Implementing on-demand microwave coupling between superconducting rf cavities with a SNAIL-based three-wave mixing component

Jeanette Simo, Alessandro Reineri, Silvia Zorzetti and Tanay Roy – URA Intern

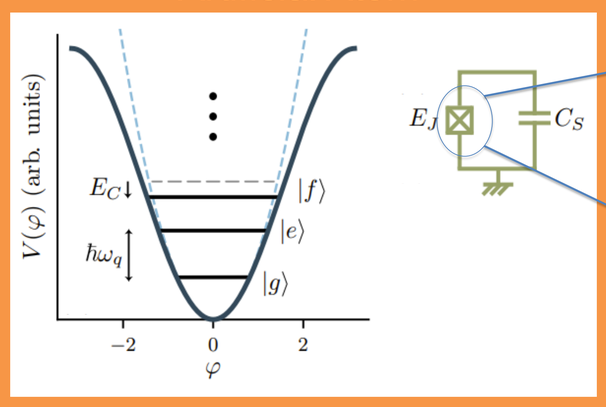
FERMILAB-POSTER-24-0210-STUDENT

Introduction

- A distributed computational paradigm is necessary to scale up and enhance computation power of a quantum computer
- To enact information exchange between computational nodes, a tunable parametric coupler would be extremely beneficial

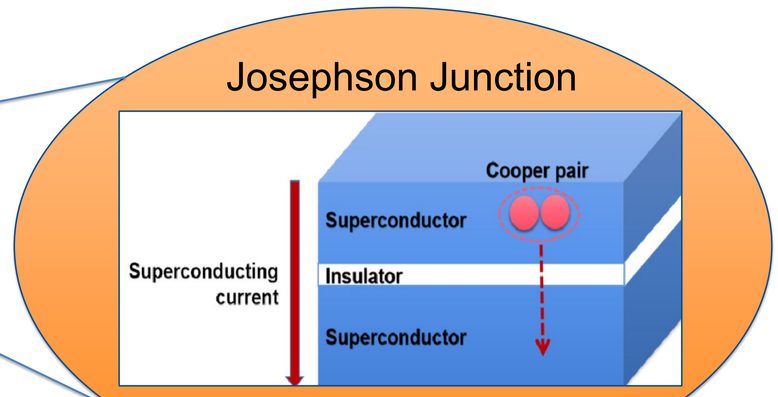
Components

Artificial Atom



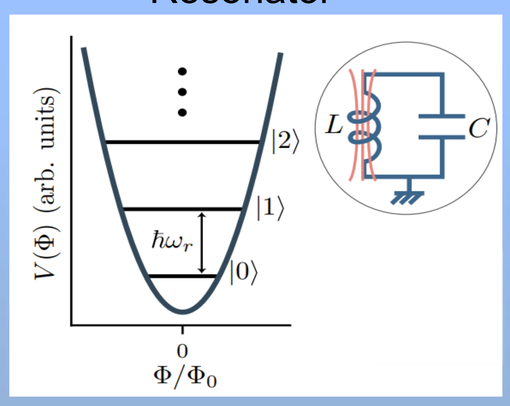
Replace the linear inductor with a Josephson Junction and you get an anharmonic oscillator: the fixed frequency Transmon

Josephson Junction



- Flow of Cooper pairs makes the supercurrent
- Cosine potential energy which adds anharmonicity to the circuit, making the energy spacing unequal

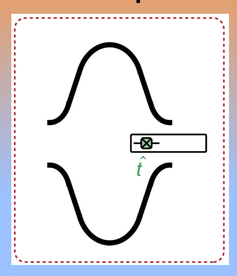
Resonator



Typical harmonic oscillator (even energy spacing): LC circuit

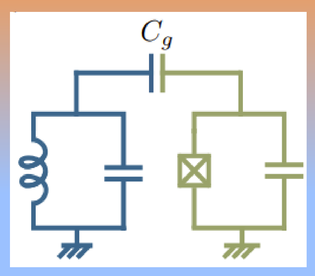
Artificial Atom Coupled to Resonator

- Coupling to a 3D cavity enables a longer coherence time because the cavity has a larger quality factor



