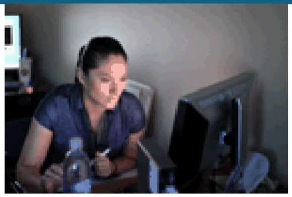
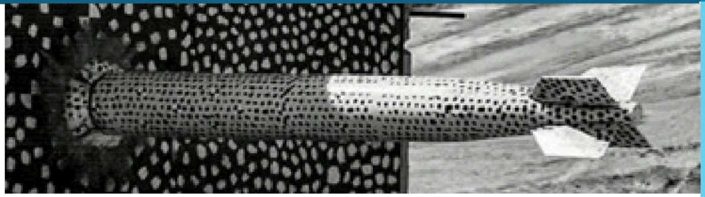
SAND2019-12846C

Superconducting resonators as diagnostics for qubit fabrication





PRESENTED BY

Rupert Lewis

Quantum Phenomena

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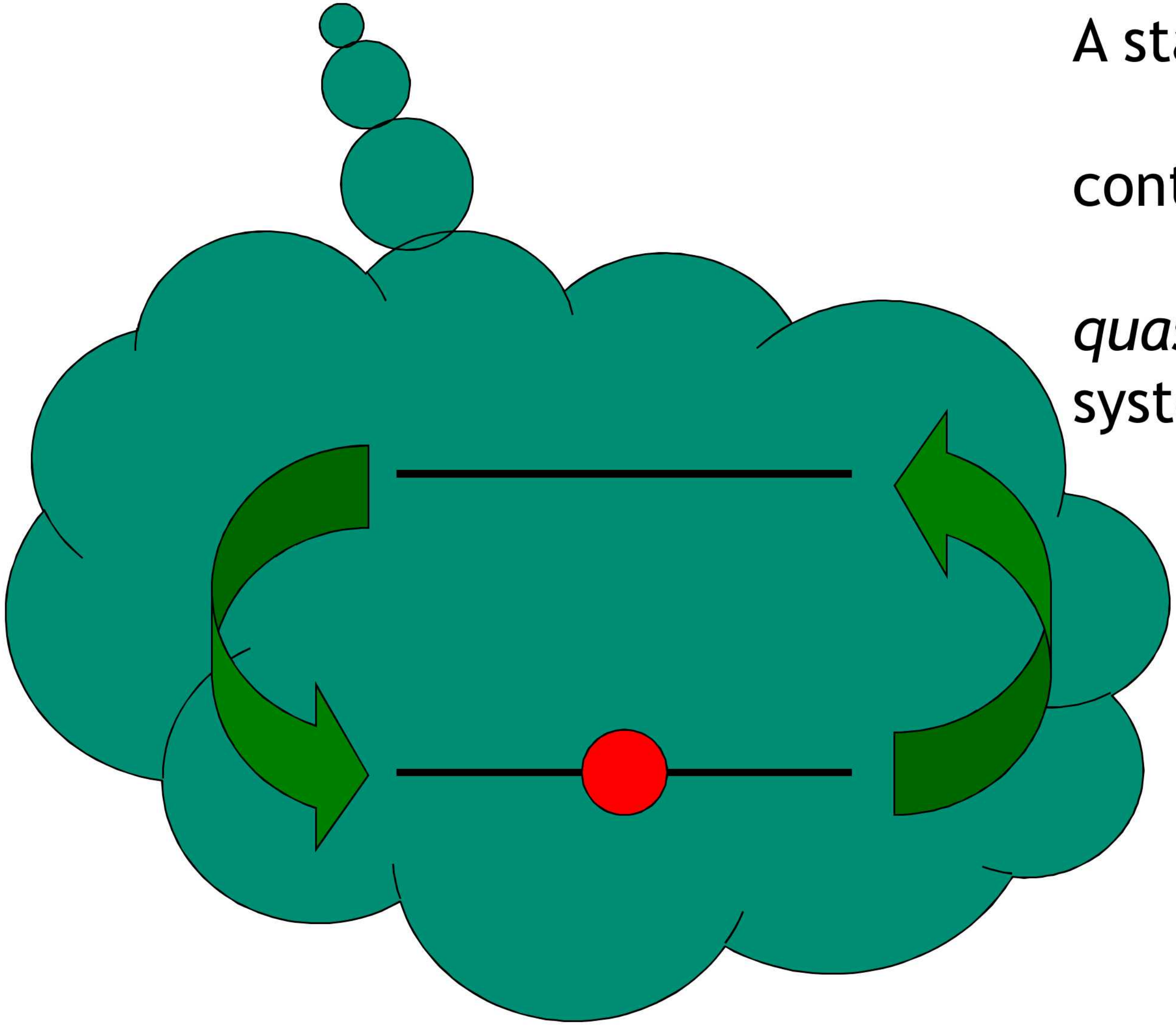
What is a Qubit?



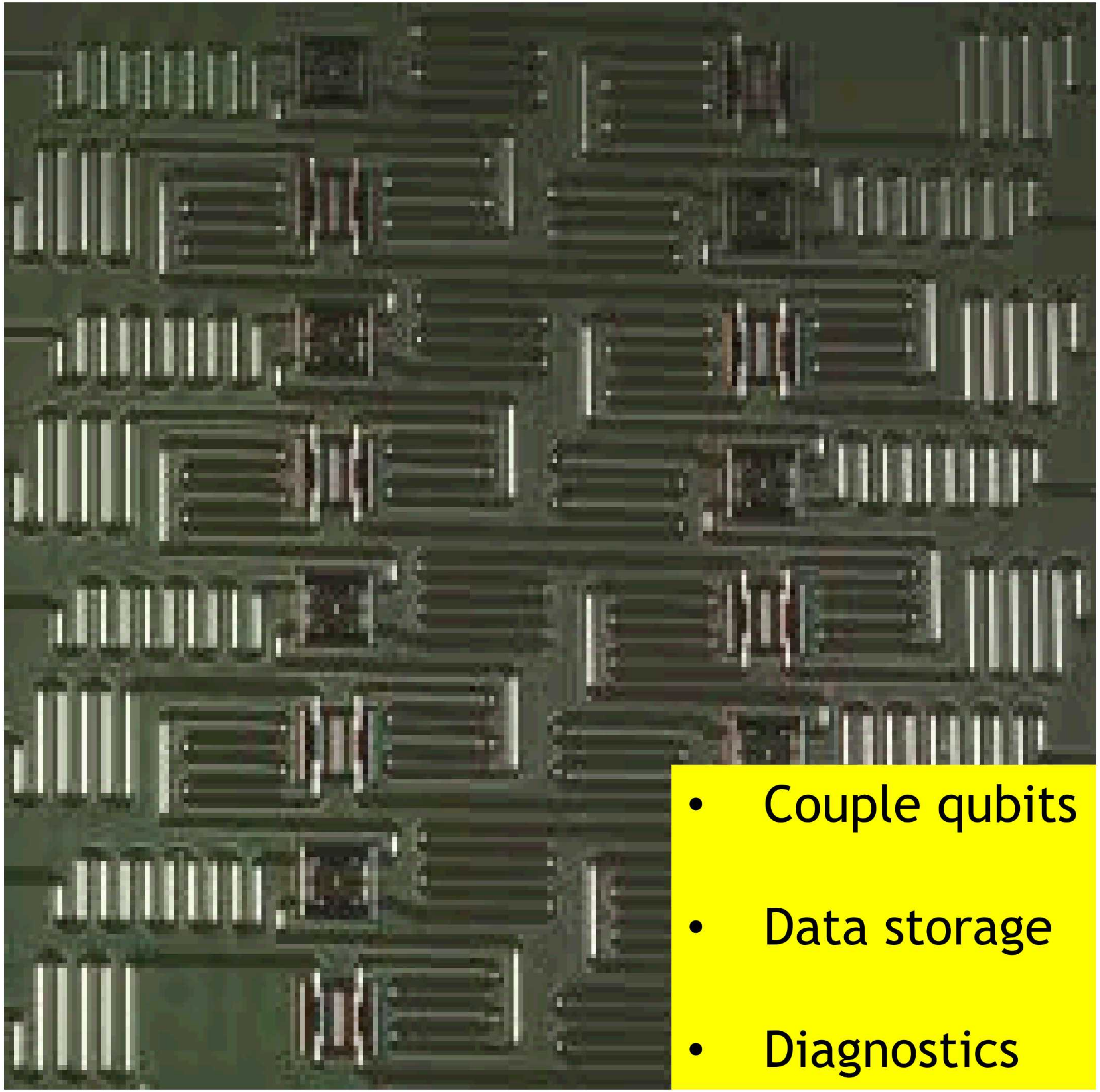
A stable,

controllable,

quasi two-level quantum system…

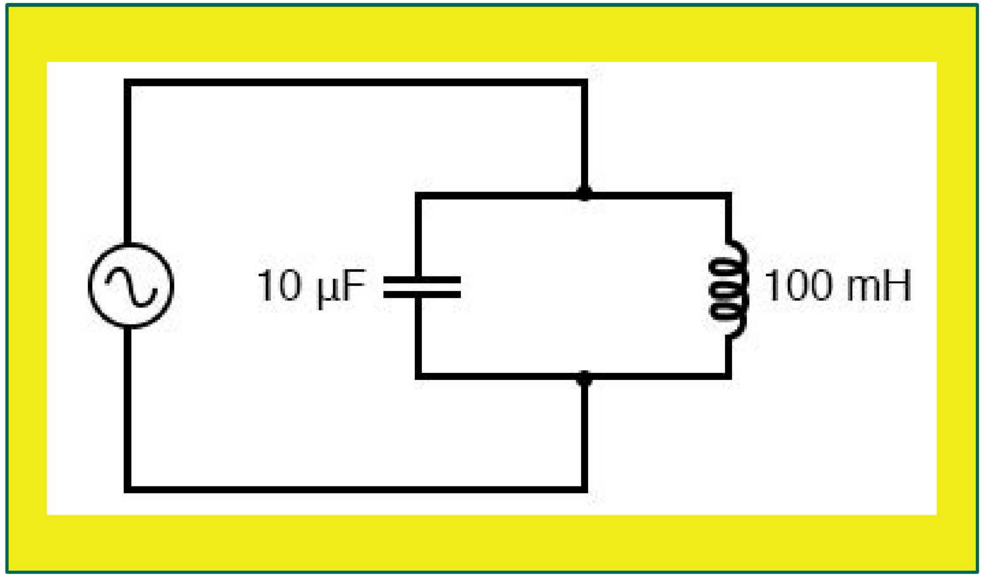
Agenda

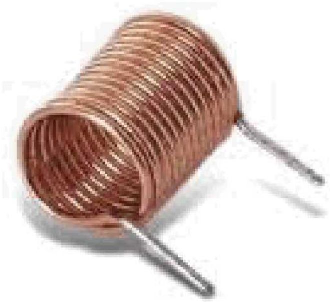
- Resonators & Qubits
- What can go wrong
- Testers/Diagnostics
- Notes and Conclusions



IBM's 16 qubit chip

Question: What is a superconducting qubit?





