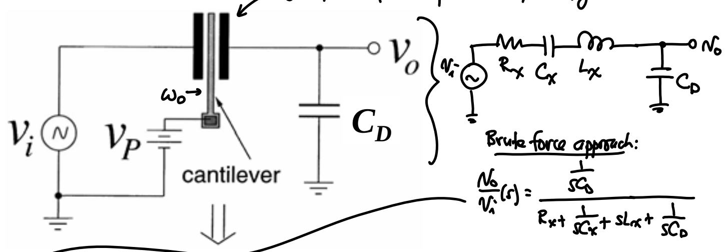
Position-to-Voltage Conversion

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

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



Brute force approach:

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

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

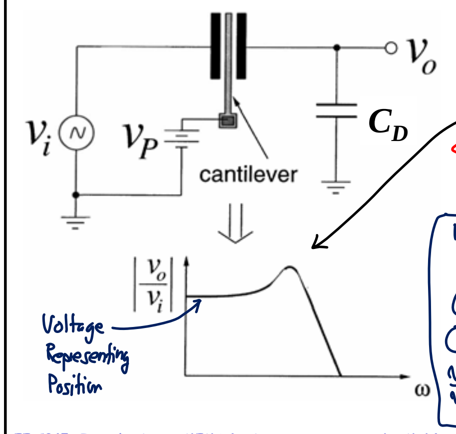
$$= \frac{C_x/C_D}{1+C_x/C_D}\frac{\frac{1+C_x/C_D}{L_xC_x}}{s^2 + s\left(\frac{R_x}{L_x}\right) + \frac{(1+C_x/C_D)}{L_xC_x}}$$

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

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

Position-to-Voltage Conversion

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



$$\frac{v_o}{v_i}(s) = \frac{C_x/C_D}{1+C_x/C_D}\cdot\frac{(\omega_o')^2}{s^2 + \left(\frac{\omega_o'}{Q'}\right)s + (\omega_o')^2}$$

DC Gain Term; 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.

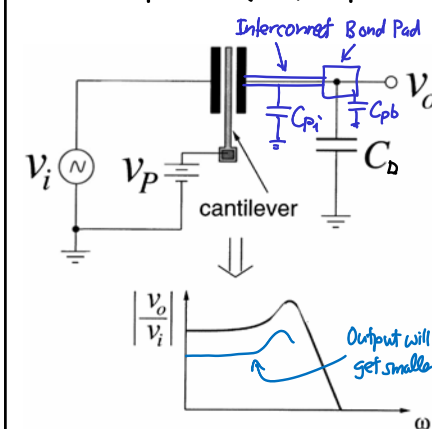
1. Get DC response → C's dominate.
2. Then:

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

Position Sensing Circuits

Problems With Pure-C Position Sensing

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



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

Integration yields displacement.

To maximize gain, minimize C_L.

⇒ Problem: parasitic capacitance

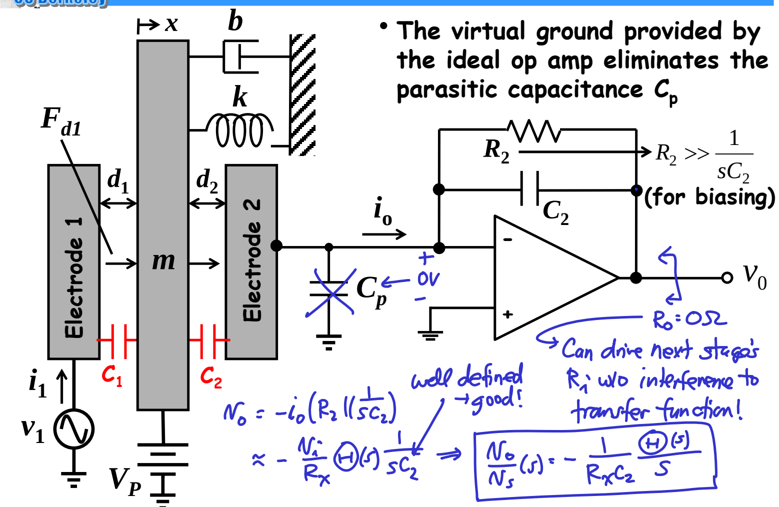
$C_D \rightarrow C_D + C_{Pi} + C_{pb}$

⇒ 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.

