QI 11: Implementations IV

Time: Wednesday 9:30–12:45 Location: BEY/0245

Invited Talk QI 11.1 Wed 9:30 BEY/0245

Nb-trilayer Josephson junction based parametric amplifiers for microwave frequency signals — •Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Parametric amplifiers have become a widely-used tool in cryogenic setups processing faint microwave signals. Such signals, with powers as low as femtowatts, are used, e.g., to read out solid state qubits or are hypothesized as signatures of dark matter. A large variety of superconducting parametric amplifiers exists, which can be broadly divided into two groups: devices based on resonators with typical bandwidth on the order of a few MHz and traveling-wave parametric amplifiers (TWPAs) providing bandwidths larger than 1 GHz. In addition to their bandwidth, dynamic range and added noise are the main parameters engineered in such devices, leading to a plethora of parametric amplifier implementations. At PTB we are exploring a range of superconducting parametric amplifiers harnessing the nonlinearity provided by Nb-trilayer Josephson junctions or by the kinetic inductance of granular aluminium thin films. In this talk I will discuss our recent results on rf-SQUID TWPAs [1] and present our implementation of dimer Josephson junction array amplifiers.

[1] V. Gaydamachenko & C. Kissling, L. Grünhaupt, Phys. Rev. Appl. 23, 064053 (2025)

QI 11.2 Wed 10:00 BEY/0245

Double-pumped Bogoliubov parametric amplifier using a superconducting Bose-Hubbard dimer — •Najmeh Etehadi Abari[1], Nicolas Zapata[1], Ioan Pop[1,2], and Anja Metelmann[1,3] — [1]Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Physics Institute 1, Stuttgart University, 70569, Stuttgart, Germany — [3]Institut de Sciences et d'Ingénierie Supramoléculaires,(ISIS, UMR7006), University of Strasbourg and CNRS, 67000 Strasbourg, France

Quantum limited standing-wave amplifiers in superconducting circuits are key tools for quantum-device readout, relying on Josephson junction or high kinetic inductance nonlinearities to convert pump energy into signal gain[1,2]. However, their performance is typically limited by operation near dynamic instability, restricting bandwidth. We discuss a class of standing-wave parametric amplifiers known as Bogoliubov amplifiers [3], which leverage double-pump drives to operate far from the instability region, thereby overcoming the intrinsic gain-bandwidth limitation. We demonstrate this concept on a Bose-Hubbard dimer formed by two coupled Kerr resonators [4], showing that double-pump driving enables tunable gain, bandwidth, and noise performance. This establishes Bogoliubov amplifiers as a promising platform for scalable qubit readout and precision quantum measurements. [1] P. Winkel, et al., Phys. Rev. Appl. 13.2 (2020). [2] D. J. Parker, et al., Phys. Rev. Appl. 17.3 (2022). [3] A. Metelmann, et al., arXiv:2208.00024 (2022). [4] N. Zapata, et al., Phys. Rev. Lett. 133. 26 (2024).

QI 11.3 Wed 10:15 BEY/0245

Universal Pulses for Superconducting Qudit Ladder Gates — Boxi Li[1,2], Francisco Cárdenas-López[1], Andrian Lupascu[3], and •Felix Motzoi[1,2] — [1]Forschungzentrum Jülich, Institute of Quantum Control — [2]Universität zu Köln — [3]University of Waterloo, Institute for Quantum Computing

In this work (PRX Quantum 6, 03035), we present a universal pulse construction for generating rapid, high-fidelity unitary rotations between adjacent qudit levels, thereby providing a prescription for any gate in SU(d). Control errors in these operations are effectively analyzed within a four-level subspace, including two leakage levels with approximately opposite detuning. By identifying the optimal degrees of freedom, we derive concise analytical pulse schemes that suppress multiple control errors and outperform existing methods. Remarkably, our approach achieves consistent coherent error scaling across all levels, approaching the quantum speed limit independently of parameter variations between levels. Numerical validation on transmon circuits demonstrates significant improvements in gate fidelity for various qudit sizes aiming for 10^-4 error. This method provides a scalable solution for improving qudit control and can be broadly applied to other quantum systems with ladder structures or operations involving multiple ancillary levels.

QI 11.4 Wed 10:30 BEY/0245

Superconducting Gralmonium Qubit Resilient to High Magnetic Fields — •Janic Beck[1], Simon Günzler[1], Dennis Rieger[1], Nicolas Gossling[1], Nicolas Zapata[1], Mitchell Field[1], Simon Geisert[1], Andreas Bacher[1], Judith Hohmann[1], Martin Spiecker[1], Wolfgang Wernsdorfer[1], and Ioan Pop[1,2] — [1]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]PI 1, Stuttgart University, 70569 Stuttgart, Germany

Superconducting qubits can be used as information engines to probe and manipulate microscopic degrees of freedom (DOF), whether intentionally designed or naturally occurring in their environment. In the case of magnetically susceptible DOF, the external magnetic field used to polarize them presents a challenge for superconductors and Josephson junctions. Here we demonstrate the operation of a granular aluminum nanojunction fluxonium qubit (Gralmonium), resilient to in-plane magnetic fields beyond one Tesla. By employing a gradiometric fluxonium design, we enhance the qubit's insensitivity to global magnetic flux fluctuations. The energy relaxation (T1 = 8 μs) and coherence (T2E = 2.5 μs) are unaffected by the magnetic field and we observe only minor changes in the qubit spectrum, caused by percent level gap suppression. The gradiometric gralmonium's field resilience highlights its potential for hybrid quantum architectures that combine superconducting qubits with spin systems.