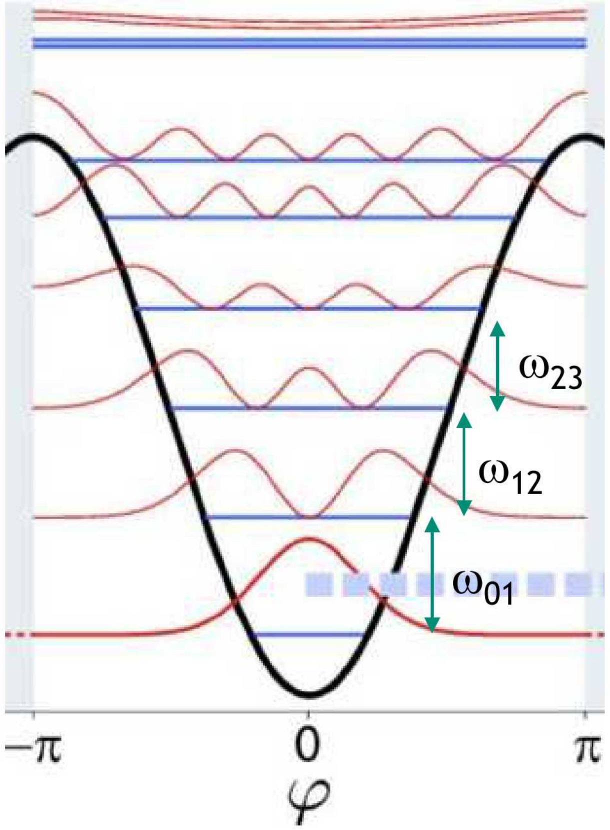
$$\omega_{01} = {}^{1}\!/_{\sqrt{LC}}$$

But Q >10^6

1 Photon

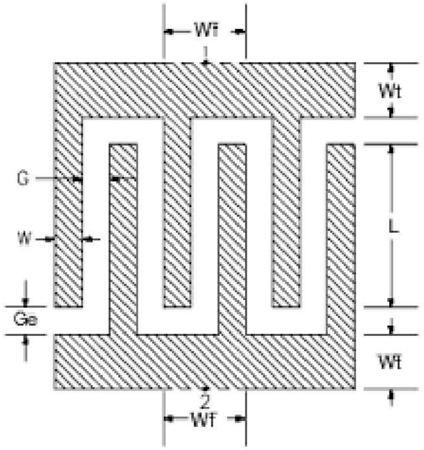
Answer: Non-linear superconducting resonator

Superconducting qubits require nonlinearity

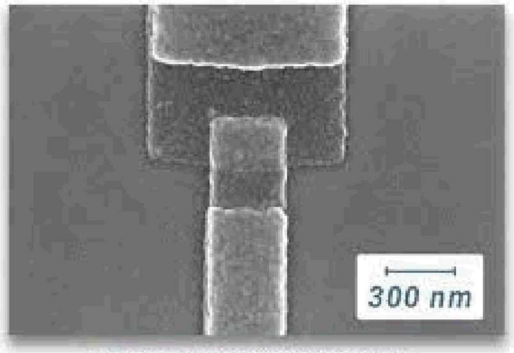


$\omega_{01} \neq \omega_{12} \neq \omega_{23}$

IDC



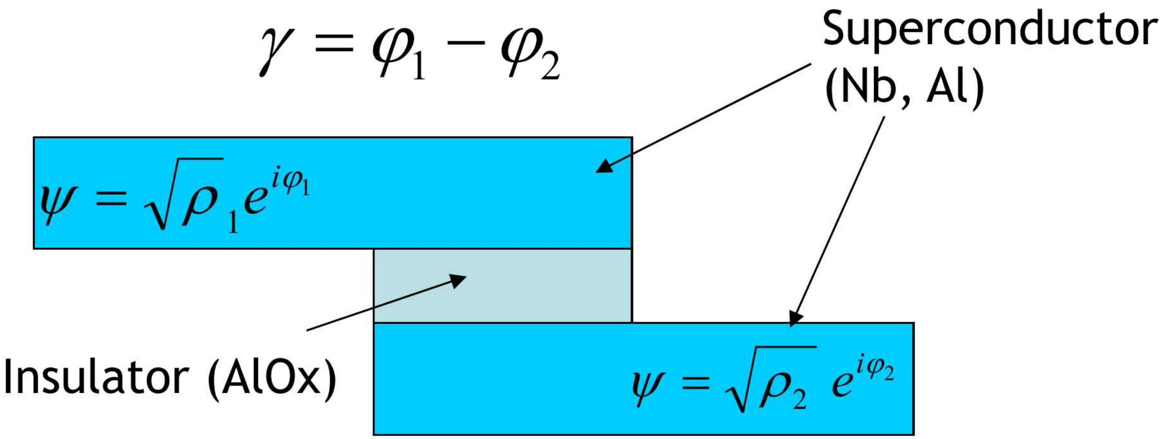
Josephson Junction

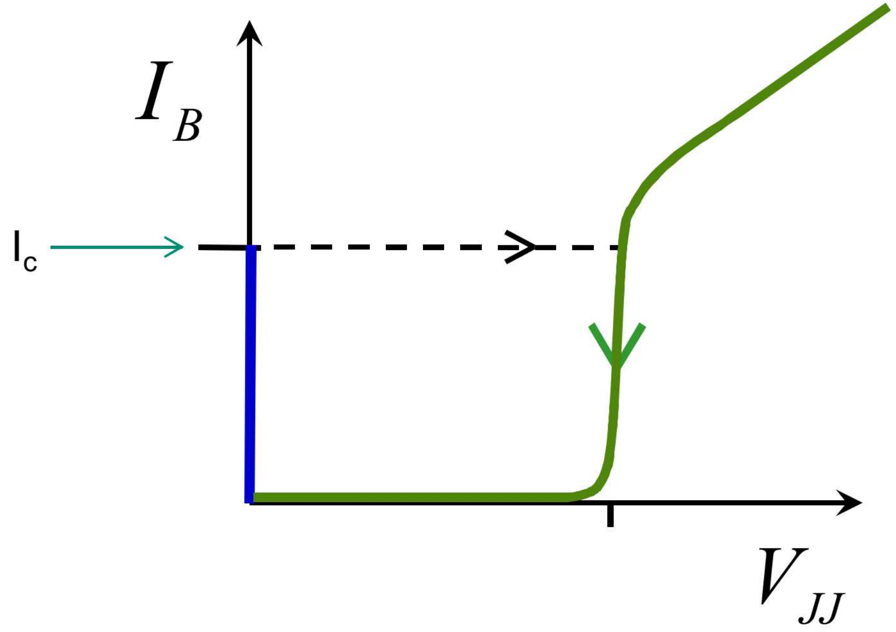


SEM image courtesy of the Institute for Quantum Computing (IQC) at the University of Waterloo

Josephson Junctions Provide Nonlinearity for Qubits

$$\gamma = \varphi_1 - \varphi_2$$





<u>Josephson equations:</u>

$$I = I_c \sin\gamma$$

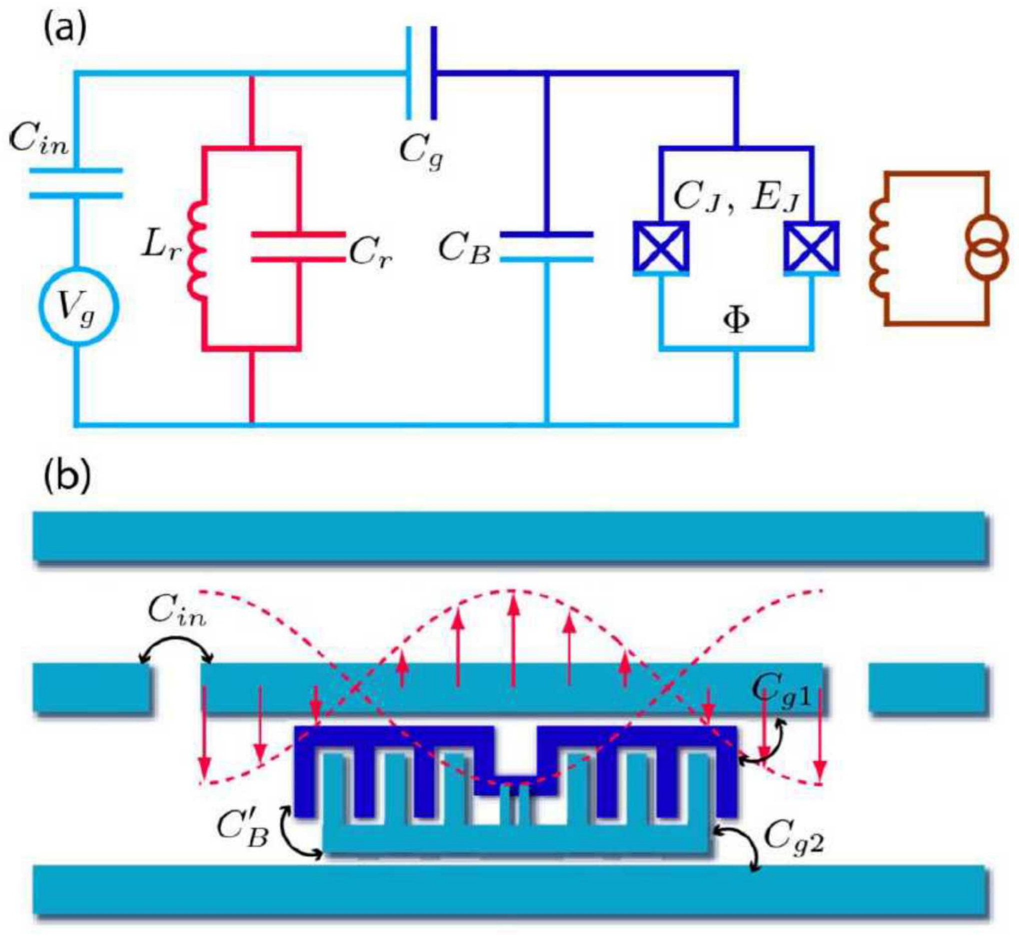
$$V = \frac{\Phi_0}{2\pi}\frac{d\gamma}{dt}$$

$$\gamma = \varphi_1 - \varphi_2$$

$$C_j = \frac{\varepsilon A}{d}$$

$$L_j = \frac{\Phi_0}{2\pi\, I_c}\frac{1}{\sqrt{1-\left(\frac{I_b}{I_c}\right)^2}}$$

