Presentation

lunes, 1 de febrero de 2016 9:24

* PhD 2001 Univ. Complutense de Madrid

  Applied Maths + Optics + CMP

* Postdoc at MPQ, Garching '01-'06. Permanent at CSIC '08-today

* Two long stays in Innsbruck: '99 (PhD), '01 (1st postdoc)

* Strange trajectory

  Maths / Nonlinear dynamics → BEC / cold atoms → Q. Optics / Q. Info → trapped ions; → Supercond Circuits; → molecular systems; → Q sensing

* Self-taught introduction to c.QED ← proof that the field has interest and potential outside solid state Phys.

  + no actual CMP background ← if I can do it, so do you

Outline

viernes, 29 de enero de 2016 19:50

* Self consistent course on
  - Superconducting circuit theory
  - Superconducting qubits
  - Circuit-QED = qubits + resonators
* Overview of advanced topics
  - Circuit-quantum annealing
  - Stabilizer codes
  - Microwave quantum photonics
  - "Ultrastrong coupling"
* Brief introduction to topics
  - Quantum Optics
  - Quantum information
  - Quantum simulation
  - Condensed Matter systems

Prerequisites:
- Quantum states
- 2nd & 1st quantization
- Diag matrices, perturbation theory

Schedule

lunes, 1 de febrero de 2016 21:59

Semana 1	
03/02/16 Miércoles	Introducción y planteamiento
	Quantum Science & circuits
Semana 2	
08/02/16 Lunes	Circuit theory: reglas
	Circuit theory: ejemplos sencillos
10/02/16 Miércoles	Circuit theory: squids
	Charge qubit
12/02/16 Viernes	Transmon
	Flux qubit
Semana 3	
15/02/16 Lunes	Transmission line quantization
	Circuit-QED setup
17/02/16 Miércoles	Cavity-QED model & strong coupling
	Cavity spectroscopy
19/02/16 Viernes	Dispersive limit: QND measurements & Hamiltonian
	Dispersive limit: photon state preparation
Semana 4	
24/02/16 Miércoles	Three-dimensional cavities and transmons
	Parity measurements & Schroedinger cats
26/02/16 Viernes	D-Wave machine I: adiabatic QC
	D-Wave machine II: setup & annealing
Semana 5	
29/02/16 Lunes	Tuneable coupling
	UCSB quantum processor: g-mon, x-mon
04/03/16 Viernes	Qubit in open line: Ohmic spin-boson model
	Single-photon, single-qubit interaction
Semana 6	
07/03/16 Lunes	Ultrastrong coupling

* 12 days - 24 lecture hours - 2 credits
* M - W - F - 9:15 - 11:00
  with 15 min break at 10:00

← I regularly need this!!!

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* People go to conferences
* Group meetings
* Complicated schedules

} flexibility

Organization

viernes, 29 de enero de 2016 20:33

* The course builds on
  - Lectures (attendance)
  - Notes (preliminary stage)
  - State-of-the-art bibliography
  - Problems
  - Presentations

* For students who need marks
  - Delivering problems (hand-written, weekly)
  - Presentations (depends on # people)
    +
    essay on a paper
  - Exam? (→ rather not, time, availability)

* Feedback appreciated: topics, depth, complexity, problems, etc (topics → flexible)

* Not a course on AMO but ... same models, emphasis on connections, interdisciplinary..

* VERY DENSE → continuity needed

- very dense → continuity [illegible]

http://juanjose.garciaripoll.com/lectures-quantum-circuits

Context

viernes, 29 de enero de 2016 20:41

'85 - Quantum Turing machine

'84 - Bennett, Brassard → quantum crypto

'94 - Shor's algorithm

} Development of Q Inf

'95 - First proposals for scalable quantum computing } Q.Comp might be feasible

'00 - Flux qubit (Mooij)

'99 - Charge qubit (Nakamura)

'02 - Phase qubit

} '00 RMP G. Schön, ugly prospects ⇒ bad T_1, T_2, ...

