Lecture 3: Benefits of Scaling II

- Announcements:
- HW#1 online yesterday; due Friday next week
- Today: We'll try to go 2 hours to make up for some of the missed time from the first week.
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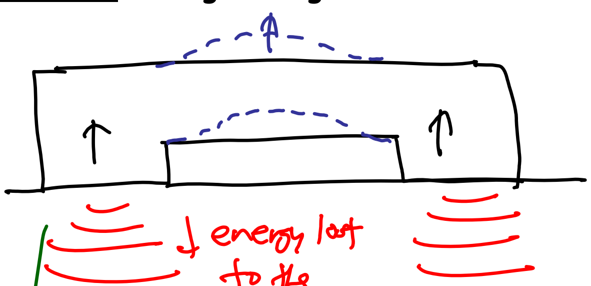
- Today:
- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Benefits of Miniaturization
  - Examples
    - —GHz micromechanical resonators
    - —Chip-scale atomic clock
    - —Thermal Circuits
- ------------------------------------
- Last Time: Going through module 2



↓ energy lost to the substrate!

8MHz → Q~6,000 anchor loss! → $Q = \frac{\text{Energy per cycle}}{\text{Energy lost per cycle}}$

↓

70MHz → Q~300

Q↓

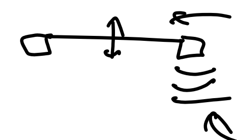
Great example of pro & con of scaling!

$\omega_o = \sqrt{\frac{k}{m}}$

$\frac{m^3}{m^2}$

③ Solutions: nanodimensions ✓

↳ this means: h = 300nm, L~1μm



smaller stiffness ↓ less

Q remains high

But: Problem: very small power handling

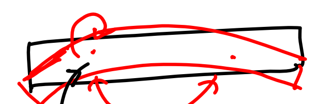
↳ smaller → less power handling

↓

Solution: use many of them → array

④ Better Solution: other geometries! ✓✓

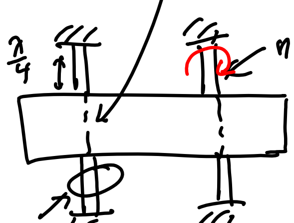
Free-Free Beam:



} side view

nodal points (where transverse motion = 0)

Top Views ↘



$\frac{\lambda}{4}$

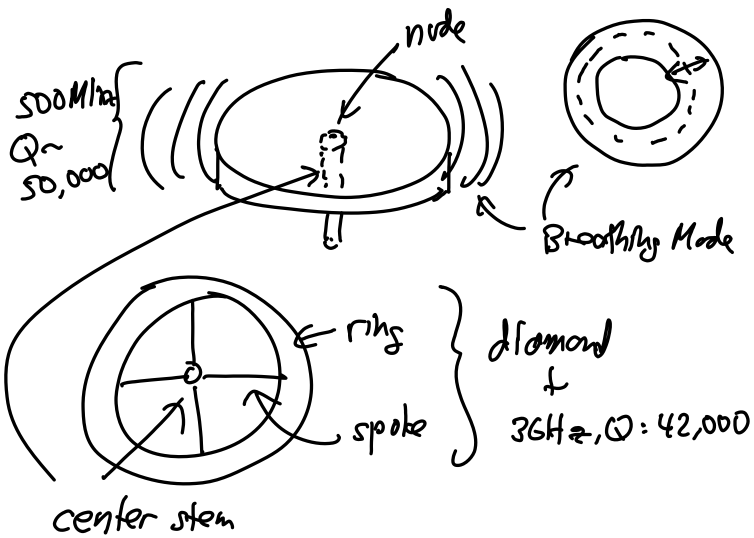
node ← put anchors @ nodes

↓

Energy Loss ↓

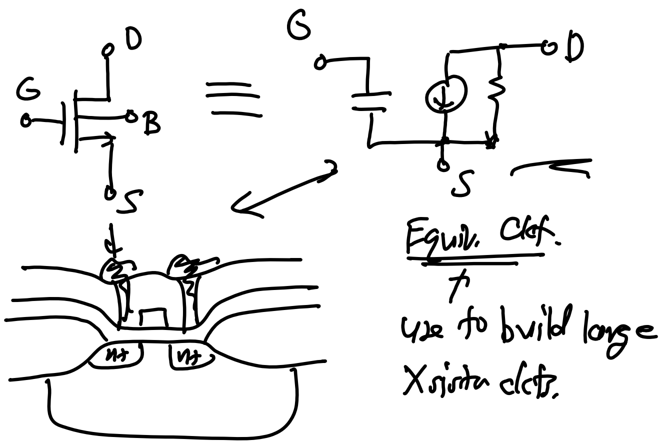
torsion

⑤ Even Better Solution: Bulk Mode Disk



Circuit Design

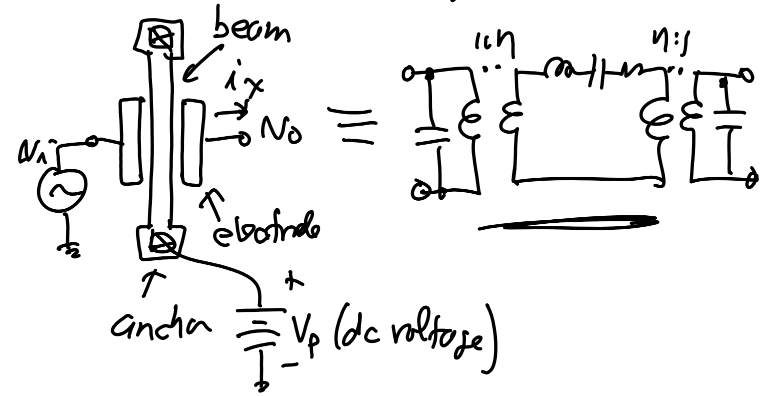
Transistor Ckts.



