TT 40: Superconductivity: Qubits 1

Time: Wednesday 9:30–13:00 Location: H48

TT 40.1 Wed 9:30 H48

Coherence of a transmon qubit under in-plane magnetic fields — •Andre Schneider[1], Alexey V. Ustinov[1,2], and Martin Weides[1,3] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]National University of Science and Technology MISIS, Moscow, Russia — [3]University of Glasgow, Glasgow, United Kingdom

Superconducting quantum circuits are versatile building elements for quantum technologies, with applications ranging from computing and simulation to sensing and metrology. The extreme sensitivity of SQUIDs to magnetic fields is used in many technological applications, and new quantum sensing schemes like the detection of amplitude and frequency of microwave signals by a superconducting transmon qubit [1] are being developed.

To identify possible fields of application, we investigate the environmental magnetic conditions for the usability of such a qubit. By placing a transmon qubit in a magnetic field, we analyze its transition frequency and coherence properties. We find that the transition frequency strongly depends on the flux penetrating the $Al/AlO_x/Al$ Josephson junction and can be modeled precisely as function of the in-plane magnetic field. We demonstrate quantum coherence up to field values of 40 mT with qubit lifetimes of $T_1 \gtrsim 0.5\mu s$ and find corresponding T_2 times resulting in a constant pure dephasing rate at any field. The possibility to operate superconducting qubits in magnetic fields far beyond the critical field of the bulk superconductor opens new avenues, for instance in quantum sensing and metrology.

[1] A. Schneider *et al.*, Phys. Rev. A **97**, 062334 (2018)

TT 40.2 Wed 9:45 H48

What Can Be Learned from Measuring Quantum Jumps of a Transmon Qubit? — •Dennis Rieger[1], Patrick Winkel[1], Ivan Takmakov[1,2], Luca Planat[3], Farshad Foroughi[3], Wiebke Hasch-Guichard[3], Kiril Borisov[2], Julian Ferrero[1], Lukas Grünhaupt[1], Daria Gusenkova[1], Fabio Henriques[1], Nataliya Maleeva[1], Alexey V. Ustinov[1], Wolfgang Wernsdorfer[1,2,3], Nicolas Roch[3], and Ioan M. Pop[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [3]Institut Néel, CNRS and Université Joseph Fourier, Grenoble, France

Resolving quantum jumps of superconducting qubits requires fast, high-fidelity readout, which can be enabled by a superconducting parametric amplifier as a first amplifier stage for the readout signal. We use the Dimer Josephson Junction Array Amplifier (DJJAA) to measure quantum jump traces of a transmon qubit dispersively coupled to a readout resonator and placed inside a 3D waveguide.

The measured coherence times of the transmon are sufficiently long compared to the integration time needed for qubit state discrimination. The quantum jumps follow Poisson statistics and we find that the T_1 during readout is significantly reduced compared to the free evolution T_1. Also, the effective qubit temperature saturates at approximately 50 mK even though the qubit is thermally anchored to the mixing chamber stage of a dilution refrigerator at 20 mK.

TT 40.3 Wed 10:00 H48

Tuning decoherence sources in Transmon qubits by electric fields — •Jürgen Lisenfeld[1], Alexander Bilmes[1], Georg Weiss[1], Rami Barends[2], Anthony Megrant[2], Julian Kelly[2], John M. Martinis[2], and Alexey V. Ustinov[1,3] — [1]Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]Google Inc., Santa Barbara — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

A major part of decoherence in superconducting quantum bits arises from their interaction with microscopic material defects forming parasitic two-state quantum systems, so-called TLS. For the further advancement of quantum processors, it is thus vital to gain a better understanding of TLS properties and how they are formed.

Here we demonstrate a new technique to tune the resonance frequencies of defects by exposing a transmon qubit circuit to a DC-electric field generated by electrodes surrounding the sample chip.

Our experiments indicate that about 50% of over 200 individually observed TLS are tuned by the electric field, as it is expected from defects residing on qubit circuit electrodes or at substrate interfaces. In comparison, practically all TLS respond to mechanical strain that is generated by a piezo actuator. Our statistical analyses of the defect's coupling strengths to the qubit, strain, and electric field reveal two distinguishable defect classes whose probable origins will be discussed.