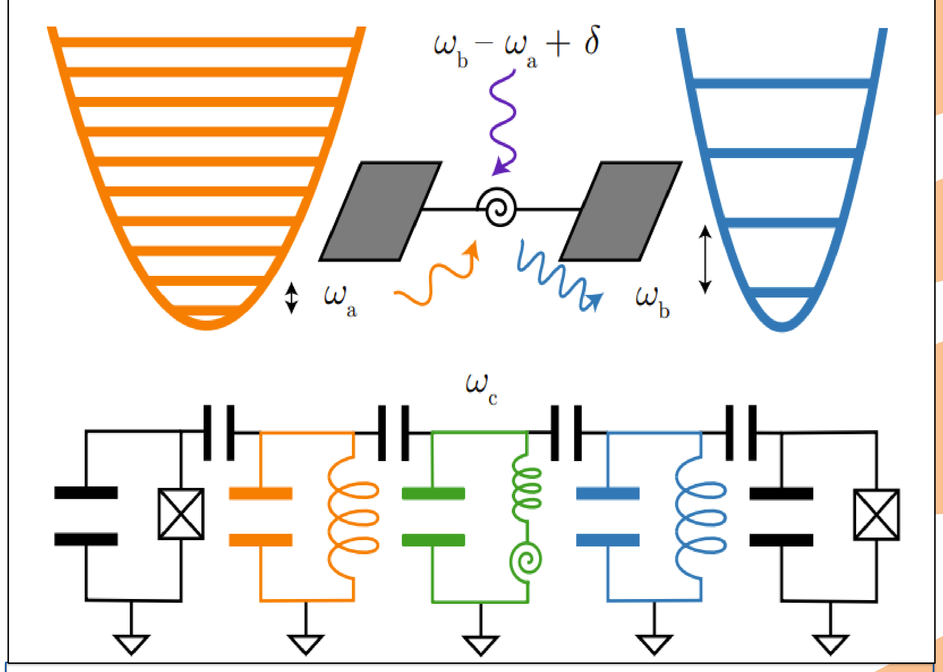
Transmon coupled to 3D cavity

=



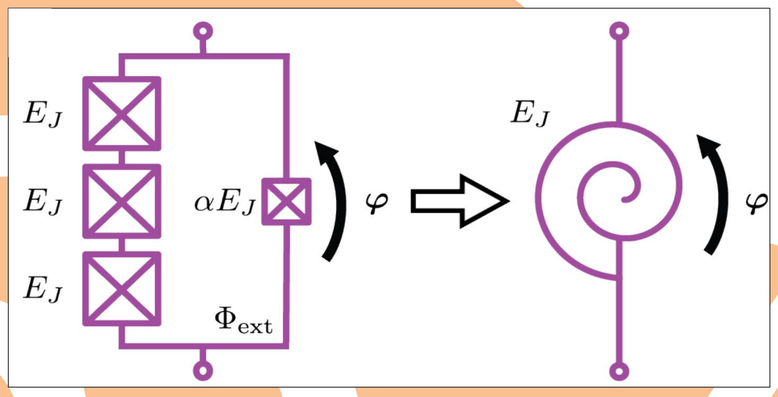
Equivalent Circuit

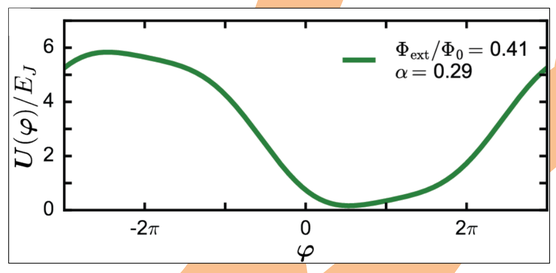
Motivation



- Preserve the quantum state and be able to retrieve it on command without disrupting the system
- SNAIL is a good candidate to realize module-module tunable-coupler-mediated communication:
  - Flux-tunable
  - Wide parameter space

What is a SNAIL?



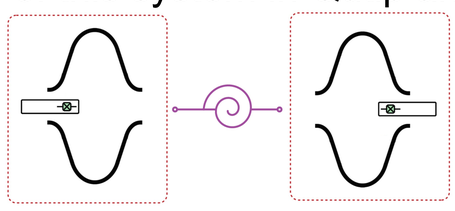


Exhibits nonlinearity, like the transmon, but also has a fourth order coupling term that can be tuned via external flux.

- SNAIL = Superconducting Nonlinear Asymmetric Inductive eLement
- The SNAIL has a cubic nonlinearity and a fourth order Kerr term that can be manipulated by tuning the external flux
- The SNAIL can act as a switch, either maximally coupling the two cavity modes together or disabling coupling entirely

Next Steps

Simulating the Hamiltonian of this system in Qutip and obtaining the coupling rate for the SNAIL.



References

[1] A. Blais, A. L. Grimsmo, S. M. Girvin, and A. Wallraff (2021). Circuit quantum electrodynamics. *Reviews of Modern Physics*, *93*(2), 025005.

[2] B. J. Chapman, et al. "High-on-off-ratio beam-splitter interaction for gates on bosonically encoded qubits." *PRX Quantum* 4.2 (2023): 020355.

[3] N. E. Frattini, et al. "3-wave mixing Josephson dipole element." *Applied Physics Letters* 110.22 (2017).

[4] Y. Zhong and P. Chen. (2023). A New Behavioral-level Model of Superconducting Josephson Junctions with Simulink. 10.21203/rs.3.rs-3432074/v1.

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

URA UNIVERSITIES RESEARCH ASSOCIATION

SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER