QI 21: Superconducting Qubits

Time: Wednesday 14:30–16:15 Location: HS II

Invited Talk QI 21.1 Wed 14:30 HS II

Mesoscopic physics challenges (in) superconducting quantum devices — •Ioan Pop — Karlsruhe Institute of Technology

Superconducting quantum bits, or qubits, are at the forefront of quantum computing research. Harnessing the low loss properties of superconductors and the nonlinearity of Josephson junctions, in recent processors tens of superconducting qubits can be engineered to exist in quantum superposition states and can be entangled. However, due to the innate complexity of solid-state physics, superconducting qubits still have to cope with various loss and decoherence mechanisms, certainly to the chagrin of quantum computing scientists, but also to the joy of mesoscopic physicists. I will discuss three mesoscopic physics phenomena which significantly complicate the task of engineering coherent superconducting hardware: ionizing radiation interactions with the device substrate, long lived two level systems which imprint a memory in the qubit's environment, and fluctuations in the transparency of aluminum oxide tunnel barriers which are at the heart of Josephson junctions.

QI 21.2 Wed 15:00 HS II

Time-resolved noise characterization tool to track fluctuating noise effects in superconducting qubits — •Abhishek Agarwal[1], Ke Wang[2,3], Brian Marinelli[2,3], Lachlan P Lindoy[1], Deep Lall[1], Yannic Rath[1], David I Santiago[2,3], Irfan Siddiqi[2,3], and Ivan Rungger[1,4] — [1]National Physical Laboratory, Teddington, United Kingdom — [2]Quantum Nanoelectronics Laboratory, Department of Physics, University of California, Berkeley, USA — [3]Applied Math and Computational Research Division, Lawrence Berkeley National Lab, Berkeley, USA — [4]Department of Computer Science, Royal Holloway, University of London, Egham, United Kingdom

Superconducting qubits have seen rapid increases in their coherence in the last few decades. However, low-frequency noise present in the qubits still causes non-Markovian errors and qubit instability. Collectively characterising different sources of low-frequency noise can be challenging, and typically noise sources such as charge parity switching and coupling to thermal fluctuators are characterised independently. In order to characterise the combined noise, we develop a tool that uses few-shot data to detect and diagnose qubit frequency fluctuations, as well as a time series segmentation tool to further disambiguate different sources of fluctuations. We demonstrate the tool by computing time and spectrally resolved noise properties. Our framework for fluctuation detection and disambiguation can be used to thoroughly characterize low-frequency noise in qubits as well as develop methods to mitigate the noise.

QI 21.3 Wed 15:15 HS II

Fast parity measurements for continuous quantum error correction on superconducting qubits — •Anton Halaski and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Continuous quantum error correction (QEC) is required in many situations in which the limit of a strong projective measurement cannot be applied. Recently, Atalaya et al. [*Phys. Rev. A* **103**, 042406 (2021)] proposed a continuous QEC scheme for quantum information applications which involve continuously varying Hamiltonians. This scheme relies on a sufficiently strong and continuous two-qubit parity measurement to extract the error syndromes. To implement such a measurement is particularly challenging, since one has to perform a fast, nonlocal measurement while at the same time not introducing any errors to the information encoded in the qubits. We investigate to what extent this task can be accomplished using current circuit QED architecture. Recent proposals for continuous parity measurements in this field rely on the so-called dispersive regime in which the transmons are far detuned from a resonator which acts as the meter for the parity measurement. As a result, transmons and resonator are only weakly coupled and the measurement is slow. We explore how one can achieve speedups by going to the quasi-dispersive regime. Measurements based on the quasi-dispersive regime could then be utilized to enhance the resilience of Atalaya et al.'s and future QEC protocols.