↑ use to build large Xsistor ckts.

Mechanical Ckt.

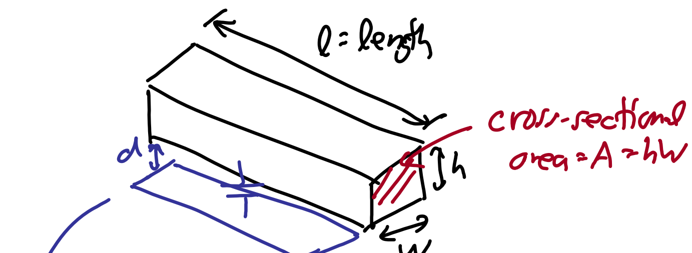
Crystal + Xtal



Thermal Ckts.

Review Electrical Resistance, First

(then, attack the thermal R analogy)



$R_e \triangleq$ electrical resistance $= \frac{l}{\sigma A}$

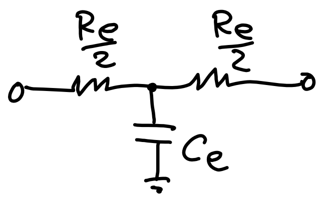
↑ electrical conductivity

C_e: electrical capacitance $= \frac{\varepsilon_0 W l}{d}$

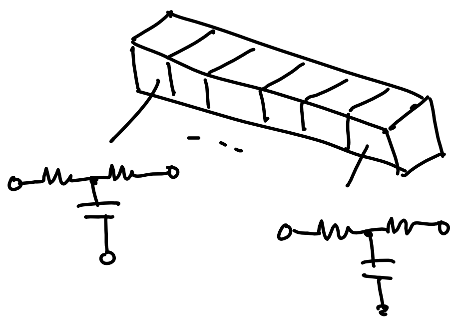
↑ permittivity

*

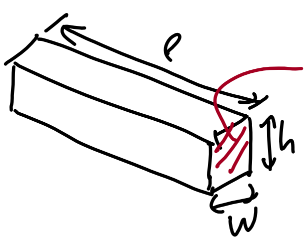
* → Stored Energy (charge energy) = $\frac{1}{2}CV^2 = E$
↑ voltage across the capacitor



⇒ if want to be more accurate:



Thermal Ckt.



⇒ Thermal Capacitance: $C_{th} = \rho V C_p$

- stores thermal energy
- ρ ← density
- V ← volume
- C_p ← specific heat

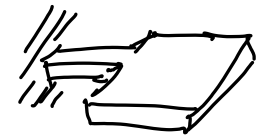
⇒ Thermal Resistance:

$R_{th} = \frac{\ell}{kA}$

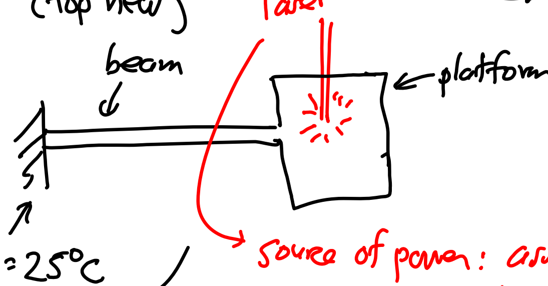
- ℓ ← length
- A ← cross-sectional area
- k ← thermal conductivity

Examples

Ex. MEMS type structure



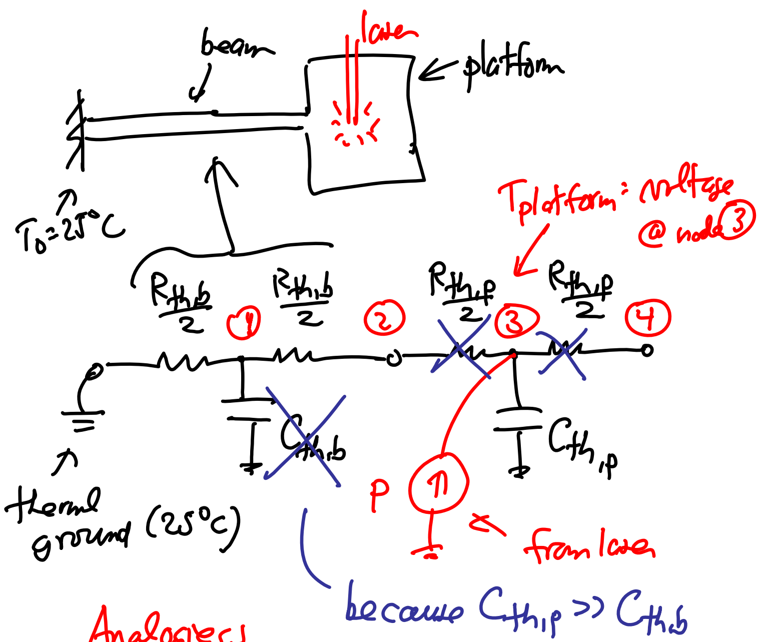
(top view)



$T_0 = 25°C$

source of power: assume all energy of laser is absorbed

What is the temperature on the platform?
↑ Voltage @ node ③



Analogies:

(temperature) T ⟶ V (voltage)

(power) P ⟶ I (current)

To Analyze:

① Remove small elements to simplify the ckt.

② $T_{platform} = P R_{th,b}$

(just like V = IR in an electrical system)

$\tau = R_{th,b} C_{th,p}$