TT 6: Transport: Quantum Coherence and Quantum Information Systems - Theory I

Time: Monday 11:00–13:00 Location: HSZ 204

TT 6.1 Mon 11:00 HSZ 204

Efficient Qubit Readout Using Josephson Photomultipliers — •Luke C. G. Govia[1], Emily J. Pritchett[1,2], Canran Xu[3], Maxim G. Vavilov[3], Britton L. T. Plourde[4], Robert McDermott[3], and Frank K. Wilhelm[1] — [1]Universität des Saarlandes, Saarbrücken, Germany. — [2]HRL Laboratories, Malibu, California, USA. — [3]University of Wisconsin-Madison, Wisconsin, USA. — [4]Syracuse University, New York, USA.

A Josephson Photomultplier (JPM) - a current-biased Josephson junction operated near its critical bias - can absorb and detect weak microwave signals with high sensitivity (PRL 107, 217401 (2011)). When strongly coupled to a high-Q transmission line "cavity", the JPM can detect single microwave photons with large bandwidth and with near unit efficiency (PRB 86, 174506 (2012)). The switching of a JPM into its voltage state acts on the adjacent cavity via the back action of photon subtraction (PRA 86, 032311 (2012)). While a destructive measurement of the microwave cavity, this switching can perform a binary non-demolition measurement of a quantum system coupled to the cavity. We present a protocol by which the presence and subsequent detection of a cavity photon by a JPM conveys information about the state of a superconducting qubit without destroying it, thus performing a quantum non-demolition measurement of the qubit's state. Multi-qubit generalizations of this protocol are discussed.

TT 6.2 Mon 11:15 HSZ 204

Controlling qubits with tight frequency separation — Daniel Egger[1], Visa Vesterinen[2], Ron Schutjens[1,2], Fadi Abu Dagga[1], Olli-Pentti Saira[2], Alessandro Bruno[2], Leo DiCarlo[2], and •Frank Wilhelm[1] — [1]Theoretical Physics, Saarland University, Saarbrücken, Germany — [2]Quantum Transport, Kavli Institute for Nanoscience, TU Delft, The Netherlands

As quantum computer architectures are scaled up, addressing multiple qubits by their individual frequencies becomes increasingly difficult. This is in particular true for superconducting transmon qubits which in themselves are anharmonic oscillators. We present a strategy to combat closeness of wanted and unwanted transitions in multiple qubits that allows to significantly reduce this problem. This Weak AnHarmonicity With Average Hamiltonian (WAHWAH)]1] technique can handle cases that go beyond the familiar DRAG method [2].This technique is based on sideband modulation. We show experimentally that this technique allows two-transmon settings with significant frequency overlap to reach fidelities, as measured by interleaved randomized benchmarking, limited by decoherence alone.

[1] R. Schutjens et al., Phys. Rev. A 88, 052330 (2013)
[2] F. Motzoi et al., Phys. Rev. Lett. 103, 110501 (2009)

TT 6.3 Mon 11:30 HSZ 204

Parity switching and decoherence by quasiparticles in single-junction transmons — •Gianluigi Catelani — Forschungszentrum Jülich, PGI-2, Jülich, Germany

Transmons are at present among the most coherent superconducting qubits, reaching quality factors of order 10^6 both in 3D and 2D architectures. These high quality factors enable detailed investigations of decoherence mechanisms. An intrinsic decoherence process originates from the coupling between the qubit degree of freedom and the quasiparticles that tunnel across Josephson junctions. In a transmon, tunneling of a single quasiparticle is associated with a change in parity. I will discuss the theory of the parity switching rate in single-junction transmons, compare it with recent measurements, and consider the role of parity switching in limiting the coherence time.

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TT 6.4 Mon 11:45 HSZ 204

Hybrid quantum magnetism in the strong and ultrastrong coupling regime — •Andreas Kurcz, Alejandro Bermudez, and Juan Jose Garcia-Ripoll — Instituto de Fisica Fundamental (IFF-CSIC), Calle Serrano 113bis, Madrid E-28006, Spain

We study a quantum setup that consist of superconducting qubit mediated resonators, where quantum magnetism arises non-perturbatively and can be understood both analytically and numerically (A. Kurcz et. al., arXiv:1310.8173). The setup exhibits a set of interspersed spin-boson lattice models [1,2] and reveals a phase transition of the Ising type [3], where both qubits and cavities spontaneously polarise and where the cavity-qubit detuning acts as the equivalent of a magnetic field. We develop a many-body correlated mean field theory that accurately predicts the nature of the ground state and that captures this phenomenon all the way, from a perturbative dispersive regime where photons can be traced out, to the non-perturbative ultrastrong coupling regime where photons must be treated on the same footing as qubits. Our ansatz also reproduces the low-energy excitations, which are described by hybridised spin-photon quasiparticles, and can be probed spectroscopically from transmission experiments in circuit-QED, as shown by Matrix-Product-State methods. Our model offers an ideal playground in order to simulate the existing many-body machinery from spin-photon waves to many body-spectroscopy.

