TT 37: Quantum Coherence, Quantum Information Systems 1

Time: Wednesday 9:30–13:15 Location: H19

TT 37.1 Wed 9:30 H19

Emission spectrum of the driven nonlinear oscillator — •Stephan Andre[1,2], Lingzhen Guo[1,3], Vittorio Peano[4], Michael Marthaler[1,2], 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]Department of Physics, Beijing Normal University, Beijing 100875, China — [4]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA

Motivated by recent "circuit QED" experiments [1,2] we investigate the noise properties of coherently driven nonlinear resonators. By using Josephson junctions in superconducting circuits, strong nonlinearities can be engineered, which lead to the appearance of pronounced effects already for a low number of photons in the resonator.

Based on a master equation approach we determine the emission spectrum and observe for typical circuit QED parameters, in addition to the primary Raman-type peaks, second-order peaks [3]. These peaks describe higher harmonics in the slow noise-induced fluctuations of the oscillation amplitude of the resonator and provide a clear signature of the nonlinear nature of the system.

[1] I. Siddiqi *et al.*, Phys. Rev. B **73**, 054510 (2006)
[2] F.R. Ong *et al.*, Phys. Rev. Lett. **106**, 167002 (2011)
[3] S. André *et al.*, Phys. Rev. A **85**, 053825 (2012)

TT 37.2 Wed 9:45 H19

Effective spinful Kitaev model and Majorana fermion mediated magnetoelectric phenomena — •Panagiotis Kotetes[1], Alexander Shnirman[2], and Gerd Schön[1] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe — [2]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Germany

Current trends in the field of quantum information relate to topological quantum computing based on Majorana fermions. In fact, recent experiments involving a Rashba spin-orbit coupled semiconducting wire in proximity to a conventional superconductor which is under the simultaneous influence of a Zeeman field, have provided striking results that could be associated with the presence of Majorana fermions. In the infinite magnetic field limit, the above system is equivalent to a spinless p-wave superconductor and can be effectively described by Kitaev's celebrated lattice model. This model owes the distinctive property of yielding Majorana fermions which are localized at the edges. So far, a vast number of previous studies were based on this mapping to Kitaev's model, neglecting in this manner the possibility of actively manipulating the spin degree of freedom. To remedy this problem, we construct an effective spinful Kitaev model that can be used for finite magnetic fields. This model opens new perspectives for spin-based quantum computing applications and provides a more general description of Majorana-fermion-mediated magnetoelectric Josephson effects, beyond 1D geometries [1].

[1] P. Kotetes, A. Shnirman and G. Schön, arXiv:1207.2691.

TT 37.3 Wed 10:00 H19

Output photon statistics in driven dissipative arrays of transmission line resonators — •Robert Jirschik and Michael Hartmann — TU Munich, Munich, Germany

Arrays of circuit cavities offer fascinating perspectives for exploring quantum many body systems in a driven dissipative regime where photon losses are continuously compensated by coherent laser drives. Here we specifically consider a scenario with input lasers of high intensity and thus high intra-resonator excitation numbers. Two different systems which depend on experimentally well controlable properties are considered:

One is a chain of nonlinear transmission line resonators driven by a single input laser, while the other one contains three transmission line resonator sites with a single non-linearity in the middle and lasers with an adjustable phase difference driving the two outer resonator sites. For both set-ups we provide results for the mean photon number and time-resolved second order correlation function of each individual site depending on their different experimental parameters.

TT 37.4 Wed 10:15 H19

A Quantum Single Photon Transistor in Circuit Quantum Electrodynamics — Lukas Neumeier, •Martin Leib, and Michael Hartmann — TU München, 85748 Garching, Germany

We propose a superconducting transmission line setup that acts as a single photon transistor for itinerant microwave signals. Photons are ideal carriers of quantum information as they rarely interact while traveling long distances which opens great possibilities for scaling up from one elementary two photon gate to many. However the advantage of great robustness with respect to environmental perturbations poses a great challenge to generate photon-photon interactions where they are needed. The enhanced light-matter interactions due to the quasi-onedimensional geometry of superconducting transmission lines and the macroscopic dipole moments of superconducting artificial atoms may provide a route out of this dilemma. In our setup a "control"-photon inverts a superconducting qubit which in turn shifts the energy of another superconducting qubit that is coupled to the transmission line of a "target"-photon. The "target"-photon is reflected if the energies of "target"-photon and superconducting qubit are degenerate and transmitted if they are sufficiently detuned. We show that this setup can be realized with flux qubits as well as with transmon qubits.

