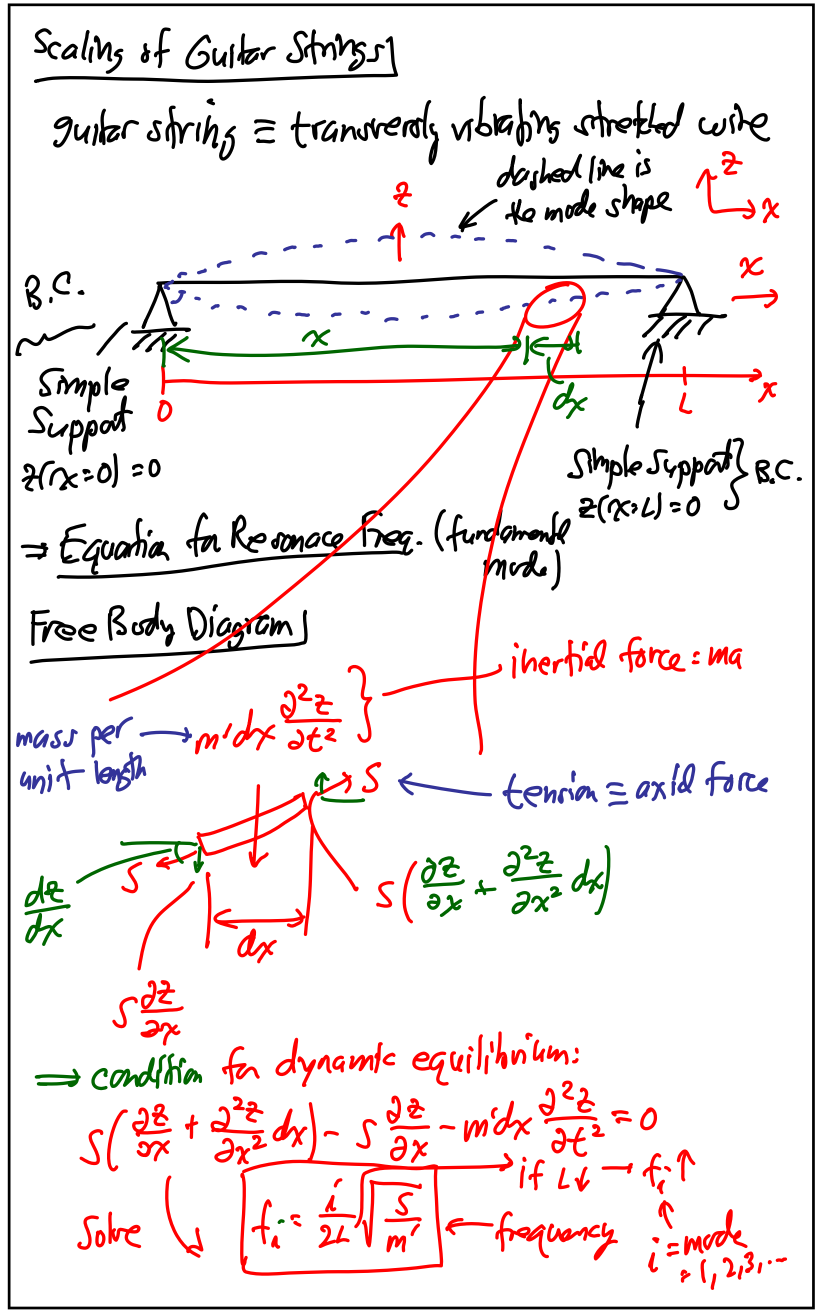
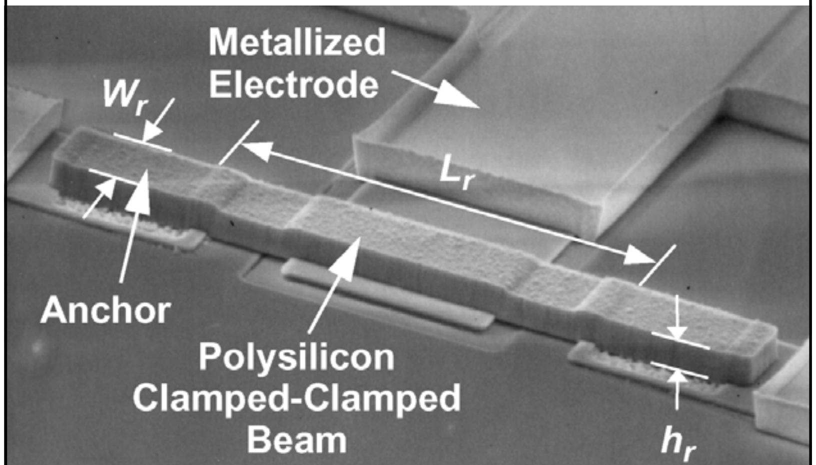
Lecture 2: Benefits of Scaling I