[1] D. Porras et. al., Phys. Rev. Lett. 108, 235701 (2012)
[2] M. Schiro et. al., Phys. Rev. Lett. 109, 053601 (2012)
[3] P. Pfeuty, Ann. Phys. 57, 79 (1970).

TT 6.5 Mon 12:00 HSZ 204

Optimizing quantum measurements in circuit QED — •Daniel Egger and Frank Wilhelm — Universität des Saarlandes, Saarbrücken, Deutschland

Manipulating quantum systems requires knowing the shape of the control pulses to achieve a desired state or specified time evolution. Optimal control is the framework in which the pulses are designed. Typically such pulses are optimal with respect to time and can be found through a gradient search [1]. In superconducting qubits these methods have been applied to gate design , usually in an idealised unitary process [2,3]. In this work we instead focus on optimizing the time evolution of systems where non-unitary processes are the source for the desired time evolution. As example we consider a measurement process in circuit QED where a "click" of the detector corresponds to a tunneling event and find control pulses that optimize a contrast. We first analyze the standard phase qubit readout, we then evaluate its generalization to the JBA.

[1] N. Khaneja *et al.*, J. Magn. Reson. **172**, 296
[2] R. Schutjens *et al.*, Phys. Rev. A **88**, 052330
[3] D. J. Egger & F. K. Wilhelm, Supercond. Sci. Technol. **27**, 014001

TT 6.6 Mon 12:15 HSZ 204

Metamaterials for circuit QED: Quantum simulations and other applications — •Bruno G. Taketani and Frank K. Wilhelm — Saarland University, Saarbrücken, Germany

The ability to design periodically structured materials not present in nature provides scientists with new tools, ranging from sub-wavelength imaging to well controlled band structures for wave propagation in photonic crystals. Superconducting metamaterials have been recently proposed to manipulate the density-of-modes of transmission lines [1]. We further build on these ideas and develop a toolbox for environment manipulation based on nano-structured, periodic, lossless, superconducting circuits. In particular we show that high density of low energy states can be achieved using a superlattice arrangement of left-handed circuit elements. Multimode, ultra-strong coupling of superconducing qubits to such engineered environments thus allow for experimental implementation of quantum simulation of interesting new phenomena as well as for complex quantum state engineering.

[1] D. J. Egger and F. K. Wilhelm, Phys. Rev. Lett. **111**, 163601 (2013)

TT 6.7 Mon 12:30 HSZ 204

Resonant versus dispersive gates in circuit quantum electrodynamics — •Per Liebermann and Frank Wilhelm — Universität des Saarlandes, Saarbrücken, Germany

Implementation of accurate two-qubit gates in the presence of decoherence is one of the main tasks of building a quantum computer. In this work we describe two superconducting qubits coupled via a resonator and perform a controlled-Z operation on them. Being able to control the qubits' transition frequencies, we compare the resonant and dispersive gate implementation of CZ [1,2], where in the latter case qubit-qubit interaction is mediated by virtual photons. We make use of the Lindblad master equation to study different regimes of resonator relaxation and qubit decoherence and their impact on gate fidelity. Finally, we discuss the tradeoff between the higher speed of the resonant gate versus the protection from the Purcell effect in the dispersive gate, which we show to usually be in favor of resonant gates.

[1] A. Blais et al., Phys. Rev. A 75, 032329 (2007)
[2] D.J. Egger and F.K. Wilhelm, Supercond. Sci. Technol. 27 (2014)

TT 6.8 Mon 12:45 HSZ 204

From Coulomb-Blockade to Nonlinear Quantum Dynamics in a Superconducting Circuit with a Resonator — Vera Gramich, •Björn Kubala, Selina Rohrer, and Joachim Ankerhold — Institut für Theoretische Physik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Motivated by recent experiments [1] on superconducting circuits consisting of a dc-voltage-biased Josephson junction in series with a resonator, quantum properties of these devices far from equilibrium are studied [2]. This includes a crossover from a domain of incoherent to a domain of coherent Cooper pair tunneling, where the circuit realizes a driven nonlinear oscillator. Equivalently, weak photon-charge coupling turns into strong correlations captured by a single degree of freedom. Radiated photons offer a new tool to monitor charge flow and current noise gives access to nonlinear dynamics, which allows us to analyze quantum-classical boundaries. Higher order resonances are discussed as well and provide new avenues for future experiments.

[1] M. Hofheinz, F. Portier, Q. Baudouin, P. Joyez, D. Vion, P. Bertet, P. Roche, and D. Esteve, Phys. Rev. Lett. **106**, 217005 (2011).
[2] V. Gramich, B. Kubala, S. Rohrer, and J. Ankerhold, accepted for publication in Phys. Rev. Lett., arXiv:1307.2495.