'04 - Charge qubit in resonator ⇒ qubits cando Rabi oscillations

'07 - Development of transmons

⋮

Cooking list

viernes, 29 de enero de 2016 20:48

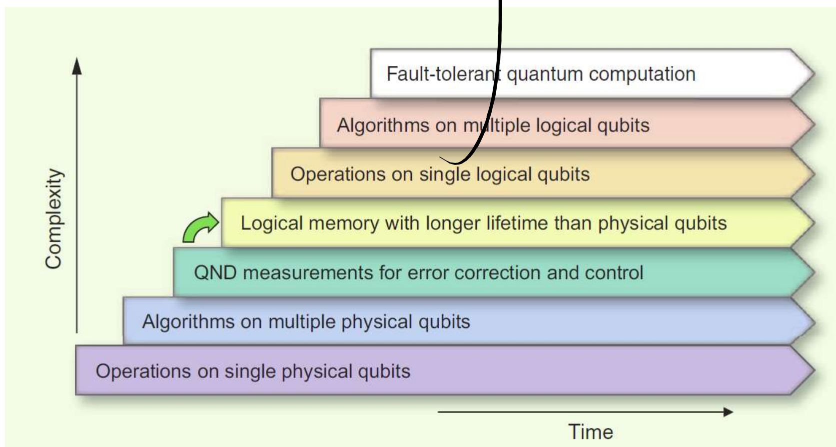
- Discrete few-level quantum systems
- Initialization $|\phi\rangle \otimes |\phi\rangle \ldots$
- Readout / measurement
- Arbitrary local gates
- One universal gate for 2-more qubits
- Large # qubits and error correction

