QI 19: Superconducting Electronics: Qubits I (joint session TT/QI)

Time: Wednesday 15:00–18:15 Location: H 0104

QI 19.1 Wed 15:00 H 0104

Simultaneous flux-locking of gradiometric fluxonium qubits — •Denis Bénâtre[1], Mathieu Féchant[1], Nicolas Zapata[1], Patrick Paluch[1], Nicolas Gosling[1], and Ioan Pop[1,2] — [1]IQMT, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany — [2]PHI, Karlsruhe Institute of Technology, Karlsruhe, Germany

Gradiometric fluxoniums are a novel type of fluxonium qubits introduced by Gusenkova et al. (Appl. Phys. Lett. 120, 2022). Benefiting from their double-loop geometry, gradiometric fluxoniums are substantially less sensitive to global magnetic fields, while retaining all regular fluxonium properties. Going further, we propose to show the simultaneous locking of a handful of gradiometric fluxoniums at a flux point corresponding to the so-called sweet spot of operation, allowing them to be used without the need for external flux biasing after locking. This is done by trapping a fluxon in the most external loop of each device with an external magnetic field while crossing the metal-to-superconductor transition.

QI 19.2 Wed 15:15 H 0104

Superconducting flux qubits with stacked Josephson junctions — •Alex Kreuzer[1], Hossam Tohamy[1], Thilo Krumrey[1], Alexandru Ionita[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie (KIT) — [2]Institut für Quantenmaterialien und -technologien (IQMT), Karlsruher Institut für Technologie (KIT)

Josephson junctions are commonly employed as nonlinear inductive components in superconducting qubits, allowing to tailor specific circuit properties. The promising flux qubit types like fluxonium or quarton qubits require compact inductances, often implemented as arrays of Josephson junctions. Challenges arise due to stray capacitance, originating from the capacitive coupling of an array island to the ground, leading to parasitic resonances at GHz frequencies that can degrade or compromise qubit performance. To address this limitation, we investigate an alternative approach: implementing qubit inductances by stacking Josephson junctions vertically. Junction stacks help to minimize the parasitic capacitance of their electrodes to the ground. We present transport characteristics of the stacks as well as microwave loss measurement data using a quarton-type flux qubit with stacked Josephson junctions. The experimental data are compared to results of numerical simulations.

QI 19.3 Wed 15:30 H 0104

Pure kinetic inductance coupling between generalized flux qubits and their readout — •Soeren Ihssen[1], Simon Geisert[1], Patrick Winkel[1,2], Martin Spiecker[1], Mathieu Fechant[1], Patrick Paluch[1,2], Nicolas Gosling[1], Nicolas Zapata[1], Thomas Reisinger[1], Wolfgang Wernsdorfer[1], and Ioan M. Pop[1,2,3] — [1]IQMT, Karlsruhe Institute of Technology, Germany — [2]PHI, Karlsruhe Institute of Technology, Germany — [3]Physics Institute 1, Stuttgart University, Germany

We develop a qubit-readout circuit coupled through the kinetic inductance of superconducting granular aluminum (grAl). Utilizing the material properties of grAl to implement the dispersive shift removes the need for electromagnetic coupling. This enables a localized tuning knob to engineer the readout independent of the capacitance matrix. If the capacitance matrix is designed to be symmetric, the qubit-readout coupling is entirely mediated by the grAl kinetic inductance. We validate the pure kinetic coupling concept and demonstrate various generalized flux qubit regimes from plasmon to fluxon, with dispersive shifts ranging from 30 kHz to 7 MHz at the half-flux quantum sweet spot. Using purely kinetic coupling, we achieve readout performance comparable to standard electromagnetic coupling, with quantum state preparation fidelity of 99.7 % and 92.7 % for the ground and excited states, respectively, and below 0.1 % leakage to non-computational states. The excited state fidelity is limited by qubit relaxation to the ground state with quantum demolishing effects below 1%.

