QI 13: Implementations: Superconducting Qubits

Time: Friday 9:30–12:45 Location: H8

Invited Talk QI 13.1 Fri 9:30 H8

Scalable control of superconducting qubits — •Stefan Filipp — Walther-Meissner-Institut, 85748 Garching — TU Munich, Physics-Department, 85748 Garching

The rapid development of quantum technologies in the recent past has led to the realization of first quantum computer prototypes that promise to outperform conventional computers in specific types of problems. However, before practical real-life problems can be solved efficiently on quantum computers we have to still tackle numerous challenges not only to enhance the coherence, but also the control of qubits. To improve the fidelity of single qubit operations we utilize closed-loop optimization methods based on high duty-cycle measurements. With piecewise-constant pulse parameterizations we are able to demonstrate short, 4ns single-qubit pulses with high fidelity and low leakage. We further explore architectures that contain 'hidden' qubits, which are not directly addressable, and experimentally demonstrate full control and measurement capabilities of such a hidden qubit. I will then discuss the impact of such restricted control capabilities on the performance of specific qubit coupling networks. I will further preview promising future directions such as the use of adiabatic gates for quantum feed-forward neural networks and multi-qubit gate operations for the efficient implementation of quantum algorithms as part of the newly formed Munich Quantum Valley, a cross-disciplinary initiative to realize a full-stack quantum computer.

QI 13.2 Fri 10:00 H8

Test and diagnostics speed up for characterizing few-qubit superconducting quantum processors — •Thorsten Last, Garrelt Alberts, Adam Lawrence, Kelvin Loh, Viacheslav Ostroukh, and Adriaan Rol — Orange Quantum Systems B.V., Lorentzweg 1, 2628 CJ Delft, NL

The combined challenge of increasing the qubit count on a quantum processor and a requirement to further reduce the qubit's error rates require novel approaches in test and qubit diagnostics. An important aspect to improve the situation is an acceleration of the development cycle for quantum processors [1]. Here we present benchmarking and diagnostic tools based on the recently established open-source platform Quantify [2] to perform end-to-end data analytics. Structured (human-assisted) characterization and a gradual enhancement of automation already led to a reduction of time for basic qubit diagnostics from months to days. The diagnostic tools for characterizing small scale superconducting quantum processors are available as software packages or fully integrated into room temperature electronic control racks. They are organized in complexity classes ranging from hardware verification, and basic single-qubit analytics up to the level of algorithmic benchmarking. Besides quantum processor diagnostics these tools are also used for full-stack system verification through experiment. [1] G.J.N. Alberts, et al., EPJ Quantum Technol. 8: 18 (2021). [2] https://quantify-quantify-core.readthedocs-hosted.com/en/0.5.3_a/

QI 13.3 Fri 10:15 H8

How to correctly account for time-varying fluxes in superconducting circuits — •Ahmed Kenawy[1], Fabian Hassler[2], David DiVincenzo[1], and Roman Riwar[1] — [1]Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich — [2]JARA-Institute for Quantum Information, RWTH Aachen University

Time-varying fluxes are a ubiquitous tool to control superconducting hardware. Surprisingly, however, the existing literature has never fully accounted for the electro-motive force induced by the magnetic field. Here, we propose a general recipe to construct a low-energy Hamiltonian, taking as input only the circuit geometry and the solution of the external magnetic fields. We apply this recipe to the example of a dc SQUID and show that the assignment of individual capacitances to each Josephson junction is possible only if we permit those capacitances to be negative, time-dependent, or even momentarily singular. Such anomalous capacitances lead, among others, to a strong enhancement of qubit relaxation rates. Then, we tackle the problem of driven topological quantum circuits, focusing on two weakly coupled Kitaev chains and study how the electro-motive force modifies the time-dependent fractional Josephson effect.