Quantum crypto

Quantum simulation

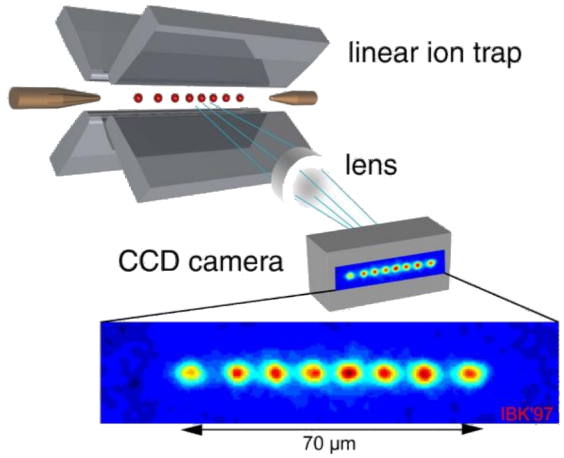
Quantum computing

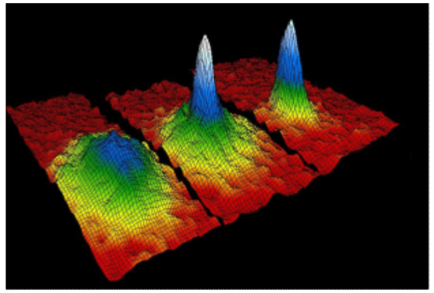
followup

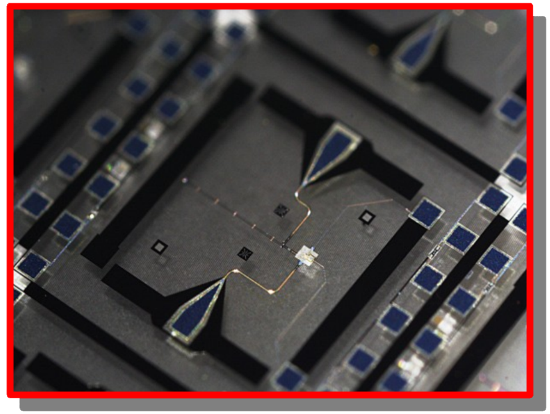


Quantum technologies

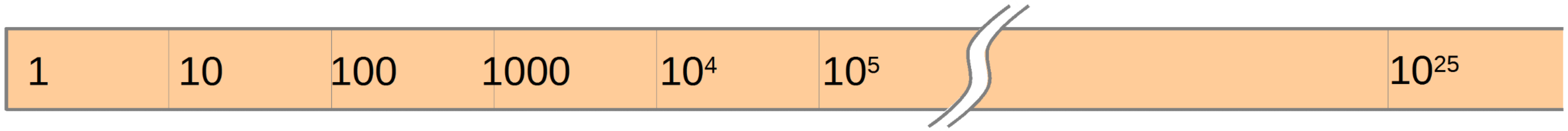
lunes, 1 de febrero de 2016 22:07

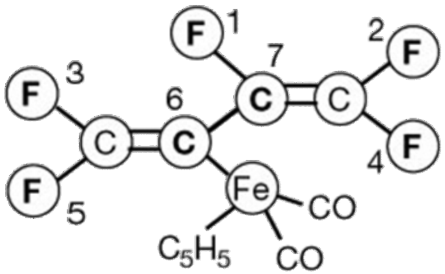


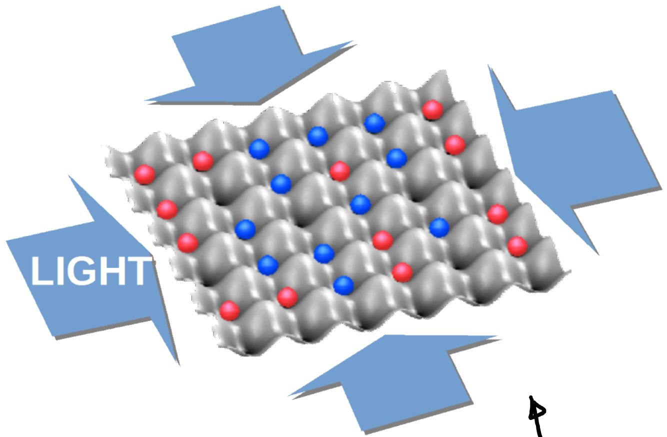


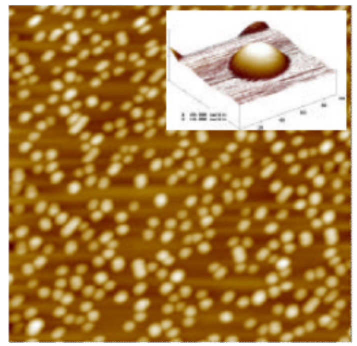


Different size scales









Different energy scales

Quantum degrees of freedom

lunes, 1 de febrero de 2016 22:10

	phonons	atom hopping	lattice	μ-wave	IR-A (NIR)	IR-C	HEF
λ	140 m	280 km	3000 km	14 mm	800 nm	300 μm	3 mm
E	8 neV	4 peV	0.4 peV	$8.6 \cdot 10^{-5}$ eV	1.5 eV	4 meV	0.4 meV
$\hbar\omega$	2 MHz	1 kHz	100 Hz	21 GHz	375 THz	1 THz	100 GHz
$k_B T$	0.1 mK	48 nK	5 nK	1 K	17857 K	48 K	4.8 K
	Ion phonons	lattice	exchange interaction in lattice				

