TT 5: Transport: Quantum Coherence and Quantum Information Systems 1 (jointly with MA and HL)

Time: Monday 9:30–12:45 Location: BH 243

TT 5.1 Mon 9:30 BH 243

Coherence in a transmon qubit with epitaxial tunnel junctions — •Martin Weides[1,4], Jeffrey Kline[1], Michael Vissers[1], Martin Sandberg[1], David Wisbey[1,2], Blake Johnson[3], Thomas Ohki[3], and David Pappas[1] — [1]National Institute of Standards and Technology, Boulder, Colorado 80305, USA — [2]Saint Louis University, St. Louis, Missouri 63103, USA — [3]Raytheon BBN Technologies, Cambridge, Massachusetts 02138, USA — [4]Karlsruhe Institute of Technology, Germany

Transmon qubits based on epitaxial tunnel junctions and interdigitated capacitors were developed. This multileveled qubit, patterned by use of all-optical lithography, is a step towards scalable qubits with a high integration density. The relaxation time T_1 is $.72 - .86$ μsec and the ensemble dephasing time T_2^* is slightly larger than T_1. The dephasing time T_2 (1.36 μsec) is nearly energy-relaxation-limited. Qubit spectroscopy yields weaker level splitting than observed in qubits with amorphous barriers in equivalent-size junctions. The qubit's inferred microwave loss closely matches the weighted losses of the individual elements (junction, wiring dielectric, and interdigitated capacitor), determined by independent resonator measurements.

TT 5.2 Mon 9:45 BH 243

Single atom lasing of a dressed flux qubit — •Gregor Oelsner[1], Pascal Macha[1], Miroslav Grajcar[2], Oleg Astafiev[3], Boris Ivanov[1], Evgeni Il'ichev[1], Uwe Hübner[1], Solveig Anders[1], and Hans-Georg Meyer[1] — [1]Institute of Photonic Technology, PO Box 100239, D-07702 Jena, Germany — [2]Department of Solid State Physics, Comenius University, SK-84248 Bratislava, Slovakia — [3]NEC Nano Electronics Research Laboratories. Tsukuba, Ibaraki, 305-8501, Japan

We study a strongly driven superconducting flux qubit coupled to a high-quality coplanar waveguide resonator. In the frame of the dressed state approach, the energy of the Rabi splitting depends on the amplitude of the microwave field and the detuning between the qubit and the microwave frequency, which also controls the level occupation. If, for a certain detuning and amplitude, this splitting is in resonance with the fundamental mode of the resonator, a lasing (damping) effect is expected. Indeed we experimentally observe an increase in the transmission amplitude as well as line width narrowing, which proofs the predicted phenomena.

TT 5.3 Mon 10:00 BH 243

Gradiometric persistent current flux qubit with tunable tunnel coupling — •Manuel Johannes Schwarz[1,2], Jan Goetz[1,2], Zhaohai Jiang[1,2], Frank Deppe[1,2], Achim Marx[1], and Rudolf Gross[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching — [2]Physik Department, TU München, Garching

The persistent current flux qubit is a Josephson junction based superconducting circuit exhibiting strong anharmonicity and excellent coherence time of more than 10 μs. However, quantum coherence deteriorates drastically away from an optimal operation point. Moreover, a controlled adjustment of the transition frequency at the optimal point requires excellent stability of the fabrication process. Here, we present the spectroscopic analysis of a gradiometric flux qubit, where the minimal transition frequency, the qubit gap, can be tuned in situ while staying at the point of optimal coherence. We show a tunability of the qubit gap from a few hundreds of megahertz to several gigahertz, making the system suitable for future experiments with coupled qubit-resonator systems.

This work is supported by the DFG via SFB 631 and by the German Excellence Initiative via NIM.

TT 5.4 Mon 10:15 BH 243

Four-level lasing in the two-qubit system — •Sergey Shevchenko[1,2], Simon van der Ploeg[2], Miroslav Grajcar[2,3], Evgeniy Temchenko[1], Alexandr Omelyanchouk[1], Evgeniy Il'ichev[2], and Hans-Georg Meyer[2] — [1]Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine — [2]Institute of Photonic Technology, Jena, Germany — [3]Comenius University, Bratislava, Slovakia

The system of two coupled qubits can be described as a quantum four-level system. To make it useful for applications, e.g. for lasing, the hierarchy of relaxation times is needed. Such a situation occurs naturally in a case of two coupled superconducting qubits [1]. We have studied both experimentally and theoretically resonant excitation and relaxation in this system [1,2]. Two types of the multi-photon transitions were demonstrated: the direct and the ladder-type ones. This can be used for the creation of the inverse population, which was discussed in relation to the possibility of three- and four-level lasing in the system [2].

