TT 58: Poster: Superconductivity II

Time: Thursday 15:00–18:00 Location: P2/OG3

TT 58.1 Thu 15:00 P2/OG3

Low temperature MMC-based muon veto for IAXO — •Daniel Unger, Christian Enss, Andreas Fleischmann, Daniel Hengstler, Ashish Jadhav, and Loredana Gastaldo — Kirchhoff Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

An array of Metallic Magnetic Calorimeter (MMC) operated at a few mK in a dilution refrigerator is considered as a possible focal plane detector for the IAXO helioscope. For such an experiment, the background rate must be smaller than $10^{-6}\,\mathrm{keV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. However, we expect the rate of events related to cosmic muons to be two orders of magnitude larger. A traditional muon veto composed by scintillating panels would have to cover the full cryostat, a volume of about $3\,\mathrm{m}^3$. A cryogenic muon veto surrounding the $150\,\mathrm{cm}^3$ volume of the detector module could veto muon related events more efficiently. We present the development of a large-area MMC-based muon veto. Muons will be detected through their energy deposition while traversing a silicon wafer with thickness of 0.4 mm and an area of $30\,\mathrm{cm}^2$. We discuss the design and the fabrication challenges of the muon veto in addition to the prototype setup for testing purposes. We aim to characterize the performance of the large silicon detector and at the same time study the spectrum of muon related events detected by the MMC array as well as of the residual background due to natural radioactivity. Finally, we evaluate the suitability of MMC arrays for low background measurements.

TT 58.2 Thu 15:00 P2/OG3

Dc-SQUID readout with high dynamic range and intrinsic frequency-domain multiplexing capability — •L. Münch, A. Abeln, N. Kahne, F. Krämer, D. Hengstler, L. Hoibl, D. Mazibrada, D. Richter, A. Stoll, A. Fleischmann, and C. Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Dc superconducting quantum interference devices (dc-SQUIDs) are periodic flux-to-voltage converters whose linear flux range is rather small. For this reason, a flux locked loop (FLL) circuit is typically used to linearize the output signal and increase the dynamic range. However, the measurement of large signals while maintaining the excellent noise performance of SQUIDs sets high demands on the digitizer sampling the SQUID signal in terms of voltage resolution. Furthermore, FLL operation often sets a practical limit for the realization of massive multi-channel SQUID systems since feedback wires have to be routed to every SQUID.

In this contribution, we discuss a SQUID readout approach which relaxes the hardware requirements of a SQUID system while maintaining a linearized output signal and a large dynamic range. At the same time, it allows for reducing the number of wires within multi-channel SQUID systems due to its intrinsic frequency-domain multiplexing (FDM) capability. We introduce the basic concept of our readout approach and demonstrate its intrinsic FDM-capability using a custom-made four channel multiplexer device. We also present a new chip design optimized for the read-out of a novel 16 x 16 pixel MMC array.

TT 58.3 Thu 15:00 P2/OG3

Integrated two-stage SQUID-chip with 6 nH input impedance — •David Mazibrada, Fabian Krämer, Alexander Stoll, Nicolas Kahne, Lukas Münch, Daniel Hengstler, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

SQUIDs are sensitive superconducting magnetic flux to voltage converters, whose operation is based on the Josephson effects. To increase the signal-to-noise ratio of a SQUID-based readout system one can amplify the signal with an N-SQUID series array. We present our first integrated two-stage chip design which combines a single current sensing dc-SQUID as front-end and a 18-dcSQUID series array as amplifier stage, in one compact, well thermalized chip. This not only eliminates the need for two separate chips, but also achieves low signal propagation delay and larger bandwidth. Compared to our most recent single-stage current sensing SQUIDs, the first stage SQUID features a 2-turn input coil with increased inductance of 6 nH increasing the input current sensitivity by a factor of about 2. To counteract the resistive heating of the two-stage setup, large thermalization pads made of gold are implemented to thermalize the resistive elements and in addition the chip can be thermally anchored to the sample holder by means of gold bonds. In future designs lossy striplines will be used in order to provide delocalized broad-band damping and suppress effects of parasitic resonances without introducing new noticeable sources of noise.