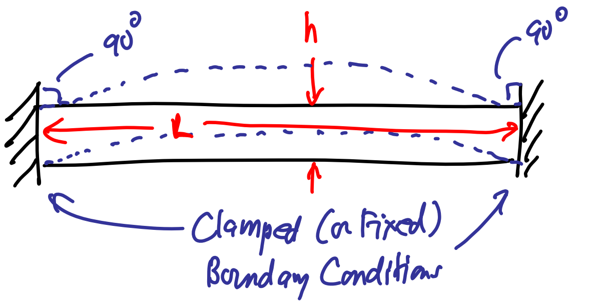
- Announcements:
- Henry Barrow Office Hour Change
  - Tu 10:30-12 noon → Tu 10-11:30 a.m.
  - Decided last time
  - Brian Pepin's office hours remain Th 10:30-12 noon
- The notes from last time are online
- Modules 1 & 2 are online
- HW#1 is online
- ---
- Today:
- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Benefits of Miniaturization
  - Examples
    - —GHz micromechanical resonators
    - —Chip-scale atomic clock
    - —Micro gas chromatograph
- ---
- Start going through module 2

over



Clamped-Clamped Beam





⇒ Eq. for resonance:

$$f_o = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = 1.03\sqrt{\frac{E}{\rho}}\frac{h}{L^2} \quad (1)$$

$L\downarrow \rightarrow f_o\uparrow\uparrow$

where $E \triangleq$ Young's modulus [GPa]

$\rho \triangleq$ density [kg/m³]

$h \triangleq$ thickness [m]

$L \triangleq$ length [m]

Example. $L = 40\mu m$, $h = 2\mu m$

polySi → $E = 150\,GPa$, $\rho = 2300\,kg/m^3$

$$\therefore f_o = (1.03)\sqrt{\frac{150G}{2300}}\frac{2\mu}{(40\mu)^2} \Rightarrow \boxed{f_o = 10.4MHz}$$

(acoustic velocity)

Scaling:

① Scale all dimensions equally by a factor S (2x, ½x)

$$f_o \sim \frac{S}{S^2} = \frac{1}{S}$$

② If scale L only: $f_o \sim \frac{1}{S^2}$ → even faster rise in f_o (but problems...)

Example:

$L = 4\mu m$ → $f_o = (1.03)(8076)\frac{2\mu}{(4\mu)^2}$

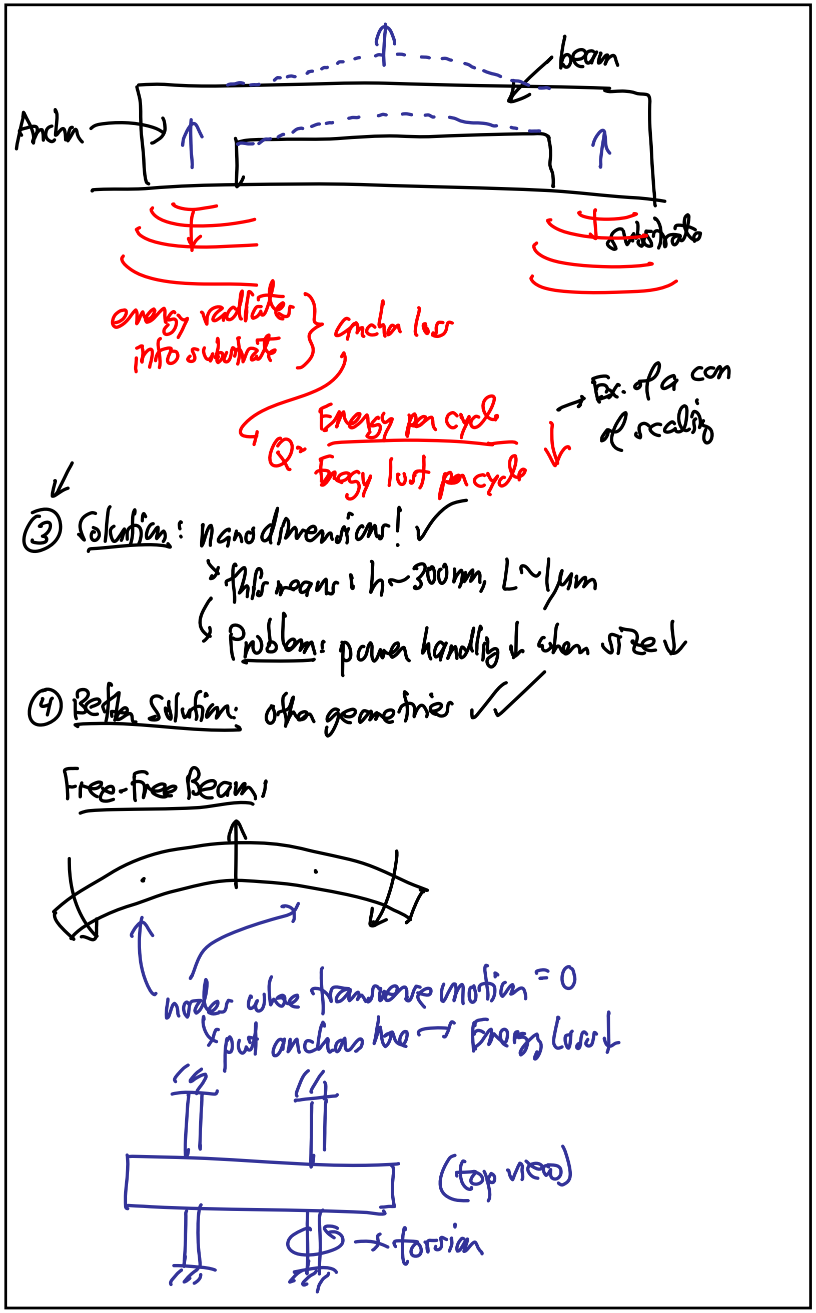
↑ ignore width effects (for now) ← questionable thing to do...

