HL 16: Transport: Quantum coherence and quantum information systems - Experiments (TT with HL)

Time: Monday 15:00–17:15 Location: H 0110

HL 16.1 Mon 15:00 H 0110

Coplanar microwave resonators for superconductor/cold atom hybrid devices — •Daniel Bothner, Dominik Wiedmaier, Benedikt Ferdinand, Martin Knufinke, Helge Hattermann, Patrizia Weiss, József Fortágh, Dieter Koelle, and Reinhold Kleiner — Physikalisches Institut and Center for Collective Quantum Phenomena in LISA$^+$, University of Tübingen, Germany

Recently, it has been demonstrated that ultracold atomic clouds can show very long coherence times on the order of 10 sec in close proximity to a superconducting chip surface [1]. Due to these extraordinarily long coherence times, atomic clouds are promising candidates as long-lived quantum memory in a future hybrid quantum processor. The realization of such a fully functioning hybrid system, however, poses severe challenges regarding the design and optimization of the superconducting chip. We will briefly discuss the relevant experimental boundary conditions and present strategies to comply with them on the way towards coherent coupling between ultracold atomic ensembles and on-chip microwave resonators. We in particular focus on how mixing normal conducting and superconducting components can outperform purely superconducting chips with respect to the requirements of the aspired hybrid system.

[1] S. Bernon *et al.*, Nature Commun. **4**, 2380 (2013)

HL 16.2 Mon 15:15 H 0110

Circuit QED with a gradiometric tunable-gap flux qubit — •Frank Deppe[1,2,3], Manuel J. Schwarz[1,2,3], Max Haeberlein[1,2,3], Jan Goetz[1,2,3], Alexander Baust[1,2,3], Peter Eder[1,2,3], Friedrich Wulschner[1,2,3], Edwar Xie[1,2,3], Ling Zhong[1,2,3], Kirill Fedorov[1,2,3], Edwin P. Menzel[1,2,3], Achim Marx[1,2,3], 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

In circuit quantum electrodynamics or quantum simulation experiments, superconducting quantum bits must combine good coherence with high in situ tunability. Often, a large anharmonicity is also desirable. Other than the popular transmon, the gradiometric tunable-gap flux qubit meets all three of these requirements. Here, we fabricate and characterize such a qubit and demonstrate its first implementation into a transmission line resonator. We show spectroscopy and first time domain results.

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HL 16.3 Mon 15:30 H 0110

Flux qubit to a transmission line — •Max Haeberlein[1,2,3], Gustav Anderson[1,2], Lujun Wang[1,2], Alexander Baust[1,2,3], Peter Eder[1,2], Michael Fischer[1,2], Jan Goetz[1,2], Edwar Xie[1,2], Manuel Schwarz[1,2], Karl Friedrich Wulschner[1,2], Ling Zhong[1,2,3], Frank Deppe[1,2], Kirill Fedorov[1,2], Hans Hübl[1,2], Achim Marx[1], Edwin Menzel[1,2], 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), Schellingstraße 4, 80799 München, Germany

Within the last decade, superconducting qubits coupled to microwave resonators have been extensively studied within the framework of quantum electrodynamics. Ultimately, quantum computing seems within reach in such architectures. However, error correction schemes are necessary to achieve the required fidelity in multi-qubit operations, drastically increasing the number of qubits involved.

In this work, we couple a flux qubit to a transmission line where it interacts with itinerant microwave photons granting access to all-optical quantum computing. In this approach, travelling photons generate entanglement between two waveguides, containing the qubit information.

In this presentation, we show experimental data on flux qubits coupled to transmission lines. Furhtermore, we will discuss entanglement generation between two separate paths.

This work is supported by the DFG via SFB 631 and EU projects CCQED and PROMISCE.

