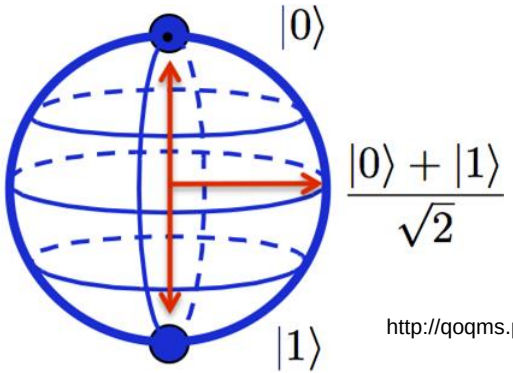
Superconducting Qubit Storage and Entanglement with Nanomechanical Resonators

A. N. Cleland and M. R. Geller, “Superconducting Qubit Storage and Entanglement with Nanomechanical Resonators,” *Phys. Rev. Lett.* **93**(7), (2004).



http://qoqms.phys.strath.ac.uk/figures/qubit.png

Group 7

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Requirements for Quantum Computing Devices

Quantum computing devices need:

1) Controllable and scalable entanglement schemes of multiple qubits

> N classical bits store N bits of information, while N qubits store up to 2^N “bits” of information when all qubits are fully entangled.

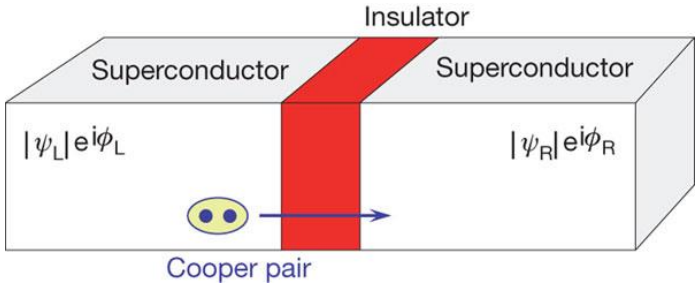
1) Qubits with sufficient quantum coherence lifetime (~ hundreds of ns)

$|c\rangle = \frac{1}{\sqrt{2}}(|0\rangle + e^{i\phi}|1\rangle)$ Decoherence loses information to the environment

1) Qubit storage and transfer devices with sufficient quantum coherence lifetime

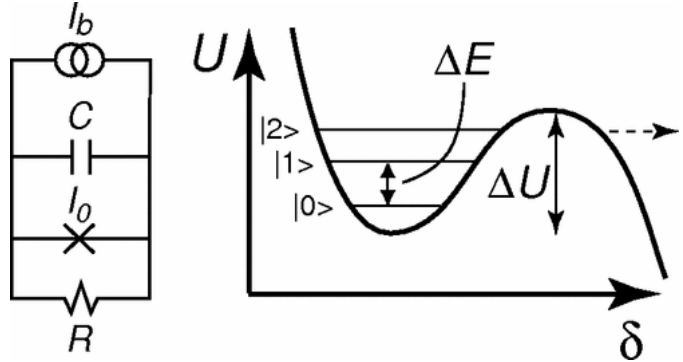
Using Josephson Junction as a Qubit

Josephson Junction



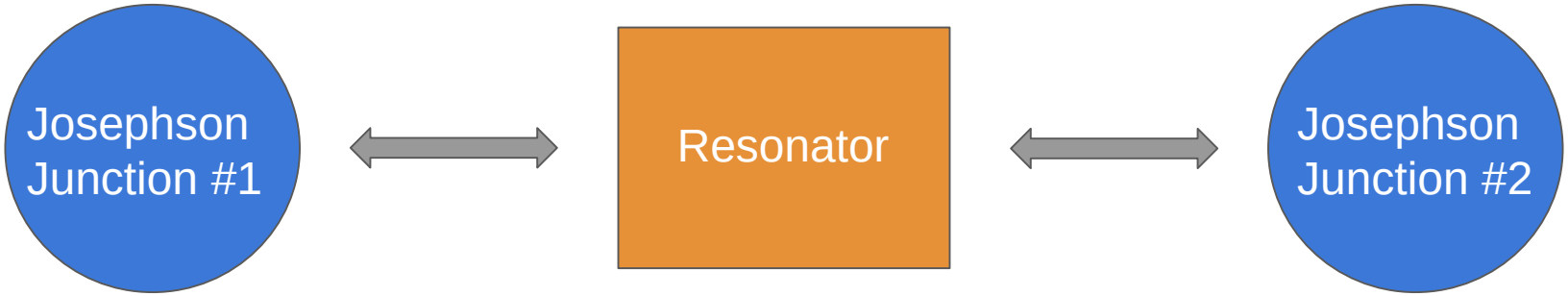
Credit: J. Q. You, F. Nori, Nature, 474, 589 (2011)