[1] E. Il'ichev, S.N. Shevchenko, S.H.W. van der Ploeg, M. Grajcar, E.A. Temchenko, A.N. Omelyanchouk, and H.-G. Meyer, Phys. Rev. B 81, 012506 (2010).
[2] E. A. Temchenko, S. N. Shevchenko, A. N. Omelyanchouk, Phys. Rev. B 83, 144507 (2011).

TT 5.5 Mon 10:30 BH 243

Observation of the Geometric Phase of a Harmonic Oscillator in Circuit Quantum Electrodynamics — •Stefan Filipp, Marek Pechal, Simon Berger, Abdufarrukh A. Abdumalikov, and Andreas Wallraff — ETH Zurich, Department of Physics, 8093 Zurich, Switzerland

Transporting a quantum harmonic oscillator state along a closed path in Hilbert space leads to a path-dependent geometric phase. However, the linearity of the system precludes its observation without a non-linear quantum probe. We therefore make use of a superconducting qubit serving as an interferometer to measure the geometric phase of a harmonic oscillator realized as an on-chip transmission line resonator [1]. We demonstrate the proportionality of the geometric phase to the enclosed area for a variety of path shapes. At the transition to the non-adiabatic regime, we analyze corrections to the geometric phase and show how entanglement between the two-level system and the harmonic oscillator leads to dephasing. This system provides a versatile tool to study adiabatic and non-adiabatic geometric phases in open quantum systems and as a resource for quantum information processing.

[1] M. Pechal, S. Berger, A.A. Abdumalikov, A. Wallraff and S. Filipp, arxiv:1109.1157 [quant-ph] (2011)

TT 5.6 Mon 10:45 BH 243

High cooperativity in a microwave resonator coupled to YIG — Hans Huebl[1], •Johannes Lotze[1], Christoph Zollitsch[1,2], Fredrik Hocke[1], Sebastian T. B. Goennenwein[1], and Rudolf Gross[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany

Understanding the coupling of magnetic moments (spins) to light fields (photons) on a quantum level is of fundamental interest. Recent work [1,2] on paramagnetic samples coupled to superconducting resonators has shown coherent coupling between microwave photons and electron spins. This coupling is enhanced compared to a single spin by a factor of $\sqrt{N}$, where N is the number of spins in the ensemble. Here, we study a bulk ferrimagnetic Ga-doped yttrium iron garnet (YIG) crystal coupled to a superconducting niobium resonator operating at 6 GHz. Measuring the transmission through the resonator in a magnetic field, we observe an anticrossing of the spin and photon dispersions with a splitting of 450 MHz. Analyzing the magnetic field dependence of the resonance linewidths in this system in the interaction regime, we find that the coupling clearly dominates the intrinsic loss rates of the spin system and the resonator, an important requirement for studying the magnon-photon interaction in the strong coupling regime. The impact of microwave power and system temperature will be critically discussed.

[1] D. I. Schuster *et al.*, Phys. Rev. Lett. **105**, 140501 (2010)
[2] Y. Kubo *et al.*, Phys. Rev. Lett. **105**, 140502 (2010)

15 min. break.

TT 5.7 Mon 11:15 BH 243

Measurement scheme for the Lamb shift in a superconducting circuit with broadband environment — •Vera Gramich[1], Paolo Solinas[2,3], Mikko Möttönen[2,3], Jukka Pekola[3], and Joachim Ankerhold[1] — [1]Institut für Theoretische Physik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany — [2]Department of Applied Physics/COMP, Aalto University, P.O. Box 14100, FI-00076 Aalto, Finland — [3]Low Temperature Laboratory, Aalto University, P.O. Box 13500, FI-00076 Aalto, Finland

Motivated by recent experiments on quantum mechanical charge pumping in a Cooper pair sluice [1], we present a measurement scheme for observing shifts of transition frequencies in two-level quantum systems induced by broadband environmental fluctuations. In contrast to quantum optical and related setups based on cavities, the impact of a thermal phase reservoir is considered. The experimental protocol to measure the Lamb shift in experimentally feasible superconducting circuits is analyzed in detail and supported by numerical simulations [2]. Therefore, we turn our attention to a brief description of the actual setup followed by an analysis of the detection proposal.

[1] A. O. Niskanen, J. P. Pekola, and H. Seppä, Phys. Rev. Lett. 91, 177003 (2003).
[2] V. Gramich, P. Solinas, M. Möttönen, J. P. Pekola, and J. Ankerhold, Phys. Rev. A 84, 052103 (2011).

