TT 23: TR: Quantum Coherence and Quantum Information Systems 2

Time: Wednesday 14:00–17:00 Location: H18

TT 23.1 Wed 14:00 H18

Dynamics of strongly coupled Qubit-TLF systems — •Clemens Müller[1,2], Jared H. Cole[3,2], Jürgen Lisenfeld[4], Pavel Bushev[4], Alexander Shnirman[1,2], and Alexey V. Ustinov[4,2] — [1]Institut für Theorie der Kondensierten Materie, KIT, Karlsruhe, Germany — [2]DFG-Center for Functional Nanostructures (CFN), Karlsruhe, Germany — [3]Institut für Theoretische Festkörperphysik, KIT, Karlsruhe, Germany — [4]Physikalisches Institut, KIT, Karlsruhe, Germany

Spectroscopy of superconducting qubits often shows clear signatures of avoided crossings, indicating the presence of intrinsic two-level fluctuators (TLFs). Experiments are usually performed when the qubit is well detuned from resonance with these TLF since they are considered a source of decoherence. Alternatively one can tune the qubit in resonance with a TLF and observe the dynamics of the coupled multi-level system. We show results on rabi-spectroscopy in and near resonance with an individual TLF in the regime where both the coupling between qubit and TLF as well as the Rabi-frequency is strong. In addition we report on driving the system with high power, when the effect of higher levels in the qubit become important. This may pave the way towards understanding the microscopic nature of the TLFs.

TT 23.2 Wed 14:15 H18

Dissipative dynamics of driven quantum systems: a combined Floquet-Van-Vleck approach — •Johannes Hausinger, Carmen Vierheilig, and Milena Grifoni — Universität Regensburg, 93040 Regensburg, Germany

We investigate open quantum systems which are coupled to a classical, time-periodic field. Popular approximations to solve those time-dependent systems are the rotating wave approximation (RWA) and/or a perturbative expansion in the driving amplitude. In our work we combine Floquet theory with Van Vleck perturbation theory, which allows us to go beyond the RWA results and to arbitrary strong driving amplitudes, thus providing insight in so far not well explored parameter regimes. Environmental influences are accounted for by solving the Floquet-Bloch-Redfield master equation for the system's dynamics.

Our approach can be applied for example to examine the behavior of qubits in the strong driving regime leading to so-called dressed states and multi-photon Rabi oscillations [1]. We solve the corresponding spin-boson problem and give analytical results for the renormalized Rabi frequency, dephasing and relaxation times of the qubit going beyond the known RWA and high-frequency results [2].

Further, we apply the above formalism to a driven qubit-detector system; i.e., we couple the qubit to a linear/nonlinear oscillator, which represents for example the read-out by a dc-SQUID and investigate the resulting modifications of the dissipative qubit dynamics.

[1] C. M. Wilson et al., Phys. Lett. **98**, 257003 (2007)
[2] J. Hausinger, and M. Grifoni, arxiv:0910.0356 (2009)

TT 23.3 Wed 14:30 H18

Josephson quartic oscillator as a superconducting phase qubit — •Alexander Zorin[1] and Fabio Chiarello[2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Istituto di Fotonica e Nanotecnologie, CNR, 00156 Rome, Italy

Due to interplay between the cosine Josephson potential and parabolic magnetic-energy potential the radio-frequency SQUID with the screening parameter value $\beta_L \equiv (2\pi/\Phi_0)LI_c \approx 1$ presents an oscillator circuit which energy well can dramatically change its shape. Ultimately, the magnetic flux bias of half flux quantum $\Phi_e = \Phi_0/2$ leads to the quartic polynomial shape of the well and, therefore, to significant anharmonicity of oscillations ($> 30\%$). We show that the two lowest eigenstates in this symmetric global minimum perfectly suit for designing the qubit which is inherently insensitive to the charge variable, always biased in the optimal point and allows efficient dispersive and bifurcation-based readouts. Moreover, in the case of a double-SQUID configuration (dc SQUID instead of a single junction) the transition frequency in this Josephson phase qubit can be easy tuned within an appreciable range allowing variable qubit-qubit and qubit-resonator couplings.