TT 37.5 Wed 10:30 H19

Josephson Junction Intersected Transmission Line Resonators — •Martin Leib and Michael J. Hartmann — TU München, 85748 Garching, Germany

Circuit quantum electrodynamics has gone a long way since the first successful demonstration of the strong coupling regime in 2004 by Andreas Wallraff and coworkers. Coherence times grew dramatically, single qubit gates are routine by now and entangling operations have been shown. The logical next step is to scale up the architectures from a few to many building blocks. The simulation of interacting many-body Hamiltonians is a promising direction of research to pursue with these setups. Every nonlinearity in classical field theory can be interpreted after quantizing the theory as an interaction between the elementary bosonic excitations of the systems which in the case of circuit QED are microwave photons. Therefore we propose as a basic building block for a interacting many body Hamiltonian simulator a transmission line resonator that is intersected by Josephson junctions. We calculate the eigenfrequencies of the transmission line resonator with a transfer matrix technique and quantize the classical theory.

TT 37.6 Wed 10:45 H19

High-Fidelity Single-Qubit Gates for Two-Electron Spin Qubits — •Pascal Cerfontaine, Fabian Brings, Tim Botzem, David DiVincenzo, and Hendrik Bluhm — 2nd Institute of Physics C, RWTH Aachen University, 52074 Aachen, Germany

Two-electron spin qubits in double quantum dots are promising candidates for quantum computation. Arbitrary single-qubit gates by electrical manipulation of the exchange interaction between two adjacent electrons while maintaining a magnetic field gradient have been demonstrated. However, simple gate constructions incur systematic gate errors in the presence of realistic experimental constraints.

We show the existence of a set of single-qubit gates obtained from simulations based on a model that reflects the experimentally important imperfections. Without decoherence, they exactly implement the desired gates.

Dephasing effects are minimized by avoiding operating points with large sensitivity to charge noise. Furthermore, we show that the gates can be fine-tuned on the experiment using an iterative optimization protocol based on the bootstrap method demonstrated in [1]. Our results should enable the complete elimination of systematic errors from an experimental realization of the gates.

[1] V. V. Dobrovitski *et al.*, Phys. Rev. Lett. **105**, 077601 (2010).

TT 37.7 Wed 11:00 H19

Cooper-pair tunneling with a resonant environment — Vera Gramich, •Björn Kubala, Selina Rohrer, Jürgen Stockburger, and Joachim Ankerhold — Institut für Theoretische Physik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Cooper-pair tunneling through a Josephson junction can be drastically influenced by the electromagnetic environment. Recent experiments [1,2] managed to combine dc-biased josephson junctions and an on-chip microwave cavity, to design an environment, where resonant coupling is achieved. In such setups, not only is the Josephson current strongly influenced by the environment, but, furthermore, the emission of energy to environmental modes can be directly monitored. The complicated cavity-junction coupling gives rise to complex physical behavior already in a classical regime, as well as in the quantum regime, which this talk will focus on.

[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] M. Blencowe, A. Armour, and A. Rimberg, arXiv:1106.5945.

15 min. break

TT 37.8 Wed 11:30 H19

Dissipatively driven Entanglement of two Nuclear Spin Ensembles in a Double Quantum Dot — •Martin J. A. Schuetz, Eric M. Kessler, Juan Ignacio Cirac, and Geza Giedke — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

Typically, quantum information schemes have been discussed in the context of isolated many-body systems subject to unitary dynamics. Here, dissipation has been identified as a mechanism that corrupts the useful quantum properties of the system under study. Recently, however, with the advent of novel ideas such as dissipative engineering, a paradigm shift could be observed in quantum physics. More and more approaches actively utilize dissipation as a driving force behind the emergence of coherent quantum phenomena. In this spirit, we propose a transport scheme for an electrically defined double quantum dot in which the two nuclear ensembles in the host environment are actively pumped into an entangled target state. Based on a self-consistent Holstein-Primakoff approximation, we derive an effective quantum master equation for the nuclear spins which features an unique entangled steady state; accordingly, long lasting entanglement is created deterministically. Prospects for the experimental realization of this proposal are briefly discussed.

TT 37.9 Wed 11:45 H19

Decoherence of a central spin coupled to a fluctuating spin bath — •Alexandre Faribault and Dirk Schuricht — Institut für Theorie der Statistischen Physik, RWTH Aachen University and JARA - Fundamentals of Future Information Technology, 52056 Aachen, Germany

When using the spin of a single electron trapped in a quantum dot as an implementation of a qubit, its hyperfine coupling to the environmental nuclear spins ultimately leads to the decoherence of any prepared state. Using the Algebraic Bethe Ansatz in conjunction with a Monte Carlo sampling procedure, we study how the electron's spin coherence factor evolves with time due to the presence of an unprepared randomly fluctuating nuclear spin bath.

TT 37.10 Wed 12:00 H19

All optical control of the spin state in the NV^--center in diamond — •Florian Hilser — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

We describe an all-optical scheme for spin manipulation in the ground-state triplet of the negatively charged nitrogen-vacancy (NV) center in diamond. Virtual optical excitation from the $^3A_2$ ground state into the ^3E excited state allows for spin rotations by virtue of the spin-spin interaction in the two-fold orbitally degenerate excited state. We derive an effective Hamiltonian for optically induced spin-flip transitions within the ground state spin triplet due to off-resonant optical pumping. Furthermore, we investigate the spin qubit formed by the Zeeman sub-levels with spin projection $m_S = 0$ and $m_S = -1$ along the NV axis around the ground state level anticrossing with regard to full optical control of the electron spin. Next we focus on cavity mediated coupling of different NV centers by extending this scheme to derive an effective spin-spin-interaction between separate NV center ground states due to exchange of a (virtual) cavity photon [1].