Josephson Junction *Phase* Qubit



- Quasi-bound states with energies ϵ_m
- Lowest states ($|0\rangle$, $|1\rangle$) define phase qubit
- Tunable energy gap $\Delta E = \epsilon_1 - \epsilon_0$

Using Resonator as Storage and Transfer Device



Many types of resonators are candidates for this JJ-Resonator architecture:

- Mechanical/Electromagnetic/Superconducting

- Solid/Cavity

Previous Work

- Long-lived coherent oscillation between quantum states had been produced in Josephson junctions. Lifetime ~ 5μs.

  Ref: Y. Yu, S. Han, X. Chu, S.-I. Chu, and Z. Wang, Science 296, 889 (2002).

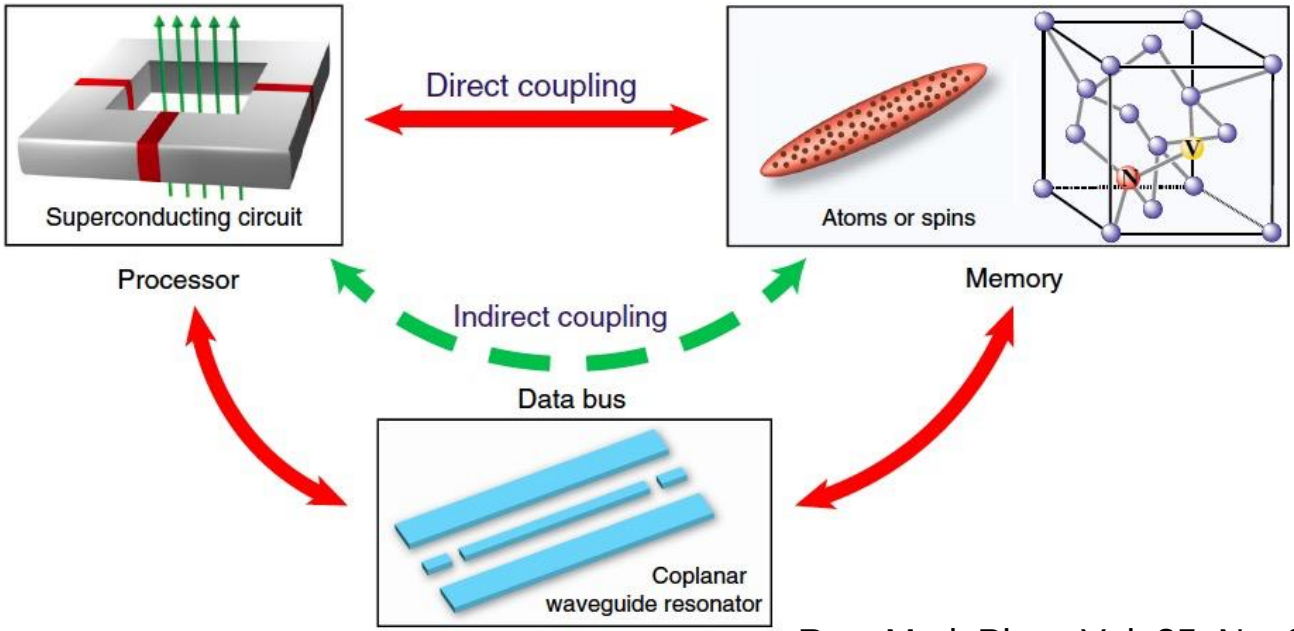
- Use of *electromagnetic* and *superconducting* resonators to couple multiple Josephson junctions was proposed

  Ref: Y. Makhlin, G. Schön, and A. Shnirman, Nature (London) 398, 305 (1999); A.Blais, A.M. van den Brink, and A.M. Zagoskin, Phys.Rev. Lett. 90, 127901 (2003); F. Plastina and G. Falci,Phys. Rev. B 67, 224514 (2003).

