TT 27: Symposium: Circuit QED

Time: Thursday 9:30–13:00 Location: H 0104

Invited Talk TT 27.1 Thu 9:30 H 0104

Single artificial-atom maser — •Yasunobu Nakamura[1,2,3], Oleg Astafiev[1,2], Kunihiro Inomata[2], Antti O. Niskanen[3,4], Tsuyoshi Yamamoto[1,2,3], Yuri A. Pashkin[1,2], and Jaw-Shen Tsai[1,2,3] — [1]NEC Nano Electronics Research Laboratories — [2]RIKEN Frontier Research System — [3]CREST-JST — [4]VTT Technical Research Centre of Finland

Masers and lasers usually involve ensemble of atoms to be excited and stimulated for emission. As those atoms are only weakly coupled to the cavity mode, a large number of atoms and strong pumping are needed for lasing in order to overcome the cavity loss and the relaxation of atoms due to spontaneous emission into other modes. However, when the coupling becomes strong even a single atom is enough for lasing, as have been demonstrated with atoms in microwave/optical cavities. We have realized an analogous single artificial-atom maser in a superconducting circuit. Josephson-junction charge qubit is used as an artificial atom with a large dipole. The qubit is coupled to a superconducting Nb coplanar-waveguide resonator at around 10 GHz and with a quality factor of 7600. The coupling strength between the qubit and the resonator is 80 MHz. Population inversion is generated by current injection: A current is injected through a voltage-biased electrode attached to the charge qubit via a highly resistive tunnel junction. In the so-called Josephson-quasiparticle process, the qubit is pumped incoherently to the upper state and emits photon into the cavity. Reference: O. Astafiev et al., Nature 449, 588 (2007).

Invited Talk TT 27.2 Thu 10:00 H 0104

Sisyphus cooling and amplification by a superconducting qubit — •Evgeni Il'ichev[1], M. Grajcar[1,2], S.H.W. van der Ploeg[1], A. Izmalkov[1], H.-G. Meyer[1], A. Fedorov[3], A. Shnirman[4], and Gerd Schoen[5] — [1]Institute of Photonic Technology, Albert-Einsteinstr 9, 07745, Jena, Germany — [2]Department of Experimental Physics, Comenius University, SK-84248 Bratislava, Slovakia — [3]Quantum Transport Group, Delft University of Technology, 2628CJ Delft, The Netherlands — [4]Institut für Theoretische Physik, Universität Innsbruck, Austria — [5]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe, Germany

Recently superconducting qubits have been shown to act as artificial two-level atoms, demonstrating many different quantum effects known in quantum optics. Coupling such qubits to resonators is quite natural extension of this analogy. Similar to laser cooling of the atomic motion we demonstrate here Sisyphus cooling of a low frequency LC oscillator coupled to a near-resonantly driven flux qubit. The analogy to the quantum optics is obvious: the LC oscillator plays the role of the mechanical degree of freedom of an atom, while the qubit mimics the electronic, laser driven, transition. We also demonstrate the counterpart of the Sisyphus cooling, namely, Sisyphus amplification.

TT 27.3 Thu 10:30 H 0104

Quantum Computation and Quantum Optics with circuit QED — •Jens Koch — Departments of Physics and Applied Physics, Yale University, New Haven, Connecticut 06520, USA

The idea of harnessing superconducting circuits to act as artificial atoms, and coupling them to microwave transmission line resonators has come a long way since its first realization in 2004. This architecture, termed circuit quantum electrodynamics (QED), has been successfully employed in a number of experiments probing fundamental aspects of quantum mechanics and quantum optics, and has enabled impressive progress towards quantum computing. At the same time, circuit QED constitutes an appealing testbed for the theoretical understanding and modeling of driven open quantum systems. This talk will give an introduction to the basics of circuit QED, and a discussion of recent results obtained with the new transmon qubit, an improved Cooper pair box immune to 1/f charge noise.

Work done in collaboration with L. S. Bishop, A. Blais, J. M. Chow, L. Frunzio, J. M. Gambetta, A. A. Houck, B. Johnson, J. Majer, J. Schreier, D. I. Schuster, A. Wallraff, T. Yu, M. Devoret, S. M. Girvin, and R. J. Schoelkopf.

TT 27.4 Thu 10:55 H 0104

Engineering coherent quantum states in superconducting systems — •Raymond W Simmonds — National Institute of Standards and Technology, Division 817.03, 325 Broadway St. Boulder, CO 80305 USA

Recently, we have taken the first step towards creating and controlling quantum information using superconducting circuits. We have observed for the first time a coherent interaction between two superconducting "atoms" (quantum bits or qubits) and an LC cavity formed by a 7 mm long coplanar waveguide resonant at approximately 9 GHz. When either qubit is resonant with the cavity, we observe the vacuum Rabi mode splitting of the qubit's spectral line. In a time-domain measurement, we observe coherent vacuum Rabi oscillations between either qubit and the resonator. Using controllable shift pulses, we have shown coherent transfer of a arbitrary quantum state. We prepare the first qubit in a superposition state, then this state is transferred to the resonant cavity and then after a short time, we transfer this state into the second qubit. These experiments show that developing custom designed quantum systems on chip is possible, opening up new possibilities for studying quantum mechanics and information science.

