TT 4: Superconductivity: Qubits I

Time: Monday 9:30–13:00 Location: H 2053

TT 4.1 Mon 9:30 H 2053

Dissipation by normal-metal traps in transmon qubits — •Roman-Pascal Riwar[1,2], Robert J. Schoelkopf[2], Leonid I. Glazman[2], and Gianluigi Catelani[1] — [1]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Departments of Physics and Applied Physics, Yale University, New Haven, CT 06520, USA

Quasiparticles are an intrinsic source of relaxation and decoherence for superconducting qubits. Recent works have shown that normal-metal traps may be used to evacuate quasiparticles, and potentially improve the qubit life time. Here, we investigate how far the normal metals themselves may introduce qubit relaxation. We identify the ohmic losses inside the normal metal and the tunnelling current through the normal metal-superconductor interface as the relevant relaxation mechanisms. We show that the ohmic loss contribution depends strongly on the device and trap geometry, as a result of the inhomogeneous electric fields in the qubit. The correction of the quality factor due to the tunnelling current on the other hand is highly sensitive to the nonequilibrium distribution function of the quasiparticles. Overall, we show that even when choosing less than optimal parameters, the presence of normal-metal traps does not affect the quality factor of state-of-the-art qubits.

TT 4.2 Mon 9:45 H 2053

Coupling transmons to traveling waves by strongly blockaded EIT — •Felix Motzoi and Klaus Molmer — Dept. of Physics and Astronomy, Aarhus University, Denmark

There are numerous proposals for entangling superconducting qubits on separated chips, which can be used for modular computing architectures. Here, we present a method that employs itinerant traveling waves, without the need for the light to be stored in the cavity or interact directly with the qubit. Rather, an EIT mechanism is controlled dispersively by the qubit in the cavity (by shifting it in and out of resonance), effectively performing a CPHASE operation. By using an ancillary transmon qubit, the light-matter coupling strength can be greatly enhanced without negatively affecting the coherence time of the device. Such a scheme can be used with coherent light fields and without the need for measurement, offering potential for high practicality.

TT 4.3 Mon 10:00 H 2053

Using Superconducting Qubits for analog Quantum Simulation — •Oscar Gargiulo[1,2], Stefan Oleschko[1,2], Phani Muppalla[1,2], Maximilian Zanner[1,2], Aleksei Sharafiev[1,2], and Gerhard Kirchmair[1,2] — [1]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Technikerstraße 21a, A-6020 Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, Technikerstraße 25, A-6020 Innsbruck, Austria

In this talk I want to present the research activities of the Superconducting Quantum Circuits group at the Institute for Quantum Optics and Quantum Information in Innsbruck. I will give an introduction to circuit quantum electrodynamics and our 3D circuit QED architecture. I will show how we want to use this architecture to realize a platform for quantum many body simulations of dipolar XY models on 2D lattices using state of the art circuit QED technology. The central idea is to exploit the naturally occurring dipolar interactions between 3D superconducting qubits to simulate models of interacting quantum spins. The ability to arrange the qubits on essentially arbitrary geometries allows us to design spin models with more than nearest-neighbor interaction in various geometries.

TT 4.4 Mon 10:15 H 2053

Fast flux control of 3D transmon qubits — •Stefan Oleschko[1,2], Oscar Gargiulo[1,2], Phani Muppalla[1,2], Maximilian Zanner[1,2], Aleksei Sharafiev[1,2], and Gerhard Kirchmair[1,2] — [1]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Technikerstraße 21a, A-6020 Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, Technikerstraße 25, A-6020 Innsbruck, Austria

An important feature in analog quantum simulation experiments with superconducting qubits [1] is the possibility to change the frequency of SQUID-based transmon qubits by applying magnetic flux. Implementing fast flux control on a transmon remains challenging in the 3D cavity architectures due to the presence of a massive metallic cavity. Here we introduce a new approach for fast flux control of 3D transmon qubits. We use a magnetic hose similar to the one proposed by C. Navau et al [2] to guide a fast flux pulse from the outside to the inside of a microwave cavity. This hose enables us to locally circumvent any magnetic shielding effects such as the appearance of eddy currents in cavities made out of copper or the Meissner effect in superconducting cavities made out of aluminum. First experiments show that the transition frequency of a transmon can be tuned within 50 nanoseconds. Besides the high speed, the frequency shift is precise, without showing any ringing or hysteresis. Using a magnetic hose with an aluminum cavity preserves the benefits of a superconducting cavity, like providing magnetic field shielding and a high internal quality factor, along with the possibility to fast-tune individual qubits.