[1] Phys. Rev. B **86** 125204

TT 37.11 Wed 12:15 H19

Nonequilibrium Landau-Zener-Stückelberg spectroscopy in a double quantum dot — •Peter Nalbach[1], Johannes Knörzer[1], and Stefan Ludwig[2] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [2]Center for NanoScience and Fakultät für Physik, Ludwig-Maximilians-Universität München, Geschwister-Scholl-Platz 1, D-80539 München, Germany

We study theoretically nonequilibrium Landau-Zener-Stückelberg (LZS) dynamics in a driven double quantum dot (DQD) including dephasing and, importantly, energy relaxation due to environmental fluctuations. We derive effective nonequilibrium Bloch equations. These allow us to identify clear signatures for LZS oscilations observed but not recognized as such in experiments [1] and to identify the full environmental fluctuation spectra acting on a DQD given experimental data as in [1]. Herein we find that super-Ohmic fluctuations, typically due to phonons, are the main relaxation channel for a detuned DQD whereas Ohmic fluctuations dominate at zero detuning.

[1] Petersson et al., Phys. Rev. Lett. 105, 246804 (2010)

TT 37.12 Wed 12:30 H19

Dynamic Generation of Thermally Stable Surface Code — •Daniel Becker[1], Tetsufumi Tanamoto[2], Adrian Hutter[1], Fabio Pedrocchi[1], and Daniel Loss[1] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Corporate R & D center, Toshiba Corporation, Saiwai-ku, Kawasaki 212-8582, Japan

Quantum memories that are based on surface codes with local qubit interactions such as Kitaev's toric code are vulnerable to thermal fluctuations. By inducing strongly non-local interactions between the qubits via a coupling to, e.g, cavity modes [1] or the spins of a ferromagnet [2], the lifetime of encoded states in the presence of a thermal environment increases exponentially with the code's size. We propose a scheme to dynamically realize such a stable quantum memory based on the toric code for qubit systems with typical two-body interactions (Ising, XY, Heisenberg), using periodic, NMR-like pulse sequences. It allows both to prepare codewords without measurements and to protect them dynamically against the time evolution of the physical qubit system. Thermal stability is achieved by weakly coupling the qubits to an additional cavity mode. We investigate how the fidelity, with which the toric code is realized, depends on the period length T of the pulse sequence and the magnitude of possible pulse errors. This allows to optimize tunable system parameters, such as T, in the presence of pulse errors and decoherence.

[1] F. Pedrocchi et al., Phys. Rev. B **83**, 115415 (2011)
[2] F. Pedrocchi et al., arXiv:1209.5289

TT 37.13 Wed 12:45 H19

Measuring ultrasmall time delays of light by joint weak measurements — •Grégory Strübi and Christoph Bruder — University of Basel, Basel, Switzerland

We propose to use weak measurements away from the weak-value amplification regime to carry out precision measurements of time delays of light. Our scheme is robust to several sources of noise that are shown to only limit the relative precision of the measurement, and not set a limit on the smallest measurable phase shift contrary to standard interferometry and weak-value based measurement techniques. Our idea is not restricted to phase-shift measurements and could be used to measure many small effects using a similar protocol.

TT 37.14 Wed 13:00 H19

Singlet-triplet qubits embodied by multi-electron quantum dots — •Sebastian Mehl[1,2] and David P. DiVincenzo[1,2] — [1]Peter Grünberg Institut (PGI 2), Forschungszentrum Jülich, D-52428 Jülich — [2]Institute for Quantum Information, RWTH Aachen, D-52056 Aachen

Singlet-triplet qubits (STQs) have attracted attention as one possible realization scheme of a logical qubit in a spin based quantum computer [1]. Commonly, the singlet and spinless triplet level of two single occupied quantum dots are defining the qubit states in these system. We describe an alternative approach to implement STQs using multi-electron quantum dots [2]. Instead of employing singly occupied quantum dots, we fill both quantum dots with three electrons. The qubit states have identical charge configurations for specific external parameters, which protects a STQ from dephasing phenomena affecting only the charge sector. Such qubits are perfectly immune gate voltages fluctuations produced by charge noise [3]. We specify the protection criteria and relate them to available materials and fabrication techniques. Furthermore, we describe full single qubit control of the three electron STQ, while pulsing via electric bias between two regimes immune to charge noise. We discuss limitations and experimental difficulties in realizing our proposed manipulation scheme.

[1] J.R. Petta et al., Science 309, 2180 (2005), A.C. Johnson et al., Nature 435, 925 (2005)
[2] L.P. Kouwenhoven et al., Rep. Prog. Phys. 64, 701 (2001)
[3] X. Hu and S. Das Sarma, PRL 96, 100501 (2006)