Overview of transmon qubit



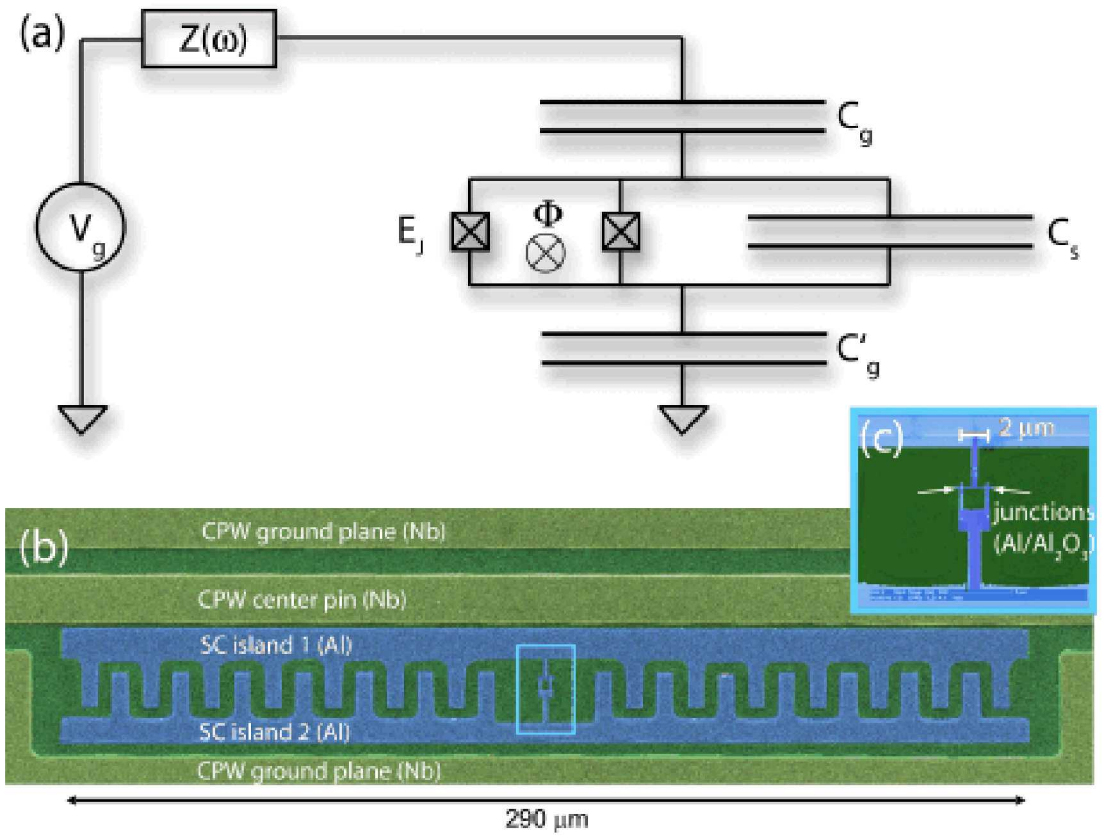
$$\hat{H} = 4E_C(\hat{n} - n_g)^2 - E_J \cos\hat{\varphi}.$$

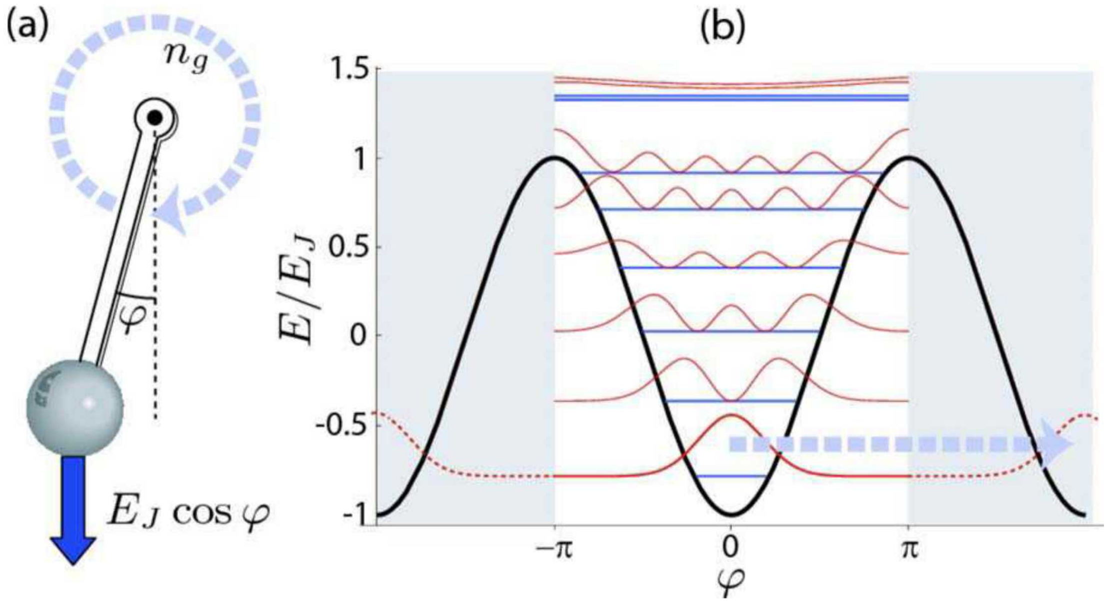
Jaynes-Cummings Hamiltonian

$$\mathcal{H} = \hbar\omega_r\left(a^\dagger a + \frac{1}{2}\right) + \frac{\hbar\Omega}{2}\sigma_z - \hbar g\left(a^\dagger\sigma^- + a\sigma^+\right)$$

J. Koch *et al.*, PRA, 76, 042319 (2007)

One view of a transmon

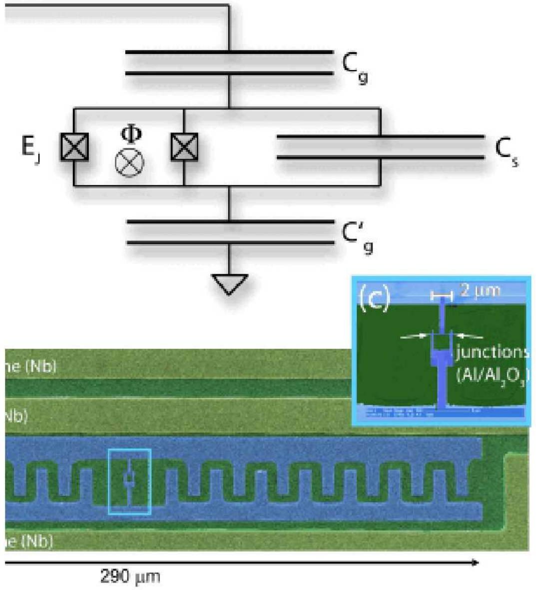




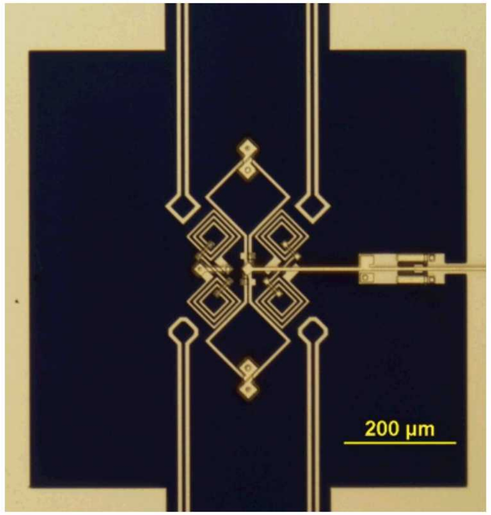
J. Koch *et al.*, PRA, 76, 042319 (2007)

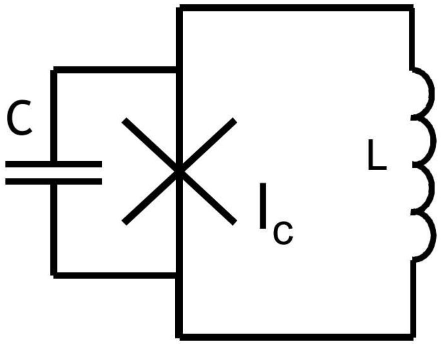
A. Hauck *et al.,* Quant. Inf. Proc. 8, 105 (2009)