TT 4.5 Mon 10:30 H 2053

Transmon qubit circuits based on semiconductor/superconductor core/shell nanowire Josephson junctions — •Patrick Zellekens[1,2], Steffen Schlör[3], Tobias Ziegler[1,2], Nicolas Güsken[1,2], Torsten Rieger[1,2], Benjamin Bennemann[1,2], Mihail Ion Lepsa[1,2], Detlev Grützmacher[1,2], Martin Weides[3], and Thomas Schäpers[1,2] — [1]Peter Gruenberg Institute 9, Forschungszentrum Juelich, 52425 Juelich, Germany — [2]JARA - Fundamentals of Future Information Technologies — [3]Physikalisches Institut, Karlsruher Institut für Technologie

State-of-the-art qubits, like the transmon, are typically tuned in frequency by a magnetic field. Our goal is to fabricate and characterize an electrically tunable qubit in the GHz regime, using a semiconductor nanowire Josephson junction as nonlinear element. Thereby it is possible to tune the resonance frequency of the qubit without a magnetic flux bias. The main limitation for the qubit performance is the semiconductor-superconductor interface as well as the coherence properties of the surrounding circuit. In order to address this issue and to optimize the interface properties, an in-situ fabrication approach was chosen, in which the nanowire is directly covered with a superconducting shell. Subsequently, Josephson junctions are fabricated and electrically characterized at low temperature. Finally, implementations as building blocks for 2-dimensional transmon qubits based on TiN will be shown.

TT 4.6 Mon 10:45 H 2053

Flux-Noise Spectroscopy on a Superconducting Transmon Qubit — •Tim Wolz[1], Andre Schneider[1], Jochen Braumüller[1], Alexey V. Ustinov[1,2], and Martin Weides[1,3] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Russian Quantum Center, Moscow, Russia — [3]Institut für Physik, Johannes Gutenberg Universität, Mainz, Germany

Superconducting qubits can act as noise sensors because their decoherence times under certain pulse sequences can be linked to the system's noise power spectral density (PSD). These sequences also set the observable frequency range of the PSD. The PSD during free evolution of the qubit can be obtained with a dynamical decoupling (CPMG-) pulse sequence, which renders the qubit only susceptible to noise within a narrow frequency band. The PSD during driven evolution is measured with a so-called spin-locking sequence, during which only noise at the Rabi frequency can affect the qubit. Both protocols were successfully tested on a flux qubit by Bylander [1] and Yan [2]. In this work, we apply these two protocols to a tunable concentric transmon [3], overcome the challenge of the transmon's low anharmonicity by using DRAG pulses and compare the PSDs of free and driven evolution. Our results show a clear $1/f$ dependence in both cases, as well as a white spectrum at frequencies above 1 MHz during free evolution. The successful application of these protocols to a transmon permits magnetic noise sensing with such a qubit in future experiments.

[1] J. Bylander *et al.*, Nat. Phys. (2011).
[2] F. Yan *et al.*, Nat. Comm. (2013).
[3] J. Braumüller *et al.*, Appl. Phys. Lett. (2016)

TT 4.7 Mon 11:00 H 2053

Adding ZZ-coupling to transmon qubits — •Alexander Stehli[1], Jochen Braumüller[1], Hannes Rotzinger[1], Andre

Schneider[1], Martin Weides[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Deutschland — [2]Russian Quantum Center, National Institute of Science and Technology MISIS, Moscow, Russia

Versatile quantum elements enable higher connectivity for quantum computing or the quantum simulation of intricate physics using only few physical qubits. In superconducting quantum circuits, the transmon qubit is the most widely used architecture, owed to its robustness and good coherence properties. While typical transmon designs solely allow for an XX-interaction between neighboring qubits, the concentric transmon [1] was predicted to feature an additional ZZ-coupling [2]. It is mediated by the non-vanishing dc magnetic field of the qubits in the flux-biased state.