QI 19.4 Wed 15:45 H 0104

Fully tunable Flux Qubits for TLS Research — •Benedikt Berlitz, Alexey V. Ustinov, and Jürgen Lisenfeld — Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Material defects forming two-level-systems (TLS) present a source of decoherence and unwanted degrees of freedom in superconducting quantum systems. The qubits in turn can be used as a tool to study the properties of TLS. We fabricated superconducting flux qubits specifically to be used as TLS detectors, aiming for good coherence in a large frequency range. The goal is to gather comparable data of many defects located within the same device. We will describe design, fabrication and measurements of the fabricated samples. Studying TLS with these tools will enhance our understanding of the underlying physics of TLS in amorphous materials and hopefully reveal a path to achieving higher coherence with superconducting qubits.

QI 19.5 Wed 16:00 H 0104

Mapping the lateral positions of individual material defects in superconducting transmon qubits — •Alexander K. Händel, Alexey V. Ustinov, and Jürgen Lisenfeld — Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Material defects are limiting the coherence of superconducting circuits and mitigating their effects is vital in the realization of functional quantum devices. With transmon qubits, the spatial distribution of most coherence breaking defects is likely to be inhomogeneous, due to the qubit's electric field strength varying greatly with position, affecting a defects participation ratio. By tuning the resonance frequency of individual defects with static electric fields induced by on-chip electrodes we are able to resolve their positions on the qubit chip. We present first results of mapping the positions of defects in a transmon qubit, distinguishing defects on the qubit capacitor from those residing on the leads of Josephson junctions. Our results identify critical circuit components which contain major defects detrimental for the qubit performance and provide valuable information to improve qubit design and fabrication methods.

QI 19.6 Wed 16:15 H 0104

Experiments on the Influence of Infrared Photons on Superconducting Qubits — •Markus Griedel[1,2], Sebastian Koch[2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Institut für Quanten Materialien und Technologien (IQMT) — [2]Physikalisches Institut (PHI) - KIT, 76131 Karlsruhe, Germany

The energy gap of superconductors allows for a large variety of ultra-low noise applications, as for instance, for using them to construct qubits. At sufficiently low temperatures, the number of excitations above the gap is generally low but not zero. Such excitations can be created by numerous external influences, including absorption of high energy particles from radioactive decay or extraterrestrial space. Also stray infrared photons play a role, since their energy is larger than the energy gap of conventional superconductors used for making qubit. One external leakage pathway is the dielectric of a coaxial cable used to manipulate and read out the qubit which connects to room temperature electronics. Here, the combination of the dielectric's transparency to infrared photons and the high infrared photon flux from elevated cryogenic temperature stages make the insertion of a low-pass filter with a sharp cutoff well below the superconducting gap frequency an important requirement.

In this contribution, we present experimental investigation of the influence of infrared photons on superconducting qubits. We have measured the dephasing and decay times as well as the qubit temperature in response to incident photon flux. We explore usage of various materials for making infrared filters.

QI 19.7 Wed 16:30 H 0104

Measuring and understanding quasiparticle effects in magnetic-field-resilient 3D transmons (Experiment) — •Jonas Krause[1], Christian Dickel[1], Giampiero Marchegiani[2], Lucas Janssen[1], Gianluigi Catelani[2,3], and Yoichi Ando[1] — [1]University of Cologne — [2]Technology Innovation Institute Abu Dhabi — [3]Forschungszentrum Juelich

Recent research shows quasiparticle-induced decoherence of superconducting qubits depends on the superconducting gap asymmetry due to the different thickness of the top and bottom films in Al-AlOx-Al junctions [1]. With magnetic-field-resilient transmons [2] we investigate this from a new angle. We present spectroscopy and parity-switching-time (τ_p) measurements of a 3D transmon up to 400 mT in-plane field.