- Coupling scheme between *beam resonator* and *charge qubit* was proposed

  Ref:A. D. Armour, M. P. Blencowe, and K.C. Schwab, Phys.Rev. Lett. 88, 148301 (2002).

Previous Work



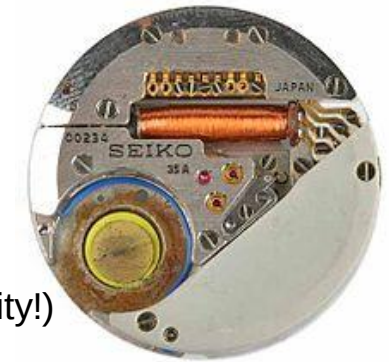
Rev. Mod. Phys. Vol. 85, No. 2, April–June 2013

Novel Features of this Architecture

- Uses *piezoelectricity* - a mechanical resonator, rather than electromagnetic or superconducting.

- Use of aluminium nitride (AIN) film.

- Potential to greatly increase the quality factor.



(Quartz watches use piezoelectricity!)

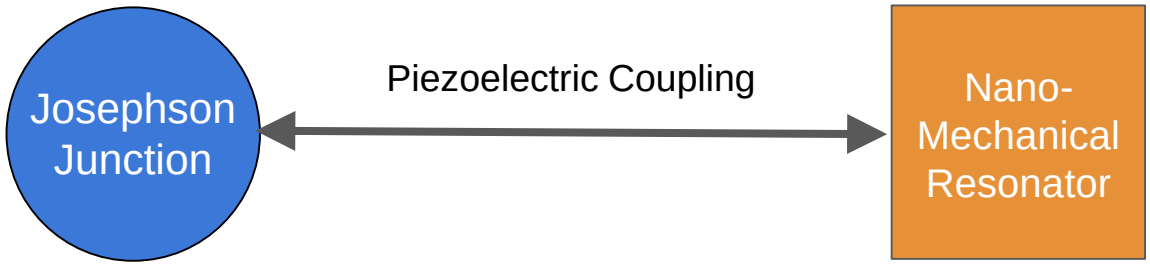
Significance of Architecture

- Short quantum coherence lifetimes are one of the biggest obstacles to quantum computing.

- Want to improve the coherence time of the resonator.

- Use of integrated-circuit mechanical resonators approach allows access to smaller dimensions.

Proposed Quantum Information Architecture



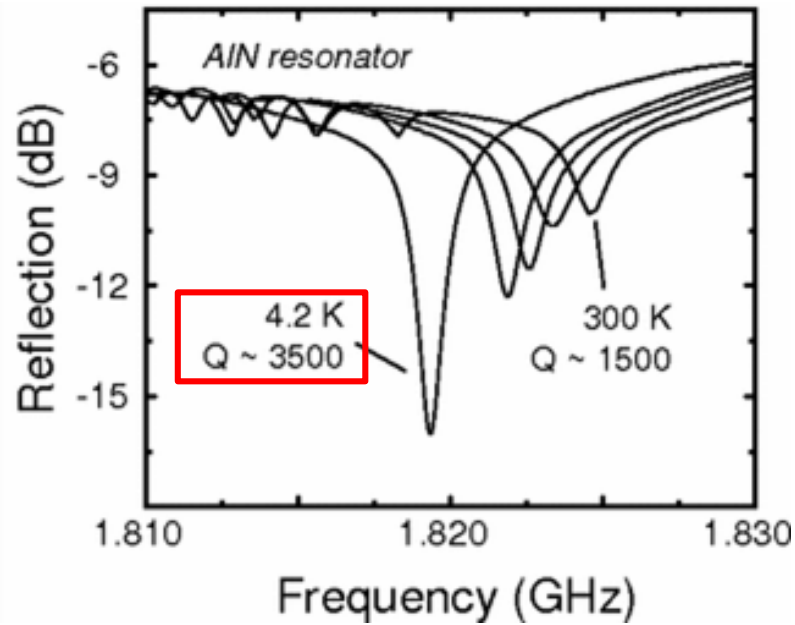
Quantum Information Processing (QIP) Operations → Tuning level spacing **Δ*E*** of JJ into resonance with $\hbar\omega_0$ of resonator → electromechanical Rabi oscillations

