

Fast flux control of noise-biased fluxonium qubits

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Fluxon states localized in ultra-heavy fluxonium circuits have demonstrated relaxation times exceeding hours near the half-flux point [1], establishing them as highly promising noise-biased qubits for quantum information storage. This exponential protection arises from a large Josephson energy barrier that strongly suppresses relaxation rate, but it also leads to vanishing matrix elements that hinder efficient qubit control [2]. We present a universal, microwave-free control scheme for such T_1 -protected qubits [3].

Our approach relies on a fluxonium circuit with in-situ tunable Josephson energy, achieved by flux biasing a dc-SQUID. This tunability allows the device to transition between a 'heavy' regime with long relaxation times and a 'light' regime where coherent manipulation is enabled. Continuous X-rotations are realized by dynamically tuning the Josephson energy to control the quantum phase tunneling rate, achieving gate times of a few nanoseconds. Continuous Z-rotations are implemented by adjusting the flux in the rf-SQUID loop to temporarily break the symmetry between fluxon states. By simultaneously controlling the flux biases in both loops, we can implement a universal single-qubit gate set. We report experimental results on gate fidelity and leakage, with idle-state T_1 times reaching several seconds, demonstrating an efficient control strategy for fluxonium-based qubits.

References

- [1] Hassani, F. et. al. (2023). Nature Communications, 14(1), 3968.
- [2] Gyenis, A. et. al. (2021). PRX quantum, 2(3), 030101
- [3] Siegele, C. A., Sokolova, A. A. et. al. (2025). Fast gates for bit-flip protected superconducting qubits. arXiv preprint arXiv:2504.04807.

Figures

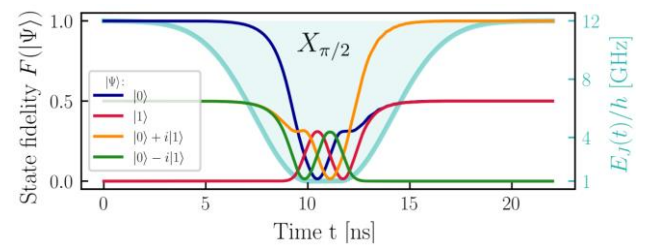


Figure 1: Tunable- E_J fluxonium: State Fidelity $F(|\Psi\rangle)$ visualized over time of the initial state $|0\rangle$ throughout a $X_{\pi/2}$ gate. The optimized, flat-top Gaussian flux pulse (turquoise curve) that varies E_J/h from 12 GHz to 1 GHz, is indicated by the secondary axis.

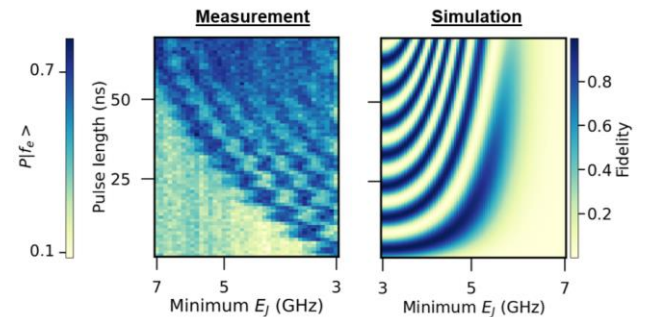


Figure 2: Oscillations of the fluxon state population as the flux drive amplitude (tuning Josephson energy E_J) and pulse length are varied on the x and y axis respectively.