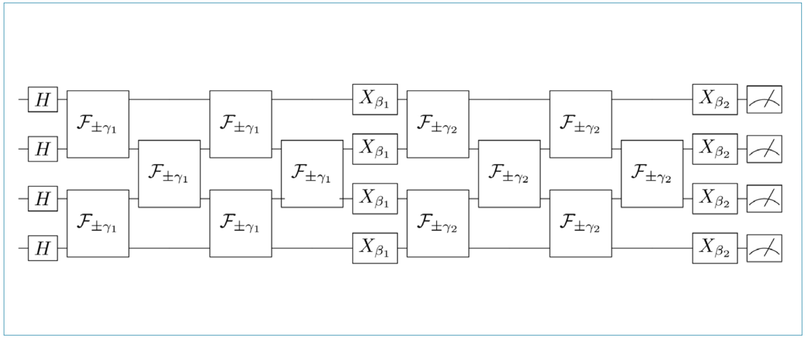
Hashim, A., et al. Optimized SWAP networks with equivalent circuit averaging for QAOA. Phys. Rev. Research 4, 033028 (11 July 2022).

Media Coverage

Optimizing SWAP networks for quantum computing, Phys.org News, August 2022



Comprehensive schematic of software-optimized SWAP networks for AQT's gates (Credit: Rich Rines, Super.tech, acquired by Infleqtion)



Schematic of SWAP networks for QAOA on four qubits (Credit: Akel Hashim, Berkeley Lab)

Scalable Randomized Benchmarking of Universal Gate Sets

THE SCIENCE

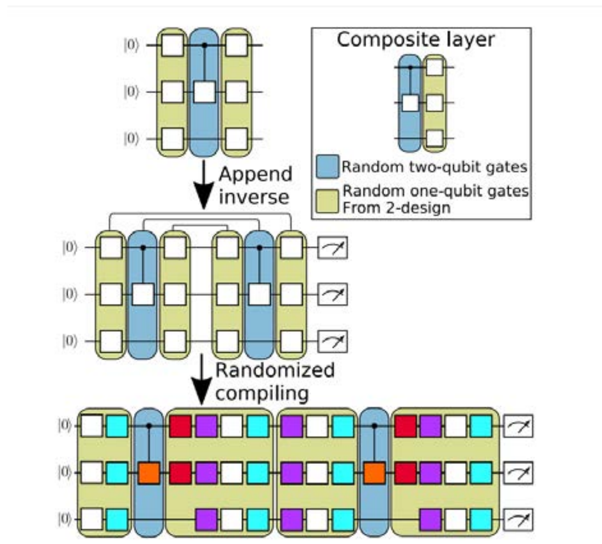
Researchers need to characterize the performance of quantum computers in a scalable way. Many commonly used tools, such as randomized benchmarking, require hard classical computation that becomes infeasible once we move past a small number of qubits or quantum gates that are easy to simulate classically. Researchers introduced a new technique, mirror randomized benchmarking (MRB), that can scale to thousands of qubits.

THE IMPACT

MRB with universal gate sets enables researchers to assess the performance of more qubits and a wider variety of gates in contrast to existing techniques. This method can be adapted to create other benchmarks, providing insights about quantum processors. For instance, researchers used this technique to characterize the amount of crosstalk on IBM and AQT processors.

SUMMARY

Researchers developed a benchmarking technique using a class of circuits called randomized mirror circuits and applied it to gate sets on two different processors, providing experimental evidence that it is reliable for measuring average error. The gate sets include universal gate sets, which are necessary for performing general quantum computation. The technique is scalably run on up to 27 qubits, and the results were analyzed to characterize further errors in the quantum system, such as crosstalk—a major error source in current processors that is not fully captured by running one- and two-qubit circuits. Such errors dominate the many-qubit regime on a 27-qubit IBM Q processor, highlighting the importance of scalable benchmarks.



Randomized mirror circuits over universal gate sets (Credit: Marie Lu, PsiQuantum)

Collaboration

This work included the collaboration of UC Berkeley, Berkeley Lab's Computing and Material Sciences Divisions, and Sandia National Laboratories.

Publications

Hines, J., et al. Demonstrating Scalable Randomized Benchmarking of Universal Gate Sets. Phys. Rev. X 13, 041030 (14 November 2023).