In this work, we explore the possibility of ZZ-interaction between two concentric transmon qubits. The qubits are galvanically coupled to maximize their mutual inductance, which is proportional to this effect. In time-resolved microwave measurements, we determine the ZZ-coupling strength from a shift of the qubit transition frequency. First experiments indicate a coupling strength on the order of several MHz.

[1] J. Braumüller *et al.*, Appl. Phys. Lett. **108**, 032601 (2016)
[2] J.-M. Reiner *et al.*, Phys. Rev. A **94**, 032338 (2016)

15 min. break.

TT 4.8 Mon 11:30 H 2053

Qubit readout using a transmon with a V-shaped energy diagram — Remy Dassonneville, Luca Planat, Javier Puertas, Farshad Foroughi, Cecile Naud, Wiebke Guichard, Nicolas Roch, and •Olivier Buisson — University Grenoble Alpes & CNRS, Institut Néel, F-38000 Grenoble, France.

The most widely used scheme to perform qubit readout in cQED relies on the dispersive coupling between a qubit and a harmonic oscillator. However, despite important progresses, implementing a fast and high fidelity readout remains nowadays a major challenge. Indeed, inferring a qubit state is limited by the trade-off between speed and accuracy due to Purcell effect and transitions induced by readout photons in the resonator. To overcome this, we introduce a new device: a transmon with a V-shaped energy diagram, embedded in 3D architecture. It is made of two transmons coupled via a large inductance[1]. The resulting circuit presents two qubits longitudinally coupled called qubit and ancilla. Using symmetry rules[2], the ancilla can be strongly coupled to the cavity while the qubit remains uncoupled. However due to their strong longitudinal coupling, the qubit state can still be inferred through the ancilla state. A theoretical study[3] has predicted a QND readout with fidelity as high as 99.9

[1] É. Dumur, et al, Phys. Rev. B 92, 020515(R) (2015).
[2] É. Dumur, et al, IEEE Trans. Appl. Supercond. 26, 1700304 (2016).
[3] I.Diniz, et al, , Phys. Rev. A 87, 033837 (2013).

TT 4.9 Mon 11:45 H 2053

Decoherence mechanisms in transmon qubits: Ultra-low frequency noise and switching events
— •Steffen Schlör[1], Andre Schneider[1], Jürgen Lisenfeld[1], Martin Sandberg[2], David P. Pappas[2], Alexey V. Ustinov[1], and Martin Weides[1,3] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Germany — [2]National Institute of Standards and Technology, Boulder, USA — [3]Institute of Physics, Johannes Gutenberg University Mainz, Germany

Today's quantum computers made of highly coherent superconducting qubits are already capable to find the electronic ground state of small molecules [1]. The complexity and number of qubits on single chips having gate fidelities at or beyond the threshold for fault-tolerant quantum computing [2] keeps growing. Their longer operation times shift the focus towards decoherence mechanisms and fluctuations occurring on time scales of hours or even days.

We present the results of such long-term measurements of a high-coherent, non-tunable transmon qubit. We perform simultaneous measurements of the qubit's relaxation and dephasing rates as well as resonance frequency shifts and analyze their correlations. These yield information about the microscopic origin of decoherence mechanisms, their interacting with the qubit, and their fluctuation dynamics. From a spectral noise analysis, we obtain evidence for the presence of a small number of dominant fluctuators.

[1] A. Kandala et al., Nature **549**(7671), 2017
[2] R. Barends et al., Nature **508**(7497), 2014

TT 4.10 Mon 12:00 H 2053

Parametrically activated two-qubit interactions in a superconducting qubit system — •Marc Ganzhorn[1], Marco Roth[2], Gian Salis[1], Nikolaj Moll[1], Sebastian Schmidt[3], and Stefan Filipp[1] — [1]IBM Research, Zurich, Switzerland — [2]RWTH, Aachen, Germany — [3]ETH, Zurich, Switzerland

A current bottleneck for quantum computation is the realization of high-fidelity two-qubit operations in arrays of more than two coupled qubits. Gates based on parametrically driven tunable couplers offer a convenient method to entangle multiple qubits by selectively activating different interaction terms in the effective Hamiltonian. Here we present experimental results on a system comprising fixed-frequency superconducting transmons capacitively coupled to a tunable coupler (in this case a flux tunable qubit). The two-qubit interactions are activated via a parametric frequency modulation. We realize different types of interactions with fidelities up to 97% by adjusting the frequency and phase of this modulation. Our experimental findings are backed by numerical simulations, revealing that the fidelities of these two qubit operations are limited by the coherence of the tunable coupler. Finally, using such a set of single and two qubit interactions, simulation of quantum systems such as molecules or spin systems could be realized.