TT 58.4 Thu 15:00 P2/OG3

Identification of noise sources in superconducting microstructures — •R. Yang, A. Fleischmann, D. Hengstler, M. Herbst, D. Mazibrada, L. Münch, A. Reifenberger, C. Ständer, and C. Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Improving the performance of a superconducting device often means identifying and eliminating noise. Many potential noise sources are independent of the specific experimental set-up and transferable across many device categories such as qubits, SQUIDs, and superconducting detectors. We have constructed a stand-alone device able to representably probe specific noise sources. The set-up consists of a Wheatstone-like bridge of microfabricated superconducting inductors and a pair of two-stage dc-SQUID read-out chains. Cross-correlation removes noise contributions from the read-out electronics giving us the sum total of all noise in the superconducting circuit. If, in comparison, the Wheatstone bridge is AC-driven, we can measure a sample material's magnetic noise via the material's complex AC susceptibility using the fluctuation-dissipation theorem. The experiment is performed at temperatures between $T = 10\,\mathrm{mK}$ and 1000 mK in the frequency range from $f = 100\,\mathrm{mHz}$ to 100 kHz on an experimental holder with excellent thermal coupling and shielding. We present first results of measurements on SiO_2 and Ag:Er thin films and compare these results with previous measurements on Au:Er. In addition, we demonstrate our device's ability to probe the dynamics of magnetic moments in a sample material.

TT 58.5 Thu 15:00 P2/OG3

Recent insights into low frequency excess flux noise in superconducting quantum devices — •Anna Ferring-Siebert, Fabian Kaap, David Mazibrada, Lukas Münch, Matthew Herbst, Andreas Fleischmann, Christian Enss, and Sebastian Kempf — Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

In many applications low frequency excess flux noise (EFN), with a frequency dependence of $1/f^\alpha$, limits the performance of superconducting quantum devices such as SQUIDs and Qubits. Although it was long believed that its magnitude expressed in units of magnetic flux $S_\Phi(1\,\mathrm{Hz})$ and exponent α are fairly independent of the device material and inductance, there meanwhile exist hints for the contrary. It is also known that EFN can depend on the equipment used for device fabrication, the reason for that however remained unknown up to now.

In this contribution, we discuss origins of fabrication induced EFN as well as means to minimize it. In particular, we show that material layers deposited with commercial deposition equipment can contain magnetic impurities causing EFN. In this context, we present how we have modified commercial sputtering sources to reduce EFN and provide evidence for a relationship between EFN amplitude and the DC magnetization of the deposited material layers. Finally, recent measurements investigating the dependence of EFN on device inductance are discussed, suggesting that energy sensitivity $\varepsilon(1\,\mathrm{Hz}) = S_\Phi(1\,\mathrm{Hz})/(2L)$, rather than magnetic flux noise, is the more appropriate metric to describe EFN.

TT 58.6 Thu 15:00 P2/OG3

Impedance engineering of flux-pumped Josephson traveling wave parametric amplifier — •Daniil E. Bazulin[1,2], Kedar E. Honasoge[1,2], Leon Koch[1,2], Niklas Bruckmoser[1,2], Yuki Nojiri[1,2], Thomas Luschmann[1,2], Achim Marx[1], Stefan Filipp[1,2,3], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Scalable quantum computing with superconducting qubits relies on efficient and fast readout of multiple qubits. This goal can be achieved by exploiting broadband Josephson Traveling Wave Parametric Amplifiers (JTWPAs). Here, we investigate fabrication and characterization of a specific type of the JTWPA based on aluminium Superconducting Nonlinear Asymmetric Inductive eLements (SNAILs) exploiting the 3-wave mixing down-conversion process. This approach allows for separating signal and pump paths, which is expected to enhance the overall JTWPA performance by mitigating back action amplification processes and avoiding the pump depletion. Additionally, we implement a single-layer 50 Ω impedance matching approach by exploiting fish-bone capacitors fabricated simultaneously with the Josephson junctions. This technique avoids using extra dielectric layers, which are typical sources of losses and noise in JTWPAs.

TT 58.7 Thu 15:00 P2/OG3

Large-scale fabrication of Josephson parametric devices — •Maria-Teresa Handschuh[1,2], Kedar E. Honasoge[1,2], Yuki Nojiri[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Daniil Bazulin[1,2], Florian Fesquet[1,2], Fabian Kronowetter[1,2,4], Michael Renger[1,2], Wun K. Yam[1,2], Achim Marx[1], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, 85748 Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany — [4]Rohde & Schwarz GmbH & Co. KG, 81671 Munich, Germany

The rapid progress in the field of quantum information processing with superconducting circuits requires the development of large-scale fabrication to increase fabrication efficiency, reproducibility as well as to reduce costs. Moreover, many advanced quantum applications and experiments rely on using multiple nominally identical chips, such as flux-driven Josephson parametric amplifiers (JPAs) [1]. To this end, the goal is to establish good control over various fabrication parameters, such as critical current density and microwave losses, in JPAs with Nb/Al-AlOx/Nb Josephson junctions on 4-inch high-resistivity silicon wafers. We provide a detailed analysis of the related parameter distribution across the wafer and make proposals for future improvements.