Programmable Heisenberg Interactions Between Floquet Qubits

THE SCIENCE

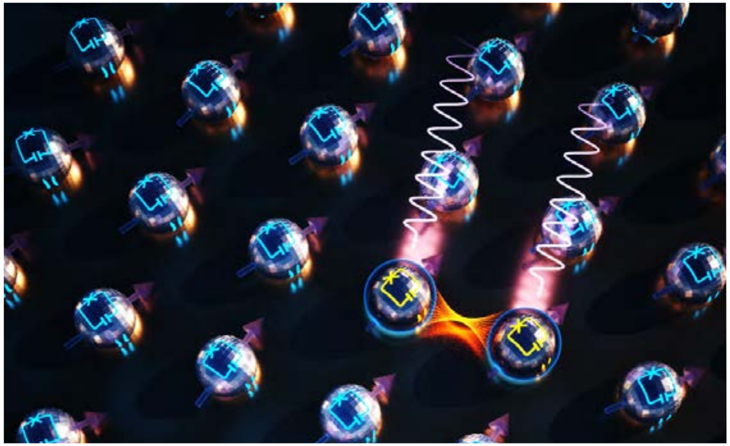
This work focuses on transforming fixed-frequency superconducting circuits into modifiable Floquet qubits. Researchers have adiabatically altered these circuits' properties, enabling more controlled and varied interactions in quantum systems. The process involves sophisticated techniques like the derivative removal by adiabatic gate (DRAG) to minimize nonadiabatic effects, thereby enhancing the precision of the quantum interactions.

THE IMPACT

This work presents a groundbreaking approach to quantum computing using fixed-frequency superconducting circuits. By adiabatically modifying fixed-frequency superconducting circuits to create Floquet qubits, the researchers have unlocked the potential for highly controlled and tunable interactions within quantum systems. The successful implementation of various quantum gates with high fidelity underscores the practicality of this approach. It demonstrates the technical feasibility and lays the groundwork for future research in quantum electrodynamics and optimal control in the Floquet framework. This research could have far-reaching implications for the advancement of quantum computing technology.

SUMMARY

This study marks a significant stride in the engineering of solid-state qubits. The ability to program Heisenberg interactions between Floquet qubits suggests a new horizon for quantum simulation and fault-tolerant quantum computation for more advanced quantum algorithms. It could significantly accelerate the development of high-performance quantum information processing systems. The demonstrated interactions form the basis for simulating complex many-body spin systems and constructing expressive quantum gate sets. With the successful implementation of two-qubit gates like iSWAP, CZ, and SWAP, along with a three-qubit CCZ gate, all boasting high fidelities, the research demonstrates the potential for more versatile and robust quantum computing platforms.



Floquet-engineered XXZ Heisenberg interaction. (Credit: Long Nguyen, Berkeley Lab)

Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory at UC Berkeley, Berkeley Lab's Computing and Material Sciences Divisions, the Korea Institute of Science and Technology, Chapman University, and the University of Rochester.

Publications

Nguyen, L.B., et al. Programmable Heisenberg interactions between Floquet qubits. Nature Physics. 20, 240–246 (2024).

Two-Photon Operations in a Qudit Quantum Processor

THE SCIENCE

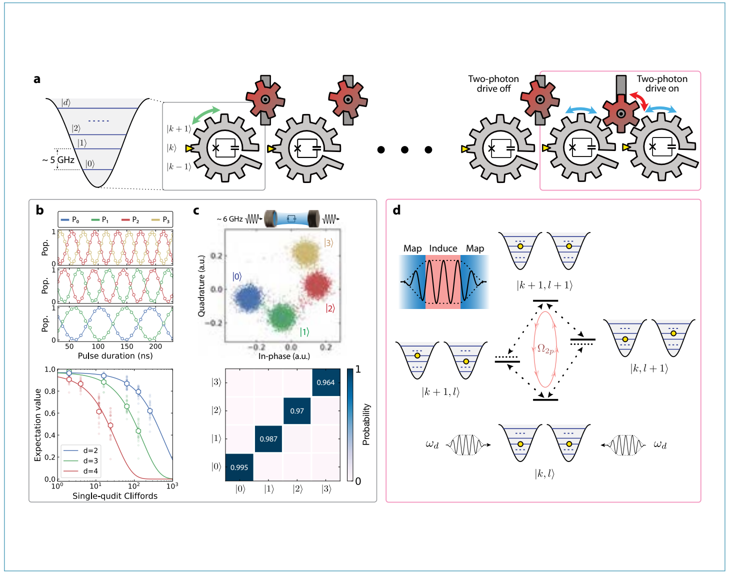
A novel approach to operating a superconducting quantum processor enabled scalable multi-qubit gates, the realization of squeezed spin states and atomic Schrödinger cat states in qudits, and the implementation of programmable qudit entanglement along a chain.