Quick overview of other types of qubits



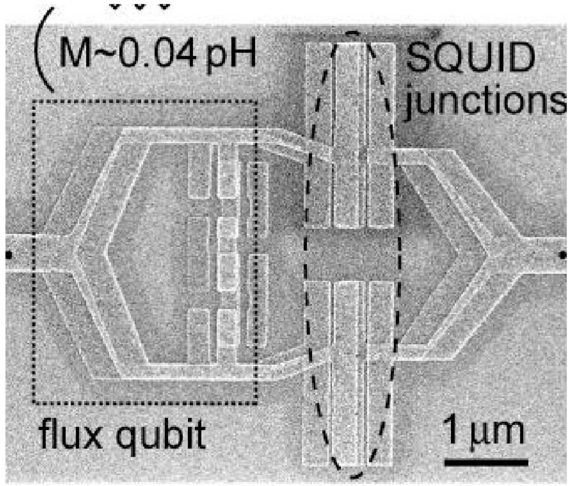
Phase qubit

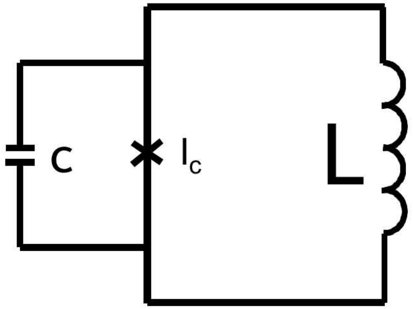


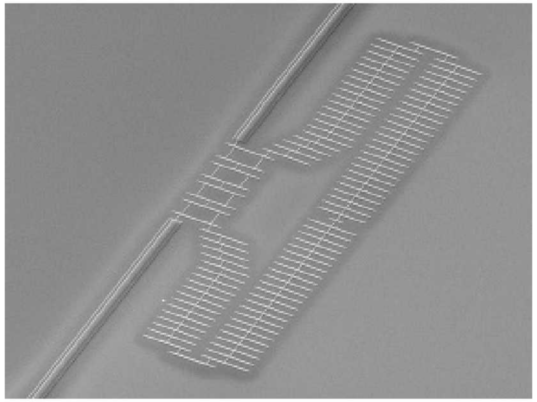


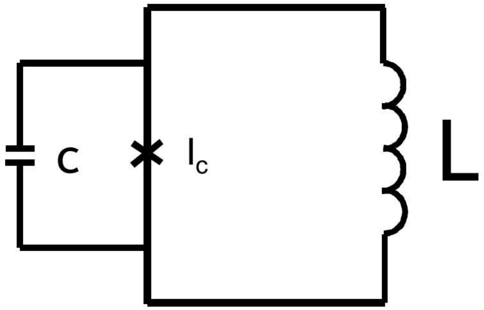
Flux qubit

Fluxonium
Yale group





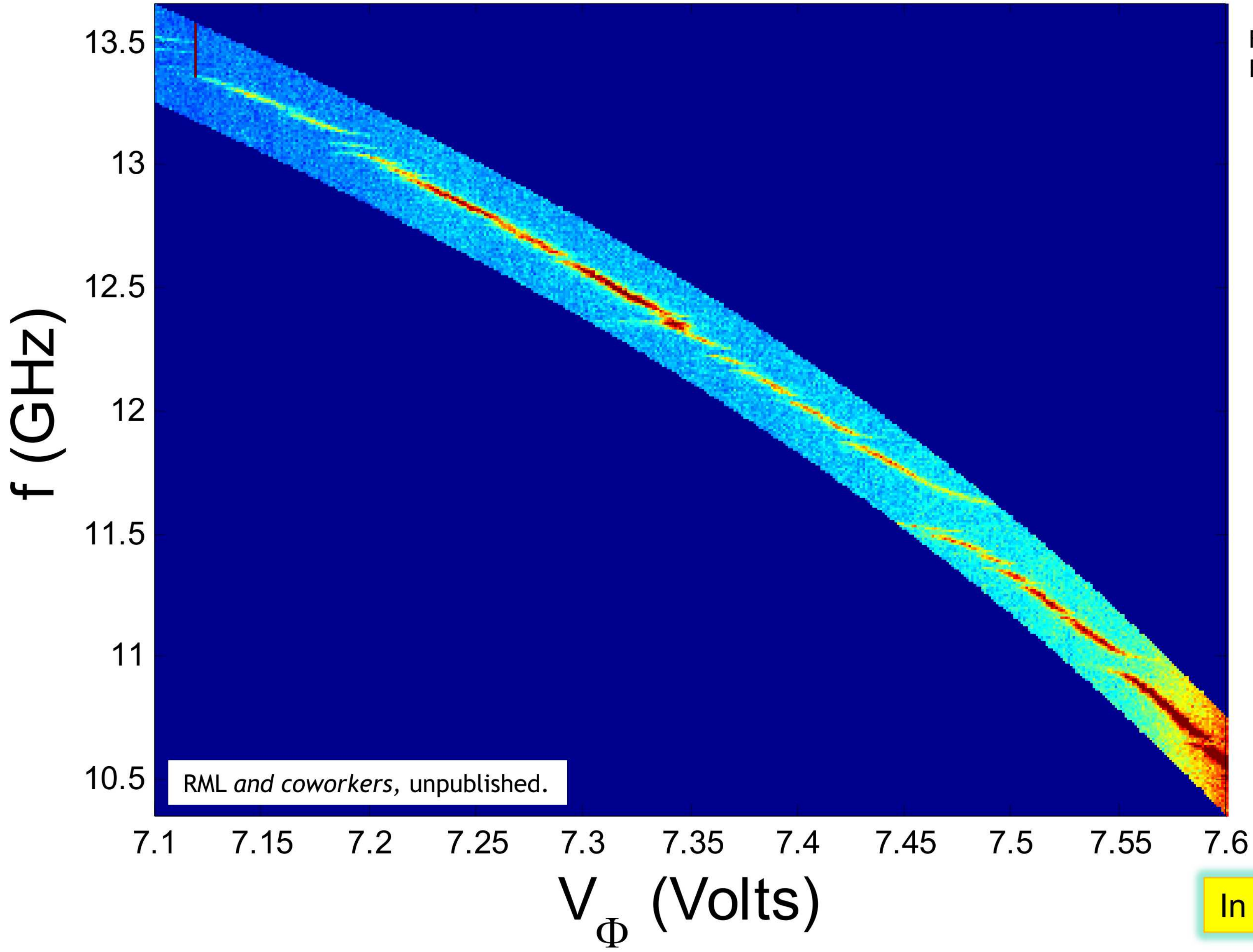




All have inductance and capacitance… & hence rf losses.

What can go wrong?
How can resonators help?

Problem: two-level fluctuators in oxides & on surfaces

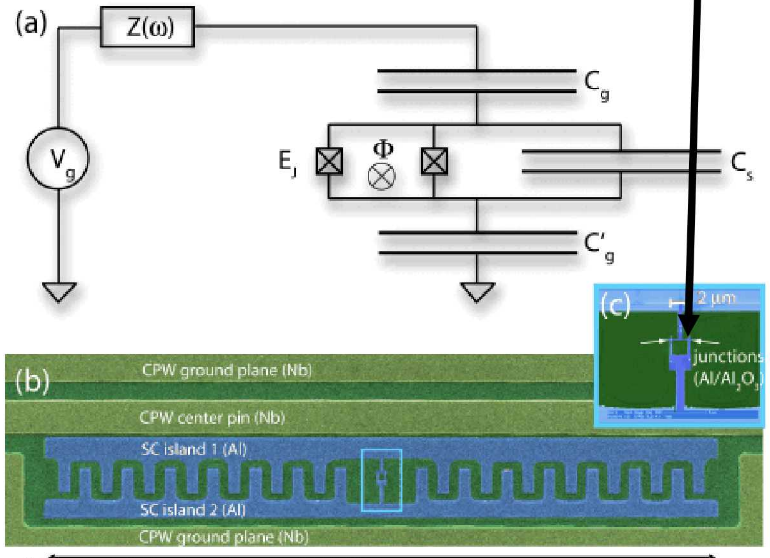


First reported by:
R.W. Simmonds *et al*. Phys. Rev. Lett. **93**, 077003 (2004).

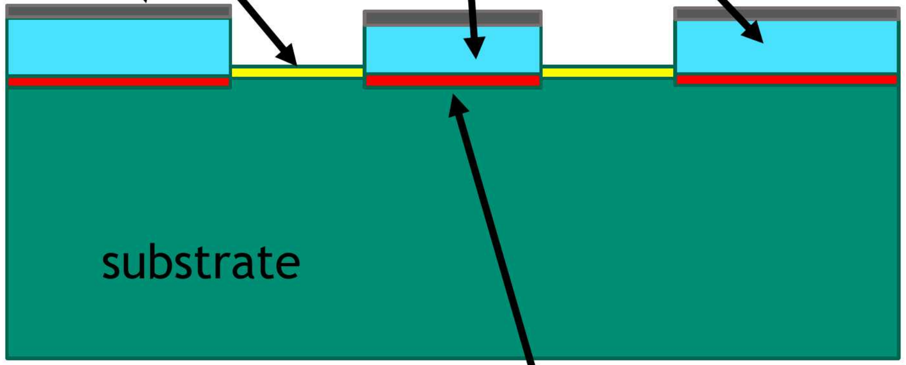
In general: ~0.7 TLS/GHz μm^2

What are the paths to decoherence

- Defects in SC
- Interface dirt
- Environment
- Trapped flux
- also, stray light



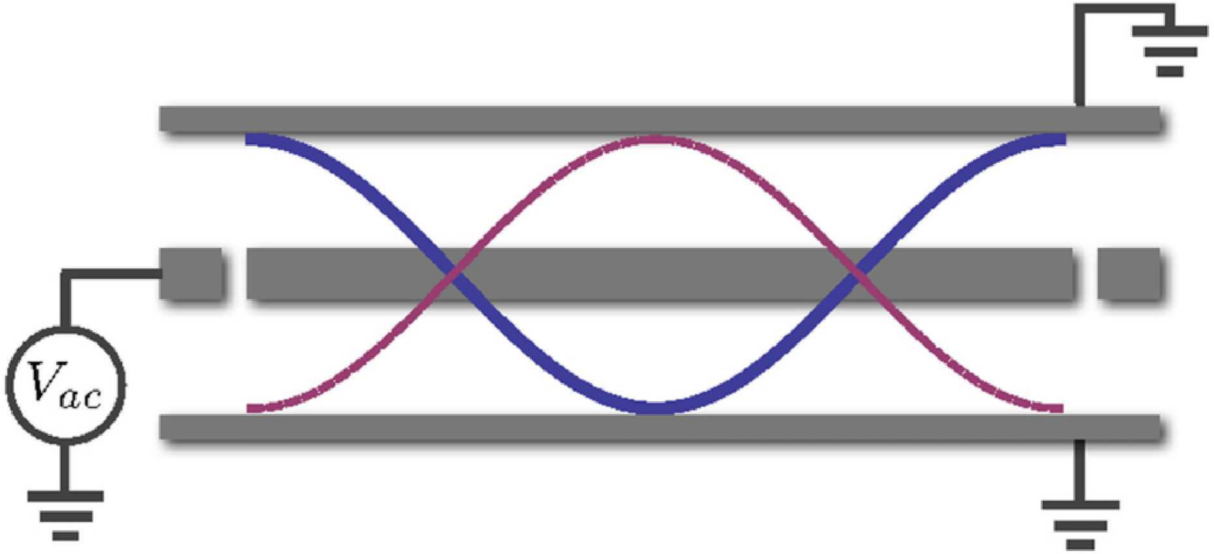
A. Hauck *et al.*, Quant. Inf. Proc. 8, 105 (2009)

