MON 14: QIP Implementations: Solid-State Devices I

Time: Monday 16:30–18:30 Location: ZHG002

MON 14.1 Mon 16:30 ZHG002

Fast quantum gates for exchange-only qubits using simultaneous exchange pulses — •Irina Heinz[1], Felix Borjans[2], Matthew J. Curry[2], Roza Kotlyar[2], Florian Luthi[2], Mateusz T. Madzik[2], Fahd A. Mohiyaddin[2], Nathaniel Bishop[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Konstanz, Germany — [2]Intel Technology Research, Intel Corporation, Hillsboro, OR, USA

The benefit of exchange-only qubits compared to other spin qubit types is the universal control using only voltage controlled exchange interactions between neighboring spins. As a compromise, qubit operations have to be constructed from non-orthogonal rotation axes of the Bloch sphere and result in rather long pulsing sequences. We theoretically develop a faster implementation of single-qubit gates using simultaneous exchange pulses and manifests their potential for the construction of two-qubit gates. We introduce faster pulse sequences and show that subsequences on three spins in two-qubit gates could be implemented in fewer steps. We experimentally demonstrate and characterize a simultaneous exchange implementation of X rotations in a SiGe quantum dot device and compare to the state of the art with sequential exchange pulses. Our findings can particularly speed up gate sequences for realistic idle times between sequential pulses and we show that this advantage increases with more interconnectivity of the quantum dots. We further demonstrate how a phase operation can introduce a relative phase between the computational and some of the leakage states, which can be advantageous for the construction of two-qubit gates.

MON 14.2 Mon 16:45 ZHG002

Sub-harmonic control of a fluxonium qubit via a Purcell-protected flux line — •Christian Schneider[1,2], Johannes Schirk[1,2], Florian Wallner[1,2], Longxiang Huang[1,2], Ivan Tsitsilin[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Klaus Liegener[1,2], and Stefan Filipp[1,2,3] — [1]Walther-Meißner-Insitut, Bayerische Akademie der Wissenschaften, 85748 Garching — [2]Technische Universität München, TUM School of Natural Sciences, 85748 Garching — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 München

Isolating qubits from environmental noise while maintaining fast, high-fidelity control is a central challenge in quantum information processing. In this talk, I present our findings on isolating a superconducting fluxonium qubit from its noisy control environment while maintaining fast, high-fidelity control. We achieve this by adding a low-pass filter below the qubit frequency, which suppresses resonant coupling between the qubit and the control channel. Although this prevents resonant qubit control, we overcome the limitation by driving the qubit at integer fractions of its transition frequency, allowing us to achieve Rabi oscillations through the Purcell-protected channel. We demonstrate coherent control using up to 11-photon processes through driving the qubit at 1/11 of its resonant frequency and have developed an effective Hamiltonian model using a Magnus expansion, which accurately predicts the observed behavior. These results open a scalable approach for fluxonium control via a single Purcell-protected channel, preserving intrinsic qubit coherence while allowing for fast, high-fidelity control.

MON 14.3 Mon 17:00 ZHG002

Transmon-based thermometrics through integrated control of cryo-system parameters and automated quantum chip diagnostics — •Thorsten Last, Adam Lawrence, Koushik Kumaran, Gerben Erens, Kelvin Loh, and Adriaan Rol — Orange Quantum Systems, Elektronicaweg 2, 2628 XG Delft, NL

Thermometric analysis of superconducting qubits gives valuable insights into their environment such as the quantum processor, the I/O unit they are connected to, and the steadily increasing number of components required for scaling the cryogenic part of the quantum system. Analyzing their various decoherence channels and minimizing their thermal load becomes increasingly important. Hence, here we report on the development of an quantum chip test setup in which cryogenic and quantum control units are fully integrated to enable efficient and automated quantum chip testing and qualification. Purpose-built cryogenic and quantum control hardware systems are integrated under a unified control software platform which provides an application-specific operating system for quantum chip control. This integrated quantum test setup offers a practical advantage in the optimization of quantum chip characterization. The unified software interface allows for intelligent feedback between quantum control parameters and cryogenic control and monitoring. We will show that this enables novel features for the prevention, diagnostics and mitigation of a range of practical issues that can occur in cryogenic chip benchmarking, as well as providing a unified interface for quantum experiments involving cryogenic parameters for utility-scale quantum processors.