TT 4.11 Mon 12:15 H 2053

Suppression of the low-frequency decoherence by Bell-state motion — •Andrey Vasenko[1] and Dmitri Averin[2] — [1]National Research University Higher School of Economics, 101000 Moscow, Russia — [2]Department of Physics and Astronomy, Stony Brook University, SUNY,Stony Brook, NY 11794, USA

As demonstrated recently, in the realistic situation when the low-frequency noises are uncorrelated among different physical superconducting qubits, transfer of individual logical qubits in arrays of physical qubits can be used to suppress the low-frequency decoherence of quantum information encoded in the logical qubits [1]. The purpose of this work is to show that, if the quantum information is encoded in the Bell-type logical states, the transfer of these states through an array of physical qubits implements simultaneously the motion-induced and spin-echo suppression of decoherence leading to a qualitatively stronger tool against the low-frequency noise than is provided by the two approaches separately [2]. We also discuss the coexistence of the motion-induced suppression of decoherence and more complicated dynamic decoupling-schemes, like Carr-Purcell pulse sequence.

[1] D. V. Averin, K. Xu, Y. P. Zhong, C. Song, H. Wang, and Siyuan Han, Phys. Rev. Lett. 116, 010501 (2016).
[2] D.V. Averin and A.S. Vasenko, in preparation.

TT 4.12 Mon 12:30 H 2053

In-situ tunable environment for superconducting qubits — •J. Goetz[1], M. Silveri[1,2], K. Y. Tan[1], M. Partanen[1], A. M. Gunyho[1], D. Hazra[1], V. Vesterinen[1,3], J. Hassel[3], L. Grönberg[3], H. Grabert[4], and M. Möttönen[1] — [1]QCD Labs, Department of Applied Physics, Aalto University, Aalto, Finland — [2]University of Oulu, Research Unit of Theoretical Physics, Oulu, Finland — [3]VTT Technical Research Centre of Finland Ltd, VTT, Finland — [4]University of Freiburg, Department of Physics, Freiburg, Germany

Superconducting quantum circuits hold great potential in providing revolutionizing practical applications such as quantum sensing or computing. However, in many cases noise limits the operation and the fidelity of these circuits. Here we introduce a concept that exploits noise instead of trying to reduce it. Our concept uses photon-assisted single-electron tunneling as a controlled source for dissipation in superconducting qubits. We show how the recently developed quantum-circuit refrigerator [1], QCR, is suitable to control the dynamics of superconducting qubits. In our experiments, the QCR works as a voltage-controlled environmental bath for the qubit. The qubit-bath coupling strength can be tuned over several orders of magnitude on a nanosecond timescale. Such a tunable environment is promising for fast qubit reset and studies of dissipative open quantum circuits. Our highly integrable circuit architecture may prove useful in the initialization of qubit arrays and in dissipation-assisted quantum annealing.

[1] K. Y. Tan, et al., Nature Commun. 8, 15189 (2017)

TT 4.13 Mon 12:45 H 2053

Rapid High-Fidelity Multiplexed Readout of Superconduct-

ing Qubits — •Johannes Heinsoo, Christian Kraglund Andersen, Ants Remm, Sebastian Krinner, Yves Salathe, Theodore Walter, Simone Gasparinetti, Jean-Claude Besse, Anton Potocnik, Christopher Eichler, and Andreas Wallraff — ETH Zürich

The duration and fidelity of qubit readout is a critical factor for applications in quantum information processing as it limits the fidelity of algorithms, which reuse qubits after measurement or apply feedback based on the measurement result. In this talk we discuss the results of a fast multiplexed readout experiment performed on five qubits with readout resonators populated for less than 200 ns. We find that the probability of assigning the individual qubit to be in the state we intended to prepare, is above 95% for all five measured qubits. In addition, the data shows that individual Purcell filters used in this experiment lead to reduced measurement induced dephasing of the qubits we did not intend to measure.