THE IMPACT

This study marks a significant stride in operating high-dimensional solid-state systems and quantum computing with a compact quantum processing unit. As the simplicity and robustness of fixed-frequency superconducting circuits with fixed coupling have allowed them to be scaled up to devices integrating hundreds of qubits, these experimental demonstrations using the same type of device without additional circuitry or instrumentation represent a potentially transformative approach to advancing quantum technologies through high-dimensional quantum operations. These are pioneering results in the field of high-dimensional quantum computing, serving as the experimental foundations for novel quantum metrology and fault-tolerant quantum information processing in the future.

SUMMARY

Researchers have demonstrated a robust, hardware-efficient, and extensible approach for operating multidimensional solid-state systems using Raman-assisted two-photon interactions. To demonstrate its efficacy, researchers constructed a set of multi-qubit operations, realized highly entangled multidimensional states, including atomic squeezed states and Schrödinger cat states, and implemented programmable entanglement distribution along a qudit array. These results are milestones for future high-dimensional quantum applications encompassing quantum sensing and fault-tolerant quantum information processing using qudits.



Overview schematic of the experiment (A) High-dimensional system constructed by linking individual qudits into an array (B and C) Local control and readout of a qudit (D) Simplified depiction of the Raman-assisted two-photon-driven dynamics (Credit: Long Nguyen, Berkeley Lab)

Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory at UC Berkeley and Korea University.

Publications

Nguyen, L.B., et al. Empowering high-dimensional quantum computing by traversing the dual bosonic ladder. arXiv:2312.17741.

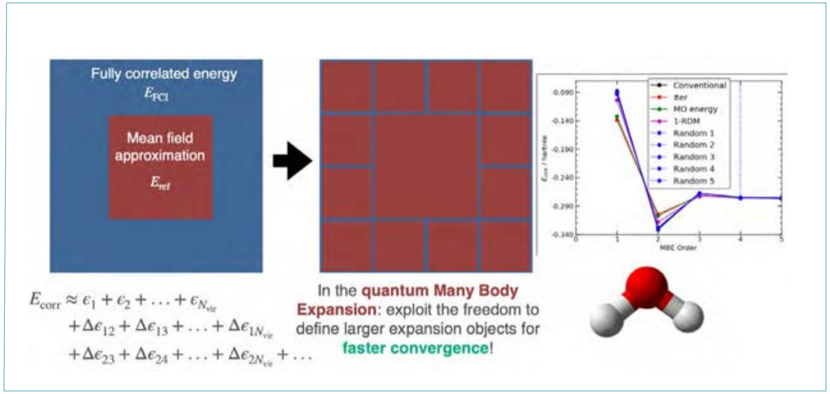
Making Small Quantum Computers Do Big Things

THE SCIENCE

Hamiltonian simulation on quantum computers promises to bring problems in chemistry, physics, and materials science that lie beyond the powers of classical computers within reach. Yet, while it is generally accepted that there are significant problems to address even with a small number of qubits, the limitations of near-term devices obscure whether any significant advances will be attainable before error correction is available. In this experimental demonstration, researchers address this problem of limited quantum resources by proposing an algorithm known as the quantum many-body expansion that calculates Hamiltonian energies for large chemical problems by breaking the system up into a series of smaller calculations requiring fewer qubits.

THE IMPACT

This project provided the first experimental demonstration of the quantum many-body expansion algorithm. It takes a currently intractable energy calculation that would conventionally need a large number of qubits, and breaks it up into a series of smaller calculations amenable to near-term hardware. This work there provides a framework to break complex chemistry and materials problems into smaller ones in a way that is chemically inspiring and requires a smaller number of quantum resources, making it amenable to near-term quantum hardware.