[1] K. G. Fedorov et al., Sci. Adv. 7, eabk0891 (2021)

TT 58.8 Thu 15:00 P2/OG3

Microwave quantum memory based on rare earth doped crystal — •Jianpeng Chen[3,1,2], Ana Strinic[3,1,2], Achim Marx[1,3], Kirill G. Fedorov[1,3], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[3,1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 Munich, Germany — [3]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany

Quantum memory is an essential element in the development of future quantum technologies, such as quantum computing circuits and quantum communication links. Specifically, crystals doped with rare earth ions are promising competitive candidates due to their long coherence times [1] and potential multiplexing capability [2]. Here, we aim to couple coherent microwave signals to rare earth ion dopants in yttrium orthosilicate crystals (Y2SiO5) at 10 mK. We will discuss the impact of the transmission line design on the efficiency of quantum information storage and its multimodality potential.

We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036).

[1] M. Zhong, Nature 517, 177 (2015)
[2] A. Ortu et al., Quantum Sci. Technol. 7, 035024 (2022)

TT 58.9 Thu 15:00 P2/OG3

Non-Markovian effects in Er:YSO — •Owen Thomas Huisman[1,2,4], Ana Strinic[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technologies, München, Germany — [4]Delft University of Technology, Delft, Netherlands

Erbium doped Y_2SiO_5 (Er:YSO) has proven to be a suitable platform to realise quantum memory protocols based on microwave ESR techniques [1]. The successful storage and retrieval of a microwave quantum state depends on the coherence and relaxation of spectral holes burned in inhomogeneously broadened spin transitions. Recent work has shown that relaxation and decoherence processes in Er:YSO at sub-Kelvin temperature may be affected by the phonon bottleneck process [2]. Several attempts have been made to develop a microscopic theory of the phonon bottleneck [3,4]. In this work, we attempt to connect the phonon bottleneck to more recent investigations of non-Markovian open quantum systems [5]. We propose an experiment to confirm the presence of non-Markovian effects in Er:YSO and justify the connection with a phonon bottleneck.

[1] S. Probst et al., Phys. Rev. B 92, 014421 (2015)
[2] R. P. Budoyoet al., Appl. Phys. Express 11, 043002 (2018)
[3] D. A. Garanin, Phys. Rev. B 75, 094409 (2007)
[4] D. A. Garanin, Phys. Rev. B 77, 024429 (2008)
[5] C.-F. Li et al., EPL 127, 50001 (2019)

TT 58.10 Thu 15:00 P2/OG3

Microwave single-shot quantum key distribution — •Florian Fesquet[1,2], Fabian Kronowetter[1,2,4], Michael Renger[1,2], Nadezhda Kukharchyk[1,2], Hans Huebl[1,2,3], Achim Marx[1], Rudolf Gross[1,2,3], and Kirill. G. Fedorov[1,2] — [1]Walther-Meißner-Institut, 85748 Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [4]Rohde & Schwarz GmbH, 81671 Munich, Germany

Security of modern classical data encryption often relies on computationally hard-to-solve problems. A potential remedy for this challenge is quantum communication (QC) which takes advantage of the laws of quantum physics to provide secure exchange of information. Here, quantum key distribution (QKD) represents a powerful tool, allowing unconditionally secure QC between remote parties. A demand for QC at microwave frequencies has emerged due to the tremendous progress in quantum information processing with superconducting circuits. To this end, we present a realization of a continuous-variable QKD protocol based on displaced squeezed microwave states. We use a Josephson parametric amplifier (JPA) to generate squeezed microwave states at cryogenic temperatures. By implementing a single-shot quadrature readout with a second JPA in the phase-sensitive regime with quantum efficiency of 38 %, we demonstrate the unconditional security of this microwave QKD protocol. We analyze these results in terms of losses and noise in order to map them on possible real-world scenarios.

TT 58.11 Thu 15:00 P2/OG3

3D-Integration of superconducting qubits using flip-chip bump bonding technology — •Franziska Wilfinger[1,2], Ivan Tsitsilin[1,3], and Stefan Filipp[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technologies (MCQST), Munich, Germany

Superconducting quantum circuits are typically realized in a planar architecture. This approach is, however limited to dozens of qubits due to the complexity of routing signal lines when scaling beyond. 3D-integration can overcome these limitations by separating circuit components on different layers and on different chips. One promising 3D-integration strategy is to assemble two chips, patterned on one side, through flip-chip bonding using indium bumps. Quantum components such as qubits and couplers containing Josephson junctions can then be separated from the control- and readout-lines on different faces. Here, we discuss design concepts and test-structures in a flip-chip architecture and their simulated performances with respect to quality factors, decay rates and gate times. Finite-element simulation is applied to extract design parameters such as the qubit coupling to readout- and control lines and to other qubits. These parameters are optimized in order to achieve a performance comparable with planar structures. Moreover, the influence of inaccuracies in fabrication is investigated by simulating varying distance parameters and analyzing their impact on relevant quantities.