QI 13.4 Fri 10:30 H8

Majorana fermions revealing the true nature of quantum phase slip junctions — •Christina Koliofoti and Roman-Pascal Riwar — Forschungszentrum Jülich, Peter Grünberg Institut (PGI-2), 52425 Jülich, Deutschland

Quantum circuit theory is a powerful and ever-evolving tool to predict the dynamics of superconducting circuits. In its language, quantum phase slips are famously considered to be the exact dual to the Josephson effect. However, if taken at face value, this duality stipulates that charge must be continuous. We propose a charge-quantization conserving description of quantum phase slips and show that this seemingly minute change gives rise to some very different predictions. When shunting a quantum phase slip junction with a topological Josephson junction, the new description leads to a complete dissappearance of the Hofstadter butterfly spectrum. For topologically trivial circuits we argue that adhering to charge quantization renders realizations of the Gottesman-Kitaev-Preskill code impossible.

QI 13.5 Fri 10:45 H8

Tunable-coupler mediated controlled-controlled-phase gate with superconducting qubits — •Niklas J Glaser[1,2], Federico Roy[1,3], and Stefan Filipp[1,2,4] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

Applications for noisy intermediate scale quantum computing devices rely on the efficient entanglement of many qubits to reach a potential quantum advantage. Although entanglement is typically generated using two-qubit gates, direct control of strong multi-qubit interactions can improve the efficiency of the process. We investigate a system of three superconducting transmon-type qubits coupled via a single flux-tunable coupler. Tuning the frequency of the coupler by adiabatic flux pulses enables us to control the conditional energy shifts between the qubits and directly realize multi-qubit interactions. To accurately adjust the resulting controlled relative phases, we describe a gate protocol involving refocusing pulses and adjustable interaction times. This enables the implementation of the full family of pairwise controlled-phase (CPHASE) and controlled-controlled-phase (CCPHASE) gates. Numerical simulations result in fidelities around 99% and gate times below 300 ns using currently achievable system parameters and decoherence rates.

15 min. break

QI 13.6 Fri 11:15 H8

Coupler-mediated unconditional reset of fixed-frequency superconducting qubits — •Gerhard Huber[1,2], Federico Roy[1,2], and Stefan Filipp[1,2,3] — [1]Walther-Meißner-Institut, Bayrische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

Advances in superconducting qubit fabrication procedures have led to energy relaxation times regularly exceeding 100 μs. Therefore, passive reset via relaxation has become unpractical, and an active reset protocol is required to achieve high repetition rate of quantum algorithms. Previous unconditional qubit reset schemes have relied on flux tunable qubits or multiple transitions over higher qubit states. We extend a previous reset scheme using flux tunable qubits to fixed frequency transmon qubits with tunable couplers. The reset pulse consists of a single parametric flux pulse on the coupler to transfer qubit excitations to a quickly decaying resonator. Our protocol does not rely on additional control lines and can be implemented on current multi-qubit architectures. Further, it can be extended to architectures where a single coupler allows for reset of multiple qubits. We present preliminary numerical and experimental results for this reset protocol demonstrating its potential usefulness.

QI 13.7 Fri 11:30 H8

Analysis of calibration techniques for single-qubit gates on a superconducting quantum computer — •Kathrin König[1],

Naoki Kanazawa[2], and Shota Nakasuji[3] — [1]Fraunhofer IAF, Freiburg, Germany — [2]IBM Research, Tokyo, Japan — [3]University of Tokyo, Tokyo, Japan

Inexact calibrated gates and environmental influences lead to imperfect outcomes of a quantum computation. We investigate two calibration techniques on an IBM quantum computer. The state-of-the art calibration uses an empirical formula to update the optimal control parameter. The compared new technique can directly estimate the parameter at arbitrary precision. We confirmed that the new technique shows higher precision with comparable accuracy.

QI 13.8 Fri 11:45 H8

Pulse class meta-optimization of continous quantum gates in transmon systems — •Francesco Preti — Forschungszentrum Jülich, Jülich, Germany

Reducing the circuit depth of quantum circuits is a crucial bottleneck to enabling quantum technology. This depth is inversely proportional to the number of available quantum gates that have been synthesized. Moreover, quantum gate synthesis and control problems exhibit a vast range of external parameter dependencies, both physical and application-specific. We address the possibility of learning families of optimal control pulses in transmon systems, which depend adaptively on various parameters, in order to obtain a global optimal mapping from the space of potential parameter values to the control space, and hence continuous classes of gates. Our proposed method is tested on different experimentally relevant quantum gates and proves capable of producing high-fidelity pulses even in presence of multiple variables or uncertain parameters with wide ranges.

