TT 38: Transport: Quantum Coherence and Quantum Information Systems - Experiment (jointly with MA, HL)

Time: Wednesday 9:30–13:00 Location: HSZ 03

TT 38.1 Wed 9:30 HSZ 03

Adiabatic two-qubit state preparation in a superconducting qubit system — •Marc Ganzhorn[1], Daniel Egger[1], Andreas Fuhrer[1], Nikolaj Moll[1], Peter Mueller[1], Marco Roth[2], Sebastian Schmidt[3], and Stefan Filipp[1] — [1]IBM Schweiz, Rueschlikon, Schweiz — [2]Department fuer Physik, RWTH Aachen, Deutschland — [3]Institut fuer Theoretische Physik, ETH Zuerich, Schweiz

The adiabatic transport of a quantum system from an initial eigenstate to its final state while remaining in the instantaneous eigenstate of the driving Hamiltonian can be used for robust state preparation. With control over both qubit frequencies and qubit-qubit couplings this method can be used to drive the system from initially trivial eigenstates of the uncoupled qubits to complex entangled multi-qubit states. In the context of quantum simulation, the final state may encode a non-trivial ground-states of a complex molecule, or the solution to an optimization problem in the context of adiabatic quantum computing. Here we present experimental results on a system comprising fixed-frequency superconducting transmon qubits and a tunable coupler to adjust the qubit-qubit coupling via parametric frequency modulation. We realize different types of interaction terms by adjusting the frequency of the modulation. A slow variation of drive amplitude and phase leads to an adiabatic steering of the system to its final state showing entanglement between the qubits.

TT 38.2 Wed 9:45 HSZ 03

Second-order decoherence mechanisms of a transmon qubit probed with thermal microwave states — •Frank Deppe[1,2,3], Jan Goetz[1], Peter Eder[1,2,3], Michael Fischer[1,2,3], Stefan Pogorzalek[1,2,3], Edwar Xie[1,2,3], Kirill G. Fedorov[1,2], Achim Marx[1], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

Using thermal microwaves as a probe, we identify three second-order decoherence mechanisms of a superconducting transmon qubit. First, we quantify the efficiency of a resonator filter in the dispersive Jaynes-Cummings regime and find evidence for parasitic loss channels. Second, we probe second-order noise in the low-frequency regime and demonstrate the expected T^3 temperature dependence of the qubit dephasing rate. Finally, we show that qubit parameter fluctuations due to two-level states are enhanced under the influence of thermal microwave states. In particular, we present experimental evidence for a model based on noninteracting two-level states.

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TT 38.3 Wed 10:00 HSZ 03

Probing broadband engineered and residual environments with a transmon qubit — •P. Eder[1,2,3], F. Deppe[1,2,3], T. Le Anh[1,2], J. Goetz[1,2], M. Fischer[1,2,3], E. Xie[1,2,3], A. Marx[1], and R. Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

Microwave beam splitters and transmon qubits are important components in circuit quantum electrodynamics (QED). Arranging two beam splitters in the form of an interferometer, we engineer a nontrivial broadband on-chip environment. We place the transmon qubit as a sensitive probe inside this environment and perform resonance fluorescence measurements. When comparing the experimental results with predictions from the spin-boson model, we find good agreement. Small deviations between experiment and theory indicate the presence of spurious electromagnetic modes. In general, our results demonstrate how to design and scale up complex circuits for experiments on propagating quantum microwaves.

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TT 38.4 Wed 10:15 HSZ 03

Chains of nonlinear and tunable superconducting resonators — •M. Fischer[1,2,3], P. Eder[1,2,3], J. Goetz[1,2], S. Pogorzalek[1,2], E. Xie[1,2,3], K. Fedorov[1,2], F. Deppe[1,2,3], A. Marx[1], and R. Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

We present the theoretical analysis and experimental study of a quantum simulation system of the Bose-Hubbard Hamiltonian in the driven dissipative regime in the realm of circuit QED. The system consists of series-connected, capacitively coupled superconducting resonators which are both nonlinear and tunable. The nonlinearity is achieved by galvanically coupled SQUIDs. They are placed in the current antinode of each resonator and can be tuned by external coils and on-chip antennas.