TT 58.12 Thu 15:00 P2/OG3

Probing the density of states of defects in superconducting flux qubits — •Benedikt Berlitz, Alexander Konstantin Händel, Alexey V. Ustinov, and Jürgen Lisenfeld — Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Material defects forming two-level systems (TLS) present a source of decoherence and unwanted degrees of freedom in superconducting quantum circuits. Current theoretical models make different assumptions about the frequency dependence of the TLS' density of states (DOS). To measure the TLS' DOS in a wide frequency range, spanning from about 0.1 to 20 GHz, we fabricated flux qubits as TLS detectors. Measuring the DOS will enhance our understanding of the underlying physics of TLS in amorphous materials.

TT 58.13 Thu 15:00 P2/OG3

Fast quantum state tomography with superconducting qubits — •Andras Di Giovanni[1], Adrian Aasen[3], Moritz Reh[3], Martin Gärttner[3], Markus Griedel[2], Hannes Rotzinger[1,2], and Alexey Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe — [2]Institut für Quantenmaterialien und Technologien, Karlsruher Institut für Technologie, Karlsruhe — [3]Kirchhoff-Institut für Physik, Heidelberg

Quantum simulators promise insights into quantum many-body problems in regimes where classical simulation methods hit a complexity wall. One challenge towards this goal is to develop well characterized building blocks that allow to scale system sizes up while conserving reliability in terms of errors. A promising platform for building such quantum simulators are superconducting quantum circuits. We characterize small-scale quantum processors in the time domain with single-shot accuracy and minimal hardware and post-processing overhead. For this purpose we use reactive basis rotations based on greedy algorithms and adaptive Bayesian tomography. We present experimental results measured on a transmon qubit and compare the data with theoretical predictions.

TT 58.14 Thu 15:00 P2/OG3

Infrared filters for superconducting qubit applications — •Markus Griedel[1,2], Sebastian Koch[2], Alex Stehli[2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Institut for Quantum Materials and Technologies (IQMT), Karlsruhe Institut for Technology (KIT) — [2]Physikalisches Institut (PHI), Karlsruhe Institut for Technology (KIT)

Superconducting qubits are manipulated and read out using microwave signals which are generated at room temperature and guided through coaxial cables to the milikelvin temperature stage. One common problem of coax cables is their high transparency to infrared radiation originating from a rather high photon flux sources at elevated temperatures of cryostat stages. Filtering out the infrared radiation requires a low-pass filter with a sharp cutoff in the micro- or low mm-wave frequency range. We present simulations as well as experimental data on a new generation of powder based filters. The samples are investigated over the full band of infrared radiation using conventional detectors as well as superconducting qubits directly.

TT 58.15 Thu 15:00 P2/OG3

Superconducting flux qubits with stacked Josephson junctions — •Alex Kreuzer[1], Hossam Tohamy[1], Thilo Krumrey[1], Markus Griedel[1,2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie (KIT) — [2]Institut für Quantenmaterialien und -technologien (IQMT), Karlsruher Institut für Technologie (KIT)

Josephson junctions are often employed as nonlinear inductive elements in superconducting qubits as they allow to tailor specific circuit properties. The promising flux qubit types as fluxonium or quarton qubits require compact inductances which are often implemented as arrays of Josephson junctions. Here, the stray capacitance originating, for instance, from the capacitive coupling of an array island to ground, introduces the major limitation of this approach, since it introduces parasitic resonances at GHz frequencies which may degrade the overall qubit performance. We explore the possibility of implementing the qubit inductances by stacking Josephson junctions vertically and thus reducing the capacitance to ground. We present transport as well as microwave measurement data of stacked Josephson junctions and flux qubits made from them. Furthermore, we present a comparison of our experimental data with a detailed numerical simulation.

TT 58.16 Thu 15:00 P2/OG3

Flux escape mitigation in gradiometric fluxonium qubits — •Denis Bénâtre[1], Mathieu Féchant[1], Martin Spiecker[1,2], and Ioan Pop[1,2] — [1]IQMT, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [2]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Superconducting fluxonium qubits have grown in the past decade as an interesting alternative to the now standard transmons. In 2022, Gusenkova et al. proposed a new design, the gradiometric fluxonium qubit, whose two loops have shown to suppress sensitivity to homogeneous magnetic field and open the door for its use in hybrid quantum systems. However, these devices undergo flux escape triggered by radioactive and cosmic impacts, and thus require shielding from ionizing radiation, e.g. in deep-underground facilities [Gusenkova et al., 2022]. We present new designs of gradiometric fluxoniums aimed at intrinsically mitigating the rate of trapped flux escape.

