EE C247B – ME C218 Introduction to MEMS Design Spring 2017

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Lecture Module 14: Sensing Circuits

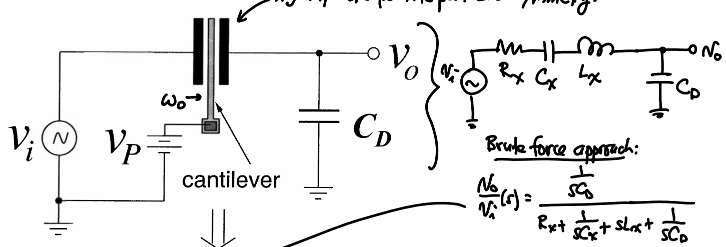
Lecture Outline

- Reading: Senturia, Chpt. 14
- Lecture Topics:
  - Detection Circuits
    - Velocity Sensing
    - Position Sensing

Position-to-Voltage Conversion

- To sense position (i.e., displacement), use a capacitive load

Again, have port-to-port I/O symmetry:



Brute force approach:

$$\frac{v_o}{v_i}(s) = \frac{\frac{1}{sC_D}}{R_x + \frac{1}{sC_x} + sL_x + \frac{1}{sC_D}}$$

$$\frac{v_o}{v_i}(s) = \frac{\frac{sC_x}{sC_D}}{sR_xC_x + 1 + s^2L_xC_x + \frac{sC_x}{sC_D}} = \frac{C_x/C_D}{1+C_x/C_D}\,\frac{1}{1 + \frac{sR_xC_x}{1+C_x/C_D} + s^2\frac{L_xC_x}{1+C_x/C_D}}$$

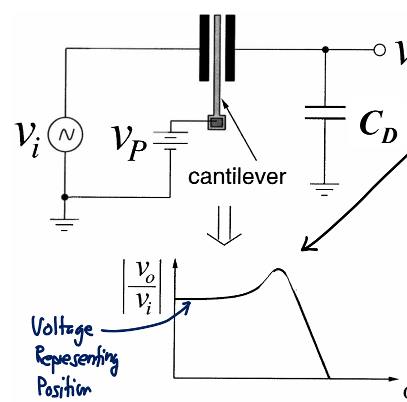
$$= \underbrace{\frac{C_x/C_D}{1+C_x/C_D}}_{\text{Gain Term}}\;\underbrace{\frac{\frac{1+C_x/C_D}{L_xC_x}}{s^2 + s\left(\frac{R_x}{L_x}\right) + \frac{(1+C_x/C_D)}{L_xC_x}}}_{\text{Freq. Dep. Term}}$$

$$\left[\omega_o^2 = \frac{1}{L_xC_x} \rightarrow (\omega_o')^2 = \omega_o^2(1 + C_x/C_D)\right]$$

$$\left[Q' = \frac{\omega_o' L_x}{R_x} \rightarrow \frac{R_x}{L_x} = \frac{\omega_o'}{Q'},\; Q' = Q\sqrt{1 + C_x/C_D}\right]$$ over ↷

Position-to-Voltage Conversion

- To sense position (i.e., displacement), use a capacitive load



$$\frac{v_o}{v_i}(s) = \underbrace{\frac{C_x/C_D}{1+C_x/C_D}}_{\text{DC Gain Term}}\;\underbrace{\frac{(\omega_o')^2}{s^2 + \left(\frac{\omega_o'}{Q'}\right)s + (\omega_o')^2}}_{\text{Low-Pass Biquad}}$$

To maximize gain → 1, need $C_D \ll C_x$. (must minimize C_D)

Note: Can use similar short-cut to the R case.

① Get DC response → C's dominate.

② Then:

$$\frac{v_o}{v_i}(s) = (\text{DC Gain}) \cdot \frac{1}{s} \cdot \mathcal{H}(s, \omega_o', Q') \cdot \omega_o' Q'$$

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Position Sensing Circuits

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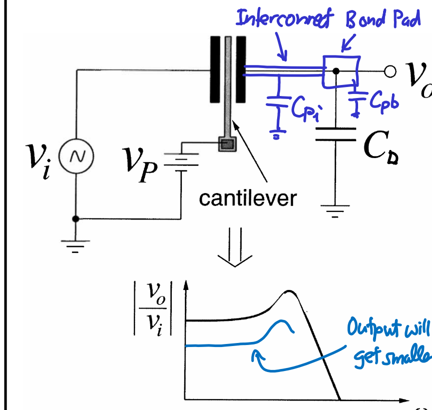
Problems With Pure-C Position Sensing

- To sense position (i.e., displacement), use a capacitive load



$$\frac{v_o}{v_i}(s) = \frac{C_x/C_D}{1+C_x/C_D}\cdot\frac{1}{s}\cdot \Theta(s,\omega_o',Q')\cdot\omega_o'\Theta'$$

Integration yields displacement.

To maximize gain, minimize C_D.

⇒ Problem: parasitic capacitance

$C_D \to C_D + C_{Pi} + C_{pb}$

⇒ DC Gain: $\frac{C_x/(C_D+C_{Pi}+C_{pb})}{1+C_x/(C_D+C_{Pi}+C_{pb})}$

Remedy: Suppress C_p via use of op amps.

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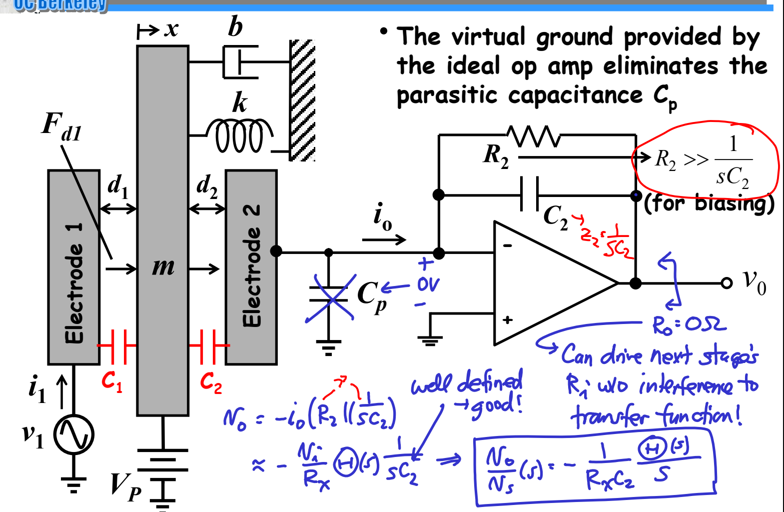
The Op Amp Integrator Advantage

- The virtual ground provided by the ideal op amp eliminates the parasitic capacitance C_p



$v_o = -i_o\left(R_2 \| \frac{1}{sC_2}\right)$ — well defined → good!

$\approx -\frac{v_i}{R_x}\Theta(s)\frac{1}{sC_2}$ ⇒ $\frac{v_o}{v_s}(s) = -\frac{1}{R_xC_2}\frac{\Theta(s)}{s}$