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Ferromagnetic Josephson junctions for pulsed-tunable coupling in superconducting qubits

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Superconducting circuits are recognized as one of the most promising platforms for scalable quantum information processing, demonstrating both quantum advantage and rapid progress in multi-qubit control [1,2]; this maturity is further emphasized by the 2025 Nobel Prize in Physics awarded to J. Clarke, M. H. Devoret, and J. M. Martinis for their pioneering contributions to superconducting quantum circuits. On Partenope, our 25-qubit transmon platform, we have built and optimized the full control stack required for reproducible, high-fidelity CZ-gate operation, establishing a baseline for algorithmic execution. Yet, scalability remains challenged by flux-line distortions, inter-channel flux crosstalk, and the requirement of persistent DC flux bias. Recently, we have demonstrated that ferromagnetic Josephson junctions can offer a novel pathway to tunability for transmon qubit by exploiting the intrinsic magnetic properties of the ferromagnetic layer within the junction [3].

In this work, we introduce the concept of a ferromagnetic tunable coupler, where the inter-qubit coupling is set by the magnetization state of a ferromagnetic Josephson junction. Unlike dc-SQUID couplers that rely on continuous flux biasing and suffer from low-frequency flux noise, this scheme exploits an intrinsic magnetic degree of freedom to realize flux-free tunability. The magnetization-dependent Josephson energy acts as an effective mutual inductance between neighboring transmons, providing programmable coupling without the need for DC-bias offsets. Operating at zero static flux reduces sensitivity to flux noise and simplifies large-scale integration.

Preliminary simulations indicate a coupling range spanning more than two orders of magnitude and a tunability compatible with high-fidelity gate operation, while preserving minimal added decoherence. This magnetization-controlled coupling paradigm provides a pulse-programmable, flux-bias-free route toward scalable superconducting processors, naturally compatible with superconducting control electronics such as SFQ-based drivers. The device concept and related patent submission [4] mark a step toward large-scale, pulsed programmable qubit architectures.

[1] Arute, F., et al., Nature 574, 505–510 (2019).
[2] Google Quantum AI, Nature 646, 825–830 (2025).
[3] H. G. Ahmad et al., Phys. Rev. B 105, 224508 (2022).
[4] European Patent Application No. 24425069.2 (submitted)

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