TT 58.17 Thu 15:00 P2/OG3

Towards millimeter-wave superconducting qubits — •Philipp Lenhard, Jürgen Lisenfeld, and Alexey V. Ustinov — Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Superconducting circuits are a promising platform to realize a solid-state quantum computer. However, scaling up to larger multi-qubit circuits is severely hindered by decoherence of various origins. While contemporary qubits are typically operated between 3 and 6 GHz resonance frequencies, here we investigate qubit designs for millimeter-wave operation frequencies between 80 and 110 GHz. We present first spectroscopic measurements of resonant energy level transitions in a current-biased Josephson junction in the millimeter-wave regime. In addition, we show simulations of designs for integrating qubits and readout resonators in 3D-waveguides.

TT 58.18 Thu 15:00 P2/OG3

Towards dissipatively coupled photon-pressure circuits — •Janis Peter, Mohamad Adnan el Kazouini, Emily Guo, Kevin Uhl, and Daniel Bothner — Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen, Germany

Photon-pressure circuits are a superconducting all-circuit equivalent of cavity optomechanics. They recently gained a lot of attention since they are providing a new toolbox for sensing and controlling radiofrequency (rf) photons by high-frequency (hf) circuits. In contrast to optomechanical systems, this platform only consists of LC circuits without any mechanical resonators. As a result they offer a larger flexibility regarding device parameters and a simplified fabrication process. Until now, photon-pressure circuits have been realized using the so-called dispersive interaction: the rf-resonator modulates the resonance frequency ω_0 of the hf-circuit. To reach the quantum regime by ground state cooling, dispersively coupled devices need to be in the so-called sideband-resolved regime, that is, the resonance frequency Ω_0 of the rf-resonator is much larger than the decay rate of the hf-circuit κ (typically several 100 kHz). Extending the quantum regime to even lower frequency photons ($\lesssim$ 1 MHz) requires a different interaction: dissipative photon-pressure coupling, where κ is modulated instead of ω_0. We present our progress on implementing a dissipative photonpressure interaction between two superconducting circuits and discuss in this context simulation, fabrication, device design and intermediate experimental milestones.

TT 58.19 Thu 15:00 P2/OG3

Towards non-classical state preparation in photon-pressure circuits — •Mohamad Adnan El Kazouini, Janis Peter, Emily Guo, Kevin Uhl, and Daniel Bothner — Physikalisches Institut, Center for Quantum Sciences (CQ) and LISA$^+$, Universität Tübingen, Germany

Photon-Pressure is a non-linear interaction between two electromagnetic modes in LC circuits, which gained considerable attention in the past years due to its unique possibilities to sense and control radio-frequency photons. To date, several milestone experiments have been performed such as interferometric radio-frequency thermometry, the observation of parametric strong-coupling, and the realization of resolved-sideband cooling of a low-frequency LC circuit ($\sim$ 100 MHz) into its quantum ground state. Although photon-pressure is in principle providing the possibilities, non-classical states like quantum squeezed and entangled states of MHz photonic modes have not been realized yet in these systems. Those states, however, have the potential to enhance quantum-limited sensing of bosonic modes in the radio-frequency regime, an application of photon-pressure systems that have been discussed for instance in the context of the search for dark-matter axions. In our poster, we will present our progress in developing photon-pressure devices that are being engineered toward the preparation of non-classical radio-frequency photon states and we will discuss the next steps and our future plans.

TT 58.20 Thu 15:00 P2/OG3

Towards room temperature microwave quantum teleportation — •Wun Kwan Yam[1,2], Michael Renger[1,2], Simon

Gandorfer[1,2], Florian Fesquet[1,2], Kedar Honasoge[1,2], Fabian Kronowetter[1,2,3], Yuki Nojiri[1,2], Achim Marx[1], Rudolf Gross[1,2,4], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, BAdW, 85748 Garching, Germany — [2]Physik-Department, TUM, 85748 Garching, Germany — [3]Rohde & Schwarz GmbH & Co. KG, 81671 Munich, Germany — [4]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Microwave quantum communication enables efficient and unconditionally secure exchange of quantum states. This paves the way towards distributed quantum computing and open-air quantum key distribution. One of the relevant quantum communication protocols is quantum teleportation. In the microwave regime, quantum teleportation has been successfully demonstrated by using superconducting Josephson circuits in a cryogenic setup. To investigate the limits of microwave quantum teleportation under more realistic application scenarios, we study the influence of thermal noise and losses in microwave communication channels. We show that the teleportation protocol is robust against noise in the feedforward channel and analyze experimental limits of distributing entanglement via thermal channels. Furthermore, we describe the experimental implementation of microwave quantum teleportation with the room temperature feedforward and consider microwave quantum teleportation in the open air.