Invited Talk TT 23.4 Wed 14:45 H18

Superconducting Flux Qubits in Circuit QED and Detection of Weak Microwave Signals — •Achim Marx[1], Alex Baust[1], Elisabeth Hoffmann[1], Matteo Mariantoni[1], Edwin P. Menzel[1], Thomas Niemczyk[1], Manuel Schwarz[1], Thomas Weissl[1], Enrique Solano[2], Juan J. Garcia-Ripoll[3], Frank Deppe[1], Hans Hübl[1], and Rudolf Gross[1] — [1]Walther-Meissner-Institut and TU München, Germany — [2]Universidad del País Vasco and Ikerbasque Foundation, Bilbao, Spain — [3]Instituto de Fisica Fundamental, CSIC, Madrid, Spain

Superconducting qubits behave as artificial two-level atoms. Coupling them to on-chip microwave resonators has given rise to the field of circuit quantum electrodynamics, where fundamental quantum properties can be investigated. Here, we present spectroscopy data on single and two flux qubits coupled to a coplanar transmission line resonator. The strong coupling regime can be readily accessed both for inductive and galvanic coupling. The inherent tunability of the artificial atoms allows to control the symmetry properties of the coupled qubit-resonator system. Systems consisting of several resonators, which can be coupled by using superconducting qubits can be used to generate quantum microwave signals. To detect such weak microwave signals on a single photon level we have developed a signal recovery method based on a cross-correlation technique. This method has been successfully applied to analyze thermal microwave states and propagating signals on a single photon level. We acknowledge support from SFB 631, NIM, UPV/EHU Grant GIU07/40 and European project EuroSQIP.

TT 23.5 Wed 15:15 H18

Spectral properties of single-qubit lasers — •Stephan André[1,2], Valentina Brosco[3], Alexander Shnirman[2,4], and Gerd Schön[1,2] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [3]Dipartimento di Fisica, Università "La Sapienza", P.le A. Moro 2, 00185 Roma, Italy — [4]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

Recent experiments demonstrated lasing and cooling of the electromagnetic field in an electrical resonator coupled to a superconducting qubit [1]. In this work, we theoretically investigate the spectral properties of single-qubit lasers by numerically solving the full Liouville equation for the density matrix. We extend the usual quantum optics description to acccount for strong qubit-resonator coupling and to include the effects of low-frequency noise.

We present results for the linewidth and the lineshape of the emission spectrum. We find that the linewidth grows with the qubit-resonator coupling strength beyond the lasing transition, thus deteriorating the lasing state [2]. Our results also show that quantum correlations have a significant effect on the spectral properties and that low-frequency noise might explain the shape and width of the emission spectrum observed in the experiment.

[1] O. Astafiev *et al.*, Nature **449**, 588 (2007)
[2] S. André *et al.*, arXiv:0908.4227 (2009)

TT 23.6 Wed 15:30 H18

Coupling of a quantum oscillator to a superconducting flux qubit at its symmetry point — •Pascal Macha[1], Arkady Fedorov[2], Alexey K. Feofanov[3], Pol Forn-Diaz[2], Evgeni Il'ichev[1], Alexey. V. Ustinov[3], Kees Harmans[2], and J. E. Mooij[2] — [1]Institute of Photonic Technology, Jena, Germany — [2]Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands — [3]Karlsruhe Institute of Technology, Germany

Resonant coupling of a quantum oscillator ($\hbar\omega > k_BT$) in the low–photon limit to a flux qubit at its symmetry point provides optimal conditions for the realization of cavity-QED experiments, i.e. long coherence times and the largest qubit–oscillator coupling. We report an experiment demonstrating this regime using the recently developed tunable gap flux qubit [1]. The control over the energy barrier height enables us to tune the gap of the flux qubit in and out of resonance with a superconducting LC resonator. We performed spectroscopic measurements of the qubit–oscillator system and demonstrate vacuum Rabi oscillations for various representative cases. We find that the decay time of these oscillations for the qubit operated at its symmetry point is not affected by 1/f flux noise and is only limited by the quality factor of the resonator. This work contributes to the development of advanced quantum information processing schemes with superconducting qubits.