QI 11.5 Wed 10:45 BEY/0245

Spin Environment of a Superconducting Qubit in High Magnetic Fields — •Simon Günzler[1], Janic Beck[1], Dennis Rieger[1], Nicolas Gosling[1], Nicolas Zapata[1], Mitchell Field[1], Simon Geisert[1], Andreas Bacher[1], Judith K. Hohmann[1], Martin Spiecker[1], Wolfgang Wernsdorfer[1], and Ioan M. Pop[1,2] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Stuttgart University, Stuttgart, Germany

We leverage the magnetic field resilience of a granular aluminum nanojunction fluxonium qubit (Gralmonium) with a gradiometric design to uncover a paramagnetic spin-1/2 ensemble, which is the dominant Gralmonium loss mechanism when the electron spin resonance matches the qubit. We also report a suppression of fast flux noise measured in Spin-Echo experiments in magnetic fields exceeding 0.4 Tesla, which suggests the freezing of surface spins. In addition to these environments, by employing an active state stabilization sequence of the qubit, we hyperpolarize long-lived two-level systems (TLS), previously speculated to also be of magnetic origin. Surprisingly, the coupling to this TLS environment remains unaffected by magnetic fields, leaving the question of their origin open. These results demonstrate the gradiometric Gralmonium's potential for hybrid quantum architectures combining superconducting qubits with spins.

30min. break

QI 11.6 Wed 11:30 BEY/0245

High-Coherence Superconducting Qubits on Wafer-Scale — •Julius Feigl[1,2], Niklas Bruckmoser[1,2], Leon M. Koch[1,2,3], David Bunch[1,2], Léa Richard[1,2], Christian Gnandt[1,2], Ivan Tsitsilin[1,2,3], Anirban Bhattacharjee[1,2], Haiyang Hu[1,2], Vera P. Bader[1,2], Lasse Södergren[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Peak Quantum GmbH, Garching, Germany

Scaling superconducting quantum processors requires fabrication processes that maintain high qubit coherence across increasingly complex multi-qubit chips. While substantial progress has been achieved for isolated, single-qubit devices, preserving these coherence levels in multi-qubit architectures remains challenging due to added fabrication steps and potential loss mechanisms. In particular, as system performance is frequently limited by the least coherent qubit, understanding coherence variations across a wafer is crucial. Therefore, we present coherence measurements from twelve transmon qubits across two chips fabricated on a 100 mm wafer. The qubits exhibit an average relaxation time of $T_1 = 236 \pm 14\,\mu$s, with the lowest device having a relaxation time of $111 \pm 30\,\mu$s. We further examine the influence of fabrication processes required for large-scale integration, such as air bridges and indium bumps, on coherence. These lead to a reduction in coherence time, providing insight into the impact of additional processing required for large-scale superconducting quantum processors.

QI 11.7 Wed 11:45 BEY/0245

A charge-basis tomographic protocol for superconducting qubits — •Elena Lupo[1], Daniel Long[2], Daniel Dahan[3], Konstantin Yavilberg[3], Malcolm R. Connolly[2], Eytan Grosfeld[3], and Eran Ginossar[4] — [1]Forschungszentrum Jülich, 52428 Jülich, Germany — [2]Imperial College London, SW7 2AZ London, UK — [3]Ben-Gurion University of the Negev, 84105 Beer-Sheva, Israel — [4]University of Surrey, GU2 7XH Guildford, UK

The use of accurate models and parameters in superconducting circuits is essential for the understanding and control of quantum states. While conventional spectroscopic techniques allow the extraction of excited-state populations, transition frequencies, and decay rates, information about quantum coherence can only be obtained through phase-sensitive methods such as quantum state tomography, which is usually performed in the system's energy basis. Here we introduce a complementary tomographic protocol for the reconstruction of the ground state of a superconducting circuit with a generic Josephson junction potential [1]. The state reconstruction is done in the basis of its relative charge across the junction - a representation that can provide new insights into the quantum circuit and can assist in validating its Hamiltonian model. The method combines the flux-tuning of a split Josephson junction and adiabatic evolution to achieve the desired density matrix reconstruction of the circuit's ground state. Further possible applications of this method include the study of hybrid superconductor-semiconductor junctions [2]. [1] Lupo et al, arXiv: 2502.07748; [2] Dahan et al, arXiv: 2502.07684.