TT 58.21 Thu 15:00 P2/OG3

Experimental investigations and flow simulation of regenerator configurations of a single stage GM-type pulse tube cooler — •Elias Eisenschmidt[1,3], Jack-Andre Schmidt[2,3], Bernd Schmidt[2,3], Jens Falter[3], and Andre Schirmeisen[2,3] — [1]Technische Hochschule Mittelhessen, Friedberg, Germany — [2]Justus-Liebig-university, Giessen, Germany — [3]TransMIT-Center for Adaptive Cryotechnology and Sensors, Giessen, Germany

Pulse tube coolers are increasingly used in industry and research due to their low vibrations and long service intervalls. The regenerator and especially the filling of the regenerator has a great influence on the cooling capacity as well as the achievable, minimum temperatures. The temperature-dependent heat storage capacity of the materials used in the regenerator is usually the main focus of attention when selecting regenerator fillings. [1, 2]

This poster deals with the pressure drop of two regenerator fillings of stainless steel spheres and sieves. Steady-state and transient measurements of the two regenerator fillings will be discussed. In comparison of the two fillings used, the meshes show lower pressure drops, resulting in a higher cooling efficiency as regenerator filling, while spheres are more cost efficient in time and acquisition.

[1] N. Almtireen et. al., J. Low Temp. Phys. 199, 1179 (2020)
[2] P. P. Steijaert, Thermodynamical aspects of pulse-tube refrigerators, Technische Universiteit Eindhoven (1999)

TT 58.22 Thu 15:00 P2/OG3

Characterization of the cooling power on a two stage 4 K pulse tube cooler operated with solenoid valves — •Xaver Herrmann[1], Jack-André Schmidt[1,2], Bernd Schmidt[1,2], Jens Falter[2], and André Schirmeisen[1,2] — [1]Institute of Applied Physics, Justus-Liebig-University Giessen, Germany — [2]TansMIT-Center for Adaptive Cryotechnology and Sensors, Giessen, Germany

Closed-cycle cryocoolers have become an important tool for low temperature scientific research[1]. Here we focus on Gifford-McMahon (GM) type pulse tube coolers (PTC), which offer low maintenance and long measurement periods. In order to create a temperature difference between the cold and hot end of the cooler, Helium is periodically compressed an expanded within the cooler. In order to do so a valve - commonly a rotary valve - allows high pressure Helium to enter the cooler or to relieve the pressure within. The high and low pressure levels are supplied by a Helium compressor[2]. In order to reduce complexity and improve flexibility of the system[3], this poster will look into the operation of a two stage 4 K PTC with solenoid valves. This removes the rotary valve from the system and therefore allows for easy access and change of parameters like high- and low-pressure duration, quiet times after high- and low-pressure pulse or frequency.

[1] R. Güsten et al., Nature 568, 357 (2019)
[2] R. Radebaugh, J. Phys.: Condens. Matter 21, 164219 (2009)
[3] S. Wild, Fortschr.-Ber. VDI Reihe 19 Nr. 105, Düsseldorf 1997

TT 58.23 Thu 15:00 P2/OG3

Development of a miniaturized, modular, nuclear demagnetization stage — •Leo Maximov[1], Nico Huber[1], Andreas Bauer[1], Keiya Shirahama[2], and Christian Pfleiderer[1] — [1]Physik-Department, Technical University of Munich, D-85748 Garching, Germany — [2]Keiyo University, Hiyoshi 3-14-1, Kohoku-ku, Yokohama, Japan

Experimental studies of condensed matter systems at sub-milli Kelvin temperatures are effectively only possible by virtue of nuclear adiabatic demagnetization refrigeration (NADR). While copper is the most commonly used refrigerant for NADR, both the development and operation of copper based NADR-stages are technically demanding and limited due to the very low starting temperatures needed for demagnetization. To overcome these limitations, hyperfine-enhanced refrigerants may be used. Here, we present the design and implementation of a compact, miniaturized, modular nuclear demagnetization stage for optional use with a conventional dilution refrigerator. Comprising a superconducting aluminum heat switch, a demagnetization stage using $PrNi_5$ with a bespoke superconducting coil, and a CMN thermometer, the setup is conceived for exploratory studies in the milli-Kelvin regime and below.