QI 13.9 Fri 12:00 H8

Magnetic field dependence of the quasiparticle parity lifetime in 3D transmons with thin-film $Al-AlO_x-Al$ Josephson junctions — •Jonas Krause[1], Lucas Jannsen[1], Christian Dickel[1], Elmore Vaal[1], Michel Vielmetter[1], Jurek Frey[2], Felix Motzoi[3], Shai Machness[2], Kelvin Loh[4], Michiel Adriaan Rol[4], Gianluigi Catelani[5], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne — [2]Quantum Computing Analytics (PGI 12), Forschungszentrum Jülich — [3]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich — [4]Orange Quantum Systems — [5]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich

Magnetic-field resilient superconducting circuits enable quantum sensing applications, hybrid quantum computing architectures, as well as studying flux noise and quasiparticle loss. Placing a thin-film aluminum transmon in a 3D copper cavity, we can measure its quasiparticle parity lifetime over a large range of magnetic fields, with inplane fields approaching 1T. The magnetic field reduces the Josephson Energy E_J, while the charging energy E_C is virtually unaffected. The transmon exhibits a parity-dependent frequency splitting. We are working on optimal control techniques for fast parity-selective gates which together with single-shot readout allow measuring the parity lifetime. The magnetic-field dependence of the parity lifetime is of interest for future topological qubits, which rely on combining superconductors with magnetic fields; additionally, it could improve the understanding quasiparticle loss in conventional superconducting qubits.

QI 13.10 Fri 12:15 H8

Towards cQED experiments with in-situ fabrication of topological insulator Josephson junctions — •Lucas Janssen, Jonas Krause, Christian Dickel, Alexey Taskin, Roozbeh Yazdampanah Ravari, Anjana Uday, Gertjan Lippertz, and Yoichi Ando — AG Ando, PH2, Universität zu Köln, Germany

Circuit quantum electrodynamics experiments with topological insulator (TI) Josephson junctions (JJs) are a promising path towards finding and studying Majorana zero modes. However, the fabrication of TI JJs is challenging. For our topological insulator, we use MBE grown ternary TI (BiSb)_2Te_3. The interface between the proximitising superconductor and the TI film is critically important for the quality of the JJ, which in turn is vital for microwave performance. Hence, we have been fabricating TI JJs with in-situ deposited niobium. However, etching the niobium to define a JJ has proven challenging. We are exploring a combination of titanium and aluminium as an alternative superconductor. An alternative to this etching step is stencil mask technology. We will present our progress in JJ fabrication and possibly first cQED measurements.

QI 13.11 Fri 12:30 H8

Mitigation of quasiparticle loss in superconducting qubits by phonon scattering — Arno Bargerbos[1], Lukas J. Splitthoff[1], Marta Pita-Vidal[1], Jaap J. Wesdorp[1], Yu Liu[2], Peter Krogstrup[3], Leo P. Kouwenhoven[1], Christian K. Andersen[1], and •Lukas Grünhaupt[1,4] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark — [3]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Most error correction schemes for future quantum processors rely on the assumption that errors are uncorrelated. However, in superconducting devices this assumption is drastically violated in the presence of ionizing radiation, which creates bursts of high energy phonons in the substrate. A mitigation technique is to place large volumes of metal on the device, capable of reducing the phonon energy to below the superconducting gap of the qubits. To investigate the effectiveness of this method we fabricate a device with four nominally identical nanowire-based transmon qubits and replace one half of the niobium titanium nitride ground plane with aluminum (Al), which has a much lower superconducting gap. We inject phonons into the substrate by voltage biasing a galvanically isolated Josephson junction and we find protection due to the Al by a factor of 2-4 in terms of qubit lifetime and excited state population. Furthermore, we turn the Al normal with a magnetic field, finding no marked change in the phonon-protection.