TT 3: Quantum Coherence and Quantum Information Systems I

Time: Monday 9:30–13:00 Location: H20

Invited Talk TT 3.1 Mon 9:30 H20

Experimental investigation of superconducting flux qubits — •Evgeni Ilichev — Institute for Physical High Technology, P.O. Box

We have investigated systems consisting of one, two, three or four flux qubits. In order to determine the magnitude of the coupling energy, we have measured the magnetic susceptibility of the qubit system through their influence on the resonant properties of a weakly coupled high-quality tank circuit. We show, that the system's Hamiltonian could be completely reconstructed from measurements far away from the common degeneracy point of a flux qubit system. The subsequent measurements around this point show complete agreement with the theoretical predictions following from its Hamiltonian. The ground state anti-crossings of the system could be read-out directly from these measurements. For a three-flux-qubit system this allows the determination of the ground-state flux diagram in the complete three dimensional flux space. We have also demonstrated that the fixed coupling energy can be varied in a wide range: from several millikelvins up to several kelvins. Recently, we have also demonstrated a tuneable coupling between flux qubits.

TT 3.2 Mon 10:00 H20

Quasiparticle transitions in Josephson charge-phase qubits with radio frequency read-out — •Jens Könemann, Hermann Zangerle, Brigitte Mackrodt, Ralf Dolata, and Alexander Zorin — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Tunneling of single quasiparticles in Josephson qubits operating on single Cooper pairs presents a serious problem. This tunneling instantly changes the working point of the qubit and, therefore, its charge state and transition frequency, which leads to decoherence. Moreover, one can expect both relaxation and excitation of the qubit induced by quasiparticle tunneling. We have investigated Al Josephson charge-phase qubits of SQUID-configuration inductively coupled to a radio-frequency tank circuit with a resonant frequency of about 77 MHz, thus enabling the readout of the state by measuring the Josephson inductance of the qubit. Depending on the flux and charge bias and the amplitude of rf-oscillations we have probed either a plain 2e-behavior in the dependence on gate charge corresponding to the ground state or a dynamic change of ground and excited states. The latter behavior is explained in terms of stochastic single quasi-particle tunneling onto and off the island of the qubit and, hence, possible transfer of energy from the quasiparticles to the qubit system. For this process we derive a selection rule which explains the observed suppression of the quasiparticle-induced transitions in the qubit operating in the magic point $q = e$

TT 3.3 Mon 10:15 H20

Temperature Dependence of Rabi Oscillations in Phase Qubits — •Jürgen Lisenfeld, Alexandr Lukashenko, and Alexey Ustinov — Physikalisches Institut III, Universität Erlangen-Nürnberg

We will present measurements of Josephson phase qubits which feature the phase eigenstates of a Josephson junction placed in a superconducting loop and biased at a magnetic flux close to one flux quantum. The phase qubit is controlled by resonant microwaves and read out by a dc-SQUID measuring its flux state. We have measured Al-based phase qubits with SiNx shunting capacitors made at UCSB [1] and our similarly designed circuits fabricated at Hypres foundry using a standard Nb-based fabrication process with SiO_2 insulation. Rabi oscillations decay at half-life times that are about 100 ns and 5 ns, respectively.

We find that the oscillation amplitude as well as decay time do not decrease up to the temperature, at which the thermal energy $k_B T$ becomes comparable to the energy level separation. The oscillations disappear at about 400 mK for the Al qubits and at about 700 mK for the qubits made of Nb. Our data point towards non-thermal origin of decoherence limiting the low-temperature performance of the phase qubits.

[1] M. Steffen, et al. Phys. Rev. Lett. **97**, 050502 (2006)

TT 3.4 Mon 10:30 H20

Reading-out the state of a flux qubit by Josephson transmission line solitons — •Arkady Fedorov[1], Alexander Shnirman[1], Gerd Schoen[1], Andreas Poenicke[1], and Anna Anna Kidiyarova-Shevchenko[2] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe, D–76128 Karlsruhe, Germany — [2]Microtechnology and Nanoscience Department, Chalmers University of Technology, 412 96 Gothenburg, Sweden

We describe the read-out process of the state of a Josephson flux qubit via solitons in a Josephson transmission line (JTL). We consider the situation where the qubit is inductively coupled to the JTL and the information about the state of the qubit is stored in the time delay of the soliton. To investigate the efficiency that can be achieved in the proposed measurement scheme for relevant experimental parameters we evaluate the delay time in three different setups: a) when the qubit is kept away from the symmetry point all the time; b) when the qubit is initially prepared at the symmetry point, but the approaching soliton pushes the qubit far from the symmetry point; c) when the qubit is near the symmetry point all the time. We analyze the relation between the delay time and the dissipation as well as the probability of errors introduced by the measurement. Finally, we compare the delay time with the characteristic time uncertainty due to jitter (thermal fluctuations) in the JTL, and we determine how many solitons are needed for a reliable measurement.