The Op Amp Integrator Advantage

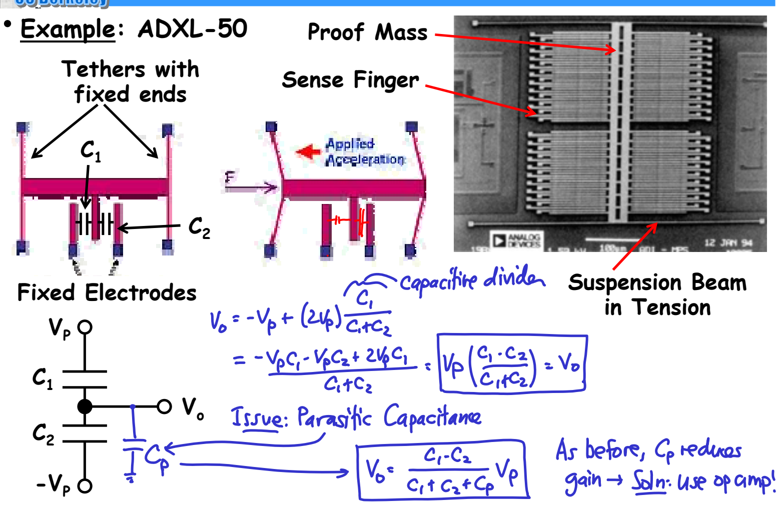
- The virtual ground provided by the ideal op amp eliminates the parasitic capacitance C_p