SC doesn't care much

→ plasmonics, vibrational spectra

Kills our superconductor

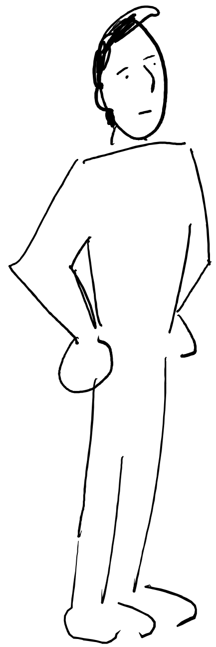
4.8 K → superconducting gap

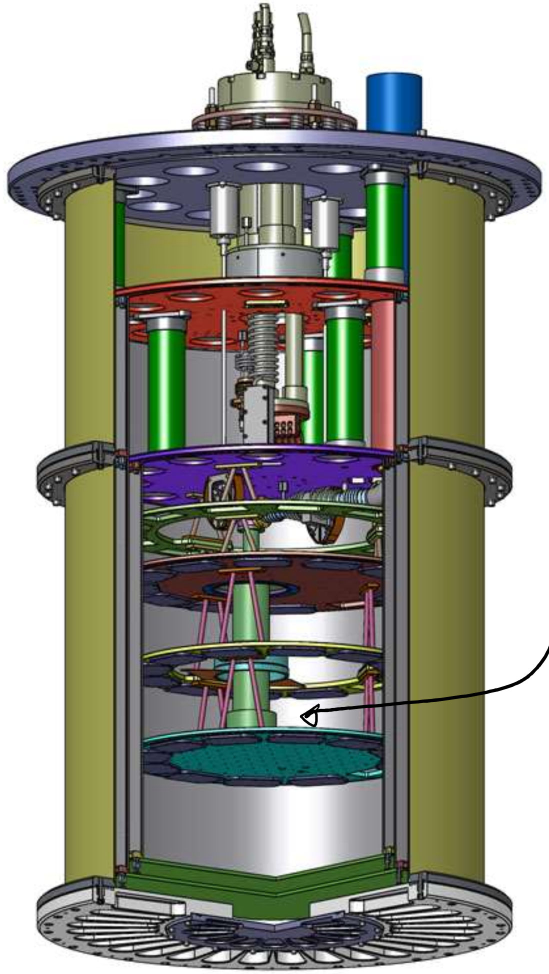
↳ telecomm, Alkali atoms

↳ Superconducting circuits, hyperfine splitting, rotational spectra, nanomechanical resonator phonons

Ingredients

Cryostats





* Big and slow cooling system that combines ^4He and ^3He
  ↳ mixture of both is endothermal and cools down to ~ 2mk from a precooled ^3He at ~ 700-800 mk

* Small working area

* Sample may heat up easily, recools slowly
  ↳ example: moving parts in a circuit w. AOM motor to move a probe transmon: 1 hr to recool

* Expensive: ^3He production linked to nuclear facilities and under strict control