The quantum many-body expansion algorithm and numerical demonstration on a model of water. (Credit: Katie Klymko, NERSC, Berkeley Lab)

SUMMARY

The quantum many-body expansion algorithm is based on the classical many-body Full Configuration Interaction method with generalizations that allow for efficient usage on a quantum computer. Researchers demonstrated its efficiency numerically for a large number of molecular systems and experimentally for the H2 molecule on the AQT hardware.

Collaboration

This work included the collaboration of NASA Ames Research Center and the University of Colorado Boulder.

Publications

Klymko, K., et al. "Making Small Quantum Computers Do Big Things with the Quantum Many-Body Expansion," manuscript in preparation.

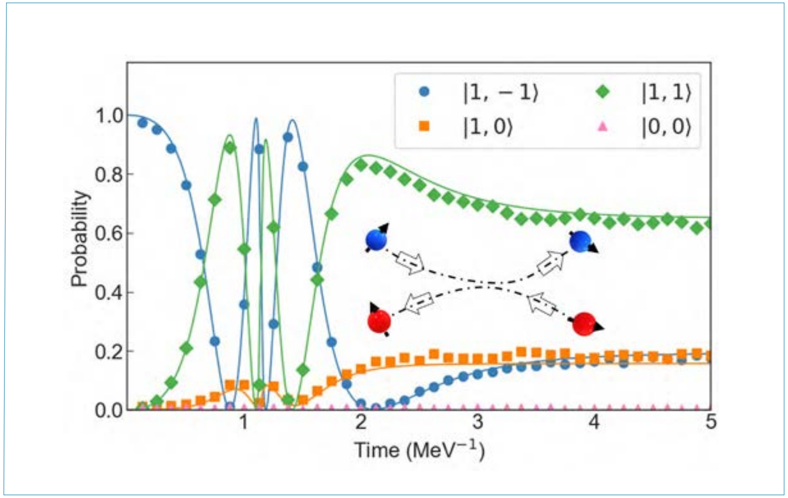
Quantum Simulations for Nuclear Physics

THE SCIENCE

Even the most powerful supercomputers cannot feasibly simulate increasingly complex nuclear reactions of interest, which prompts the exploration of alternatively using quantum computing. In this study, the researchers simulated a nuclear scattering event using a co-processing algorithm that broke the problem into components executed on classical and quantum computers.

THE IMPACT

This work constitutes a preliminary demonstration of experimentally applying quantum computing to nuclear physics. Using classical and quantum computers to perform the simulation also illustrates the ability to explore this application in the near term with smaller-scale quantum processors. This project's success motivates continuing to apply quantum computing to nuclear simulations.



Researchers simulated the scattering between two neutrons and achieved precision results through various error mitigation strategies (Credit: Francesco Turro, University of Washington)

SUMMARY

To address the search for additional methods to simulate nuclear reactions as certain problems become beyond current capabilities, the scattering between two neutrons was simulated using a combination of classical and quantum computers. First, the algorithm was developed and partitioned into two distinct parts, one of which was performed on a classical computer and the other on a quantum computer. After implementing several strategies to improve the accuracy of the quantum computer, the researchers successfully conducted the nuclear scattering simulation. The spatial evolution was computed with a classical computer, and the spin evolution with the AQT quantum processor. This represents an initial exploration of experimentally using quantum computers in nuclear physics simulations, helping to unite the two fields in this collaborative work. With the initial success of this project on a relatively small system, researchers hope this provides momentum toward simulating more complicated nuclear reactions on larger systems.

Collaboration

This work included the collaboration of Lawrence Livermore National Laboratory and the University of Trento institutions.

Publications

Turro, F., Demonstration of a quantum-classical coprocessing protocol for simulating nuclear reactions. Phys Rev A 108, 032417 (2023).