The magnetic field tunes the transmon frequency f_{01} without a strong reduction in T_2^*. The gap asymmetry, initially close to hf_{01}, causes a non-monotonic evolution of τ_p. After an increase with in-plane field up to 150 mT, τ_p decreases at higher fields. Higher Josephson harmonics are needed to accurately model the spectrum [3]. At low fields, small parity splitting requires qutrit pulse sequences for parity measurements. Magnetic fields are an interesting tuning knob to study quasiparticle loss and gap engineering because they allow changing both the gap and gap difference. Charge-parity measurements are also a readout mechanism for topological qubits which often require high fields.
[1] G. Marchegiani et al., RX Quantum 3 (2022) 040338
[2] J. Krause et al., Phys. Rev. Applied 17 (2022) 034032
[3] D. Willsch et al., arXiv:2302.0919

QI 19.8 Wed 16:45 H 0104

Measuring and understanding quasiparticle effects in magnetic-field-resilient 3D transmons (Theory) — Jonas Krause[1], Christian Dickel[1], Giampiero Marchegiani[2], Luc Janssen[1], •Gianluigi Catelani[2,3], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne, Germany — [2]Quantum Research Center, Technology Innovation Institute, UAE — [3]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Juelich, Germany

In this talk, we present the modeling of the charge-parity lifetime (τ_p) of a magnetic-field resilient 3D transmon [1]. Experimentally, the lifetime τ_p depends non-monotonically on the in-plane magnetic field. We explain this unexpected behavior within a generalized approach to quasiparticle decoherence. The model accounts for the transmon being a SQUID measured mainly at the bottom sweet spot and for the magnetic field tuning (Fraunhofer effect). It also incorporates effects of temperatures on the order of the transmon frequency. At zero field, the qubit frequency f_{01} is nearly resonant with the superconducting gap difference [2], so quasiparticle tunneling gives a sizable contribution to the parity-switching rate $1/\tau_p$. Increasing the in-plane field, f_{01} decreases and becomes detuned from the gap difference, causing the initial growth in τ_p, while photon-assisted qubit transitions increase producing the subsequent decay at higher fields. We show that τ_p and the qubit lifetime T_1 can be consistently described by the model.
[1] J. Krause et al., Phys. Rev. Appl. 17 (2022) 034032
[2] G. Marchegiani et al., PRX Quantum 3 (2022) 040338

QI 19.9 Wed 17:00 H 0104

Near quantum-limited amplification up to 1 T using granular aluminum — •Nicolas Zapata[1], Ivan Takmakov[1,2], Dennis Rieger[1,2], Simon Günzler[1,2], Ameya Nambisan[1], Thomas Reisinger[1], Wolfgang Wernsdorfer[1,2], and Ioan Pop[1,2] — [1]IQMT, Karlsruhe Institute of Technology, 76131 Karslruhe, Germany — [2]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Josephson Junction based amplifiers have become essential components for the readout of microwave quantum circuits. Despite the advances made over the last decade, they still have limited applicability in systems that require high magnetic fields. The use of high kinetic inductance materials like granular Aluminum (grAl), opens the path for low noise amplification in Tesla fields thanks to their in-plane resilience [1] and negligible high order non-linearities [2], which is particularly attractive for the readout of semiconducting spin-qubits [3] and single molecular magnet qubits [4]. Here we present a non-degenerate parametric amplifier made of two coupled grAl resonators forming a Bose-Hubbard dimer [5, 6]. We report near quantum-limited 20 dB amplification, with an instantaneous bandwidth of few MHz and signal-to-pump detuning above 100 MHz, which was stable up to 1 T.
[1] K. Borisov et al., Appl. Phys. Lett. 117 (2020) 120502
[2] N. Maleeva et al., Nat. Commun. 9 (2018) 3889
[3] J. Stehlik et al., Phys. Rev. Appl. 4 (2015) 014018
[4] C. Godfrin et al., Phys. Rev. Lett. 119 (2017) 187702
[5] C. Eichler et al., Phys. Rev. Lett. 113 (2014) 110502
[6] P. Winkel, I. Takmakov et al., Phys. Rev. Appl. 13 (2020) 024015