Materials

lunes, 1 de febrero de 2016 22:12

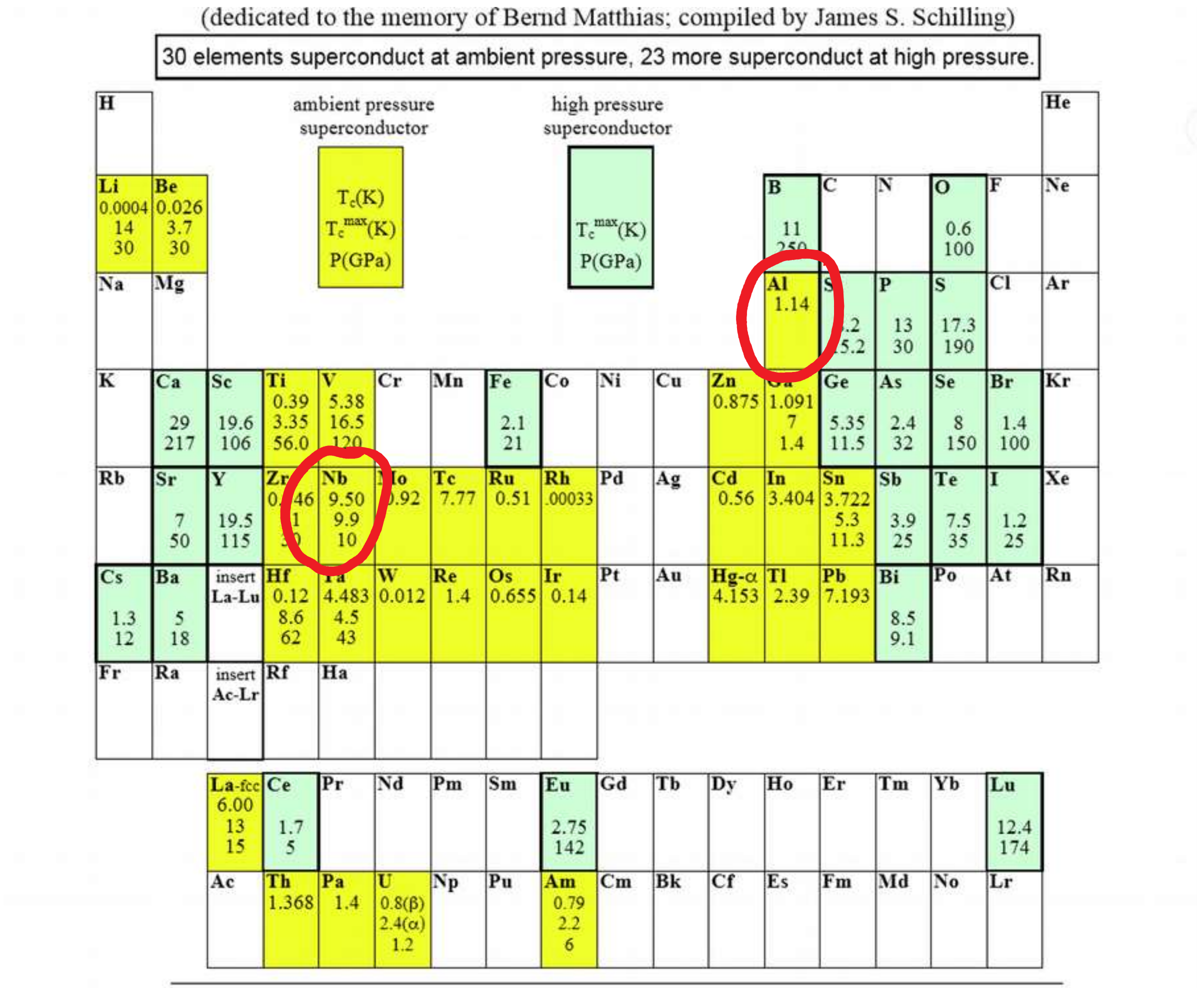
* We rely mostly on Aluminum and Niobium

* Al is a Type I, easy to print, lower T_c

* Nb is Type II, higher T_c, not good for fine detail

* $\Delta_{Al} \sim 3.4 \times 10^{-4}\ eV \sim 82\ GHz$

  $\Delta_{Nb} \sim 30.5\ 10^{-4}\ eV \sim 737\ GHz$



M. Debessai, T. Matsuoka, J.J. Hamlin, W. Bi, Y. Meng, K. Shimizu, and J.S. Schilling, J. Phys.: Conf. Series **215**, 012034 (2010).
High pressure data for Ca and Be: K. Shimizu email from 9 Dec 2013.

Circuit elements

domingo, 31 de enero de 2016 21:38

Components

- Capacitors
- Inductors
- Junctions
- Signal generators
- Amplifiers

~ Optics

- Mirrors
- Waveguides
- Atoms
- Lasers
- Photodetectors

High level

* Qubits
  - Flux qubit
  - Charge qubit
  - Transmon
  - Fluxonium
  - X-mon
  - G-mon
* Photons
  - L-C resonators
  - SQUIDS
  - Waveguides < coplanar, coaxial, striplines
  - 3D cavities

