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Design of an analog quantum simulators with superconducting transmon qubit

Analog quantum computing is emerging as a powerful approach for addressing computationally intractable problems in quantum many-body physics. Classical computers struggle to simulate these systems due to the exponential growth in computational resources required as system size increases. Unlike digital quantum computers, which rely on discrete qubits and gate-based operations, analog quantum computers use continuous variables to directly model quantum dynamics. This allows for a more natural representation of quantum systems, minimizing the need for error-prone digital decompositions. However, this advantage comes at a cost: analog quantum computing requires specialized hardware architectures tailored to specific problems, sacrificing the flexibility of digital approaches.

In this direction, the Quantum Architecture for Theory & Technology (QUART&T) project aims to develop a quantum device composed of multiple coupled superconducting qubits and resonators, designed for efficient quantum simulations of many-body interactions, including (p, d), (p, ^{3}H), and (p, ^{3}He) scattering processes and possibly real time-evolution of models mimicking lattice models with gauge degrees of freedom. The project focuses on key technological advancements, such as implementing all-to-all coupling through tunable couplers, integrating high-coherence superconducting qubits, and exploring higher-dimensional quantum systems (qudits) to enhance computational capabilities.

As an initial step for this project, we are conducting an in-depth study on tunable couplers due to their significant advantages in building analog quantum simulators. Notably, these couplers allow for parametrically controlled communication between qubits, which enables real-time regulation of how each quantum element contributes to the system's time evolution by simply adjusting an external parameter. Moreover, tunable couplers can enhance communication between quantum elements, effectively creating a fully configurable network up to all-to-all connectivity configuration. These couplers leverage on tunable elements, such as a Direct Current Superconducting QUantum Interference Device (DC-SQUID) that can be tuned with an external magnetic flux.

In this presentation, we will outline the general aim of the project, the preliminary simulation results for the Hamiltonian that governs the desired evolution, and the first simulated design that will implement it.

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