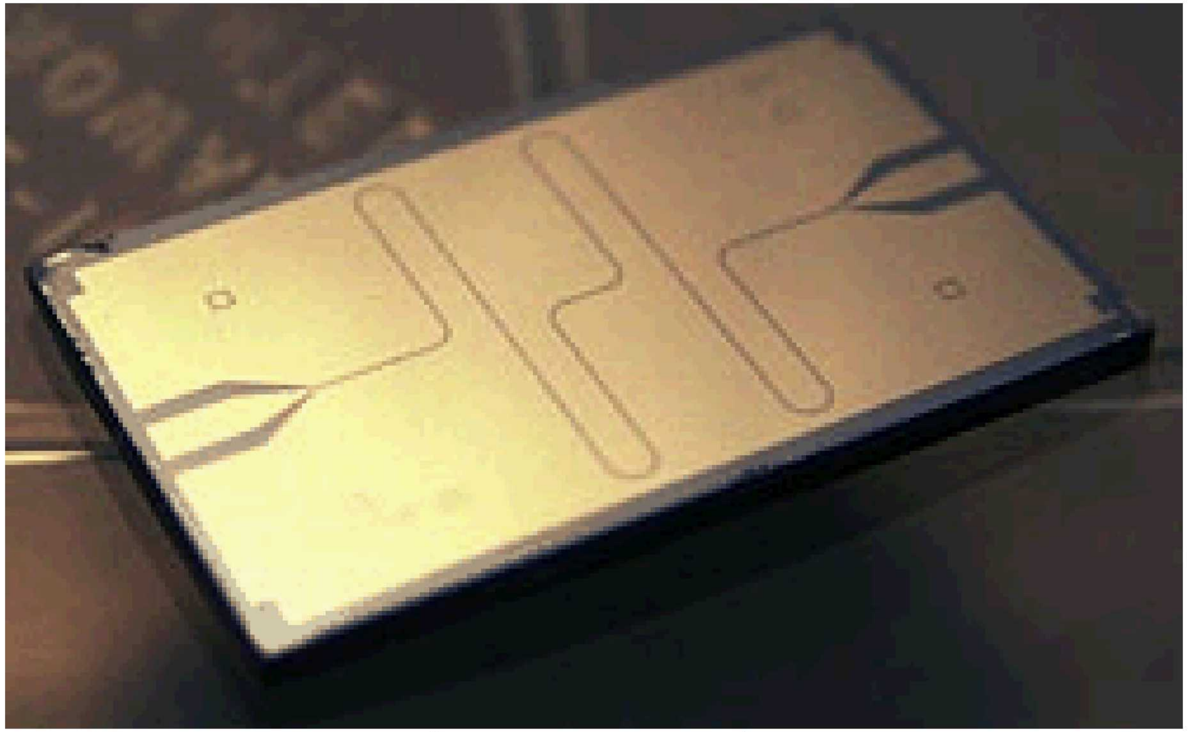


Hence qubit fab is:

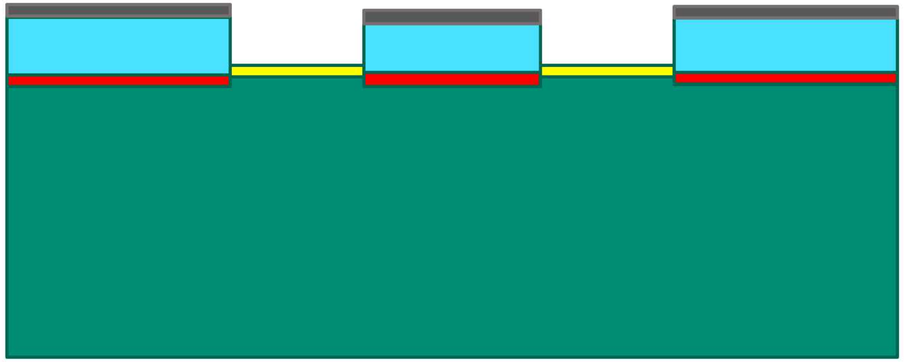
Single layer of metal + stitching
On low loss substrates
No interlayer dielectrics!

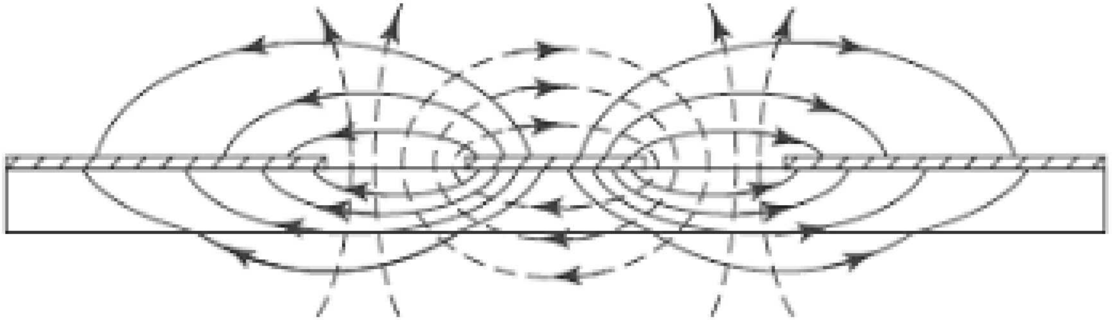
Superconducting Resonators have many of the same features as qubits