HL 16.4 Mon 15:45 H 0110

Ultrastrong coupling of a flux qubit — •A. Baust[1,2,3], E. Hoffmann[1,2,3], M. Haeberlein[1,2,3], M. J. Schwarz[1,2,3], P. Eder[1,2,3], J. Goetz[1,2,3], F. Wulschner[1,2,3], E. Xie[1,2,3], L. Zhong[1,2,3], K. G. Fedorov[1,2,3], E. P. Menzel[1,2,3], F. Deppe[1,2,3], A. Marx[1,2,3], and R. 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

Circuit quantum electrodynamics has not only become a versatile toolbox for quantum information processing, but is also a powerful platform for the investigation of light-matter interaction. The coupling strength between microwave resonators and qubits acting as artificial atoms can be tuned over several orders of magnitude and can even reach the regime of ultrastrong coupling. We present spectroscopic data of a flux qubit coupled galvanically to the signal lines of two coplanar stripline resonators. We discuss the complex mode spectrum and show that the coupling strength between the qubit and one resonant mode reaches 17% of the respective mode frequency. Noticably, the high coupling strength is reached solely by the geometric layout of the qubit without utilizing additional coupling elements such as Josephson junctions. Our data exhibit a pronounced Bloch-Siegert shift and therefore represent an experimental evidence for the breakdown of the Jaynes-Cummings model.

This work is supported by the DFG via SFB 631 and EU projects CCQED and PROMISCE.

HL 16.5 Mon 16:00 H 0110

Characterization of superconducting transmission line resonators — •Jan Goetz[1,2], Philipp Summer[1,2], Sebastian Meier[1,2], Marta Krawczyk[1], Max Häberlein[1,2], Alexander Baust[1,2,3], Karl Friedrich Wulschner[1,2], Edwar Xie[1,2,3], Peter Eder[1,2], Michael Fischer[1,2], Manuel Schwarz[1,2], Ling Zhong[1,2,3], Frank Deppe[1,2], Kirill Fedorov[1,2], Hans Hübl[1,2], Achim Marx[1], Edwin Menzel[1,2], 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

Superconducting transmission line resonators are widely used in circuit quantum electrodynamics experiments as quantum bus or storage devices. For these applications, long coherence times, which can be linked to the internal quality factor of the resonators, are crucial. Here, we show a systematic study of the internal quality factor of niobium thin film resonators. We analyze different cleaning methods and substrate parameters for coplanar waveguide as well as microstrip geometries. In addition, we investigate the impact of a niobium-aluminum interface which is necessary for galvanically coupled flux qubits made from aluminum. This interface can be avoided by fabricating the complete resonator-qubit structure using $Al/AlO_x/Al$ technology during fabrication.

This work is supported by the DFG via SFB 631 and EU projects CCQED and PROMISCE.

HL 16.6 Mon 16:15 H 0110

Superconducting on-chip microwave interferometers — •Edwin P. Menzel[1,2,3], Michael Fischer[1,2,3], Christian Schneider[1,2,3], Alexander Baust[1,2,3], Peter Eder[1,2,3], Jan Goetz[1,2,3], Max Haeberlein[1,2,3], Manuel Schwarz[1,2,3], Karl Friedrich Wulschner[1,2,3], Edwar Xie[1,2,3], Ling Zhong[1,2,3], Frank Deppe[1,2,3], Kirill Fedorov[1,2,3], Hans Huebl[1,2,3], Achim Marx[1,2,3], 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

In the realm of all-microwave quantum computation, information is encoded in itinerant microwave photons propagating along transmission lines. In such a system unitary operations are implemented by linear elements such as beam splitters or interferometers. However, for two-qubit operations non-linear gates, e.g., c-phase gates are required. In this work, we investigate superconducting interferometers as a building block of a c-phase gate. We experimentally characterize their scattering properties and compare them to simulation results. Finally, we discuss our progress towards the realization of a c-phase gate.

This work is supported by the DFG via SFB 631 and the EU projects CCQED and PROMISCE.