TT 58.24 Thu 15:00 P2/OG3

Study of the magnetocalotic effect in $[Ni(C_4H_3O_4)_2(H_2O)_4]$ - A Potential Realization of a Spin-1 Spatially Anisotropic Square Lattice with Ferromagnetic Interactions — •Petro Danylchenko, Róbert Tarasenko, Erik Čižmár, Vladimír Tkáč, Alžbeta Orendáčová, and Martin Orendáč — Institute of Physics, Faculty of Science, Pavol Jozef Šafárik University, Park Angelinum 9, 04154 Košice, Slovakia

The magnetocaloric effect in $[Ni(C_4H_3O_4)_2(H_2O)_4]$ was investigated using specific heat and magnetization measurements in the temperature range from 0.4 K to 50 K in magnetic fields up to 7 T. A magnetic entropy change -11.2 $JK^{-1}kg^{-1}$ at a temperature of about 3.5 K is achieved for magnetic field of 7 T. The temperature dependence of the magnetic specific heat in a zero magnetic field was compared with an $S = 1$ model with single-ion anisotropy parameters D and E (axial and rhombic). The best agreement was found for the parameters $D/k_B = 7.82$ K and $E/k_B = 2.15$ K. The divergence which appears between experimental and theoretical data at non-zero magnetic fields indicates the presence of additional factors in the system such as exchange interaction between magnetic ions. Broken-symmetry DFT calculations provided the values of ferromagnetic exchange interactions, $J_1/k_B = 1.50$ K and $J_2/k_B = 1.44$ K. The presence of such ferromagnetic correlations may explain the enhanced magnetocaloric effect. *Supported by project No. APVV-18-0197.*

TT 58.25 Thu 15:00 P2/OG3

Noise thermometers for mK- and μK-temperatures in high magnetic fields — •Pascal Willer, Christian Ständer, Nathalie Probst, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

To measure the temperature in the presence of high magnetic fields is one of the big challenges in solid state physics labs. We developed a prototype of a cross-correlated, current sensing noise thermometer for mK-temperatures for application in high magnetic fields. The basic concept relies on the thermal motion of charge carriers in a bulk metal resistor. Two DC-SQUIDs detect the corresponding noise signal which is then recorded via two identical but independent amplifier chains. The method of cross correlation is used to eliminate uncorrelated noise contributions from the amplifier chains. As resistor materials we use the alloys $Ag_{60}Cu_{40}$ as well as $Pt_{92}W_8$, the latter being characterized by an extremely small temperature dependence of the electrical resistivity as well as the smallest magneto-resistance known to date. We show that this approach towards a relative primary thermometer for high magnetic fields is able to cover the complete temperature range below 4 K. We discuss the design and the necessary considerations of both thermometers and present first experimental results at mK temperatures.

TT 58.26 Thu 15:00 P2/OG3

Variable temperature probe stick with 2D coil system — •Claudia Köhn[1], Sylke Bechstein[2], and Doreen Wernicke[3] — [1]Entropy GmbH, Abbestr. 2-12, 10587 Berlin — [2]PTB, Abbestr. 2-12, 10587 Berlin — [3]Entropy GmbH, Gmunder Str. 37a, 81379 München

Within a technology transfer cooperation with PTB, Entropy made a probe stick for characterization of superconducting devices commercially available. It is an easy to use dip stick that can be cooled down directly in the liquid helium transport vessel while providing the possibility to vary temperature and apply magnetic fields.

The stick has two temperature stages. A 4.2 K stage and one with variable temperature (vT) stage, that can be heated up to 10 K with a temperature stability of 1 mK.

The device under test at the vT stage is placed inside a 2D coil system providing up to 500 mT parallel and 100 mT perpendicular to the chip. Homogeneity is 5% within a 1.5 mm radius around the center in the chip plane. At the moment we are optimizing the fabrication process of the coil bodies to provide better homogeneity of the magnetic field perpendicular to the chip.

TT 58.27 Thu 15:00 P2/OG3

Cryogenic scanning tunneling microscope — •Julia Besproswanny[1], Sebastian Schimmel[1], Ronny Schlegel[2], Danny Baumann[2], Bernd Büchner[2], Ralf Voigtländer[2], Dirk Lindackers[2], and Christian Hess[1] — [1]University of Wuppertal, 42119 Wuppertal, Germany — [2]IFW Dresden, 01069 Dresden, Germany

We report the construction of a compact cryogenic scanning tunneling microscope. The design will allow to study local electronic structures at temperatures down to 2.5 K and magnetic fields of up to 15 T with atomic resolution in real space and a high energy resolution of 2 meV at 6 K. The microscope has a scanning range of 1μm x 1μm and a built-in cleaving mechanism that renders it possible to cleave the samples at a cryogenic temperature. Samples can be exchanged within a day while the measurement time can reach up to 6 weeks. These qualities combined with its compact and portable design make this STM a comfortable tool to study low temperature phenomena, e.g. superconductivity.

