Building Block For Universal Continuous Variables Computation In Superconducting Devices

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Introduction & Motivation

Quantum Processing Units (QPUs) are advancing rapidly across multiple platforms. While discrete-variable systems dominate current quantum computing, continuous-variable (CV) quantum computation offers relevant advantages:

- Encodes information in infinite-dimensional Hilbert spaces
- Natural for bosonic systems
- Potentially more efficient for some algorithms (boson sampling, machine learning, etc.)

Universal Gate Set

Rotation

$$H_{\text{eff},R} \approx g_{mr}^2/\Delta_r \left(a^\dagger a\, \sigma_{gg}^{(r)} - a a^\dagger\, \sigma_{ee}^{(r)}\right)$$

Displacement

$$H_D = \omega_m a^\dagger a + \Omega_D \left(a e^{-i\omega_D t} + a^\dagger e^{i\omega_D t}\right)$$

Squeezing

$$H_S = g_s/2 \left(a^\dagger a^\dagger + aa\right)\left(\sigma_{++}^{(f)} - \sigma_{--}^{(f)}\right)$$

Kerr

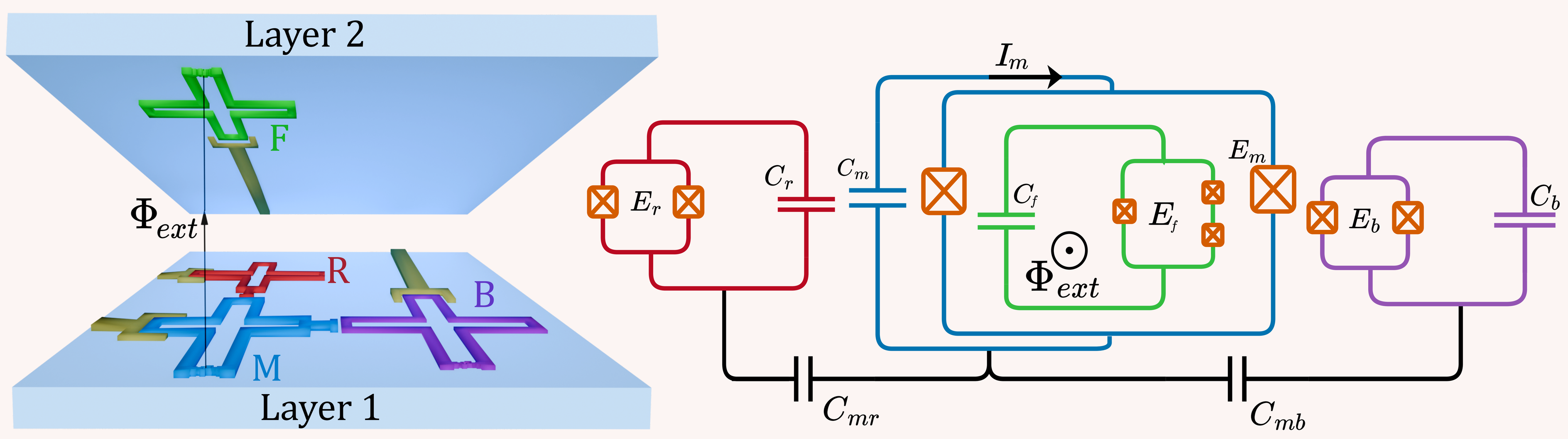
$$H_{\text{eff},K} = \omega' a^\dagger a + \omega_q' \sigma_z^{(f)} + \kappa_0 \sigma_z^{(f)} \left[a^\dagger a + \left(a^\dagger a\right)^2\right]$$

Beam-Splitter

$$H_{\text{eff},B} = \sum_{k=1,2} \frac{g_{mb}^2}{\Delta_b} a_k^\dagger a_k + g_{\text{eff},B}\left(a_1^\dagger a_2 + a_2^\dagger a_1\right)$$