circuit theory

Prospects and trends

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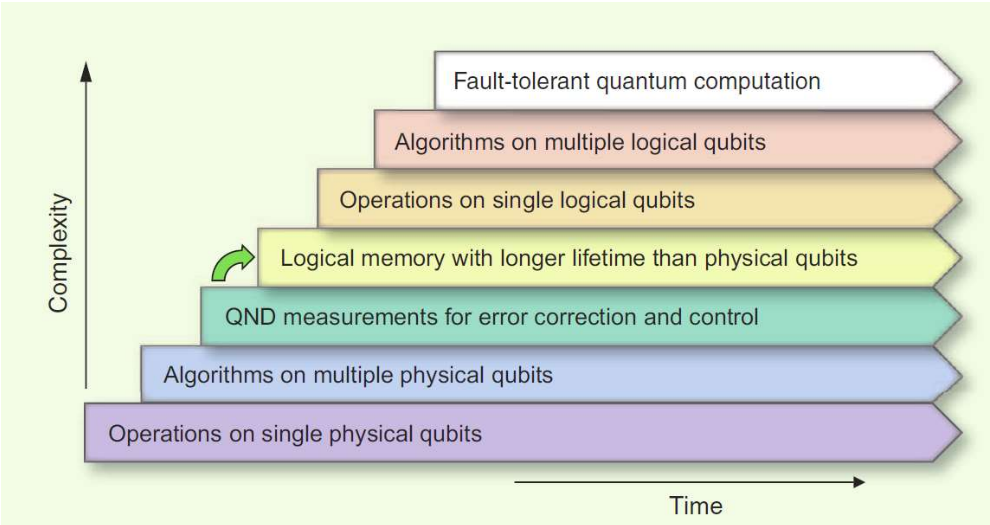
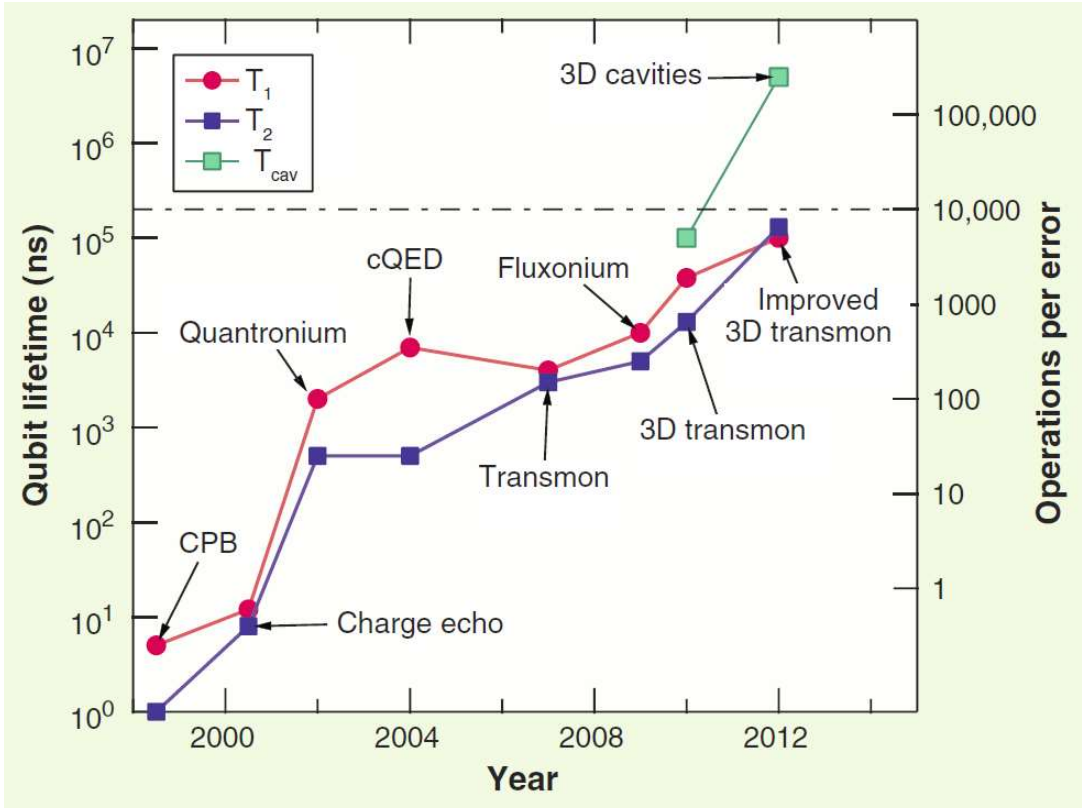


