YIQIS 2020

Contribution ID: **17** Type: **Oral**

Full control of nonlinear processes in Josephson parametric amplifiers for readout of superconducting qubits

Wednesday, 30 September 2020 17:00 (15 minutes)

In the last decade, Superconducting Quantum Circuits (SQCs) based on Josepshon Junctions (JJs) showed that a working quantum processor can be successfully built and operated to perform Quantum Information Processing (QIP) on a system made of many superconducting qubits. The key ingredient to reach such an achievement are the endless possibilities allowed by SQCs in order to efficiently control and readout superconducting qubits, and the research on these interface devices is at the edge of technological advances in QIP. Efficient readout of superconducting qubits requires coherent amplification of single microwave photon signals while preserving a high Signal to Noise Ratio (SNR) in order to reach high single-shot readout fidelity. This task can be achieved by driving parametric processes in superconducting nonlinear oscillators, allowing coherent energy transfer between a strong pump and a single microwave photon signal that carries the result of a Quantum Non-Demolition measurement on a qubit. Thanks to these techniques, it is possible to build Quantum Limited Amplifiers (QLA) that can generate well detectable signals with SNR being degraded only by the least amount imposed by quantum mechanical principles. A QLA can be built around Josephson microwave circuits that synthesize nonlinear Hamiltonians with the required characteristics, and established devices are nowadays used in every superconducting quantum computing experiment. However, the trigonometric nature of the Josephson nonlinearities makes their independent control a challenging task. We show how is possible to improve the synthesis capabilities of Josephson Hamiltonians with a "Gradiometric SNAIL Parametric Amplifier"(G-SPA), a novel Josephson parametric amplifier that allows complete tuning of its nonlinearities via in-situ magnetic fluxes. Our approach expands the tunability range of the parametric processes, allowing independent choice of their participation in the treatment of single photon signals and opening to many new applications for these devices.

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Session Classification: Invited