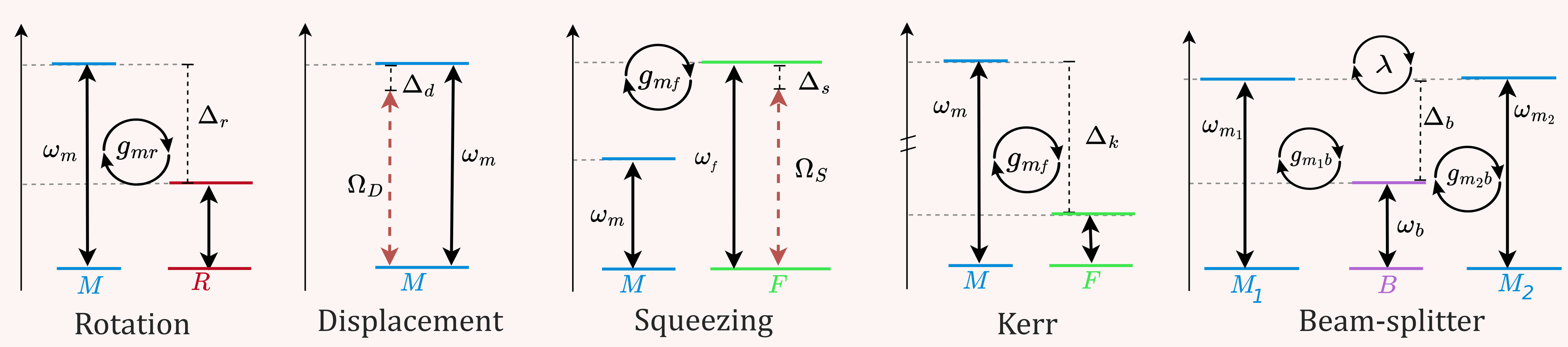
System Architecture

Our building block consists of a two-layer superconducting circuit:

