TT 32 Transport: Quantum Coherence and Quantum Information Systems - Part 2

Time: Thursday 14:00–17:45 Room: HSZ 304

TT 32.1 Thu 14:00 HSZ 304

Voltage control in a three-junction flux qubit — •Luca Chirolli and Guido Burkard — Department of Physics-University of Basel-Basel-Switzerland

By means of a general circuit analysis, we study a superconducting flux qubit with three Josephson junction in which enhanced control is achieved by introducing electrostatic gates. We discuss the additional terms in the single-qubit Hamiltonian due to an applied gate voltage.

[1] G.Burkard, Phys.Rev.B 71, 144511 (2005)
[2] J.E.Mooij et al., Science 285, 1036 (1999)

TT 32.2 Thu 14:15 HSZ 304

Inductive effects in tunable capacitive coupling of charge qubits — •Carsten Hutter and Alexander Shnirman — Institut für Theoretische Festkörperphysik, Universität Karlsruhe, D–76128 Karlsruhe, Germany

Recently, tunable capacitive [1] and inductive [2] coupling of Josephson charge and flux qubits have been proposed. Here, we concentrate on coupling of charge qubits via a Josephson junction, which provides a tunable effective capacitance. For this situation, it was suggested [3], that the capacitive coupling could be accompanied by an inductive one. We clarify the situation by considering the limits where the Josephson energy of the coupling junction is much greater (much smaller) than its charging energy, $E_J \gg E_c$ ($E_J \ll E_c$). In the limit $E_J \ll E_c$, the inductive coupling appears as a small correction to the capacitive one. It will however play a role at the point, where the capacitive coupling vanishes. In the limit $E_J \gg E_c$, we find that the inductive coupling dominates over the capacitive one.

[1] D. V. Averin and C. Bruder, Phys. Rev. Lett. 91, 057003 (2003).
[2] B. L. T. Plourde *et al.*, Phys. Rev. B 70, 140501(R) (2004).
[3] A. Zorin, cond-mat/0510435 (2005)

TT 32.3 Thu 14:30 HSZ 304

Readout of a Flux Qubit Using a Capacitive Bias — •Frank Deppe[1,2,3], Shiro Saito[2,3], Kosuke Kakuyanagi[2,3], Takayoshi Meno[4], Kouichi Semba[2,3], Hideaki Takayanagi[2,3], and Rudolf Gross[1] — [1]Walther-Meissner-Institut, Garching, Germany — [2]NTT Basich Research Laboratories, NTT Corporation, Atsugi, Japan — [3]CREST JST, Saitama, Japan — [4]NTT AT, Atsugi, Japan

A promising candidate for the basic information unit for (future) scalable solid state based quantum computing is the Mooij flux qubit [1]. It consists of a superconducting loop with 3 Josephson junctions. The flux signal of the qubit states ((anti-)clockwise circulating current) can be detected with a superconducting quantum interference device (SQUID). We successfully implemented a novel variant of the pulse&hold switching method. Creating the SQUID bias current via a coupling capacitor instead of the usual coupling resistor allows faster switching pulses while keeping proper filtering conditions for the bias line. The bias capacitor also reduces external low frequency noise. Our setup allows a direct comparison between resistive and capacitive environment on the *same* qubit. We present the results of measurements on a SQUID/flux qubit system based on nanoscale Al/AlO_x/Al junctions. In time domain experiments near the qubit magic point we find a slighly reduced dephasing time $T_2 \approx 150$ ns for the capacitive bias compared to 250 ns for the resistive bias. The reults indicate that the impact of external low frequency on qubit phase coherence is small in our system.

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[1] J. E. Mooij et al., *Science* **285**, 1036 (1999)

TT 32.4 Thu 14:45 HSZ 304

On-chip Quantum Information Processing in Circuit QED — •Henning Christ[1], Matteo Mariantoni[2], and Enrique Solano[1,3] — [1]Max-Planck Institute for Quantum Optics, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany — [2]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Walther-Meissner-Strasse 8, D-85748 Garching, Germany — [3]Sección Física, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Apartado 1761, Lima, Peru

We consider an on-chip linear array of flux-based qubits inside individual quasi-1D superconductive resonators and introduce, in the context of quantum information theory, different possibilities of realizing quantum computation with suitably designed long-lived qubits. In particular, we present in a comparative manner the advantages and disadvantages of establishing on-chip quantum communication protocols via single photon exchange or via novel continuous-variable schemes. For the purpose, the latter turn out to be the most promising avenue given that single-photon detectors are still unavailable in the microwave domain. Finally, we propose a deterministic single-qubit teleportation protocol based on unitary generation of qubit-cavity Schrödinger cats, where no single-photon detector is needed.