Qutrit Randomized Benchmarking

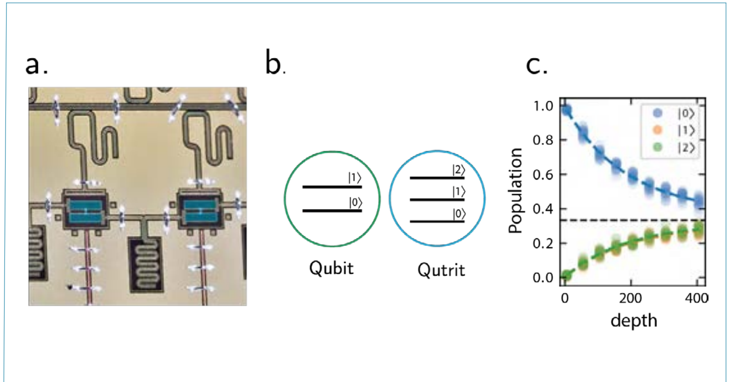
THE SCIENCE

Ternary quantum processors offer significant computational advantages over conventional qubit technologies, leveraging the encoding and processing of quantum information in qutrits (three-level systems). To evaluate and compare the performance of such emerging quantum hardware, robust benchmarking methods are essential for a higher-dimensional Hilbert space. Researchers demonstrated extensions of the industry-standard Randomized Benchmarking (RB) protocols, an error characterization method developed and used extensively for qubits suitable for ternary quantum logic.

THE IMPACT

Error rates cause decoherence (loss of information) and problems with the execution of quantum logic gates, which corrupt the results. A growing number of qubits or qutrits increases the propensity for errors, so finely describing these errors—error characterization—allows researchers to overcome them and design better algorithms and processors.

A key challenge is that, as the number of qubits or qutrit increases, so does the complexity of the error. Techniques like RB have become standard for error characterization for qubit-based processors. RB averages all possible errors into a single number, enabling meaningful comparison across systems. However, existing techniques for benchmarking qubit processors are insufficient for qutrit systems. It is possible to expand these techniques for benchmarking of qutrit processors.



Randomized benchmarking of a single qutrit (Credit: Alexis Morvan, Berkeley Lab)

SUMMARY

Using a superconducting five-qutrit processor, researchers encountered single-qutrit gate infidelity as low as 2.38×10−3. Through interleaved RB, this qutrit gate error is largely limited by the native (qubit-like) gate fidelity, and simultaneous RB was employed to characterize cross-talk errors fully. Finally, cycle benchmarking was done at a two-qutrit CSUM gate to obtain a two-qutrit process fidelity of 0.82. Results demonstrate a RB-based tool to characterize the overall performance of a qutrit processor and a general approach to diagnose control errors in future qudit hardware

Collaboration

This work included the collaboration of the Quantum Nanoelectronics Laboratory at UC Berkeley, Berkeley Lab's Materials Science Division, the University of Rochester, and the Massachusetts Institute of Technology.

Publications

Morvan, A., et al. Qutrit Randomized Benchmarking. **Phys. Rev. Lett. 126, 210504 (May 2021)**.

Media Coverage

Raising the Bar in Error Characterization for Qutrit-Based Quantum Computing, HPCwire News, September 2021

Experimental Characterization of Crosstalk Errors with Simultaneous Gate Set Tomography

THE SCIENCE

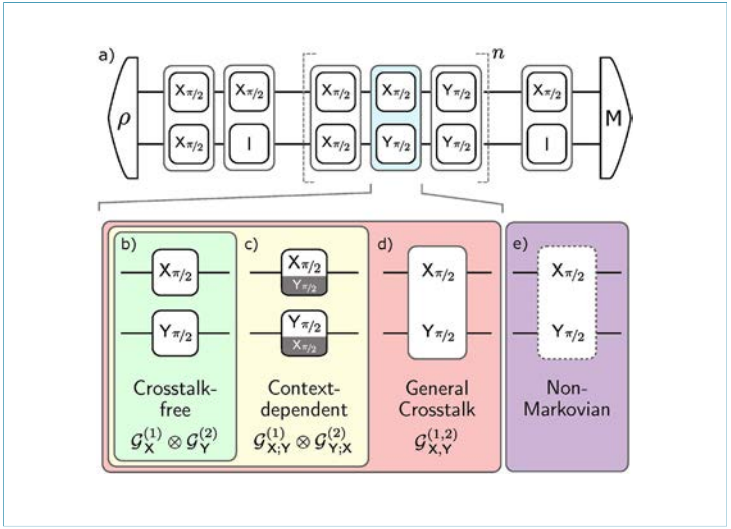
A central challenge in quantum information is the prevalence of errors affecting current quantum processors. These errors come in many forms and it can be challenging to understand and model them in detail. Here, we develop and demonstrate simultaneous gate set tomography (sGST) to characterize errors occurring on two qubits when gates are applied to both. This method can distinguish between errors that are isolated on individual qubits, are correlated between the qubits, or entangle the qubits, allowing for an accurate model of errors on a particular gate set.