TT 40.4 Wed 10:15 H48

Resolving the Positions of Parasitic Defects in Superconducting Qubits — •Alexander Bilmes[1], Anthony Megrant[2], Julian Kelly[2], Rami Barends[2], John M. Martinis[2], Weiss Georg[1], Alexey V. Ustinov[1,3], and Jürgen Lisenfeld[1] — [1]Karlsruhe Institute of Technology, 76137 Karlsruhe, Germany — [2]Google Inc., Santa Barbara, USA — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

We demonstrate a new technique to identify the spatial positions of decoherence-inducing material defects known as Two-Level-Tunneling systems (TLS) in superconducting qubits. For this, we operate a transmon qubit circuit in a DC-electric field that is generated by several electrodes surrounding the sample chip, and study the TLS response by monitoring their resonance frequencies using qubit swap spectroscopy. By comparing measured and simulated coupling strengths of TLS to each DC-electrode, we obtain information about the possible locations and hosting interfaces of observed surface TLS. This method is applicable to any ready-made transmon qubit, and opens a path for the optimization and verification of qubit fabrication procedures by directly indicating which circuit interfaces must be improved in order to enhance qubit coherence.

TT 40.5 Wed 10:30 H48

A Two-Level-System sensor derived from a superconducting qubit. — •Alexander Bilmes[1], Ioan Pop[1], Martin Weides[2], Alexey V. Ustinov[1,3], and Jürgen Lisenfeld[1] — [1]Karlsruhe Institut für Technologie, Wolfgang-Gaedestr. 1, 76131 Karlsruhe — [2]University of Glasgow, Schottland — [3]Russian Quantum Center, MISIS, Moscow 119049, Russia

Since the first experimental realization of superconducting qubits in the 2000s, Two-Level-Systems (TLS) are a main and yet unsolved source of noise and decoherence in quantum circuits. The microscopic origin of TLS in the microfabricated devices is manifold. Tunnelling ions, impurities, trapped electrons and adsorbates are the most common and competeng models explaining formation of TLS in dielectrics and interfaces of the circuits. While examination of TLS in ready-made qubits [1,2] is a useful method to improve the sample geometry and fabrication, another complementary approach is to actively study the TLS nature in specially tailored quantum circuits [3,4]. A novel TLS-sensor has been derived from a transmon-qubit architecture where the Josephson junction is shunted by a small capacitor containing a sample dielectric. This allows for exploring of TLS hosted in dielectric films, bulks and at circuit surfaces. Here, we present the proof of principle for TLS-detection in amorphous AlOx films using such a TLS-sensor, which opens up further possibilities for TLS-studies. [1] J. Lisenfeld et al., Sci. Rep. 6 (23786) (2016) [2] A. Bilmes et al., Phys. Rev. B 96, 064504 (2017) [3] B. Sarabi et al., Phys. Rev. Lett. 116, 167002 (2016) [4] J. Brehm et al., Appl. Phys. Lett. 111, 112601 (2017)

TT 40.6 Wed 10:45 H48

Time-resolved tomography of a compact 3D quantum memory — •Michael Renger[1,2], Edwar Xie[1,2,3], Frank Deppe[1,2,3], Qi-Ming Chen[1,2], Michael Fischer[1,2,3], Stefan Pogorzalek[1,2], Kirill G. Fedorov[1,2], Achim Marx[1], and Rudolf Gross[1,2,3] — [1]Walther- Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

We realize a quantum memory by coupling a transmon qubit to a rectangular 3D cavity resonator [1]. Exploiting the multimode structure of the 3D cavity enables us to use single resonator for storage and readout purposes, thereby significantly enhancing scalability. Compared to the bare qubit, the T_1-time of the memory is 6 times longer. We accurately characterize the loss of quantum information during the storage and retrieval process by performing quantum process tomography on our memory system and find a process fidelity of 88%. A detailed error budget analysis enables us to estimate the fidelity losses caused by decoherence, thermal excitations, state leakage and inaccurate state preparation. We investigate the dynamical behavior of our system with time-resolved tomography and a master equation approach.

We acknowledge support by the German Research Foundation through FE 1564/1-1 and the Excellence Cluster MCQST, the Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No 820505).

[1] E. Xie *et al.*, Appl. Phys. Lett. **112**, 202601 (2018)

TT 40.7 Wed 11:00 H48

Dispersive Readout of AC-Driven Qubits — •Sigmund Kohler — Instituto de Ciencia de Materiales de Madrid, CSIC

We present a unified picture of dispersive readout of quantum systems in and out of equilibrium. A cornerstone of the approach is the backaction of the measured system to the cavity obtained with non-equilibrium linear response theory. It provides the dispersive shift of the cavity frequency in terms of a system susceptibility [1] as well as resonance conditions that relate the cavity transmission to spectral properties and Berry phases [2]. Examples are the readout of detuned qubits and thermally excited multi-level systems. For ac-driven quantum systems, we identify the relevant Fourier component of the susceptibility and introduce a computational scheme based on Floquet theory. The theory is applied to Landau-Zener-Stückelberg-Majorana interference in Si/SiGe double quantum dots, where the interference patterns exhibit a harp-like stemming from the valley degree of freedom [3]. The theoretical and experimental interference patterns show a striking agreement.