Experimental Measurement of Resonator Quality Factor

Demonstrated large *Q* for AlN dilatational resonator

↓

Long energy lifetimes (300 ns) required for Quantum Information Processing operations **feasible!**



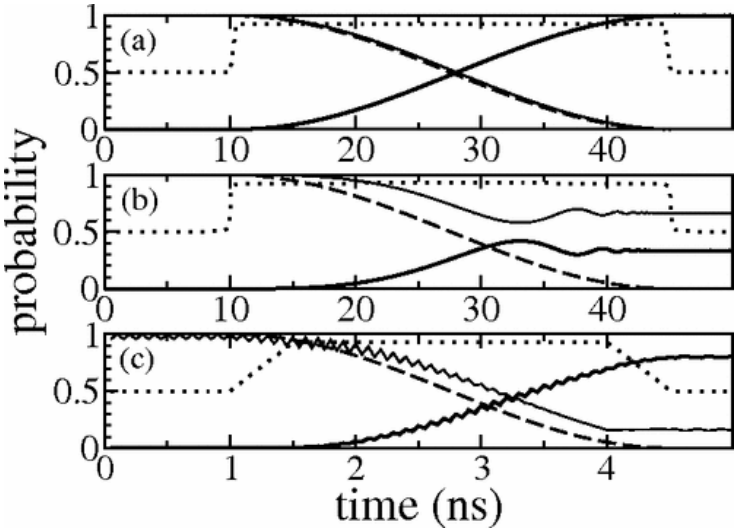
Simulations of Quantum Information Processing Operations

1. Qubit Storage:

Successful Storage →

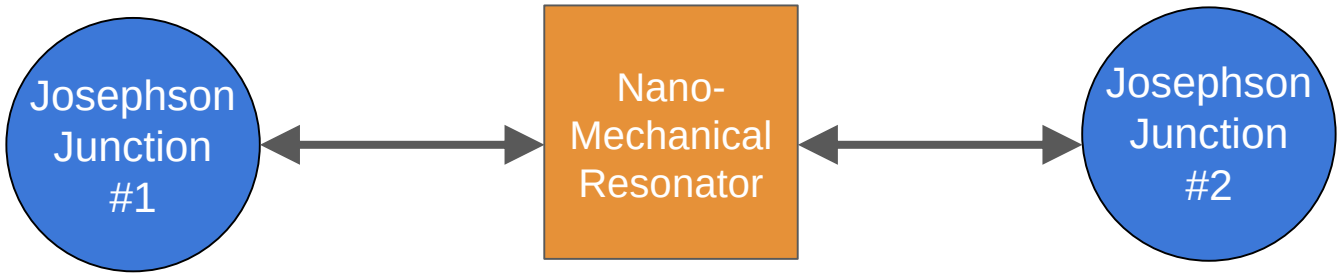
Incorrect Bias Current Profile, Storage Fails →

Larger Resonator, Storage Performs Poorly →



Qubit storage in resonator: probabilities of |10⟩ *and* |01⟩ *states*

Simulations of Quantum Information Processing Operations



2. Qubit Transfer:

a. Store JJ state into resonator.
b. Read out same state into 2nd JJ.