THE IMPACT

One of the leading errors afflicting current quantum processors is crosstalk, namely coherent errors that can lead to unintended operations on multiple qubits simultaneously. With sGST, we are able to determine accurate models of crosstalk errors, which we demonstrate on both superconducting and trapped ion based quantum processors. With detailed understanding of the nature of crosstalk errors, we can design tailored mitigation or recalibration strategies to account for these errors. Moreover, this framework can be naturally extended to the many-qubit regime, by considering only models that include low-weight, few-qubit crosstalk errors. This extension would make it possible to comprehensively characterize, and then potentially mitigate, crosstalk errors even in many-qubit devices.

SUMMARY

We used simultaneous gate set tomography to study crosstalk errors in both a multi-qubit trapped ion platform and a multi-qubit transmon platform. In both systems, we find significant crosstalk errors, but there is no evidence for



Process by which GST circuits are generated and possible models of increasing complexity to fit to results. (Credit: Kevin Young, Sandia Labs)

entangling or correlated errors. Our analysis fits a hierarchy of models to data, ranging from a crosstalk-free model to a general model that can encompass arbitrary crosstalk errors. This makes it possible to perform statistically rigorous tests for the presence of entire classes of crosstalk errors.

Collaboration

This work included collaboration between Berkeley Lab, UC Berkeley, and Sandia National Laboratories..

Publications

Rudinger, K., et al. Experimental characterization of crosstalk errors with simultaneous gate set tomography. PRX Quantum, 2(4), 040338.

Researcher Larry Chen adjusts quantum computing electronics

Building the **Quantum Workforce**

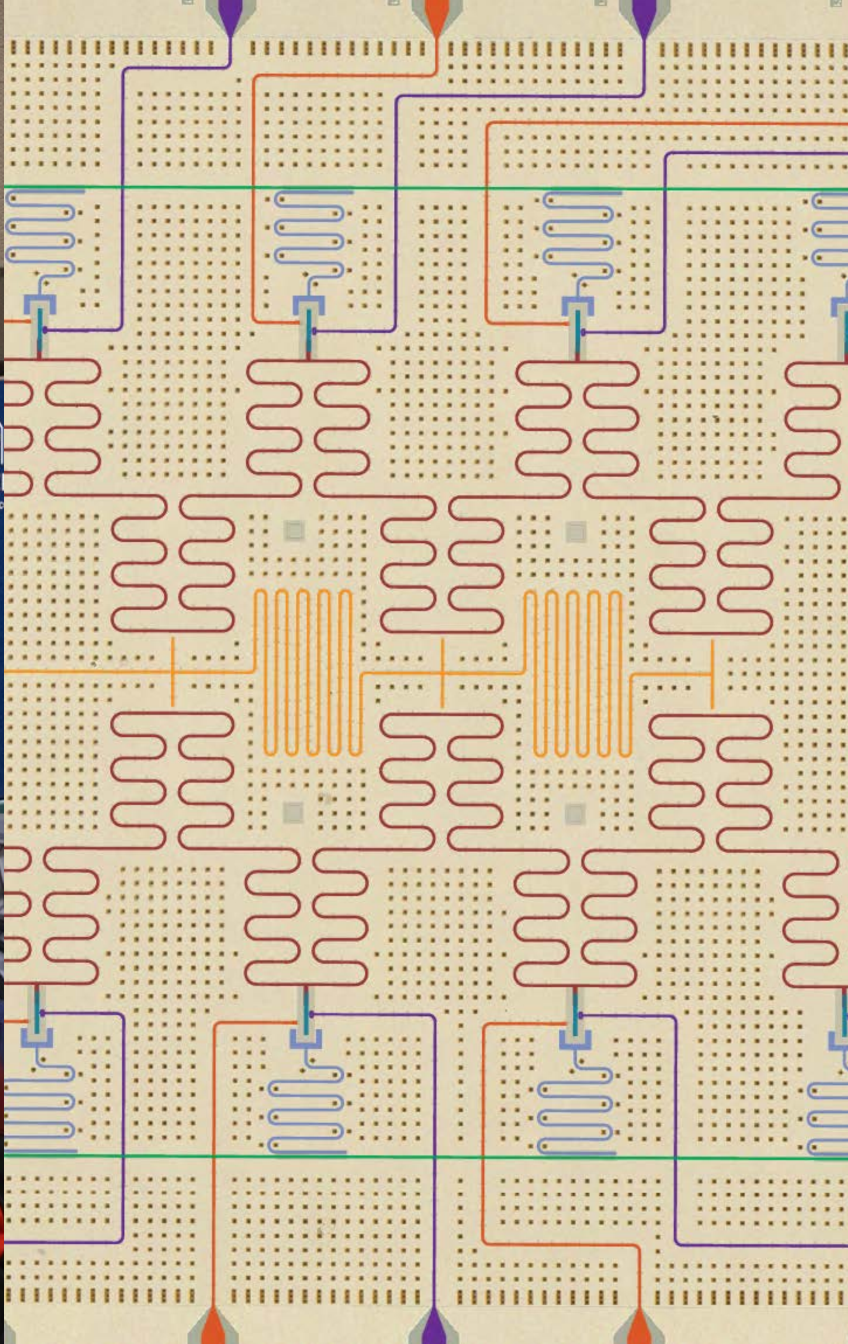
Since its foundation, AQT has incorporated scientists from different backgrounds and fields to become a collaborative hub for the broader national and international community and to train the quantum workforce.