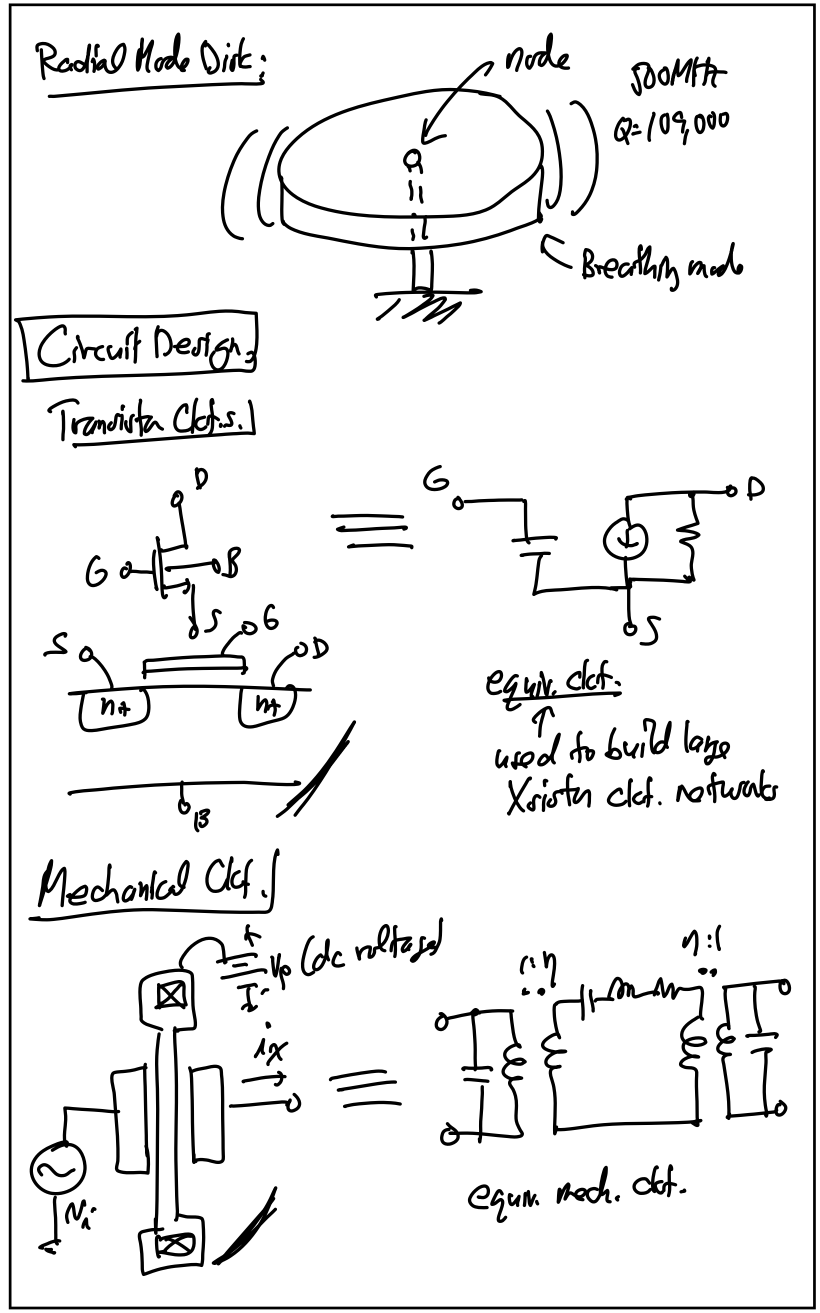
$f_o = 1.04\,GHz!$ ~800 MHz

Remarks.

① Eq. (1) not accurate when $L \approx h$.

② When $L \approx h$ (or when it isn't more than 10×h) → get anchor loss problems


beam
Anchor
substrate
energy radiates into substrate
anchor loss
Q = Energy per cycle / Energy lost per cycle
Ex. of a con of scaling
③ Solution: nanodimensions!
this means: h~300nm, L~1μm
Problem: power handling ↓ when size ↓
④ Better Solution: other geometries
Free-Free Beam:
nodes where transverse motion = 0
put anchors here → Energy loss ↓
(top view)
torsion


Radial Mode Disk:
node
500MHz
Q=109,000
Breathing mode
Circuit Design:
Transistor Ckts.:
equiv. ckt.
used to build large Xistor ckt. networks
Mechanical Ckt.:
Vp (dc voltage)
equiv. mech. ckt.