QI 11.8 Wed 12:00 BEY/0245

Magnetic-Field and Temperature Limits of a Kinetic-Inductance Traveling-Wave Parametric Amplifier — Lucas M. Janssen[1], Farzad Faramarzi[2], Henry G. LeDuc[2], Sahil Patel[3,2], Gianluigi Catelani[4,5], Peter K. Day[2], Yoichi Ando[1], and •Dickel Christian[1] — [1]Physics Institute II, University of Cologne, Germany — [2]Jet Propulsion Laboratory, Caltech, USA — [3]Department of Applied Physics and Materials Science, Caltech, USA — [4]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Germany — [5]Quantum Research Center, TII, Abu Dhabi, UAE

Kinetic-inductance traveling-wave parametric amplifiers (KI-TWPAs) offer broadband near-quantum-limited amplification with high saturation power. In this work [1], we study how magnetic field and temperature affect the performance of a KI-TWPA based on a thin-NbTiN inverse microstrip with a Nb ground plane. This KI-TWPA can provide substantial signal-to-noise ratio improvement (ΔSNR) up to in-plane magnetic fields of 0.35 T and out-of-plane fields of 50 mT, considerably higher than what has been demonstrated with TWPAs based on Josephson junctions [2]. We also find that the gain does not degrade when the temperature is raised to 3 K (limited by the Nb ground plane) while ΔSNR decreases with temperature consistently with expectation. The operability of KI-TWPAs in high magnetic fields opens the door to a wide range of applications in spin qubits, spin ensembles, topological qubits, low-power NMR, and the search for axion dark matter.

[1] Janssen et al., PR Appl. 2024 [2] Janssen et al., arXiv:2509.15043

QI 11.9 Wed 12:15 BEY/0245

Toward Chemically Resilient Superconducting Qubit Fabrication — •Niklas Bruckmoser[1,2], Leon M. Koch[1,2,3], Thomas Brenninger[2], Ivan Tsitsilin[1,2,3], Amanda Scoles[1,2], David Bunch[1,2], Julius Feigl[1,2], Lea Richard[1,2], Christian Gnandt[1,2], Christian M.F. Schneider[1,2], Vera P. Bader[1,2], Haiyang Hu[1,2], Lasse Södergren[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, BAdW, Germany — [3]Peak Quantum GmbH, Germany

As superconducting quantum processors scale up, there is an increasing need for fabrication methods that combine low loss with high yield. One promising strategy is the implementation of subtractive processes that also withstand aggressive interface cleaning, particularly by replacing aluminum with chemically resilient materials. In this talk, we demonstrate a fully subtractive process for niobium-based air bridges that are used as interconnects as well as vacuum-gap capacitors. Rigorous surface cleaning allows us to achieve mean internal quality factors of coplanar waveguide resonators exceeding $Q_{\mathrm{int}} = 7.9 \times 10^6$ in the single-photon limit, with no detectable added loss from air bridges. By integrating large vacuum-gap capacitors into transmon qubits, we observe median lifetimes above $T_1 = 50\ \mu$s.

Building on this platform, we share our first exploratory efforts toward the implementation of chemically resilient Josephson junctions. At this early stage, we focus on challenges and discuss pathways to achieve a scalable, high-yield, and low-loss fabrication process.

QI 11.10 Wed 12:30 BEY/0245

TiN superconducting resonators: influence of sputter conditions on Qi(T) and TLS-based loss modeling — •Benedikt Schoof[1], Moritz Singer[1], Harsh Gupta[1], Simon Lang[2], and Marc Tornow[1,2] — [1]TUM CIT, 85748 Garching, Germany — [2]EMFT, 80686 Munich, Germany

We investigate how reactive sputter conditions affect the internal quality factor as a function of temperature (Qi(T)) of TiN coplanar-waveguide resonators. TiN films were grown on high-ohmic silicon (100) under varied substrate temperature (RT to 500 C), pressure (2 mbar to 18 mbar) and N2/Ar gas flow ratio (0.0 to 1.0). Electrical characterization yielded resistivity values in the range of 100 microOhm cm to 100 milliOhm cm and Tc values from 0.5 K to 5.1 K, which together with XPS, XRD and ToF-SIMS data were correlated with the Qi(T) data extracted from CPW resonators fabricated from these films. We find that films sputtered at elevated substrate temperature exhibit higher Qi (0.8e6) in the single-photon regime at 100 mK and are well described by a standard additive loss model with a single two-level-system (TLS) component. In contrast, room-temperature sputtered films require two distinct TLS contributions to reproduce the full Qi(T) dependence, indicating multiple dielectric defect populations or enhanced interfacial disorder introduced during low-temperature growth. Tc shows only a weak correlation with Qi, confirming that superconducting transition metrics alone do not capture the relevant microwave loss mechanisms. Our results provide quantitative guidance for optimizing TiN resonators for superconducting-qubit applications.