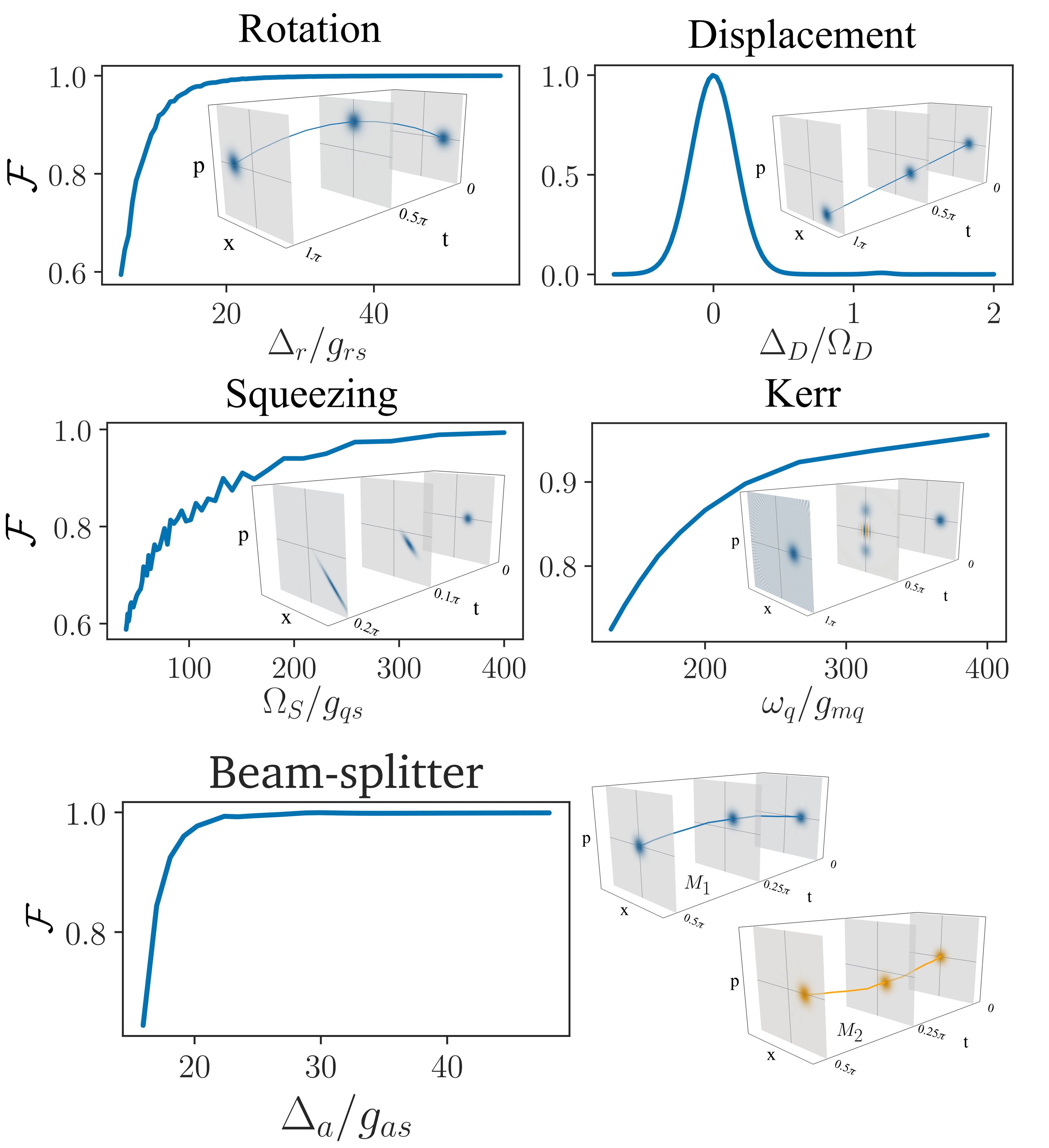


Circuit Hamiltonian

$$H = \omega_m a^\dagger a + \sum_{i=f,r,b} \frac{\omega_i}{2}\sigma_z^{(i)} + g_{mf}\left(a^\dagger + a\right)^2 \sigma_x^{(q)} + \sum_{j=r,b} g_{mj}\left(a^\dagger + a\right)\sigma_x^{(j)},$$



Gate Implementation



Results & Performance

Rotation	Displacement	Kerr	Squeezing	Beam-Splitter
$\mathcal{F} = 98\%$	$\mathcal{F} = 99\%$	$\mathcal{F} = 87–92\%$	$\mathcal{F} = 92\%$	$\mathcal{F} = 95\%$
~1 ns	~20 ns	~138 μs	~300 ns	~12 ns

Challenge: Kerr operation requires longer interaction times, but recent advances in coherence times (hundreds of μs) make this feasible.

Five gates, one chip: Universal quantum computation with continuous variables

ABSTRACT

Over recent decades, quantum computing has experienced significant advancements, with superconducting circuits emerging as one of the leading platforms. Within this landscape, an alternative to the traditional use of qubits and discrete gates is encoding information in the quadratures of bosonic modes—a framework known as continuous-variable (CV) quantum computation. In this approach, universal computation requires five operations: rotation, displacement, squeezing, a nonlinear effect such as Kerr interaction, and a beam-splitter operation for multimode coupling. This work proposes a scalable superconducting circuit capable of implementing all operations required for a universal CV gate set. The core of our architecture features a modular, multilayer circuit with a DC-SQUID encoding the CV mode and auxiliary qubits mediating specific interactions. Using Hamiltonian engineering techniques and numerical simulations, we identify circuit parameters that selectively activate each interaction within a range compatible with current superconducting hardware. These parameters yield fidelities exceeding 90% between the total and effective circuit Hamiltonians. One of the key challenges for achieving universality lies in generating a controllable nonlinear interaction. We address this by implementing a tunable Kerr interaction —an excitation-conserving operation— through dynamic control of the superconducting mode's anharmonicity via an external magnetic flux. Our proposal offers a promising and experimentally viable building block for constructing large-scale CV quantum processors based on superconducting platforms due to its modular structure, high gate fidelity, and alignment with current experimental capabilities.

More info at

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