[1] F. G. Paauw, A. Fedorov, C. J. Harmans, and J. E. Mooij, PRL **102**, 090501 (2009)

15 min. break

TT 23.7 Wed 16:00 H18

Selection rules for multiphoton excitations in a qubit-resonator system — Thomas Niemczyk[1], •Frank Deppe[1,2], Hans Huebl[1], Edwin Menzel[1], Fredrik Hocke[1], Elisabeth Hoffmann[1,2], Manuel Schwarz[1], Achim Marx[1], and Rudolf Gross[1,2] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik Department E23, Technische Universität München, 85748 Garching, Germany

The theoretical analysis of a qubit-resonator system reveals selection rules at certain symmetry points of the qubit. In the case of a superconducting flux qubit, this symmetry of the double-well potential can be broken in a controlled way by changing the external magnetic field. Only then, odd and even multiphoton processes can coexist at the same flux bias. We illustrate this phenomenon with spectroscopy measurements of a superconducting flux qubit strongly coupled to an onchip coplanar waveguide resonator. Our studies extend up to three-photon driving and clearly show the transition from strict selection rules to a regime of coexistent multiphoton excitations.

Financial support via SFB631 and the Excellence Initative via NIM is gratefully acknowledged.

TT 23.8 Wed 16:15 H18

Strong coupling of two flux qubits to a colanar waveguide resonator — •Thomas Niemczyk[1], Hans Huebl[1], Frank Deppe[1,2], Edwin Menzel[1], Manuel Schwarz[1], Elisabeth Hoffmann[1,2], Fredrik Hocke[1], Achim Marx[1], and Rudolf Gross[1,2] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik Department E23, Technische Universität München, 85748 Garching, Germany

The field of circuit QED opens new possibilities in both quantum information processing and studies of fundamental quantum mechanics "on a chip". Central building blocks are qubit circuits, which interact with on-chip superconducting microwave resonators. Of particular importance is the strong-coupling regime, where the coupling strength exceeds all relevant decay rates in the system. Here, we present spectroscopic measurements on two superconducting flux qubits strongly coupled to a coplanar waveguide resonator.
Finacial support via SFB631 and the Excellence Initative via NIM is gratefully acknowledged.

TT 23.9 Wed 16:30 H18

Dual-path measurements of propagating microwave signals at the quantum level for circuit QED — •Edwin P. Menzel[1], Matteo Mariantoni[1], Frank Deppe[1], Miguel Angel Araque Caballero[1], Alexander Baust[1], Elisabeth Hoffmann[1], Thomas Niemczyk[1], Achim Marx[1], Rudolf Gross[1], Enrique Solano[2], Kunihiro Inomata[3], Tsuyoshi Yamamoto[3,4], and Yasunobu Nakamura[3,4] — [1]Walther-Meissner-Institut and TU München, Garching, Germany — [2]Universidad del Pais Vasco and Ikerbasque Foundation, Bilbao, Spain — [3]RIKEN, Wako, Japan — [4]NEC Corporation, Tsukuba, Japan

Few-photon propagating microwave signals can be characterized by means of a beam splitter and two amplification chains. We show that such a setup is robust against random noise added by the amplifiers. Even if this noise is much larger than the signal itself, the first two signal moments and, hence, Gaussian states can be analyzed via correlation measurements. We discuss possible applications of the dual-path method for detecting squeezed states generated by a superconducting Josephson parametric amplifier and in circuit QED setups.

We acknowledge support from SFB631, NIM, UPV/EHU Grant GIU07/40 and European project EuroSQIP.

TT 23.10 Wed 16:45 H18

Josephson current and quantum cavity modes — Jakob Hammer[1] and •Marco Aprili[2] — [1]Universität Regensburg, Germany — [2]Laboratoire de Physique des Solides, France

Extended Josephson junctions support resonant quantum cavity modes in the weak link. We succeeded to excite selected modes in a controlled manner and to detect this excitations as modifications of the Fraunhofer interference pattern of the junction. Furthermore very small numbers of thermally excited photons are reflected in the shape of the switching current histogram. In addition we observed an increase of the Josephson critical current when the microwave frequency is slightly detuned from the cavity mode resonance. This effect is consistant with cavity induced phase cooling.