QI 8: Implementations III

Time: Tuesday 14:00–15:30 Location: BEY/0137

QI 8.1 Tue 14:00 BEY/0137

Proposal of multi-mode couplers for all-to-all connectivity and long distance couplings for superconducting qubits — •Zhongyi Jiang[1,2], Mira Sharma[2], Simon Geisert[3], Sören Ihssen[3], Ioan Pop[3,4,5], and Mohammad Ansari[1] — [1]Peter Grünberg Institute PGI-12, Forschungszentrum Jülich, Jülich 52425, Germany — [2]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [3]IQMT, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [4]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [5]Physics Institute 1, Stuttgart University, 70569 Stuttgart, Germany

The low connectivity in superconducting systems has become a crucial bottleneck for scaling up superconducting QPU and implementing error correction. Building on our previous theory of multi-mode couplers, we propose a coupler and QPU design with superconducting qubits that support native all-to-all connectivity and long distance couplings. In our design, each module consists of a central multi-mode coupler with qubits around it. The central coupler provides all-to-all coupling within the module. Between the modules, central couplers are coupled via a bus coupler. The central couplers and the bus coupler together provide long-distance coupling among qubits in different modules. We give theory analysis and numerical simulations for such a QPU design. We believe this gives a feasible path for scaling up superconducting qubits.

QI 8.2 Tue 14:15 BEY/0137

Accelerated CZ gates on Tunable Fluxonium architecture — •Aneesh Anand Kamat[1,2], Dimitrios Georgiadis[1,3], Francisco Cárdenas-López[1], and Felix Motzoi[1,3] — [1]Peter Grünberg Institute, Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

Fluxonium qubits offer superior coherence for large-scale superconducting processors, but their protected nature complicates standard entangling schemes due to smaller matrix elements. The Fluxonium-Transmon-Fluxonium (FTF) architecture leverages a flux-tunable Transmon coupler to mediate interaction, enabling stronger effective couplings for fast gates. We analyze the error budget for a flux-controlled CZ gate in the FTF architecture by characterizing the dominant leakage channels for experimentally realized systems, and developing the strategies to remove them using quantum optimal control.

QI 8.3 Tue 14:30 BEY/0137

Realising Superconducting Qubit Architectures using Scalable Flip-Chip Integration — •Anirban Bhattacharjee[1,2], Lea Richard[1,2], Julius Feigl[1,2], Ivan Tsitsilin[1,2,3], Niklas Bruckmoser[1,2], Johannes Schirk[1,2], João Romeiro[1,2], David Bunch[1,2], Leon Koch[1,2,3], Haiyang Hu[1,2], Lasse Södergren[1,2], Christian Schneider[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Peak Quantum GmbH, Garching, Germany

Flip-chip integration technologies have emerged as a promising approach to scale superconducting qubits. This enables flexible signal routing and minimizes crosstalk. Separating the qubit chip from the control chip, consisting of microwave signal lines, allows tackling fabrication challenges independently. In this work, we use high quality indium bumps for inter chip bonding and polymer spacers to achieve precise control of inter chip spacing and alignment. We demonstrate qubits exhibiting average relaxation times of $T_1 = 102 \pm 13\mu s$ and microwave resonators with quality factors of $Q_{int} \geq 10^6$, demonstrating that our techniques do not degrade the resonator or qubit performance. We also report our ongoing work in realizing high fidelity two-qubit gates using a tunable coupler architecture, an essential step towards scaling up superconducting quantum processors using flip-chip technologies.

QI 8.4 Tue 14:45 BEY/0137

Inherent crosstalk in superconducting circuits — •Balázs Gulácsi and Guido Burkard — University of Konstanz, Konstanz, Germany

Crosstalk refers to unwanted qubit addressing. This is particularly detrimental for scaling quantum information systems because unintended interactions limit overall performance. For superconducting qubits, tunable couplings and frequency tunability achieved through externally applied magnetic fluxes enable high-fidelity entangling gates; however, they also introduce crosstalk through flux linkage. In this work, we are investigating the impact of time-dependent external-flux-aware circuit quantization on superconducting qubit couplings. We find that non-trivial couplings emerge between capacitively linked qubits when the magnetic flux threading one qubit's loop varies in time, in a manner analogous to Faraday's law of induction. These effects influence the performance of parametrically activated two-qubit gates and enable flux noise to propagate even to fixed-frequency transmons.

QI 8.5 Tue 15:00 BEY/0137

Ultrafast Single Qubit Gates through Multi-Photon Transition Removal — •Yuan Gao[1,2], Asier Galicia[1,2], José Da Costa Jesus[3,4], Yebin Liu[1], Yorgo Haddad[1,2], Dmitriy Volkov[1,2], Jéferson Guimarães[1,2], Harsh Bhardwaj[1,2], Markus Jerger[1], Marc Neis[1,2], Boxi Li[3], Francisco Cárdenas-López[3], Felix Motzoi[3,4], Pavel Bushev[1], and Rami Barends[1,2] — [1]Institute for Functional Quantum System (PGI-13), Forschungszentrum Jülich, Jülich, Germany — [2]Department of Physics, RWTH Aachen University, Aachen, Germany — [3]Institute for Quantum Control (PGI-8), Forschungszentrum Jülich, Jülich, Germany — [4]Institute for Theoretical Physics, University of Cologne, Cologne, Germany

Qubits typically have multilevel structures making them prone to unwanted transitions from fast gates. Previous works focus on suppressing leakage by mitigating the first to second excited state transition, overlooking multi-photon transitions, and achieving faster gates with further reductions in leakage has remained elusive. Here, we demonstrate single qubit gates with a total leakage error consistently below 2.0×10^{-5}, and obtain fidelities above 99.98% for pulse durations down to 6.8 ns for both X and $X/2$ gates. This is achieved by removing direct transitions beyond nearest-neighbor levels using a double recursive implementation of the Derivative Removal by Adiabatic Gate (DRAG) method, which we name the R2D method. We also introduce an approach for amplifying leakage error that can precisely quantify leakage rates below 10^{-6}. The presented approaches can be readily applied to other qubit types as well.

QI 8.6 Tue 15:15 BEY/0137

Analytical blueprint for 99.999% single-qubit gate fidelities via multi-photon error suppression on present hardware — •José Diogo Da Costa Jesus[1,2], Boxi Li[1,2], Francisco Cárdenas-López[1], and Felix Motzoi[1,2] — [1]Forschungszentrum Jülich — [2]University of Cologne

To attain high-fidelity single-qubit gates on a quantum processor, precise control of the quantum system is required. Nevertheless, such operations suffer from a plethora of errors arising from residual couplings to higher levels, resulting in leakage and phase errors that limit gate accuracy and make this task significantly challenging. Here, we demonstrate that single-qubit gate errors on the order of 10^(-5) can be achieved by introducing simple control methods based on multi-derivative pulse shaping, termed R1D and R2D, which correct the leading sources of error and enable gate infidelities below 10^(-5) for a 7ns pi-rotation in a superconducting ladder system. Moreover, we show that for a gate duration below ten nanoseconds, modeling the ladder as a three-level system does not provide an adequate description, because multi-photon transitions involving the third excited state become a major source of error. Based on this formalism, we also obtain analytical expressions for the drive amplitude and drive detuning allowing further error suppression and simplifying the calibration process. These results demonstrate that analytical pulse-shaping techniques can substantially improve single-qubit gate performance.