AQT hosts undergraduate students for extended thesis projects, often for a year or more. It also offers an ideal training laboratory for graduate students and postdocs to engage with projects from materials and fabrication to quantum algorithms and applications. While training on AQT projects, students and postdocs collaborate with researchers from National Labs and industry, integrating them into the wider quantum information research community.

AQT offers additional educational opportunities for high school and undergraduate students. AQT has partnered with Berkeley Lab's K-12 STEM Education and Outreach program, and the Sustainable Research Pathways program at the Sustainable Horizons Institute.

AQT students and graduate alumni have taken positions in prominent research institutions and companies worldwide, including Google, quantum startups Alice & Bob and PsiQuantum, the Korea Institute of Science and Technology, the Yale Quantum Institute, and the University of Rochester.

AQT staff regularly conduct colloquia and equipment calibration



"My experience at AQT was transformative, offering me a unique platform to engage with top-tier quantum technologies and collaborate with brilliant minds in the field. The guidance and mentorship I received were instrumental in shaping my trajectory. Now, on this new stage, I am very excited to share the rich experience and joy that AQT has brought with my new group members."

YOSEP KIM,

Assistant Professor, Korea University

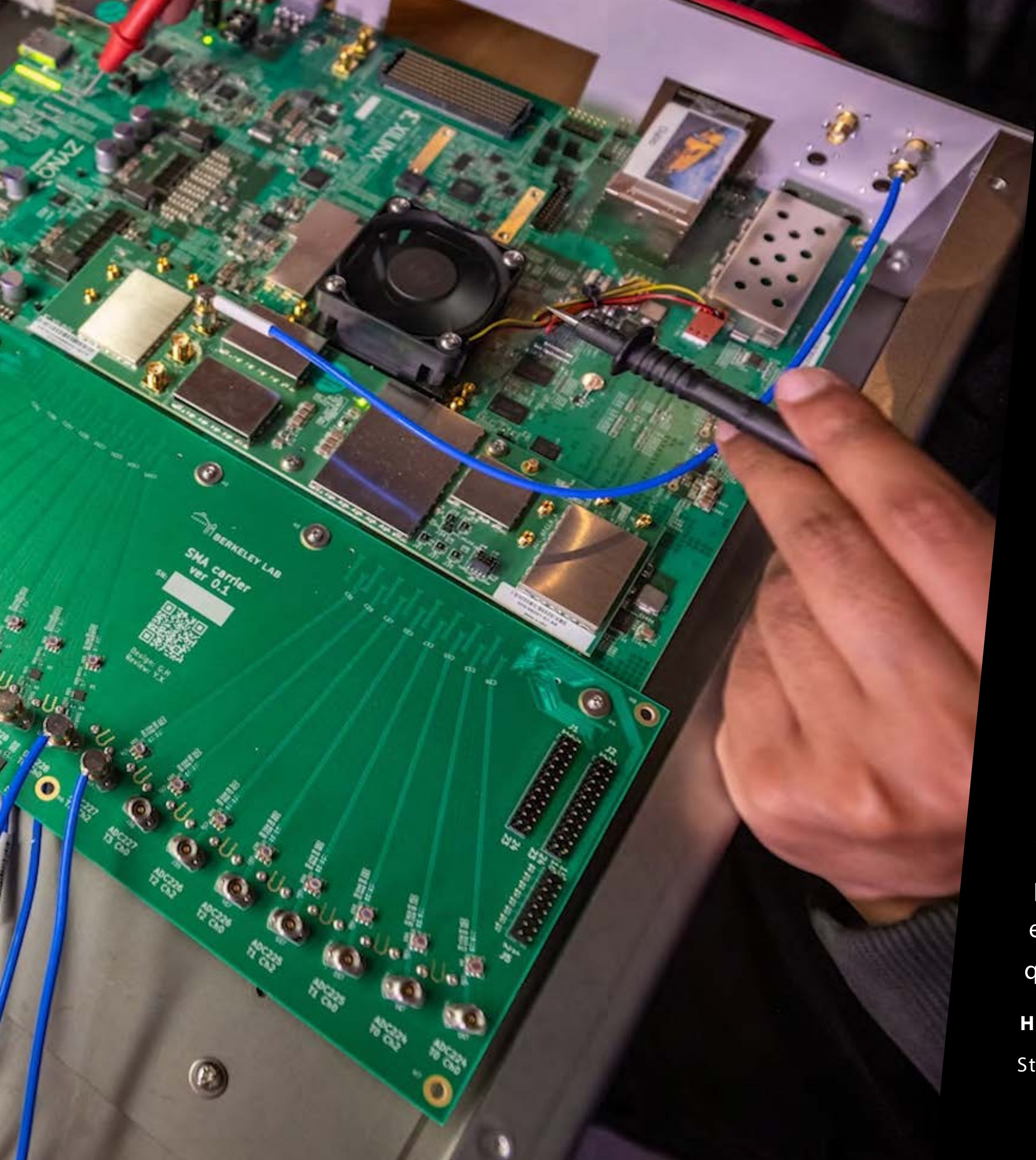
Novel 8-qubit QPU Spidernet8

"Being part of such a large community with a range of research interests means there is always someone whose work can inform yours and vice versa. There is a constant dialogue between the different research thrusts, which enables AQT to be such a vibrant and productive research environment."

MERRELL BRZECZEK,

Graduate Student Researcher, UC Santa Barbara

Left: Advanced flip-chip bonder to fabricate 3D quantum processors