QI 21.4 Wed 15:30 HS II

Exploring the Fidelity of Flux Qubit Measurement in Different Bases via Quantum Flux Parametron — •Yanjun Ji[1], Susanna Kirchhoff[1,2], and Frank K. Wilhelm[1,2] — [1]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52045 Jülich, Germany — [2]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany

High-fidelity qubit measurement is essential for building practical quantum computing systems. We investigate methods for maximizing the measurement fidelity of flux qubits using a quantum flux parametron (QFP) readout scheme. Theoretical modeling and numerical simulations are conducted to explore the impact of different measurement bases on the fidelity for single flux qubit and coupled two-qubit systems. Our simulations show that for single qubit systems dressed bases consistently outperform bare bases. For coupled qubit systems, two measurement schemes are compared: sequential and simultaneous. Both schemes focus on reading out a single target qubit within coupled qubit systems. The results indicate that the highest fidelity can be achieved through either sequential measurement in the dressed basis over a longer duration or simultaneous measurement in the bare basis over a shorter duration. However, sequential measurement schemes offer more robust readouts with higher fidelity than simultaneous schemes, which introduce complexity from interactions between QFPs. Our analysis quantifies achievable fidelities for various configurations, offering valuable insights for optimizing measurement processes in emerging quantum computing architectures.

QI 21.5 Wed 15:45 HS II

High-derivative DRAG for error reduction in two-qubit and qudit gates — •Boxi Li[1,2], Francisco Cárdenas-López[1], José Jesus[1,2], Adrian Lupascu[3], Tommaso Calarco[1,2,4], and Felix Motzoi[1,2] — [1]Forschungszentrum Jülich — [2]University of Cologne — [3]University of Waterloo — [4]Università di Bologna

To overcome the challenges posed by the finite coherence time of quantum systems, an important task is devising rapid and precise control schemes. For superconducting qubits, analytical control methods based on the system's Hamiltonian are often favoured over general numerical optimization for practical experimental implementation. In this presentation, we introduce an analytical control framework using multi-derivative pulse shaping, based on the Derivative Removal via Adiabatic Gate (DRAG) technique. This approach provides an efficient, parameterized pulse Ansatz that can simultaneously suppress multiple control errors, including nonperturbative effects and multi-photon dynamics.

In this presentation, we apply this control method both to the Cross-Resonance CNOT gate and to two-level rotations in a Transmon qudit. In both cases, multiple errors are present due to the presence of a much larger Hilbert space than the targeted computational levels, where single-derivative correction brings little help. Correction of errors beyond leakage such as ZZ error is also demonstrated. Experimental testing on IBM's quantum platform results in a two to three-fold improvement for the CNOT gate on several publicly available qubits.

QI 21.6 Wed 16:00 HS II

High-derivative DRAG for error reduction in single-qubit gates — •José Diogo da Costa Jesus[1,2], Boxi Li[1,2], Francisco Cárdenas-López[1,2], Felix Motzoi[1,2], and Tommaso Calarco[1,2,3] — [1]Forschungszentrum Jülich — [2]University of Cologne — [3]Università di Bologna

To overcome the challenges posed by the finite coherence time of quantum systems, an important task is devising rapid and precise control schemes. For superconducting qubits, analytical control methods based on the system's Hamiltonian are often favoured over general numerical optimization for practical experimental implementation. We introduce an analytical control framework using multi-derivative pulse shaping, based on the Derivative Removal via Adiabatic Gate (DRAG) technique. This approach provides an efficient, parameterized pulse Ansatz that can simultaneously suppress multiple control errors, including nonperturbative effects and multi-photon dynamics.In this presentation, we show that multiple leakage channels are present in single-qubit gates when approaching the speed limit. By introducing high-derivative corrections, these errors can be systematically removed. We also show that a better understanding of the effective model reveals improved prediction of pulse parameters, significantly simplifying

the experimental calibration procedure. We derive and optimize different DRAG pulses to minimize leakage and maximize the fidelity of single-qubit gates, demonstrating the need for pulses beyond the current standard for faster single-qubit gates.