[1] S. Kohler, Phys. Rev. A **98**, 023849 (2018).
[2] S. Kohler, Phys. Rev. Lett. **119**, 196802 (2017).
[3] X. Mi, S. Kohler, J. R. Petta, Phys. Rev. B **98**, 161404(R) (2018).

15 min. break.

TT 40.8 Wed 11:30 H48

Coherence of a granular aluminum fluxonium qubit — •Martin Spiecker, Lukas Grünhaupt, Daria Gusenkova, Nataliya Maleeva, Sebastian T. Skacel, Ivan Takmakov, Francesco Valenti, Patrick Winkel, Hannes Rotzinger, Alexey V. Ustinov, and Ioan M. Pop — Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

A promising alternative for the implementation of superinductors, compared to the predominantly used mesoscopic Josephson junction arrays, is granular aluminum (grAl), with a microstructure consisting of pure aluminum grains embedded in an AlOx matrix, effectively forming a self-assembled Josephson junction network [1]. This material offers a large kinetic inductance, while its non-linearity is orders of magnitude smaller than that of Josephson junction arrays [2]. We present a fluxonium qubit employing a granular aluminium superinductor with coherence times T up to 23 μs and T up to 30 μs at the flux bias sweet spot. The measured T approaches the limit 2 * T [3]. These coherence times recommend granular aluminum for increasingly complex protected superconducting quantum circuits, while they also evidence the need to further investigate and mitigate loss mechanisms in high impedance circuits.

[1] Grünhaupt et al., Phys. Rev. Lett. 121, 117001 (2018)
[2] Maleeva et al., Nat. Commun. 9, 3889 (2018)
[3] Grünhaupt and Spiecker et al., arXiv:1809.10646 (2018)

TT 40.9 Wed 11:45 H48

Design and fabrication of a granular aluminum fluxonium qubit — •Lukas Grünhaupt[1], Martin Spiecker[1], Daria Gusenkova[1], Nataliya Maleeva[1], Sebastian T. Skacel[1,2], Ivan Takmakov[1,2,3], Francesco Valenti[1,4], Patrick Winkel[1], Hannes Rotzinger[1], Alexey V. Ustinov[1,3], and Ioan M. Pop[1,2] — [1]Physikalisches Institut, KIT, Karlsruhe, Germany — [2]Institute of Nanotechnology, KIT, Karlsruhe, Germany — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia — [4]Institute for Data Processing and Electronics, KIT, Karlsruhe, Germany

Superconducting materials with low microwave losses and high kinetic inductance are a valuable resource in quantum circuit design, enabling the design of so-called superinductors, which can provide electromagnetic environments with characteristic impedance larger than the resistance quantum $R_Q = 6.5$ kΩ. To implement superinductors, a promising alternative to the predominantly used mesoscopic Josephson junction arrays is granular aluminum (grAl). Its microstructure consists of pure aluminum grains embedded in an AlO_x matrix, effectively forming a compact self-assembled Josephson junction network. We present a superconducting fluxonium qubit employing a superinductor with impedance Z $> R_Q$, fabricated from a grAl thin film, in-situ integrated with a conventional Al/AlO_x/Al Josephson junction. The measured qubit spectrum is in good agreement with the fluxonium Hamiltonian.

TT 40.10 Wed 12:00 H48

Coherent Revival of Ramsey Oscillations in the Fluxonium Qubit Coupled to a bath of Harmonic Oscillators — •Farshad Foroughi[1], Mattia Mantovani[2], Karthik Bharadwaj[1], Remy Dassonneville[1], Luca Planat[1], Sebastien Leger[1], Etienne Dumur[4], Yuriy Krupko[1], Wolfgang Belzig[2], Cecile Naud[1], Olivier Buisson[1], Nicolas Roch[1], Gianluca Rastelli[2,3], and Farshad Foroughi[1] — [1]Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble, France — [2]Fachbereich Physik, Universität Konstanz, Konstanz, D-78457 , Germany — [3]Zukunftskolleg, Universität Konstanz, D-78457, Konstanz, Germany — [4]The institute for Molecular Engineering, University of Chicago, Chicago, IL, United States

We realized a 2D fluxonium qubit coupled to 12 on-chip lumped element resonators. The oscillators are composed of chain of SQUIDs in series with an interdigited capacitor. Careful choice of number of SQUIDs let putting the 12 resonators equally spaced around the qubit frequency. Moreover by applying a global DC external magnetic field to the loop of SQUIDs one can fine tune the resonant frequencies of the modes. We used a fast flux line to control the frequency of the fluxonium qubit and hence coupling between it and and the resonators. We have studied theoretically the emerging spin-boson Hamiltonian for this particular circuit with the perspective of measuring revival effects in the coherent oscillations of the qubit. We implemented the measurements, revealing the effect on the qubit dynamics of a non-dissipative bath formed by a discrete set of harmonic oscillators.