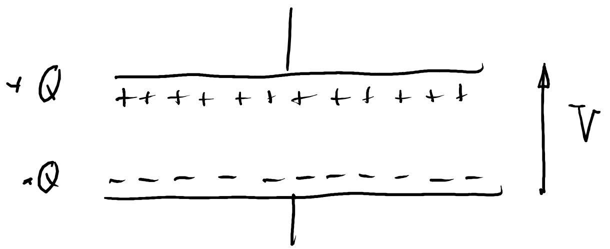


Superconducting Circuits for Quantum Information: An Outlook
M. H. Devoret and R. J. Schoelkopf
Science 2013

Capacitor

domingo, 31 de enero de 2016 10:20

capacitor



* Using Gauss's law

$$Q \sim \varepsilon_0 \iint E \cdot dA \Rightarrow Q \propto E \Rightarrow Q \propto V$$

* We introduce a proportionality constant C : $Q = CV$

* For two plates $C = \frac{\varepsilon A}{d}$ $\begin{cases} \varepsilon = \text{dielectric constant} \\ A = \text{area} \\ d = \text{plate separation} \end{cases}$

* Charging energy

$$W = \int_0^Q V(q)\, dq = \frac{1}{2C} Q^2$$ → energy needed to load the capacitor

* For Cooper pairs, $Q = 2eN \Rightarrow W = E_c \cdot N^2 = \frac{2e^2}{C} \cdot N^2$

* Current-voltage relation $I = \frac{dQ}{dt} = C\dot{V}$: we need a time varying voltage to establish a current

Inductor

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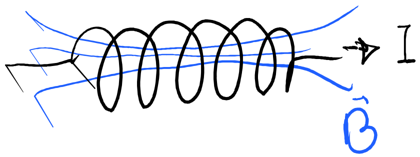

* A current circulating through a solenoid, or for that matter a cable, induces a magnetic field. When that current changes, the varying field generates an electric field that opposes the current

$$\frac{dI}{dt} \neq 0 \Rightarrow \frac{dB}{dt} \neq 0 \Rightarrow E \neq 0 \Rightarrow V \neq 0$$

* We assume that the circuit is linear: $V = L\dot{I}$ L = inductance

* The energy required to establish an ideal current I starting from zero

$$W = \int_0^T P(t)\,dt = \int_0^T I \cdot V \cdot dt = \int_0^T L \cdot I \cdot \frac{dI}{dt}\,dt = \frac{1}{2} L I^2$$

($P(t)$ ← power)

* Flux: let's introduce $\phi = \int_0^t V(t)\,dt$, $V = \frac{d\phi}{dt}$, $W = \int_0^t \frac{1}{L}\phi\dot{\phi}\,dt = \frac{1}{2L}\phi^2$

LC-Resonator

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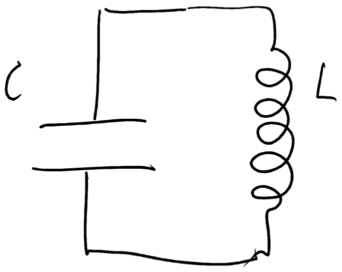
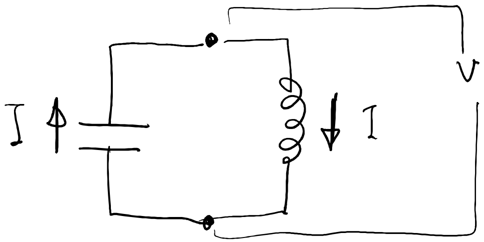