TT 5.8 Mon 11:30 BH 243

Lasing, trapping states, and multistability in circuit quantum electrodynamical analog of a single-atom injection maser — •Michael Marthaler[1], Juha Leppäkangas[1,2], and Jared Cole[1,3] — [1]Institut für Theoretische Festkörperphysik and DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany — [2]Applied Quantum Physics Laboratory, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden — [3]Chemical and Quantum Physics, School of Applied Sciences, RMIT University, Melbourne 3001, Australia

We study a superconducting single-electron transistor (SSET) which is coupled to a LC oscillator via the phase difference across one of the Josephson junctions. This leads to a strongly anharmonic coupling between the SSET and the oscillator. The coupling can oscillate with the number of photons, which makes this system very similar to the single-atom injection maser. However, the advantage of a design based on superconducting circuits is the strong coupling and existence of standard methods to measure the radiation field in the oscillator. This makes it possible to study many effects that have been predicted for the single-atom injection maser in a circuit quantum electrodynamics setup.

TT 5.9 Mon 11:45 BH 243

Towards photon quantum gates in circuit qed — •Lukas Neumeier, Martin Leib, and Michael Hartmann — TU München, Munich,Germany

Quantum information processing can be decomposed into quantum channels and quantum gates. Photons are well suited for transferring information whereas stationary qubits offer better perspectives for implementing gates. Traditionally in circuit qed quantum gates are therefore realized by interactions between stationary superconducting qubits. As opposed to this we analyze a circuit qed setup where itinerant microwave photons, confined to two one dimensional transmission-lines, interact at a localized superconducting qubit. We provide results for reflection and transmission spectra and photon measurement probabilities for both waveguides which depend on the incoming single or two-photon pulses.

TT 5.10 Mon 12:00 BH 243

Bose-Hubbard dynamics in a chain of nonlinear superconducting transmission-line resonators — •Martin Leib and Michael J. Hartmann — TU München,Munich,Germany

Quantum mechanical many body physics offers many interesting phenomena and its simulation in well controlable experimental setups is therefore attracting increasing attention. We propose a superconducting circuit setup where microwave photons in an array of transmission line resonators interact due to an intrinsic nonlinearity of the resonators. We show that a transmission line resonator which is intersected by a Josephson junction can be approximatly described as a harmonic oscillator with a Kerr nonlinearity, making the whole array of resonators a quantum simulator for a Bose-Hubbard Hamiltonian. Strong nonlinearities and long coherence times can be easily achieved in superconducting circuits and in addition individual readout and control of resonators can be realized with current state of the art experimental techniques.

TT 5.11 Mon 12:15 BH 243

Backaction of Microwave Photon Detection by a Strongly Coupled Josephson Junction — •Emily Pritchett[1], Luke Govia[2], Seth Merkel[3], and Frank Wilhelm[1] — [1]Saarland University, Saarbrucken, Deutschland — [2]University of Waterloo, Waterloo, Canada — [3]IBM Watson Research Center, Yorktown Heights, USA

We analyze the functionality of on-chip Josephson junctions as single microwave photon detectors, as has been demonstrated recently [1]. The Josephson junction device, which we refer to as a Josephson Photomultiplier (JPM), acts as a nearly perfect binary detectors of microwave photons by undergoing an observable switching event when there are one or more photons in an incident cavity. We analyze the backaction of this switching event on the state of incident light, including the energy dissipation and dephasing affecting an imperfect JPM. This analysis improves the efficiency and fidelity with which a JPM reconstructs the state of light in an incident transmission line 'cavity', which are commonly used to store and transfer quantum states in implementations of circuit-QED.

[1] Chen et al., arXiv:1011.4329

TT 5.12 Mon 12:30 BH 243

Time-resolved qubit readout via nonlinear Josephson inductance — •Georg Michael Reuther[1], Peter Hänggi[1], and Sigmund Kohler[2] — [1]Institut für Physik, Universität Augsburg, Universitätsstr. 1, 86159 Augsburg, Germany — [2]Instituto de Ciencia de Materiales de Madrid (CSIC) C/Sor Juana Inés de la Cruz 3, Cantoblanco 28049 Madrid, Spain

We propose a generalization of dispersive qubit readout which provides the time evolution of a flux qubit observable. Our proposal relies on the non-linear coupling of the qubit to a harmonic oscillator with high frequency, representing a dc-SQUID. Information about the qubit dynamics is obtained by recording the oscillator response to resonant driving and subsequent lock-in detection. We simulate this measurement process for the example of coherent qubit oscillations and, in doing so, we corroborate the underlying measurement relation. In addition, we derive a quantum master equation for the qubit alone. With this at hand, we investigate the dependence of qubit dephasing on the measurement backaction that is induced by the oscillator driving [1].

[1] Georg M. Reuther, David Zueco, Peter Hänggi, and Sigmund Kohler, New J. Phys. 13, 093022 (2011)