TT 40.11 Wed 12:15 H48

FPGA-based Platform for Control and Readout of Superconducting Qubits — •Richard Gebauer[1], Nick Karcher[1], Oliver Sander[1], Martin Weides[2,3], Alexey V. Ustinov[2,4], and Marc Weber[1] — [1]Institute for Data Processing and Electronics, KIT, Karlsruhe, Germany — [2]Physikalisches Institut, KIT, Karlsruhe, Germany — [3]School of Engineering, University of Glasgow, Glasgow, United Kingdom — [4]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia

A typical measurement setup for superconducting qubits consists of arbitrary waveform generators, signal recorders, and vector network analyzers. Although sufficient for simple experiments, this approach is limited due to long communication delays, poor scalability, and static pulse sequences. A faster, more integrated and more flexible solution for qubit readout and control is FPGA-based custom hardware. It not only reduces costs and space requirements but also simplifies measurements and enables many-qubit experiments as well as advanced control schemes like quantum feedback where a low response time is critical.

We developed a flexible FPGA-based integrated platform to control and read out superconducting qubits which also enables fast feedback loops to manipulate qubits depending on their measured state. The platform allows arbitrary X and Y rotations around the Bloch sphere and enables the user to perform all standard measurements needed for single qubit characterization. We will give a short overview about the platform features and capabilities. Furthermore, we present different experimental applications including results on quantum feedback.

TT 40.12 Wed 12:30 H48

Qubit Measurement by Multichannel Driving — Joni Ikonen[1], •Jan Goetz[1], Jesper Ilves[1], Aarne Keränen[1], Andras M. Gunyho[1], Matti Partanen[1], Kuan Y. Tan[1], Dibyendu Hazra[1], Leif Grönberg[2], Visa Vesterinen[1,2], Slawomir Simbierowicz[2], Juha Hassel[2], and Mikko Möttönen[1] — [1]QTF Centre of Excellence, Department of Applied Physics, Aalto University, P.O. Box 15100, FI-00076 Aalto, Finland — [2]VTT Technical Research Centre of Finland, QTF Center of Excellence, P.O. Box 1000, FI-02044 VTT, Finland

We theoretically propose and experimentally implement a method of measuring a qubit by driving it close to the frequency of a dispersively coupled bosonic mode [1]. The separation of the bosonic states corresponding to different qubit states begins essentially immediately at maximum rate, leading to a speedup in the measurement protocol.

Also the bosonic mode can be simultaneously driven to optimize measurement speed and fidelity. We experimentally test this measurement protocol using a superconducting qubit coupled to a resonator mode. For a certain measurement time, we observe that the conventional dispersive readout yields close to 100 % higher average measurement error than our protocol. Finally, we use an additional resonator drive to leave the resonator state to vacuum if the qubit is in the ground state during the measurement protocol. This suggests that the proposed measurement technique may become useful in unconditionally resetting the resonator to a vacuum state after the measurement pulse.

[1] Ikonen, et al., arXiv 1810.05465

TT 40.13 Wed 12:45 H48

Low frequency excess flux noise in dc-SQUIDs — •Anna Ferring, Andreas Fleischmann, Christian Enss, and Sebastian Kempf — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Low frequency excess flux noise strongly impairs the performance of superconducting quantum devices (SQDs) such as SQUIDs and Qubits. It is, for example, the dominating mechanism causing decoherence in flux or phase Qubits and makes SQUID based measurements of low frequency signals rather challenging. Recent experiments strongly hint for surface adsorbates as an origin of this noise contribution. But even though more and more information on its origin and physical properties are gathered, a lot of open questions remain such as whether additional sources of low frequency excess flux noise exist.

In this contribution, we show indications for a correlation between the noise amplitude of dc-SQUIDs and the dc-magnetization of material layers used for device fabrication. This suggests that low-frequency excess flux noise is to some extend caused by the conditions of the fabrication process. We further present a SQUID setup which allows for temperature dependent cross-correlation measurements of the magnetic flux noise of a sample SQUID. Finally, we discuss the scaling of low frequency excess flux noise of simple washer SQUIDs with device inductance showing that the energy sensitivity rather than the magnetic flux noise is the more appropriate figure of merit for describing low frequency excess flux noise.