* Choose nodes and define voltage / current variables



* current sinking into the capacitor = current flowing through inductors

$$I_{cap} = \frac{dQ}{dt} = \frac{d}{dt}(CV) = C\frac{dV}{dt}$$

$$\dot{I}_{ind} = -\frac{1}{L} V$$

$$C\ddot{V} = \frac{1}{L} V \Rightarrow \frac{d^2}{dt^2} V = -\frac{1}{CL} V = -\omega V$$

$$\omega = \frac{1}{\sqrt{LC}}$$

* Some numbers

arxiv: 1005.1559

$C = 0.5\ pF$

$L = 1.5\ nH$

$$CL \simeq 0.25 \times 10^{-12} \underbrace{\frac{C}{V}}_{pF} \cdot 1.5 \cdot 10^{-9} \underbrace{\frac{V}{C s^{-2}}}_{nH} = 0.375 \cdot 10^{-21} s^2$$

$$\omega = 2\pi \cdot 8.22\ GHz$$

LC Resonator

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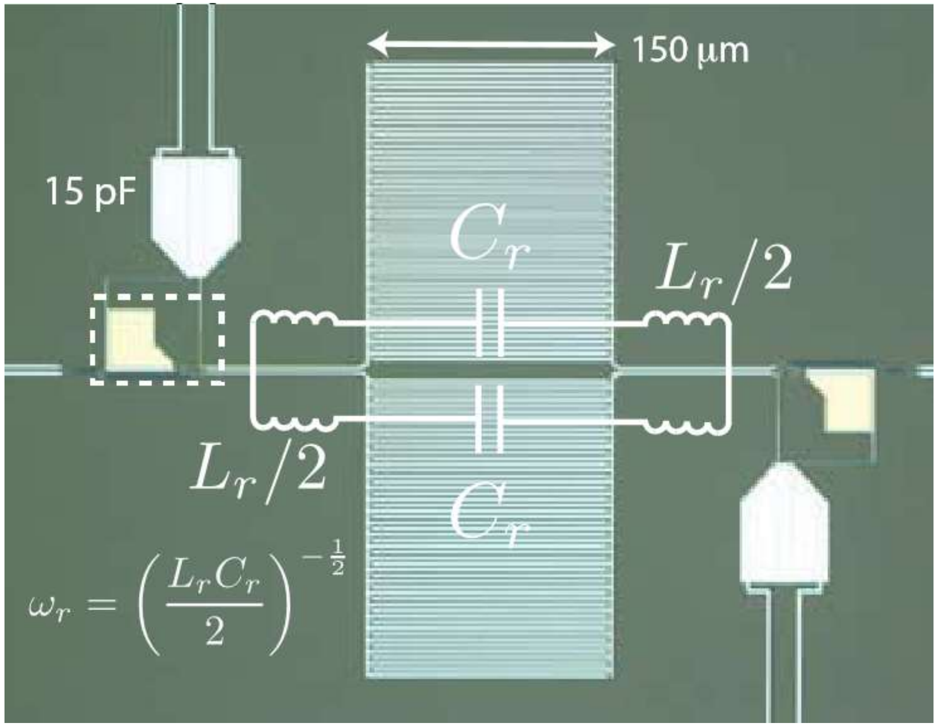

$C_r = 0.5\,pF$

$C_{TOT} = \frac{C_r}{2} = 0.25\,pF$

$L_r = 1.5\,nH$

$\omega = \left(0.25 \cdot 10^{-12} \frac{V}{C} \times 1.5 \cdot 10^{-9} \frac{V}{C/s^2}\right)^{-1/2}$

$= 2\pi, 8.2\ GHz$

$\omega = 2\pi, 8.2\ GHz \leftrightarrow T_Q = 0.4\ K$

If we assume that temperature is below T_Q then we should see quantum fluctuations

$H = \hbar\omega a^\dagger a$

We work under the assumption that there are no other degrees of freedom