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TT 38.5 Wed 10:30 HSZ 03

Towards a scalable 3D quantum memory — •Edwar Xie[1,2,3], Frank Deppe[1,2,3], Daniel Repp[2], Peter Eder[1,2,3], Michael Fischer[1,2,3], Jan Goetz[1,2,3], Kirill G. Fedorov[1], Achim Marx[1], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

For superconducting qubits dispersively coupled to 3D cavity resonators both T_1-and T_2-times in excess of $100\,\mu$s have been achieved. However, the 3D cavities are bulky in comparison with their (slightly less coherent) 2D counterparts. A more scalable device can be built by exploiting the multi-mode structure of the 3D cavity. Here, we present an experimental study on such a device: a transmon qubit capacitively coupled to two distinct modes of a single 3D cavity. We engineer the fundamental and the first harmonic mode of a single cavity in such a way, that the former one couples well to the external feedline, whereas the latter does not. The qubit is dispersively coupled to both modes with a rate $g/2\pi \simeq 60\,$MHz. Using a second-order coupling protocol, we observe an enhancement in qubit lifetime by a factor of 3 compared to the pure qubit lifetime and find that this value is not limited by fundamental constraints.

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TT 38.6 Wed 10:45 HSZ 03

Finite-time correlations of balanced two-mode squeezed microwave states — •Kirill Fedorov[1,2], Stefan Pogorzalek[1,2], Patrick Yard[1,2], Peter Eder[1,2,3], Michael Fischer[1,2,3], Jan Goetz[1,2], Edwar Xie[1,2,3], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

Generation of balanced two-mode squeezed states is a key task in quantum communication and illumination with continuous variables, as it enables distribution of quantum entanglement between distant parties. For this reason, the investigation of such states is of high interest in the field of propagating quantum microwaves. In our work, we perform tomography of balanced two-mode squeezed microwave states which are created by the means of two flux-driven Josephson parametric amplifiers generating orthogonally squeezed states at the inputs of a 50 : 50 microwave beam splitter. We study finite-time correlations in order to measure a characteristic time of entanglement decay in quantum channels. Our studies show that quantum communication and illumination protocols with continuous-variable propagating microwaves are experimentally feasible.

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TT 38.7 Wed 11:00 HSZ 03

Impact of noise on entanglement of two-mode squeezed microwave states — •S. Pogorzalek[1,2], K. G. Fedorov[1,2], P. Yard[1,2], P. Eder[1,2,3], M. Fischer[1,2,3], J. Goetz[1,2], E. Xie[1,2,3], A. Marx[1], F. Deppe[1,2,3], and R. Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

Propagating quantum signals in the form of microwave two-mode squeezed states (TMSSs) can be generated by utilizing Josephson parametric amplifiers (JPAs). In our experiments, we employ two flux-driven JPAs at the inputs of an entangling hybrid ring in order to generate TMSSs between the hybrid ring outputs. This allows us to generate quantum entangled propagating microwave signals suitable for quantum communication and sensing applications such as quantum teleportation and quantum radar. However, the performance of these schemes may drastically depend on the amount of environmental noise in the communication channels. We study this dependence experimentally by controlling the amount of excess noise in different parts of the setup. Finally, we investigate the robustness of entanglement to thermal and shot noise via a negativity criterion and determine fundamental negativity-versus-noise limits.

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15 min. break.