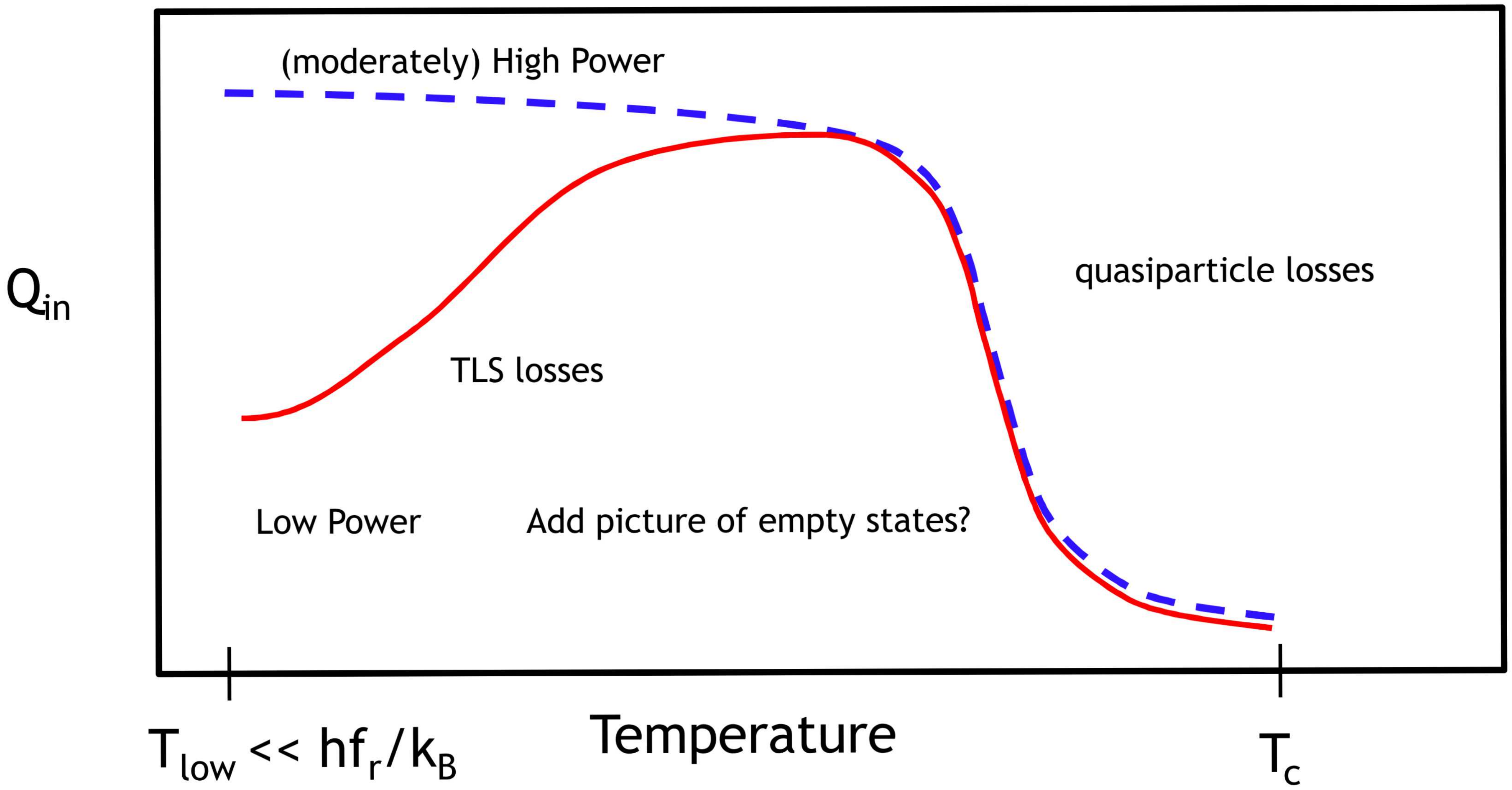
cross-section view



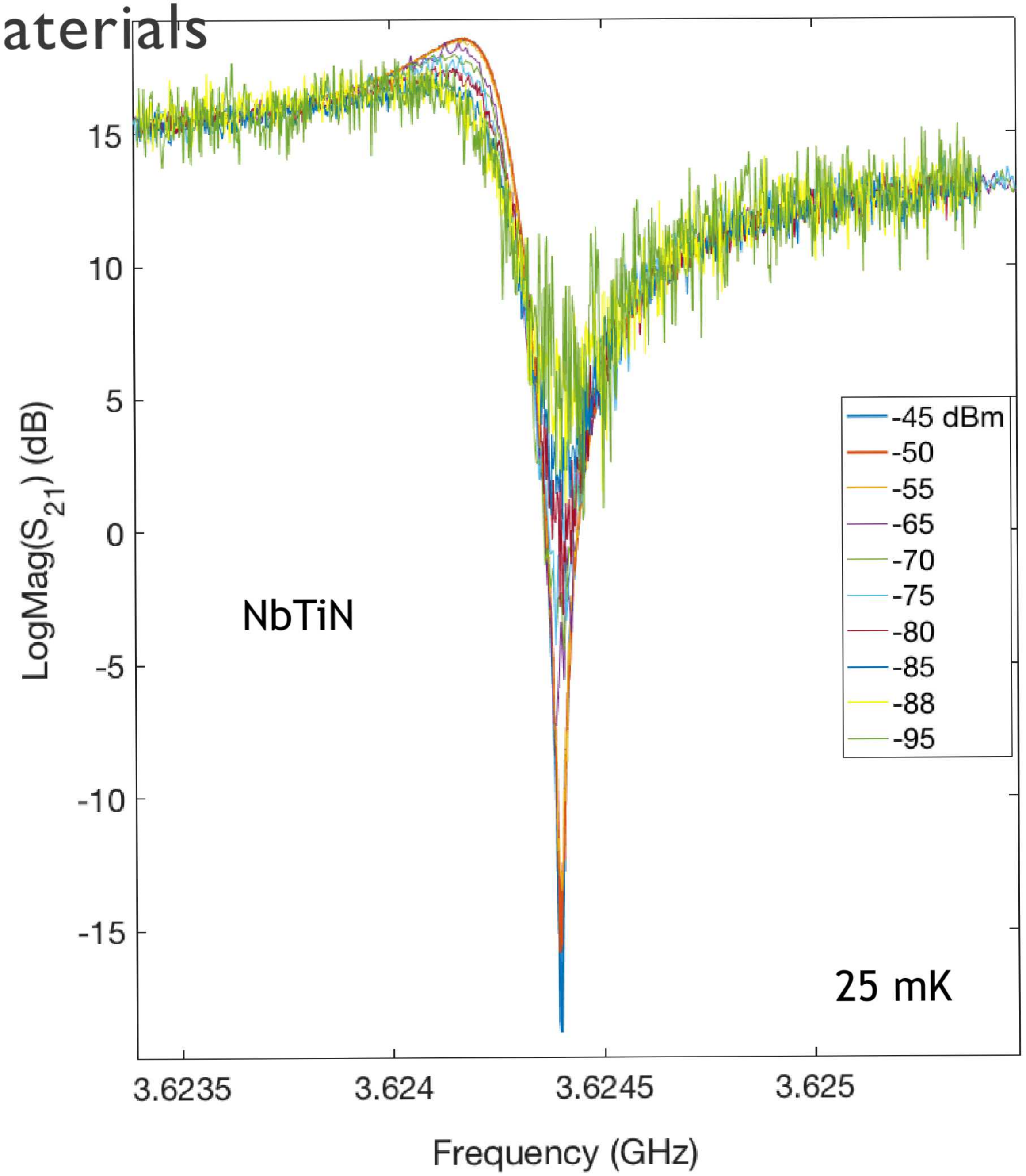


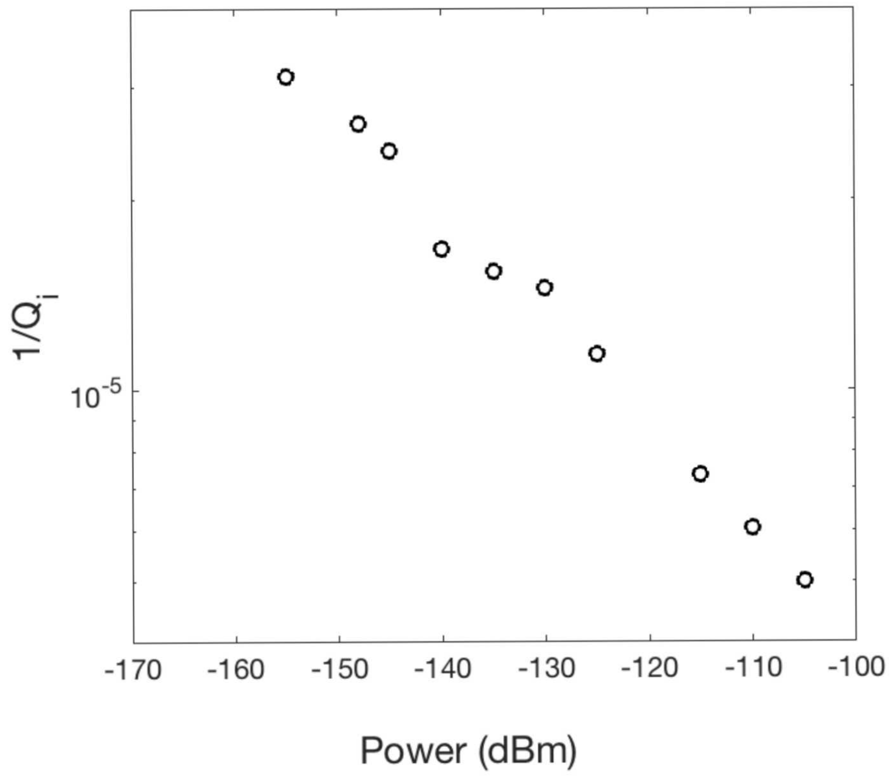
But simpler to measure

What to expect from Q as the resonator is cooled

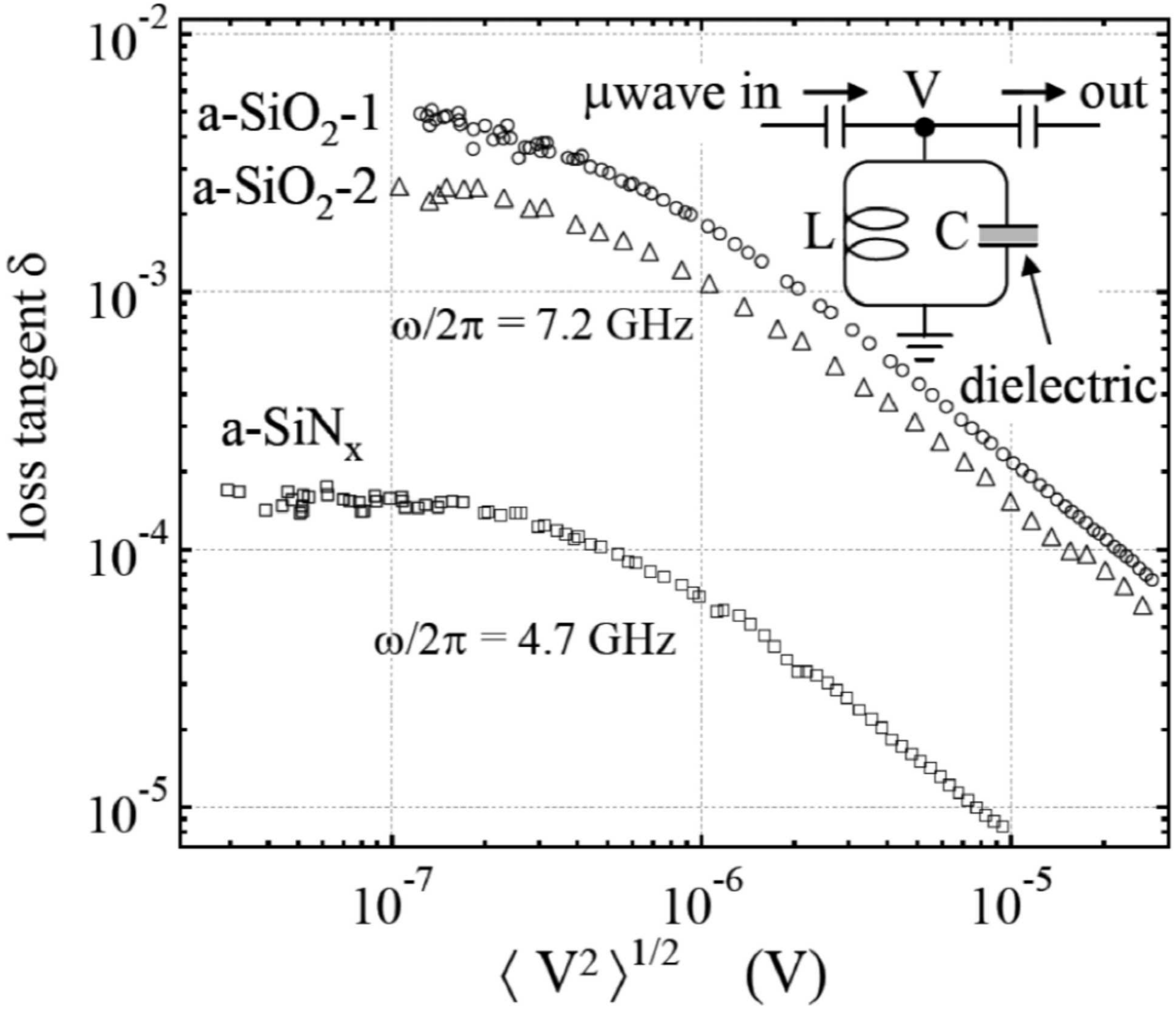