TT 58.28 Thu 15:00 P2/OG3

Cyclotron resonance on germanium probed by coplanar microwave resonators — •Anastasia Bauernfeind, Frederik Bolle, Martin Dressel, and Marc Scheffler — 1. Physikalisches Institut, University of Stuttgart, Stuttgart, Germany

Cyclotron resonance is a powerful way to investigate the Fermi surface of various materials. In our research we performed cyclotron resonance experiments on the semiconductor germanium by using metallic coplanar waveguides (CPW). In comparison to conventional three-dimensional cavity resonators, CPW resonators have the advantage of multiple well-accessible resonances. Furthermore, CPWs open the possibility of implementation in a dilution refrigerator, which makes the performance down to the mK regime possible, which is also interesting for Kondo insulators. By using a superconducting magnet (up to 8T) and the access to a broad frequency range in the microwave regime (up to 25 GHz), we were able to investigate the cyclotron resonance in germanium in detail. Here we analysed the frequency-, temperature- (2-40K) and power dependence of the cyclotron resonance signal. Beside the investigation of the electronic bands, we present interesting phenomena like the generation of charge carriers by the power of the microwave electric field and the process of impact ionization in p-doped germanium.

TT 58.29 Thu 15:00 P2/OG3

Sample environment communication protocol (SECoP) — •Klaus Kiefer[1], Georg Brandl[2], Niklas Ekström[3], Enrico Faulhaber[4], Thomas Herrmannsdörfer[5], Bastian Klemke[1], Thorsten Kracht[6], Anders Pettersson[3], Lutz Rossa[1], and Markus Zolliker[7] — [1]HZB, Berlin — [2]FZJ, Garching — [3]ESS, Lund — [4]TUM, Garching — [5]HZDR, Dresden — [6]DESY, Hamburg — [7]PSI, Villigen

We would like to present the Sample Environment Communication Protocol (SECoP), a software and initiative that addresses the standardization of communication between instrument-control software, sample-environment equipment (SE), and acquisition of metadata. The International Society for Sample Environment (ISSE) has developed SECoP in order to support a wide research community by tackling the challenges of data acquisition in daily laboratory routine, ([1] and references therein). Using SECoP as a common standard for controlling SE equipment will save resources and intrinsically give the opportunity to supply standardized and FAIR-data compliant SE metadata. It will also supply a well-defined interface for user-provided SE equipment, e.g. shared by different research facilities and of industry. In this poster presentation we will give an overview of the present status of SECoP and the developments within the SECoP@HMC project supported by the Helmholtz Metadata Collaboration. We would also like to advertize the SECoP booth at the exhibition of this conference, a possibility to get a first practical experience with SECoP.

[1] K. Kiefer et al., J. Neutron Res. 21, 181 (2020)

TT 58.30 Thu 15:00 P2/OG3

Lab::Measurement – measurement control with Perl 5 — Mia Schambeck, Erik Fabrizzi, Simon Reinhardt, and •Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

`Lab::Measurement` is a collection of object-oriented Perl 5 modules for control of test and measurement devices. It allows for quickly setting up complex tasks with diverse hardware. Instruments can be connected via GPIB (IEEE 488.2), USB, or VXI-11 / raw network sockets on Ethernet. Internally, third-party backends as, e.g., Linux-GPIB, the NI-VISA library, or Zurich Instruments' LabOne API are used, in addition to lightweight drivers for USB and TCP/IP-based protocols. This enables cross-platform portability of measurement scripts between Linux and Windows machines. Based on roles within `Moose` that provide communication standards such as SCPI, dedicated instrument driver classes take care of internal details. A high-level sweep layer allows for fast and flexible creation of nested measurement loops, where, e.g., several input variables are varied and data is logged into a customizable folder structure. Sweeps can also be retrieved directly from an instrument as, e.g., a spectrum or network analyzer. Further features include live plotting and obtaining attested timestamps for measurement data. Recent enhancements focus on support for the Nanonis Tramea quantum measurement system and for fast measurements using arbitrary waveform generators as voltage sources. `Lab::Measurement` is free software and available at `https://www.labmeasurement.de/`

[1] S. Reinhardt *et al.*, Comp. Phys. Comm. **234**, 216 (2019)

TT 58.31 Thu 15:00 P2/OG3

Modeling a vibrating carbon nanotube Josephson junction — •Andreas K. Hüttel[1,2], Keijo Korhonen[2], and Pertti Hakonen[2] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Low Temperature Laboratory, Department of Applied Physics, Aalto University, P.O. Box 15100, 00076 Aalto, Finland

A carbon nanotube suspended between superconducting electrodes acts simultaneously as nanomechanical resonator and as a Josephson junction. Its energy-dependent density of states and with that position-dependent critical current further adds to the complexity of the system, as does both mechanical and electronic nonlinearity.

Using parallelized Julia code[1], we numerically solve the coupled differential equation system of the driven (via an ac gate voltage and/or ac current or voltage bias) system for realistic device parameters and characterize the evolving steady state. Specific attention is given to the impact of the Josephson junction behaviour on the mechanical resonance frequency and the vibration amplitude, and on the impact of the carbon nanotube motion on the phase evolution of the junction.

[1] https://julialang.org/