Opposite: RF mixing module, QubiC 2.0



"At AQT, I worked on developing the code for qubit control and on implementing qubit tune up on a new quantum processor. The internship was very important to me, because I learned firsthand what it's like to work in this field. I have decided to pursue a career in physics and engineering with the focus on quantum informational sciences."

HARSHITA JOANNA KRUPADANAM, Student, UC Berkeley

Community Engagement

In addition to AQT-led sessions and workshops at major conferences, such as the IEEE International Conference on Quantum Computing and Engineering and the American Physical Society's March Meeting 2024, AQT seminars are conducted regularly with renowned scientists from industry, academia, and national laboratories in the United States and worldwide. More than 25+ AQT colloquia have been hosted, virtually or on-site, bringing together the local research and international community to discuss the latest advances in the field that complement AQT's significant work in quantum gate synthesis, efficient compilation, quantum noise characterization, quantum benchmarking, quantum algorithm execution, classical control electronics, and control firmware. These seminars are publicly available online.

2023 IEEE Quantum Week March controls workshop led by AQT

In-depth tours are organized for undergraduate students, visitors, and organizations to inspire interest in quantum computing and showcase AQT's unique full-stack superconducting platform, which features an open-access model, state-of-the-art gate fidelities, and increasing quantum volume.

AQT's interdisciplinary exploration also included collaborations with locally based visual artists. Three quantum artworks, also currently showcased in the laboratory, are directly inspired by AQT's work.

Consistent communications campaigns translate the value of AQT's research to the public.

aqt.lbl.gov

AQT

BERKELEY LAB

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