TT 32.5 Thu 15:00 HSZ 304

Theory of Microwave Homodyne Tomography of Quantum Signals — •Matteo Mariantoni[1], Markus J. Storcz[2], Frank K. Wilhelm[2], William D. Oliver[3], Andreas Emmert[1], Achim Marx[1], Rudolf Gross[1], Henning Christ[4], and Enrique Solano[4,5] — [1]Walther-Meissner-Institut, Walther-Meissner-Str. 8, D-85748 Garching, Germany — [2]Department Physik, ASC and CeNS, Ludwig-Maximilians-Universität, Theresienstr. 37, D-80333 München, Germany — [3]MIT Lincoln Laboratory, 244 Wood Street, Lexington, Massachussets 02420, USA — [4]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany — [5]Sección Física, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Apartado 1761, Lima, Peru.

Weak quantum signals cannot be detected using standard ultra-low-noise cryogenic amplifiers or the state-of-the-art available classical methods. As a consequence, the measurement of nonclassical states of microwave electromagnetic radiation is a fundamental problem and necessity in the novel field of circuit QED [1] (see TT 19, E. Solano).

We propose a microwave quantum homodyne detection technique that enables the measurement of quantum states at the level of single photons and allows the reconstruction of their Wigner function through microwave quantum homodyne tomography. Our method is based on a superconducting hybrid ring acting as an on-chip microwave beam splitter (see also presentation TT 19, A. Emmert). This work was supported by the SFB 631 of the DFG.

[1] M. Mariantoni *et al.*, cond-mat/0509737.

TT 32.6 Thu 15:15 HSZ 304

Mesoscopic Superpositions, Nonclassical States, and their Measurement in Circuit QED — •Markus J. Storcz[1], Matteo Mariantoni[2], Andreas Emmert[2], Rudolf Gross[2], Frank K. Wilhelm[1], Henning Christ[3], and Enrique Solano[3,4] — [1]Department Physik, ASC and CeNS, Ludwig-Maximilians-Universität, Theresienstr. 37, 80333 München, Germany — [2]Walther-Meissner-Institut, Walther-Meissner-Str. 8, 85748 Garching, Germany — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — [4]Sección Física, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Apartado 1761, Lima, Peru

We propose a novel scheme consisting of a superconducting qubit coupled to a microwave cavity with an additional transverse control line. We show that an orthogonal and strong classical driving allows for the simultaneous implementation of Jaynes-Cummings and anti-Jaynes-Cummings dynamics, opening new avenues in the generation of nonclassical states and mesoscopic superpositions (Schrödinger cats). Moreover, the proposed set-up can also be used for implementing a projective qubit measurement and for reconstructing the associated field Wigner function. Relevant decoherence aspects and specific design parameters for a superconducting charge qubit inside a coplanar waveguide resonator are presented.

This work was supported by the SFB 631 of the DFG.

TT 32.7 Thu 15:30 HSZ 304

Microshort induced pinning potential for a Josephson vortex, probed in the quantum limit with microwave spectroscopy. — •Astria Price, Alexander Kemp, and Alexey V. Ustinov — Physikalisches Institut III, Universitaet Erlangen-Nuernberg, Erlangen D-91058, Germany

A long annular Josephson junction with a lithographic microshort, produced by widening a short section of the junction, constitutes a vortex qubit candidate in which the height of the microshort induced potential barrier seen by a Josephson vortex is tuned via an applied magnetic field. We investigate the energy level structure of the vortex potential in this type of junction by means of microwave spectroscopy, and compare the results to a model based on the one-dimensional sine-Gordon equation. Applying bias current creates a metastable state for the vortex, in which it is pinned by either the magnetic field or the microshort, and escapes via thermal activation or quantum tunnelling. We measure the energy level separation between the ground and first excited states of the vortex in both types of metastable potential well, and extract the cross-over temperature from thermal activation to quantum tunnelling as a function of bias current and magnetic field strength.

— 15 min. break —

TT 32.8 Thu 16:00 HSZ 304

Observation of Rabi oscillations in a phase qubit — •J. Lisenfeld[1], A. Lukashenko[1], S. Shitov[2], and A.V. Ustinov[1] — [1]Physikalisches Institut III, Universität Erlangen, Germany — [2]Institute of Radio Engineering and Electronics, Moscow, Russia

Quantum bits based on superconducting tunnel junction circuits are promising candidates to realize solid-state quantum computation. A phase qubit is formed from an rf-SQUID, whose Josephson phase eigenstates are used as logical states [1]. Those are mapped to macroscopically distinct flux states in the readout process, which is based on quantum tunneling stimulated by a short pulse of magnetic flux.