HL 16.7 Mon 16:30 H 0110

Towards chains of tunable and nonlinear superconducting microwave resonators — •Michael Fischer[1,2], Friedrich Wulschner[1,2], Udo Schaumburger[1,2], Max Haeberlein[1,2], Manuel Schwarz[1,2,3], Peter Eder[1,2,3], Edwin Menzel[1,2,3], Kirill Fedorov[1,2], Jan Goetz[1,2], Edwar Xie[1,2], Ling Zhong[1,2,3], Frank Deppe[1,2,3], 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 present an experimental feasibility study of chains of tunable and nonlinear superconducting microwave resonators within the realm of circuit QED. We describe the fabrication and experimental characterization of the components required to realize nonlinear resonators with tunable anharmonicity, capacitively coupled resonator chains and on-chip parallel plate capacitors. We discuss possible error sources in the fabrication and characterization processes. Furthermore, simulations based on existing theories are performed to identify accessible parameter ranges.

This work is supported by the DFG via SFB 631 and the EU projects CCQED and PROMISCE.

HL 16.8 Mon 16:45 H 0110

Probing the Interaction of Microscopic Material Defects with Quasiparticles using a Superconducting Qubit — •Alexander Bilmes[1], Jürgen Lisenfeld[1], Andreas Heimes[2], Sebastian Zanker[2], Gerd Schön[2], Georg Weiss[1], and Alexey V. Ustinov[1] — [1]PI, Fakultät für Physik, KIT, Wolfgang-Gaede-Straße 1, 76131 Karlsruhe, Germany — [2]TFP, Fakultät für Physik, KIT, Wolfgang-Gaede-Straße 1, 76131 Karlsruhe, Germany

Two-Level-Systems (TLS) are one of the main sources of decoherence in superconducting nano-scale devices such as SQUIDs, photon detectors, resonators and quantum bits (qubits), although the TLS' microscopic nature remains unclear. We use a superconducting phase qubit to detect TLS contained within the tunnel barrier of the qubit's Josephson junction. We coherently operate *individual* TLS by resonant microwave pulses and access their quantum state by utilizing their strong coupling to the qubit. Our previous measurements of TLS coherence in dependence of the temperature indicate that quasiparticles may give rise to TLS energy loss and dephasing. Here, we probe the TLS-quasiparticle interaction using a reliable method of *in-situ* quasiparticle injection via an on-chip dc-SQUID that is pulse-biased beyond its critical current. The quasiparticle density is calibrated by measuring associated characteristic changes to the qubit's resonance frequency and energy relaxation rate [1]. We will present experimental data that clearly show the influence of quasiparticles on TLS coherence.

[1] M. Lenander et al., Phys.Rev. B 84, 024501 (2011).

HL 16.9 Mon 17:00 H 0110

Incoherent Two-Level Fluctuators inside the Josephson junction of a Superconducting Qubit — •Saskia Meissner, Jürgen Lisenfeld, Alexey V. Ustinov, and Georg Weiss — Physikalisches Institut, KIT Karlsruhe

Spectroscopy on qubits based on Josephson junctions reveals the precence of defects like quantum coherent tunneling systems (TS) as well as two-level fluctuators (TLF). TLF are incoherent tunneling particles which are described by dissipative quantum tunneling theory. Due to the coherent interaction of qubit and the TS, it is possible to probe individual TLF that themselves are coupled to a tunneling system.

Here we perform high resolution defect spectroscopy by tuning the TS and TLF asymmetry energies with external strain applied to the qubit chip. Slow fluctuators induce telegraph noise in the resonance frequency of TS. Fast fluctuators create double resonances of TS in the manner of two frequency branches. Apparently, the two-level fluctuator causes a rapid modulation of the asymmetry energy of the tunneling system on top of the static strain tuning. We perform time domain analyses of TS resonance frequencies with the goal of reconstructing the TLF deformation potential and the TLF-TS interaction potentials.