Characterization of Fluxonium Qubits

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Principal investigator(s): Ivan Pechenezhskiy
User(s): Benjamin Byrd, Kesavan Manivannan

Affiliation(s): Syracuse University
Primary CNF Tools Used: Army Research Office
Contact: ivpechen@syr.edu, babyrd@syr.edu, kmanivan@syr.edu
Primary CNF Tools Used: ASML DUV Stepper, JEOL 6300, PT770, Heidelberg Mask Writer - DWL2000

Abstract:

We fabricate and characterize superconducting fluxonium qubits made of nano-scale Josephson junctions as their primary element. Fluxonium qubits are one of the leading candidates for building scalable quantum computing processors owing to their very high (millisecond-long) characteristic times and large anharmonicity [1].

A more rigorous characterization and mitigation of the correlated noise channels affecting this class of qubits is required to further improve the qubit performance to a level where fault-tolerant processors can be built. We aim to study the different extrinsic and intrinsic decoherence mechanisms that couple to this superconducting qubit and attempt to mitigate them.

Summary of Research:

Superconducting quantum systems play a vital role in quantum computing. Superconducting qubits are lithographically defined devices in which the information is stored in quantum degrees of freedom of anharmonic oscillators. Josephson tunnel junctions provide the necessary anharmonicity. A fluxonium qubit has a small Josephson junction shunted by two large capacitor pads and a chain of Josephson junctions acting as a large inductor [2].

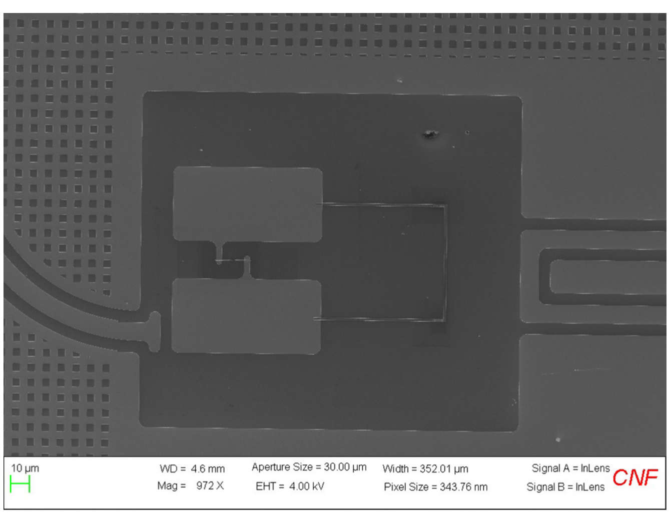

Figure 1: Scanning electron microscopy image of the fluxonium qubit showing the capacitor pad, single Josephson junction and the chain of Josephson junctions.

The flux bias through the formed loop can be tuned to vary the properties of this qubit. When a half-integer superconducting flux quantum threads the loop, the qubit exhibits a very high coherence and large anharmonicity.

The scanning electron microscopy image of our fluxonium qubit fabricated at CNF is displayed in Figure 1. The figure shows the two large niobium capacitor pads that set the capacitive energy scale $E_C/h \sim 1.4$ GHz. The small Josephson junction between the pads determines the Josephson energy $E_J/h \sim 2.3$ GHz. The array of 130 Josephson junctions to the immediate right of the pads is associated with the inductive energy $E_L/h \sim 0.5$ GHz. The capacitor pads are 40 μm × 80 μm in size and are patterned during the photolithography stage. The 90 nm × 100 nm Al-AlO_x-Al small junction and the array junctions, each of which have a dimension of 1.3 μm × 0.1 μm, are fabricated using the electron-beam lithography tool at CNF and electron-beam evaporator at Syracuse University. The Hamiltonian of the qubit can be tuned by modifying the properties of the above elements. The flux bias line can be seen on the right of Figure 1. Each qubit is capacitively coupled to a coplanar waveguide resonator, shown on the left of Figure 1, for dispersive readout of the qubit state.

The fabricated devices are cooled down to less than 10 mK for measurements. Microwave electronics at room temperature is used to manipulate and read out the qubit. Figure 2 shows the data from microwave transmission through a feedline coupled to the readout cavity as a function of flux bias through the loop. This flux-periodic feature is the tell-tale sign of the qubit ring being galvanically closed and the fabricated qubits fully functional. The qubit spectroscopy data in Figure 3 shows the two fundamental transitions, from the ground to the first excited state and from the ground to the second

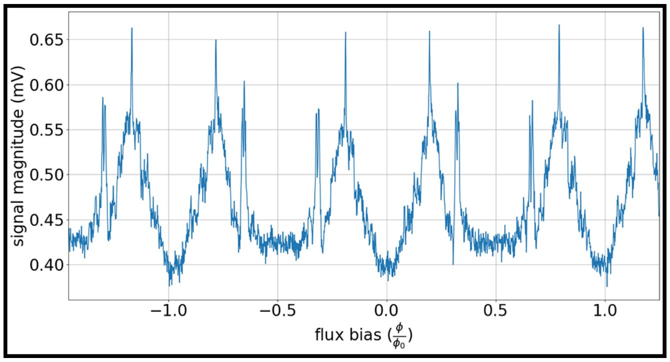

Figure 2: Flux-periodic transmission signal magnitude of the resonator coupled to the fluxonium qubit.

excited state, as a function of the flux through the loop. There is a reasonable agreement between the intended characteristic energy parameters and the ones obtained from fits to the spectrum showing the robustness of the fabrication procedure [3].

In the near future, going beyond the tune-up measurements, we would like to characterize the effect of decoherence due to injected quasiparticles in our fluxonium qubits.

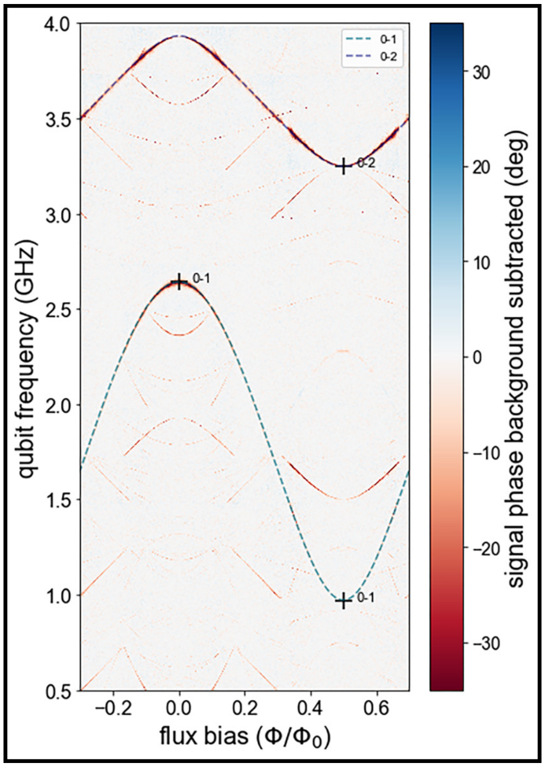

Figure 3: Fluxonium qubit spectrum showing the ground to the first excited and the ground to the second excited transitions.

References:

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[2] L. Nguyen, et al. High-Coherence Fluxonium Qubit. Phys. Rev. X, 9, 041041 (2019). https://doi.org/10.1103/PhysRevX.9.041041.

[3] V. Iaia, et al. Phonon downconversion to suppress correlated errors in superconducting qubits. Nature Communications, 13, 6425 (2022). https://doi.org10.1038/s41467-022-33997-0.