TT 3.5 Mon 10:45 H20

Dynamics of a flux qubit coupled to a nonlinear structured environment — •Marnix Wakker[1], Francesco Nesi[2], Cristiane Morais Smith[1], and Milena Grifoni[2] — [1]Institut for Theoretical Physics, University of Utrecht — [2]Institut for Theoretical Physics, University of Regensburg

We investigate the dynamical decoherence and dephasing of a quantum two-state system (qubit) where the environment is formed by a broadened localized nonlinear mode. This situation mimics recent experimental set-ups [1,2] where the flux qubit is coupled to a DC-SQUID, the latter used as a flux-sensitive Josephson inductor for qubit readout. Depending on the amplitude of the readout resonant driving, the SQUID behaves as a linear or a nonlinear oscillator. We consider the case of a flux qubit coupled to a SQUID considered as a nonlinear environment, which is itself coupled to an Ohmic bath. For small nonlinearities, we can find an effective bath description for the environment seen by the qubit. The problem can in fact be mapped onto a spin-boson model with a structured spectral density containing two or more peaks. For vanishing nonlinearity, the spectral density shows a single braodened peak centered at the SQUID plasma frequency. By calculating the qubit's dynamics within the non-interacting-blip approximation, effects of the non-linearity show up in multiple Rabi peaks, a feature which could also be experimentally detected.

[1] P. Bertet *et* al., Phys. Rev. B **79**, R100501 (2004). [2] J.C. Lee *et* al., IEEE Trans. Appl. Superconductivity **15**, 841 (2005).

TT 3.6 Mon 11:00 H20

Quantum state preparation via Landau-Zener tunneling — •Sigmund Kohler[1], Martijn Wubs[1], Peter Hänggi[1], Keiji Saito[2], and Yosuke Kayanuma[3] — [1]Institut für Physik, Universität Augsburg — [2]University of Tokyo, Japan — [3]Osaka Prefecture University, Japan

The coupling of a qubit to a circuit-QED mode can induce Landau-Zener transitions of the qubit upon switching the magnetic flux that penetrates the superconducting loop. The adiabatic energies of this system are characterized by multiple exact and avoided level crossings, so that the usual two-level Landau-Zener formula is no longer applicable. We derive selection rules for the multi-level transitions and present an exact expression for the corresponding transition probabilities. Applications include quantum state preparations like single-photon generation and the controllable creation of qubit-oscillator entanglement. [1] K. Saito, M. Wubs, S. Kohler, P. Hänggi, and Y. Kayanuma, Europhys. Lett. **76**, 22, (2006).

15 min. break

TT 3.7 Mon 11:30 H20

One-qubit laser and cooler — Julian Hauss[1], •Carsten Hutter[1,2], Arkady Fedorov[1], Alexander Shnirman[1], and Gerd

Schön[1] — [1]Institut für Theoretische Festkörperphysik, Universität Karlsruhe, D-76128 Karlsruhe, Germany — [2]Department of Physics, Stockholm University, AlbaNova University Center, SE-10961 Stockholm, Sweden

We consider a setup performing Rabi spectroscopy of a superconducting qubit. The system consists of a slow electromagnetic or nanomechanical oscillator coupled to a resonantly driven superconducting qubit. When the Rabi frequency of the qubit coincides with the eigenfrequency of the oscillator the latter can be driven into a strongly non-equilibrium state. Experiments of this type have recently been performed [1].

We find that by introducing detuning in the driving of the qubit one can create a population inversion at the Rabi frequency and this can lead to a "lasing" behavior of the qubit-oscillator system. In particular we consider a situation when the qubit is kept at its symmetry point where the decoherence due to $1/f$ noise is minimal. Then the coupling to the oscillator is quadratic and the system realizes a "single-atom-two-photon laser".

[1] E. Il'ichev et *al.*, Phys. Rev. Lett. **91**, 097906 (2003)

TT 3.8 Mon 11:45 H20

Quantum Theory of Cavity-Assisted Sideband Cooling of Mechanical Motion — •Florian Marquardt[1], Joe P. Chen[2], Aashish A. Clerk[3], Jack G. E. Harris[2], and Steven M. Girvin[2] — [1]Arnold Sommerfeld Center for Theoretical Physics, Department für Physik und Center for NanoScience, Ludwig-Maximilians Universität München, Germany — [2]Department of Physics, Yale University, New Haven, USA — [3]Department of Physics, McGill University, Montreal, Canada

We present a fully quantum theory describing the cooling of a cantilever coupled via radiation pressure to an illuminated optical cavity. Applying the quantum noise approach to the fluctuations of the radiation pressure force, we derive the opto-mechanical cooling rate and the minimum achievable phonon number. We find that reaching the quantum limit of arbitrarily small phonon numbers requires going into the good cavity (resolved phonon sideband) regime where the cavity linewidth is much smaller than the mechanical frequency and the corresponding cavity detuning. This is in contrast to the common assumption that the mechanical frequency and the cavity detuning should be comparable to the cavity damping.