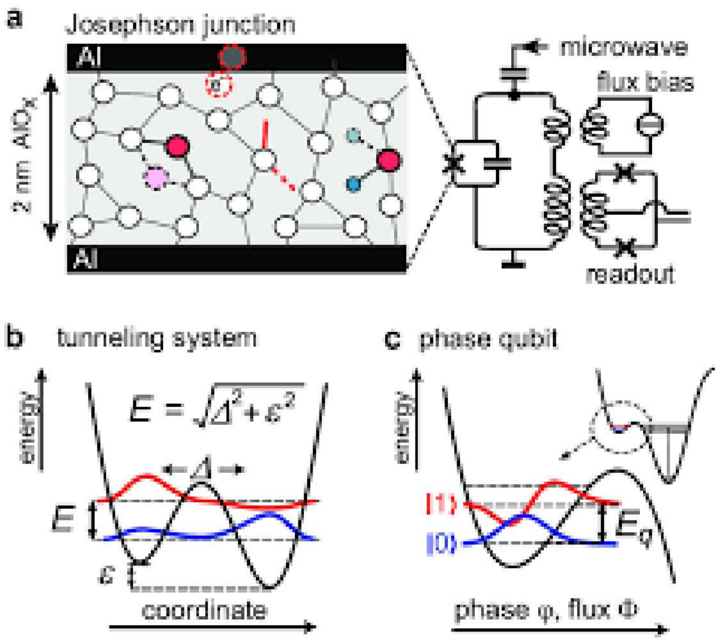
New materials





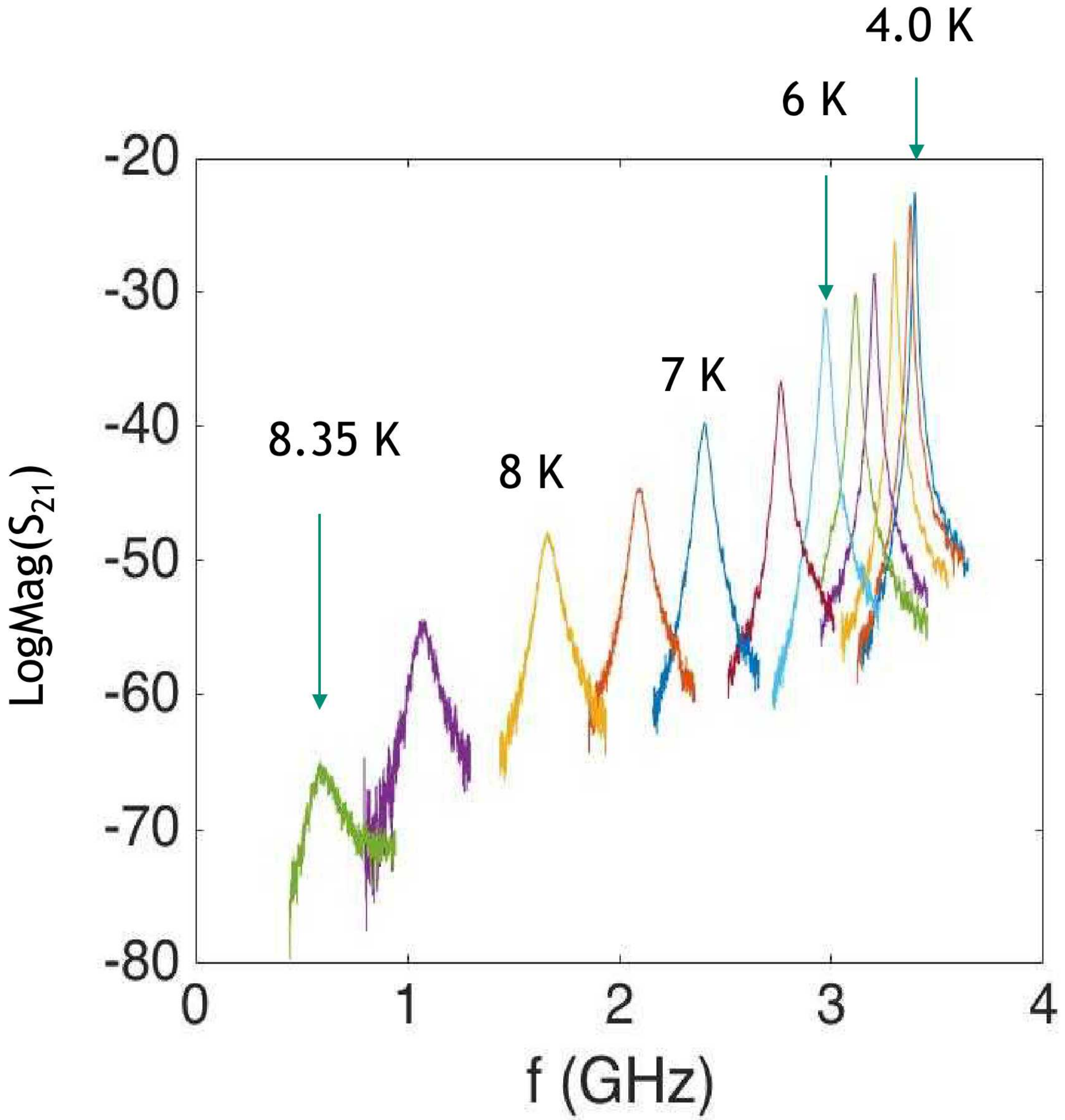
Low Power Q probes losses due to two-level-systems Oxides

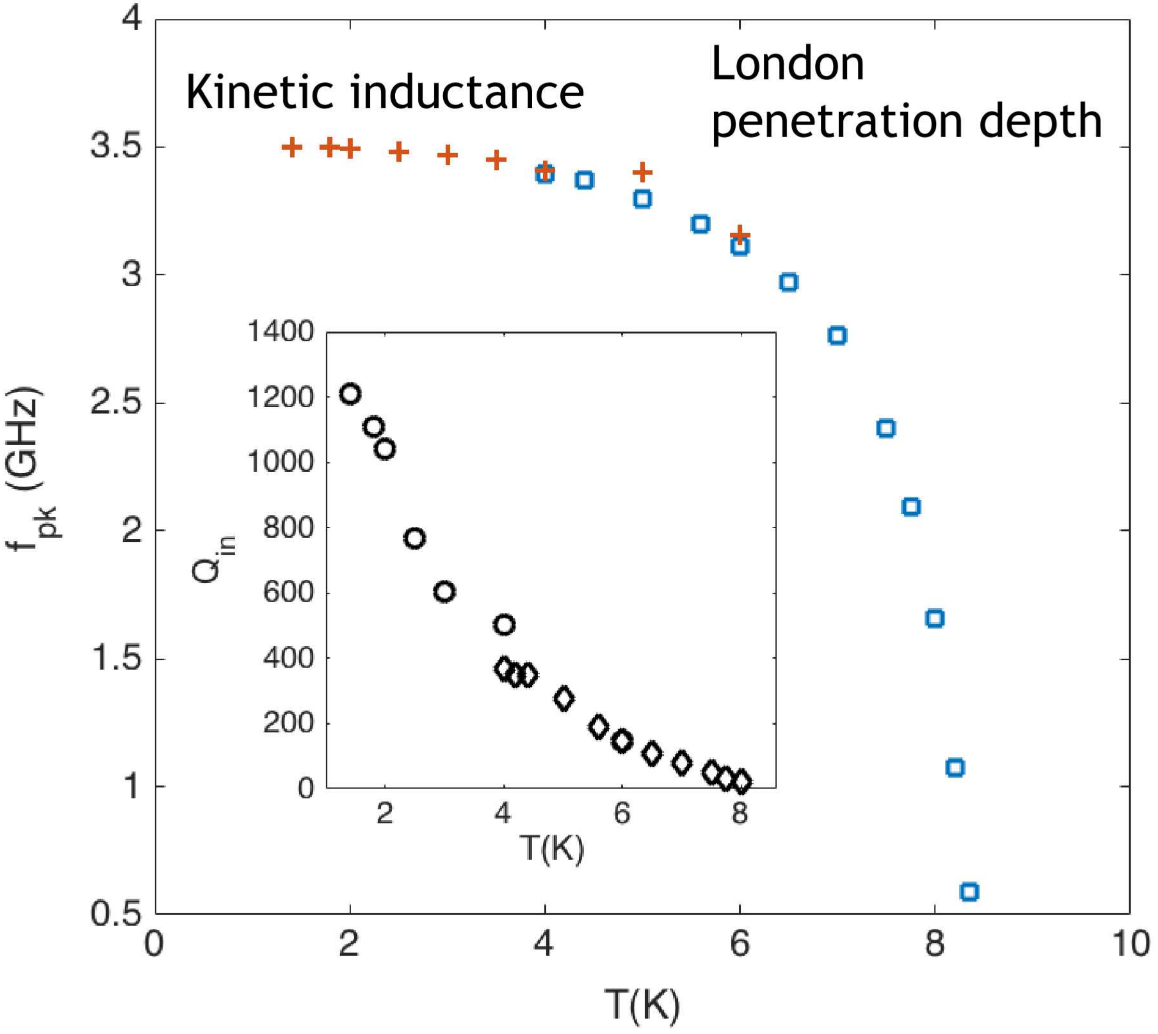




John M. Martinis *et al.,* Phys. Rev. Lett. **95**, 210503 (2005).