15 min. break

TT 27.5 Thu 11:35 H 0104

Observation of Berry's Phase in a Superconducting Qubit Embedded in a Cavity — •Peter Leek[1], Johannes Fink[1], Alexandre Blais[2], Romeo Bianchetti[1], Martin Goeppl[1], Jay Gambetta[3,4], David Schuster[4], Luigi Frunzio[4], Robert Schoelkopf[4], and Andreas Wallraff[1] — [1]Department of Physics, ETH Zürich, Switzerland — [2]Département de Physique, Université de Sherbrooke, Québec, Canada — [3]Institute for Quantum Computing, University of Waterloo, Canada — [4]Departments of Applied Physics and Physics, Yale University, USA

In quantum information science, the phase of a wavefunction plays an important role in encoding information. While most experiments in this field rely on dynamic effects to manipulate this information, an alternative approach is to use geometric phase, which has been argued to have potential fault tolerance [1]. Here we demonstrate the controlled accumulation of a geometric phase, Berry's phase, in a superconducting qubit, manipulating the qubit geometrically using microwave radiation, and observing the accumulated phase in an interference experiment [2]. This is achieved using the excellent phase coherence and qubit control possible in Circuit QED [3]. We find excellent agreement with Berry's predictions, and also observe a geometry dependent contribution to dephasing.

[1] J.A. Jones *et al.*, Nature 403, 869 (2000). [2] P.J. Leek *et al.*, Science, 22 November 2007 (10.1126/science.1149858). [3] A. Wallraff *et al.*, Nature 431, 162 (2004).

TT 27.6 Thu 12:00 H 0104

Strong squeezing in a solid state system — •Michael Marthaler[1], Alexander Shnirman[2], and Gerd Schön[1] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe, D-76128, Germany — [2]Institut für Theoretische Physik, Universität Innsbruck, A-6020 Innsbruck, Austria

A Superconducting Single Electron Transistor (SSET) coupled to an anharmonic oscillator can be used to create a strongly squeezed distribution of photon number states. The transitions caused by quasiparticle tunneling in the SSET have a sharp cut-off, resulting from the vanishing density of states inside the gap. This creates a strong nonlinearity in the rates which increase the number of photons in the oscillator. If the dissipation in the oscillator is low we produce a nearly pure Fock state.

TT 27.7 Thu 12:15 H 0104

Dissipation in circuit QED — •Stephan André[1], Valentina Brosco[1], Gerd Schön[1], and Alexander Shnirman[1,2] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe, Germany — [2]Institut für Theoretische Physik, Innsbruck, Austria

Recently many experimental and theoretical works realized concepts originally introduced in the field of quantum optics [1,2]. In the present work, we study the dynamics of a flux qubit coupled to a slow LC-oscillator in presence of noise. The qubit is driven to perform Rabi oscillations, and the Rabi frequency is tuned to resonance with the oscillator. When the qubit driving frequency is blue-detuned, the system exhibits lasing behaviour; for red detuning, the qubit cools the oscillator. We analyze the effects of different types of environment on the dynamics of this system. We show that there is a remarkable dependence of the lasing and cooling on the noise spectrum acting on the qubit.

[1] E. Il'ichev et al., Phys. Rev. Lett. **91**,097906 (2003).
[2] J.Hauss et al. cond-mat/0701041

TT 27.8 Thu 12:30 H 0104

Quantum Zeno Effect in Detection of Itinerant Microwave Photons — •Ferdinand Helmer[1], Matteo Mariantoni[2], Enrique Solano[1], and Florian Marquardt[1] — [1]Arnold Sommerfeld Center for Theoretical Physics, Department für Physik, Center for NanoScience, Ludwig-Maximilians-Universität Müunchen, Germany — [2]Walther Meissner Institut, Bayerische Akademie der Wissenschaften, Garching b. München, Germany

We propose and analyze a scheme for detecting single microwave photons traveling along a superconducting transmission line on a chip. The setup exploits a nonlinear coupling between different modes in a transmission line resonator, brought about by the interaction with a superconducting qubit (as demonstrated in recent experiments). The backaction produced by the measurement device may produce a fundamental limit for the fidelity of photon detection in any such scheme. This is a consequence of the Quantum Zeno effect, and we discuss both analytical estimates and quantum trajectory simulations of the measurement process.

TT 27.9 Thu 12:45 H 0104

Single Photon Generation in Superconducting Microwave Cavities — •Giuseppe Mangano[1,2], Jens Siewert[1,2], and Giuseppe Falci[1] — [1]MATIS CNR-INFM & DMFCI, Università di Catania, I-95125 Catania, Italy — [2]Institute für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany

Circuit quantum electrodynamics (circuit QED) in superconducting nanocircuits provides a new system analogous to quantum-optical cavity QED. A particular advantage of circuit QED is the flexibility with respect to system parameters that allow to drive the setup in various regimes. Thus, it opens a playground to test in this solid-state system many effects that have been predicted in quantum optics. One particularly interesting problem is the generation and detection of nonclassical cavity states such as photon number states (despite the fact that up to date there is no single-photon detector for these microwave photons). In a recent experiment, generation of single photons relied on spontaneous emission events has been demonstrated in a circuit QED architecture [1]. Here we propose an alternative method to trigger the emission of a single photon into the cavity by applying the stimulated Raman adiabatic passage (STIRAP) invoking a third level of the Cooper-pair box. The method requires a leaky cavity [2], otherwise the STIRAP protocol could not generate single photons as in circuit QED the capacitive atom-cavity coupling is fixed.

[1] A. A. Houck, et al. Nature 449, 328-331 (2007).
[2] A. Kuhn, et al. Appl. Phys B 69, 373 (1999).