We experimentally demonstrate the preparation of an arbitrary quantum state in such a system, which has been fabricated using our design at a standard foundry. Rabi oscillation, a spectroscopic measurement of the dephasing time and evidence of qubit coupling to parasitic resonators are presented. From upcoming data on the temperature dependence of decoherence processes we hope to clarify whether the observed Rabi-type oscillations, alternatively, originate from a classical junction dynamics in the microwave field [2].

[1] R.W. Simmonds et al., Phys. Rev. Lett. 93, 077003 (2004)
[2] N. Grønbech-Jensen and M. Cirillo, Phys. Rev. Lett. 95, 067001 (2005)

TT 32.9 Thu 16:15 HSZ 304

Adiabatic passage in superconducting nanocircuits — •Jens Siewert[1,2], Tobias Brandes[3], and Giuseppe Falci[1] — [1]MATIS-INFM, CNR and DMFCI, University of Catania, I-95125 Catania, Italy — [2]Institut fuer Theoretische Physik, University of Regensburg, D-93040 Regensburg, Germany — [3]Department of Physics, The University of Manchester, Manchester M60 1QD, United Kingdom

With the rapid technological progress in quantum-state engineering in superconducting devices there is an increasing demand for techniques of quantum control. Stimulated Raman adiabatic passage (STIRAP) is a powerful method in quantum optics which has remained largely unknown to solid-state physicists. It is used to achieve highly efficient and controlled population transfer in (discrete) multilevel quantum systems. Apart from other potential applications in solid-state physics, adiabatic passage offers interesting possibilities to manipulate qubit circuits, in particular for the generation of nonclassical states in nanomechanical or electromagnetic resonators. In this contribution, we explain the idea of the method and describe examples of controlled quantum dynamics in superconducting nanocircuits by applying adiabatic passage.

TT 32.10 Thu 16:30 HSZ 304

Macroscopic quantum dynamics in one-dimensional Josephson junction arrays — •Mikhail V. Fistul — Theoretische Physik III, Ruhr-Universität Bochum, D-44801 Bochum Germany

I present a theoretical study of the current-voltage characteristics (I-V curves) of one-dimensional Josephson junction arrays containing small Josephson junctions. The transport properties of such a system are determined by the dynamics of both "classical" degrees of freedom, i.e. the phases of superconducting order parameter in leads, and the macroscopic quantum degrees of freedom, i.e. the Josephson phases of intrinsic junctions. I will show that at low temperature and in a particular regime characterizing by a large damping in leads and a small damping in an internal part of the system, the I-V curves are determined by the quantum correlations of Josephson phases, and therefore, it allows to obtain a direct information on the macroscopic quantum dynamics, i.e. macroscopic quantum tunneling of vortices or Coulomb blockade of Cooper pairs. In the framework of this analysis the Cooper pair cotunneling regime [1] and the superconductor-insulator transition [2] in Josephson junction arrays will be discussed.

[1] S. V. Lotkhov, S. A. Bogoslovsky, A. B. Zorin, and J. Niemeyer, Phys. Rev. Lett. 91, 197002 (2003)
[2] E. Chow, P. Delsing, and D. B. Haviland, Phys. Rev. Lett. 81, 204 (1998)

TT 32.11 Thu 16:45 HSZ 304

Quantum tunneling of semifluxons in 0-π-0 long Josephson junction: Theory — •Edward Goldobin[1], Karl Vogel[2], Oliver Crasser[2], Reinhold Walser[2], Wolfgang Schleich[2], Dieter Koelle[1], and Reinhold Kleiner[1] — [1]Universität Tübingen, Physikalisches Institut - Experimentalphysik II, Auf der Morgenstelle 14, D-72076, Tübingen, Germany — [2]Universität Ulm, Abteilung Quantenphysik, D-89069 Ulm, Germany

We consider a system of two semifluxons of opposite polarity in a 0-π-0 long Josephson junction, which classically can be in one of two degenerate states: $\uparrow\downarrow$ or $\downarrow\uparrow$. When the distance a between the 0-π boundaries (semifluxon's centers) is a bit larger than the crossover distance a_c, the system can switch from one state to the other due to thermal fluctuations or due to quantum tunneling. We map this problem to the dynamics of a single particle in a double well potential and estimate parameters for which quantum effects emerge. We also determine the classical-to-quantum crossover temperature as well as the tunneling rate (energy level splitting) between the states $\uparrow\downarrow$ and $\downarrow\uparrow$. This system may be a promising candidate for realization of qubits since semifluxons represent the ground state of the system. See [1] for details.