Design…

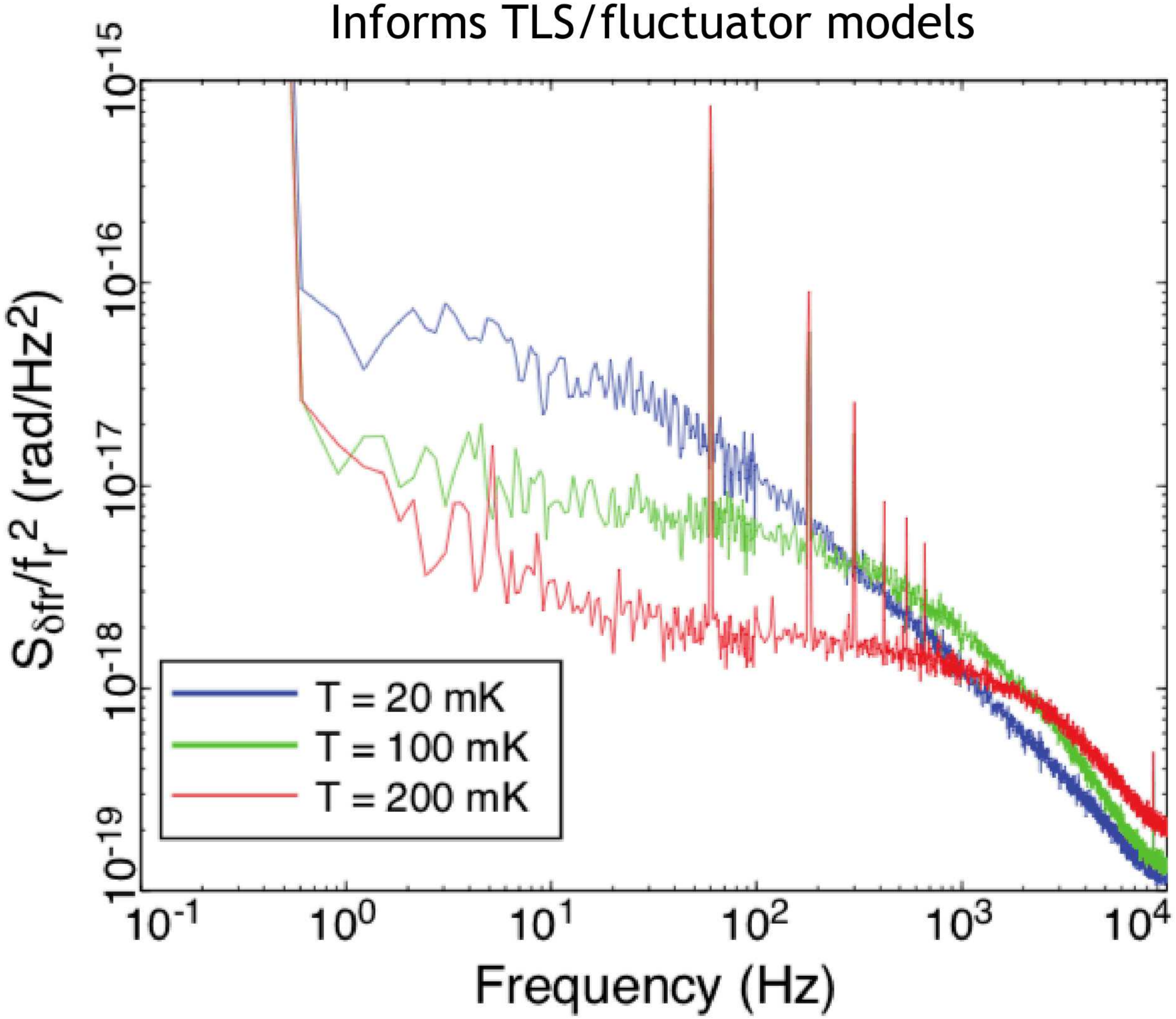


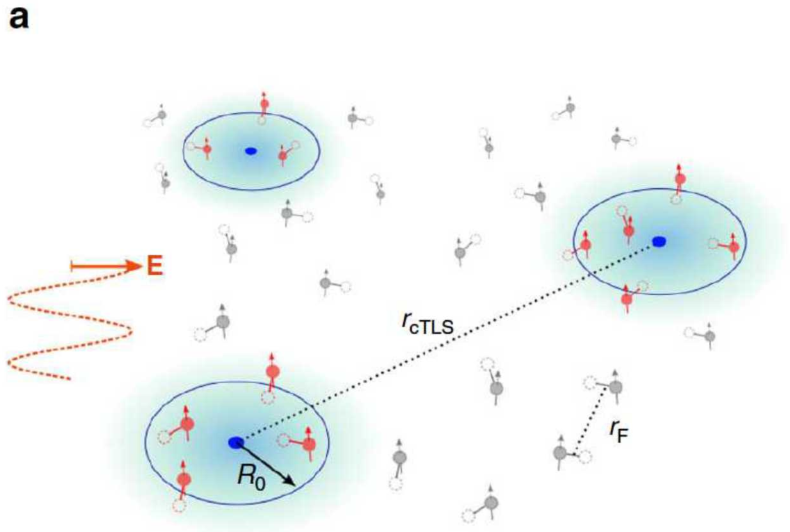


f_{pk}: thermal shifts, quasiparticles, kinetic inductance
Q: internal losses in the resonator

Noise spectroscopy

Informs TLS/fluctuator models





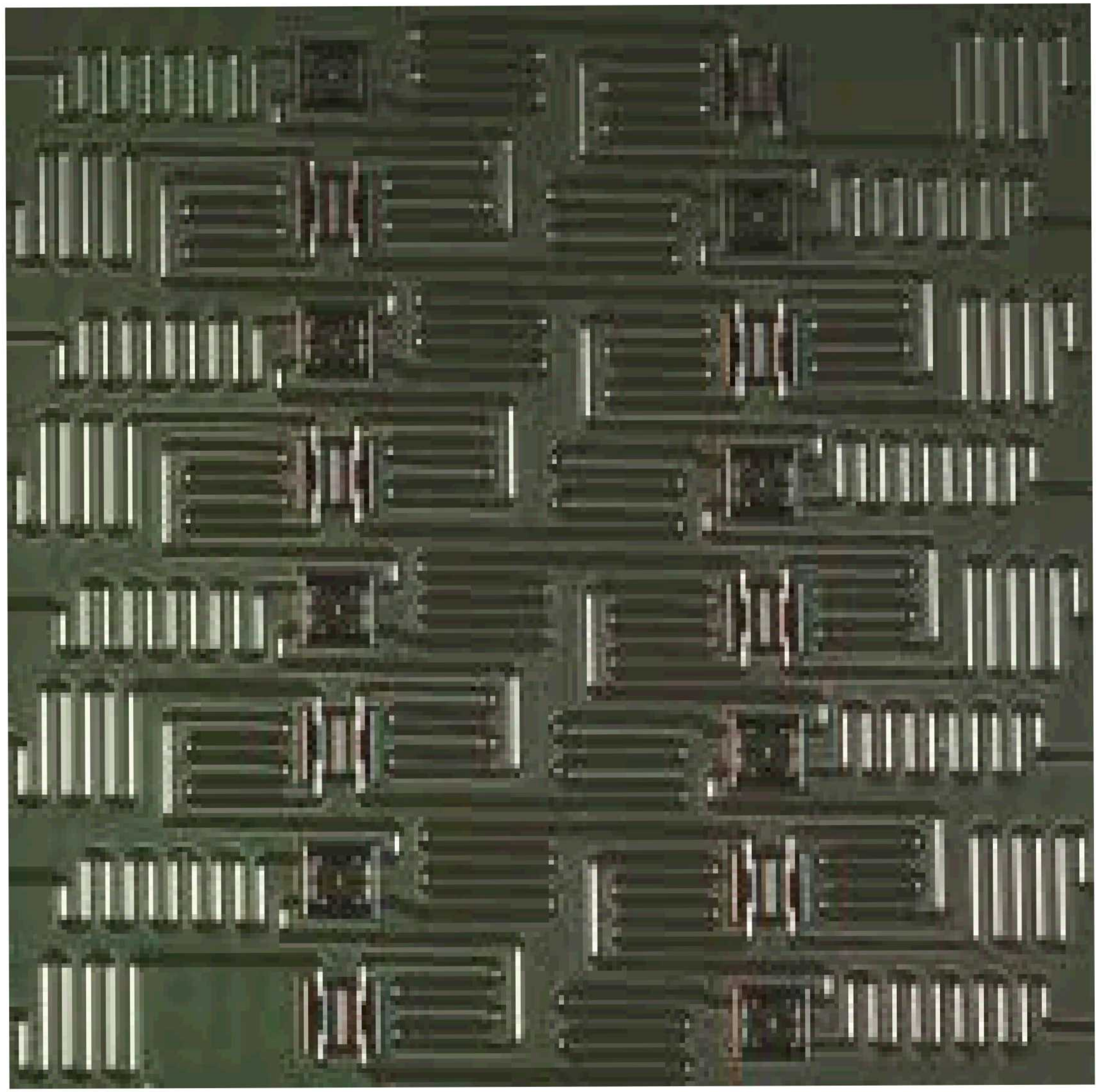
S. de Graaf et al, NATURE COMMUNICATIONS (2018).

From: Christopher McKenney, “Two Level Systems (TLS) Noise and RF Readouts”, 4th Microresonator Workshop 29th July, 2011.

Conclusions

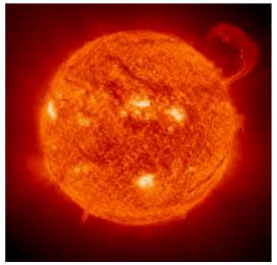
Resonators are

- Integral to QC
- Materials
- Diagnostics



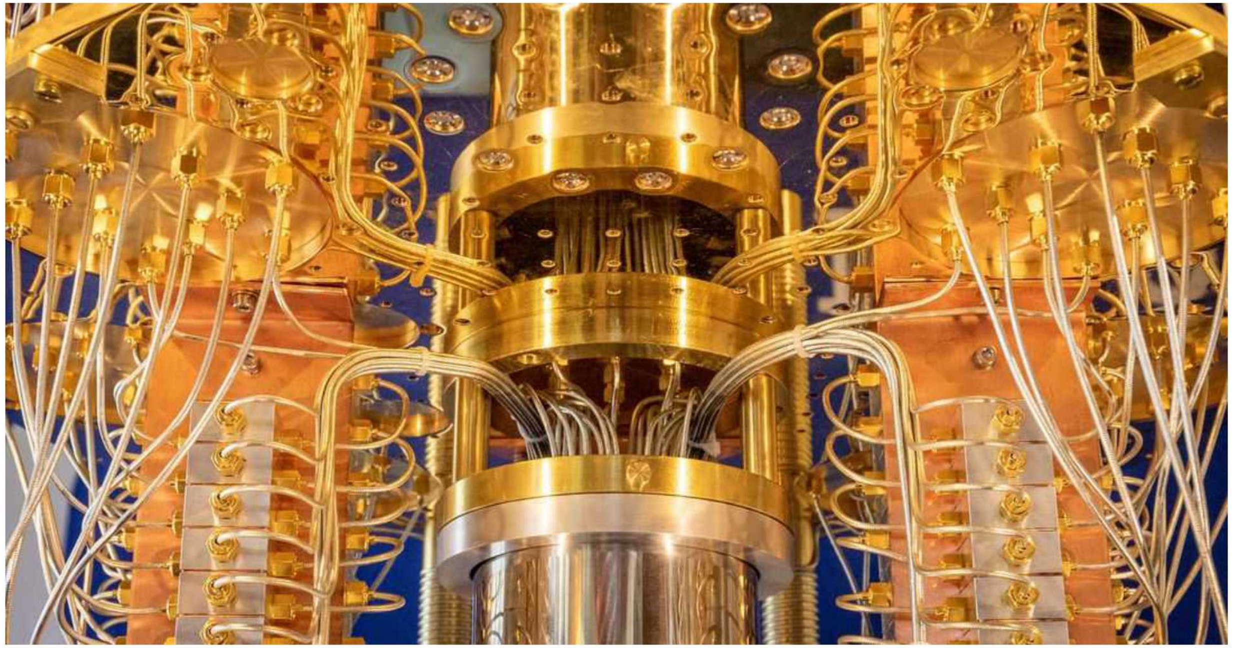
Questions?

Chemistry



plasmas

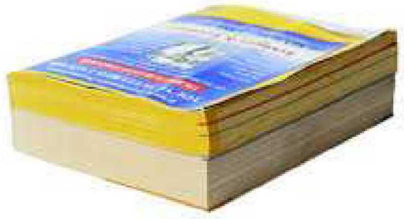
Secure communications

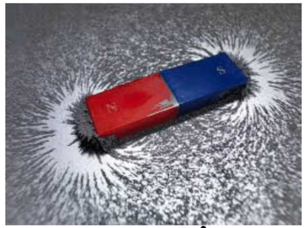


Physics

Superconductivity

Quantum Info





magnetism

Games!

Requirements for QC