MON 14.4 Mon 17:15 ZHG002

Optimized flip chip bonding for 3D integrated superconducting quantum circuits — •Lea Richard[1,2], Julius Feigl[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Lasse Södergen[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften

In order to use quantum computing to tackle classically intractable problems, quantum processors must grow to larger scales. Yet, in current planar architectures, routing multiple lines to an increasing number of qubits while minimizing crosstalk remains a significant challenge. 3D-integration techniques, such as flip-chip bonding enable more efficient connectivity. However, implementing a novel circuit geometry introduces challenges, including maintaining high coherence and preserving precise parameter targeting. Flip-chip bonding relies on indium bump bonds to mechanically and galvanically connect two separate chips. The additional fabrication steps can lead to new loss channels and degrade overall system performance. Moreover, in superconducting quantum circuits, capacitances and inductances are determined by the design of the electrodes. In a flip-chip assembly, these parameters depend on the gap separating the bonded chips and variations during the bonding process can limit accurate parameter targeting. To address these challenges, we present the fabrication of high-thickness indium bumps and the development of an optimized flip-chip bonding process for high-coherence quantum circuits. Additionally, we introduce a method for improving interchip spacing control and parameter targeting using polymer spacers.

MON 14.5 Mon 17:30 ZHG002

Passive leakage removal unit based on a disordered transmon array — •Gonzalo Martín-Vázquez[1,2], Taneli Tolppanen[2], and Matti Silveri[2] — [1]Departamento de Física Aplicada II, Universidad de Sevilla, E-41012 Seville, Spain — [2]Nano and Molecular Systems Research Unit, University of Oulu, FI-90014 Oulu, Finland

Leakage out from the qubit subspace compromises standard quantum error correction protocols and poses a challenge for practical quantum computing. We propose a passive leakage removal unit based on an array of coupled disordered transmons and last-site reset by feedback-measurement or dissipation. We find that the unit effectively removes leakage with minimal effect to the qubit subspace by taking advantage of energy level disorder for qubit subspace and resonant leakage energy levels. There are two optimal measurement rates for removing leakage, which we show analytically to correspond to characteristic time scales of leakage propagation and disintegration in the system. The performance of the leakage removal unit depends on the strength of disorder, coupling between the transmons, and the length of the array. We simulate the system under experimentally feasible parameters and present an optimal configuration. Our approach is readily compatible with existing superconducting quantum processors considering realistic conditions.

MON 14.6 Mon 17:45 ZHG002

Josephson Qubits with a DC Voltage Drive — •Florian Höhe[1], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Superconducting qubits utilize a Josephson junction as a nonlinear element to create a non-linear oscillator with unequally spaced energy levels. Coherent AC pulses, resonant with the transition frequency between the two lowest energy eigenstates, $|0\rangle$ and $|1\rangle$, enable quantum gate operations while leaving higher energy states largely unaffected.
In Josephson-photonics devices, a DC-biased Josephson junction generates excitations within a microwave LC resonator. Although the

resonator's energy levels are equally spaced, the intrinsic nonlinearity of the drive can be exploited to suppress the $|1\rangle \rightarrow |2\rangle$ transition. This effectively turns the system into a two-level qubit that can be controlled by tuning the Josephson energy through a SQUID, eliminating the need for AC pulses.
In this work, we propose a method for implementing both single- and multi-qubit gates for qubits based on DC-biased Josephson junctions. The typically large Josephson energy in these devices may allow for fast and efficient gate operations.

MON 14.7 Mon 18:00 ZHG002

Robust, fast and high-fidelity composite single-qubit gates for superconducting transmon qubits — •Hristo Tonchev[1], Boyan Torosov[2], and Nikolay Vitanov[1] — [1]Center for Quantum Technologies, Department of Physics, Sofia University, James Bourchier 5 blvd., 1164 Sofia, Bulgaria — [2]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tsarigradsko chaussee, 1784 Sofia, Bulgaria

We introduce a novel quantum control method for superconducting transmon qubits that significantly outperforms conventional techniques in precision and robustness against coherent errors. Our approach leverages composite pulses (CP) to effectively mitigate system-specific errors, such as qubit frequency and anharmonicity variations. By utilizing CP, we demonstrate both complete and partial population transfers between qubit states, as well as the implementation of two essential single-qubit quantum gates. Simulations reveal substantial reductions in common error rates and gate durations. The effectiveness of our method is validated through four independent verification techniques, underscoring its potential for advancing quantum computing with superconducting qubits.

MON 14.8 Mon 18:15 ZHG002

Characterization of Impedance-Matched Broadband Josephson Parametric Amplifier — •Maria-Teresa Handschuh[1,2], Kedar E. Honasoge[1,2], Florian Fesquet[1,2], Simon Gandorfer[1,2], Achim Marx[1,2], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meissner-Institute, 85748 Garching, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Josephson parametric amplifiers (JPAs) are essential tools in experiments involving superconducting quantum circuits due to their near quantum-limited performance. However, traditional JPAs suffer from narrow bandwidths and limited compression powers, which restricts their applicability in systems requiring broader frequency range and higher signal powers. In this talk, we present the design and characterization measurements of a broadband JPA that integrates an on-chip impedance-matching circuit based on two coupled resonators. Gain measurements reveal a spectral bandwidth enhancement of nearly two orders of magnitude, as compared to conventional JPAs. In addition, we present the noise performance across a wider frequency range, highlighting the amplifier's suitability for advanced quantum applications.