TT 38.8 Wed 11:30 HSZ 03

Tailoring coupling in artificial superconducting quasi-spins — •Alexander Stehli, Jochen Braumüller, Andre Schneider, Hannes Rotzinger, Martin Weides, and Alexey V. Ustinov — Physikalisches Institut, Karlsruhe Institute of Technology

Due to their intrinsic coherence and easy accessibility, superconducting circuits are a promising platform for building a universal quantum computer. Such devices could solve virtually any quantum problem, however many qubits are required in order to achieve quantum supremacy. A more direct, alternative approach is provided by analog quantum simulation. By synthesizing the Hamiltonian of a quantum system with a simulator, the eigenstates and time evolution are investigated without accessing the original system.

In this work, we explore the properties of two coupled concentric transmon qubits. We show strong XX-interaction with a coupling strength of 12 MHz between the qubits. This value is extracted from spectroscopy measurements and confirmed by vacuum Rabi oscillations, in good agreement with electrodynamic calculations.

These results pave way towards future experiments on the quantum dynamics of larger systems with multiple artificial quasi-spins. The concentric transmon is expected also to feature ZZ-coupling, when biased at frequencies away from the flux sweet spot. Depending on the accessible parameter range, the simulation of the Fermi-Hubbard model is offered by a theoretical model. In this contribution, we will show our experimental and numerical data and provide an outlook on performing quantum simulation with concentric transmon qubits.

TT 38.9 Wed 11:45 HSZ 03

Probing the strong coupling regime between microwave resonators and YPc_2 molecule ensembles — •Yannick Schön[1], Eufemio Pineda[2], Hannes Rotzinger[1], Marco Pfirrmann[1], Andre Schneider[1], Julius Krause[1], Sebastian T. Skacel[1], Mario Ruben[2], Alexey V. Ustinov[1], and Martin Weides[1,3] — [1]Karlsruhe Institute of Technology, Institute of Physics — [2]Karlsruhe Institute of Technology, Institute of Nanotechnology — [3]Johannes Gutenberg-University Mainz, Institute of Physics

We investigate magnetic molecule ensembles with microwave signals in the low GHz range. This offers a measurement and manipulation framework, which can reliably be integrated into hybrid quantum systems, and facilitates joint applications of magnetic molecules in the rapidly growing field of quantum information processing.

The studied material family of lanthanide or metal Phtalocyanine 2 compounds exhibits a wide range of splittings between their electronic states, as well as molecular anisotropy, depending on the central ion. Our setup facilitates probing dynamics of different molecules with a 3d cavity in dependence of temperature, power or magnetic field.

In particular, the strong coupling of Yttrium Pc2 (YPc_2) to microwave resonators has been investigated between 25 mK and 20 K, and compared to simulation based on input-output theory. The extracted parameters contain information about the sample transitions, their linewidth, and coupling strength down to the quantum regime. Furthermore, on-chip integration of molecule ensembles with superconducting niobium 2d resonators is demonstrated.

TT 38.10 Wed 12:00 HSZ 03

A pulsed electron paramagnetic resonance spectrometer operating at millikelvin temperatures — •Stefan Weichselbaumer[1,2], Christoph W. Zollitsch[1,2], Kai Müller[1,2], Petio Natzkin[1,2], Sebastian T. B. Goennenwein[1,2,3], Martin S. Brandt[2,4], Rudolf Gross[1,2,5], and Hans Huebl[1,2,5] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Institut für Festkörperphysik, Technische Universität Dresden, Dresden, Germany — [4]Walter Schottky Institut, Technische Universität München, Garching, Germany — [5]Nanosystems Initiative Munich, Munich, Germany

Electron paramagnetic resonance (EPR) is an ubiquitous spectroscopy tool which is employed in many areas of research. One critical aspect for any application is the sensitivity of the spectrometer which scales with the degree of spin polarization in the sample. In the paramagnetic case, this spin polarization is determined by the ratio of magnetic field and temperature, B/T. Here, we report on the implementation of a pulsed EPR spectrometer using superconducting microwave resonators, operating at millikelvin temperatures. We investigate a spin ensemble of phosphorus donors embedded in an isotopically purified nuclear spin free ^{28}Si environment, which exhibits a thermal spin polarization close to unity at 50 mK. Our high sensitivity allows for single-shot measurements with an exceptional signal-to-noise ratio SNR $\gg 1$ for approximately 10^8 spins.