QI 19.10 Wed 17:15 H 0104

Phase-flux symmetries in three-wave mixing Josephson travelling wave parametric amplifiers — •Daniil E. Bazulin[1,2], Kedar E. Honasoge[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Thomas Luschmann[1,2], Achim Marx[2], Stefan Filipp[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Enabling the three-wave mixing process in Josephson Travelling Wave Parametric Amplifiers (JTWPAs) requires inversion symmetry breaking of an effective potential. This task can be achieved in various ways by exploiting either flux- or phase-bias regimes. Moreover, common JTWPA coupling schemes additionally introduces two distinct possibilities of flux or phase pumping. As the result, we identify four interrelated bias and pump schemes, which we theoretically and experimentally analyze in our samples based on Superconducting Nonlinear Asymmetric Inductive Elements (SNAILs). We show that the nonlinear behavior of such a JTWPA strongly depends on the chosen bias-pumping scheme, unraveling novel experimental control schemes for optimal JTWPA performance.

QI 19.11 Wed 17:30 H 0104

rf-SQUID-based three-wave-mixing traveling-wave parametric amplifier — •Victor Gaydamachenko, Christoph Kissling, Marat Khabipov, Fabian Kaap, Sergey Lotkhov, Ralf Dolata, Alexander B. Zorin, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Traveling-wave parametric amplifiers (TWPAs) are one of the most promising devices for the improvement of the readout efficiency of fW-range microwave signals at a bandwidth of several GHz. By adding only a minimal amount of noise close to the absolute limit allowed by quantum mechanics, quantum technologies and other applications benefit from their usage. We realize a TWPA based on an array of 2000 rf-SQUIDs with phase-matching achieved by periodic capacitance loading, which we optimized by time-domain circuit simulations. Our TWPA is fabricated using Nb/Al-AlO$_x$/Nb trilayer technology. In the three-wave mixing regime the device provides an average gain of 18 dB between 3 and 7 GHz and exhibits a saturation power of approximately -90 dBm. Here, we present the design and experimental results including noise characterization of the device.

QI 19.12 Wed 17:45 H 0104

Frequency targeting and geometric effects in fabrication of superconducting tunable resonators — •Maria-Teresa Handschuh[1,2], Kedar E. Honasoge[1,2], Wun Yam[1,2], Florian Fesquet[1,2], Achim Marx[1], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Achieving a high-volume and high-quality fabrication process of uniform nonlinear resonators based on Josephson junctions is one of the central challenges in applied quantum information processing with superconductors. Here, we report on the realization of a reliable fabrication process for Nb resonators with Al/AlOx/Al Josephson junctions and circuits on 4-inch high-resistivity silicon wafers, ensuring precise control over relevant parameters. We address the challenges associated with the large-scale fabrication by investigating the impact of geometric irregularities on device performance, including finite-size geometry effects and center-to-edge effects. Undesired frequency shifts can arise from variations in device dimensions and inhomogeneous oxidation techniques. We overcome these challenges by a systematic analysis, allowing us to improve the controllability and accuracy of resonator frequency tuning. This enables the reproducible fabrication of low-loss tunable resonators for quantum information processing applications.

QI 19.13 Wed 18:00 H 0104

Characterizing the origin of non-Markovian noise in superconducting qubits and its effect on quantum algorithms — •Ivan Rungger, Abhishek Agarwal, Lachlan Lindoy, Deep Lall, and Francois Jamet — National Physical Laboratory, Teddington TW11 0LW, United Kingdom

Non-Markovian noise can be a significant source of errors in superconducting qubits. It is caused by ubiquitous effects such as quasiparticle induced charge parity fluctuations, as well as frequency fluctuations induced by two level systems or other defects. We develop a method based on mirrored pseudo-identity gates to characterise the non-Markovian noise in qubits [1]. We show that Markovian noise models fail to capture the experimental behaviour, and that only by including the non-Markovian components one can describe the experiments. We further present fast time-resolved characterization techniques that allow us to identify the physical origin of the non-Markovian noise.

We find large changes of the dominating noise contributions, such as qubit frequency fluctuations, over both long time-scales of hours and days, and also over very short micro-seconds time-scales. We show that the developed noise model allows us to predict and then mitigate the effects of noise in quantum computing applications.

[1] A. Agarwal, L. P. Lindoy, D. Lall, F. Jamet, I. Rungger, arXiv:2306.13021 (2023)