TT 3.9 Mon 12:00 H20

Phase Purcell effect and the crossover to strong coupling in dispersive circuit QED — •Ioana Serban[1,2], Frank Wilhelm[2], and Enrique Solano[1] — [1]Ludwig-Maximilians-Universitaet, Munich, Germany — [2]Institute for Quantum Computing, Waterloo, Canada

We study the decoherence of a superconducting qubit due to the dispersive coupling to a damped harmonic oscillator. We go beyond the weak qubit-oscillator coupling, which we associate with a phase Purcell effect, and enter into an unexplored decoherence regime, solving a theoretical inconsistency in existing models: the divergence of the qubit dephasing rate in the absence of environment. Our results can be applied, with small adaptations, to a large variety of other physical systems, e.g. trapped ions and cavity QED, boosting theoretical and experimental decoherence studies.

TT 3.10 Mon 12:15 H20

2D Cavity Grid Quantum Computing — •Ferdinand Helmer[1], Jan von Delft[1], Matteo Mariantoni[2], Florian Marquardt[1], and Enrique Solano[1] — [1]Arnold-Sommerfeld-Center for Theoretical Physics, Ludwig-Maximilians-Universität, Munich, Germany — [2]Walther-Meissner-Institut, Garching/Munich, Germany

We propose a novel scheme for scalable solid state quantum computing, where superconducting on-chip microwave resonators (cavities) are arranged in a two-dimensional grid, coupling to superconducting qubits (charge or flux) at the intersections. We analyze how tasks of quantum information processing can be implemented in such a topology, including efficient two-qubit gates between any two qubits, initialization and read-out. The effects of decoherence, fabrication imperfections and inhomogeneities will be addressed. This work is supported by the SFB 631.

TT 3.11 Mon 12:30 H20

Theoretical and experimental studies of circuit QED systems — •Frank Deppe[1], Matteo Mariantoni[1], Shiro Saito[2], Takayoshi Meno[3], Kouichi Semba[2], Hideaki Takayanagi[4], and Rudolf Gross[1] — [1]Walther-Meißner-Institut, Garching/München, Germany — [2]NTT BRL, NTT Corp., Atugi, Japan — [3]NTT AT, NTT Corp., NTT, Japan — [4]Tokyo Univ. of Science, Tokyo, Japan

In recent years, the interaction between a superconducting qubit and and on-chip microwave resonator has been investigated in several theoretical and experimental studies. We performed microwave spectroscopy on a system composed of a superconducting flux qubit and the single mode of an LC circuit resonator. The LC resonator is formed by the capacitance and line inductance of the shunting circuit of the DC SQUID used to read-out the qubit state. Our implementation of circuit QED provides a counterpart to experiments where the state of the microwave field is detected. The spectroscopy data shows clear evidence of the coupled system. The coupling constant is of the order of a few tens of megahertz. We also performed simulations of a dissipation-less driven Jaynes-Cummings model in order to estimate the effective number of photons present in the resonator. A possible interesting application of our architecture would the generation of microwave single photons. This work is supported by the DFG via SFB 631.

TT 3.12 Mon 12:45 H20

Nonlinear interaction and two-mode squeezing with superconducting flux qubits. — Matteo Mariantoni[1], Frank Deppe[1], Rudolf Gross[1], Frank Wilhelm[2], and •Enrique Solano[3,4] — [1]Walther-Meissner-Institut, Garching, Germany — [2]IQC and University of Waterloo, Waterloo, Canada — [3]Ludwig-Maximilians-Universität, Munich, Germany — [4]Pontificia Universidad Católica del Perú, Lima, Peru

The interaction between superconducting quantum circuits and on-chip microwave resonators represents a rich field of research. We focus on the general, nonlinear interaction of a superconducting flux qubit with three modes of a coplanar wave-guide resonator and show how to implement, through suitable resonant conditions, a first-order Hamiltonian that yields nondegenerate, two-mode squeezing of the cavity field. Furthermore, we study the coherent properties of this engineered interaction and prove that it is able to generate a high degree of entanglement, while approaching perfect squeezing at the cavity output. Finally, we consider a realistic scenario including the presence of decoherence effects to evaluate the robustness of the proposed squeezing mechanism. This work is partially supported by the DFG via SFB 631.