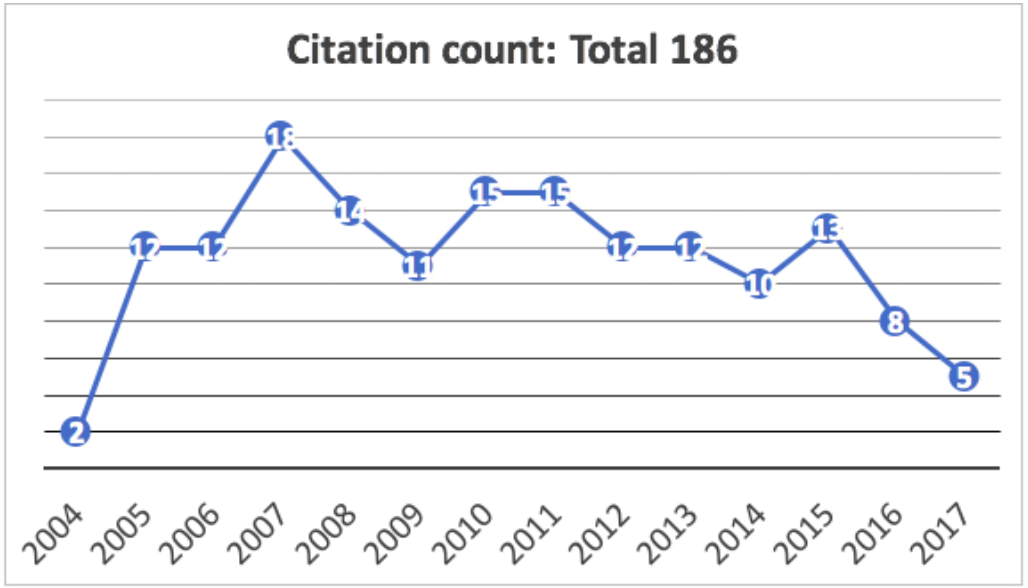
3. Qubit Entanglement:

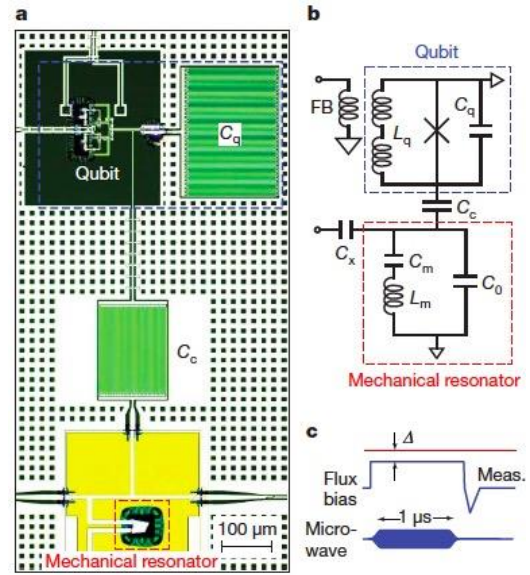
a. Create |100⟩ + |001⟩ superposition.
b. Swap resonator and 2nd JJ states

Conclusion: Architecture is Feasible

1. The feasibility of the architecture
2. Preview paper introduced the new architecture, and follow up paper discusses actually building it. The initial idea is a solid prototype of continuing research, and the following paper has been cited 1386 times.

Citation Count





Follow-up paper: 1386 times.
NATURE. Vol 464, 697-703. April 2010

Motivation | Background | Previous Work | What's New | Significance | Methods | Results | Conclusions | **Critique**

Critique: Preview Paper Tries to “Do it All”

1. Limited discussion on noise and background analysis.

2. Needed to read a lot of extra references (not suitable for PRL).

3. Did not communicate the motive clearly.

4. The abstract is not very clear: no conclusion added and no explanation of significance for quantum information technology.

5. As a preview paper, authors tried to address too many details in too short of a paper.

Summary

- **Challenge of creating scalable quantum information architectures** with long coherence times may be addressed with the use of coupled Josephson Junctions

- **Nanomechanical resonators have sufficiently high quality factors** to serve as coupling devices between Josephson Junctions

- **Theoretically demonstrated the feasibility of performing quantum information processing operations** with this architecture

- Good paper, but **tries to accomplish too much as a preview paper**