[1] Phys. Rev. B. **72**, 054527 (2005).

TT 32.12 Thu 17:00 HSZ 304

Non-Markovian dynamics of double quantum dot charge qubits due to a phonon bath — •Jens Eckel, Stephan Weiss, and Michael Thorwart — Institut fuer Theoretische Physik IV, Universitaetsstrasse 1, 40225 Duesseldorf

We investigate the decoherent dynamics of charge qubits in two particular setups: (i) GaAs double quantum dots and (ii) two single P donor ions in a Si host lattice. In both cases, one excess electron is shared and a single charge qubit is formed. In particular, we study the charge qubit coupled to acoustic phonons which induce a non-Markovian dynamical behavior of the oscillations between the two charge states. Upon applying the numerically exact quasiadiabatic propagator path-integral scheme for both setups, the reduced density matrix is calculated, thereby avoiding the Born-Markov approximation. The damped coherent oscillations of the electron between the two dots determine a quality factor whose dependence on the lattice temperature, on the size of the quantum dots, as well as on the interdot coupling is studied systematically [1]. The comparison with the recent experimental result by Hayashi and coworkers [2] for double quantum dots will be discussed.

[1] M. Thorwart, J. Eckel and E. R. Mucciolo, Phys. Rev. B, in press.
[2] T. Hayashi et al., Phys. Rev. Lett. 91, 226804 (2003).

TT 32.13 Thu 17:15 HSZ 304

How fat is Schrödinger's cat? — •Benjamin Abel, Florian Marquardt, and Jan von Delft — Ludwig-Maximilians-Universität, Arnold Sommerfeld Center for Theoretical Physics and Center for Nanoscience,Theresienstr. 37, 80333 München

Recent experiments have tried to produce superpositions of "macroscopically distinct" quantum states, e.g. in small superconducting quantum interference devices (SQUIDs) or in microwave cavities. These superpositions are commonly referred to as "Schrödinger cat states"(1). In this work, we provide an answer to the following important question: "How 'macroscopic' is such a superposition?". We present a general measure of the distance between two arbitrary many-body states forming such a superposition, going beyond previous works that only considered a special class of possible states (2). After illustrating its general features, we apply our measure to experiments employing three-junction SQUIDs (Mooij), where the ground state at half a flux quantum is a superposition of clockwise and counterclockwise flowing supercurrents: $|\Psi\rangle = (|\mathrm{left}\rangle + |\mathrm{right}\rangle)/\sqrt{2}$.

[1] E. Schrödinger, *"Die gegenwärtige Situation in der Quantenmechanik"*, Naturwissenschaften, **48**, 807, **49**, 823, **50**,844 (1935).
[2] W. Dürr, C. Simon, and J. I. Cirac, Phys. Rev. Lett. **89**, 210402 (2002).
[3] J. E. Mooij, *et al.*, Science **285**, 1036 (1999).

TT 32.14 Thu 17:30 HSZ 304

Investigation of the ground state of Nb charge-phase qubits —
•Hermann Zangerle, J. Könemann, B. Mackrodt, R. Dolata, S. A. Bogoslovsky, M. Götz, and A. B. Zorin — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

There are several implementations of qubits built of small Josephson junctions. The Bloch transistor included in a superconducting loop can serve as a so-called charge-phase qubit with both electrostatic and magnetic control of its quantum state. For readout the device is inductively coupled to a rf-driven tank circuit. Applying chemical-mechanical polishing technique we have fabricated from Nb/Al/AlO_x/Nb sandwich the charge-phase qubits with junction size of 60 nm by 60 nm and nominal critical current of the single junction of about 50 nA. Our all-Nb samples of gradiometer design include the transistor in the loop and the tank circuit inductance on the same chip. The high critical temperature of Nb and our circuit layout make it possible to precharacterize the samples at 4.2 K. We report the radio-frequency measurements of Nb qubit circuits with characteristic ratio of the Josephson to charging energy E_J/E_c between 1 and 2 carried out at 20 mK. Due to appreciable charging energy E_c of about 50 μeV the transistor critical current was remarkably modulated by the gate. We investigated the ground state of our qubit samples as a function of two control parameters: flux Φ and charge Q. The sample with the energy ratio $E_J/E_c \sim 1$ allowed to map the complete ground state energy surface $E(\Phi, Q)$.