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TT 38.11 Wed 12:15 HSZ 03

Engineering the parity of light-matter interaction in superconducting circuits — •J. Goetz[1], C. Besson[1,2], P. Eder[1,2,3], M. Fischer[1,2,3], S. Pogorzalek[1,2,3], E. Xie[1,2,3], K.G. Fedorov[1,2], F. Deppe[1,2,3], A. Marx[1], and R. Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

In physics, parity describes the symmetry properties of quantum states and operators under spatial inversion. It has manifold applications in the standard model, quantum information and field theory. We present a novel technique for the in-situ control of the interaction operator parity in superconducting quantum circuits. Using a tunable-gap gradiometric flux qubit, which exhibits both a dipole and a quadrupole moment, we can precisely engineer the interaction parity with spatially shaped microwave fields. Our highly symmetric sample architecture enables a complete parity inversion and the observation of transparency induced by longitudinal coupling. In a second step, we couple the qubit to a resonator and, in this way, activate quadrupolar transitions similar to those in multi-electron atoms. Our work paves the way towards parity based quantum simulation and physical applications based on longitudinal light-matter interaction.

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TT 38.12 Wed 12:30 HSZ 03

Near quantum-limited amplification and conversion based on a voltage-biased Josephson junction — •Salha Jebari[1,2], Florian Blanchet[1,2], Romain Albert[1,2], Dibyendu Hazra[1,2], and Max Hofheinz[1,2] — [1]CEA, Grenoble,France — [2]Université Grenoble Alpes, Grenoble, France

Recent experiments with superconducting circuits consisting of a DC voltage-biased Josephson junction in series with a resonator have shown that a tunneling Cooper pair can emit one or several photons with a total energy of 2e times the applied voltage. We present microwave reflection measurements on the device in , indicating that amplification is possible with a simple DC voltage-biased Josephson junction. We also show that this amplification adds noise close to the limit set by quantum mechanics for phase preserving amplifiers. For low Josephson energy, transmission and noise emission can be explained within the framework of P(E) theory of inelastic Cooper pair tunneling and are related to the fluctuation dissipation theorem (FDT). We also experimentally demonstrate, by controlling the applied DC voltage, that our device can act as both an amplifier and a frequency converter. Combined with a theoretical model, our results indicate that voltage-biased Josephson junctions might be useful for amplification near the quantum limit, being powered by simple DC voltage and providing a different trade-off between gain, bandwidth and dynamic range, which could be advantageous in some situations.

TT 38.13 Wed 12:45 HSZ 03

Josephson-photonics devices as source of non-classical microwave radiation — •Björn Kubala[1], Joachim Ankerhold[1], Chloe Rolland[2], Marc P. Westig[2], Iouri Moukharski[2], Daniel Esteve[2], and Fabien Portier[2] — [1]Institute for Complex Quantum Systems and IQST, Ulm University, Ulm, Germany — [2]CEA Saclay, Gif-sur-Yvette, France

Sources of non-classical photons have important applications in quantum communication and sensing technologies. With non-classical microwave sources these are extended to circuit-QED setups extensively used for various quantum information tasks.

Here, we report recent experimental result, demonstrating that a dc-biased Josephson junction embedded in a carefully engineered electromagnetic environment constitutes a new source of bright non-classical radiation. We will explain, why in such a "Josephson-photonics" device with a single mode of large impedance strongly anti-bunched photons are produced, opening the path to a single-photon source in the microwave range. A Cooper-pair crossing a junction, which is coupled to two resonators, under the proper dc-bias emits a pair of photons into the two resonators and thus produces correlated light with strongly reduced noise [1]. Measurements of this noise reduction factor demonstrate the non-classical nature of the light source.

[1] A. D. Armour, B. Kubala, and J. Ankerhold, Phys. Rev. B **91**, 184508 (2015)