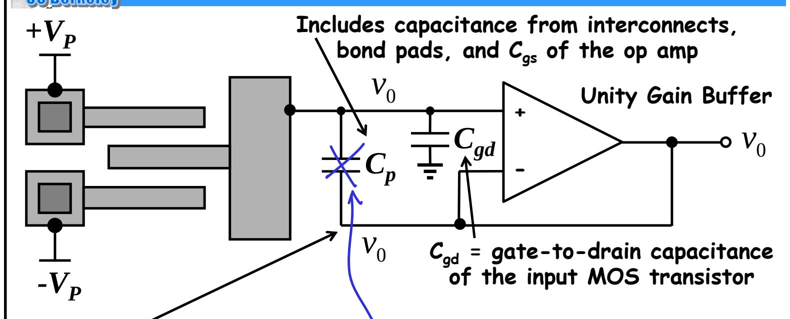
Differential Position Sensing

Differential Position Sensing

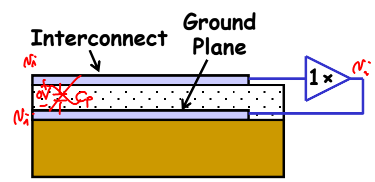
- **Example**: ADXL-50

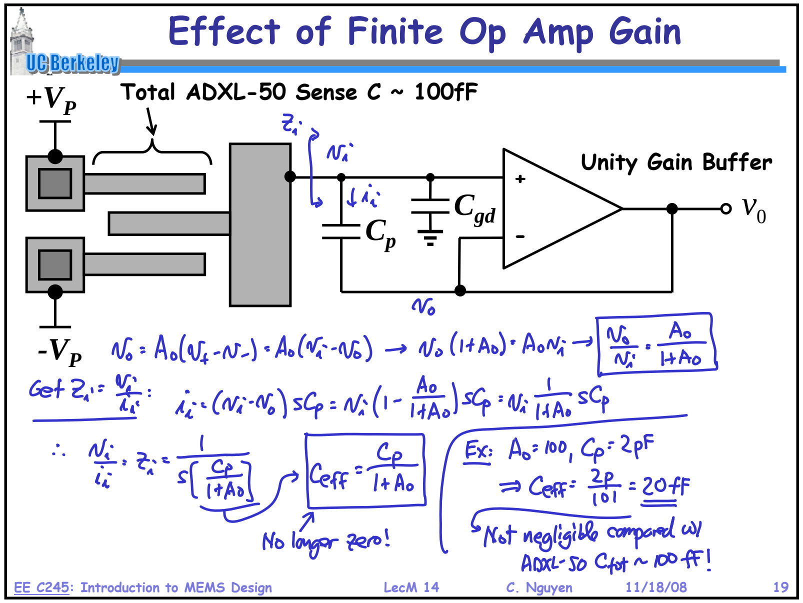


Buffer-Bootstrapped Position Sensing



- Bootstrap the ground lines around the interconnect and bond pads
  - No voltage across C_p
  - It's effectively not there!




Effect of Finite Op Amp Gain
UC Berkeley
+V_P
Total ADXL-50 Sense C ~ 100fF
Unity Gain Buffer
C_p
C_gd
V_0
-V_P
v_o = A_o(v_+ - v_-) = A_o(v_i - v_o) → v_o(1+A_o) = A_o v_i → v_o/v_i = A_o/(1+A_o)
Get Z_i = v_i/i_i : i_i = (v_i - v_o) sC_p = v_i (1 - A_o/(1+A_o)) sC_p = v_i (1/(1+A_o)) sC_p
∴ v_i/i_i = Z_i = 1 / (s[C_p/(1+A_o)])
C_eff = C_p/(1+A_o)
No longer zero!
Ex: A_o = 100, C_p = 2pF
⇒ C_eff = 2p/101 = 20fF
Not negligible compared w/ ADXL-50 C_tot ~ 100fF!
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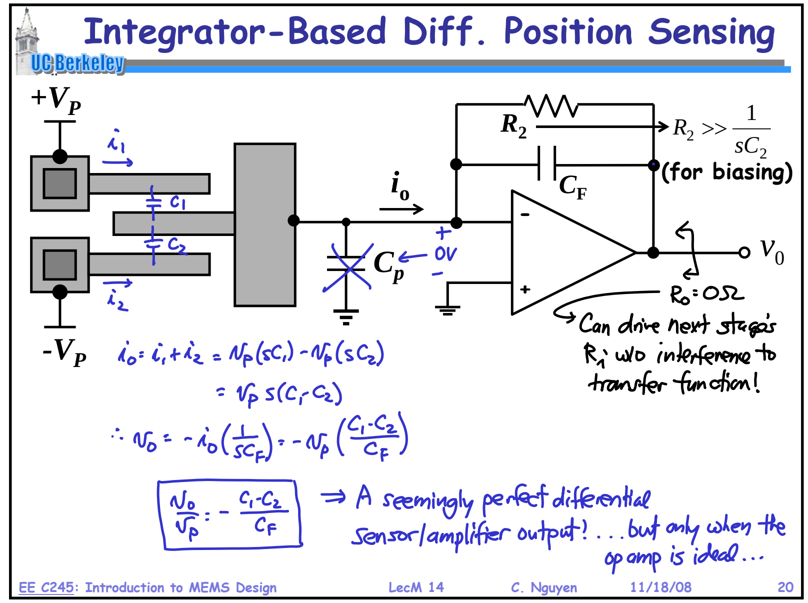
Integrator-Based Diff. Position Sensing
UC Berkeley
+V_P
R_2
R_2 >> 1/(sC_2)
(for biasing)
C_F
i_o
C_1
C_2
C_p
+ 0V -
V_0
R_o = 0Ω
Can drive next stage's R_i w/o interference to transfer function!
-V_P
i_o = i_1 + i_2 = v_P(sC_1) - v_P(sC_2)
= v_P s(C_1 - C_2)
∴ v_o = -i_o(1/(sC_F)) = -v_P((C_1 - C_2)/C_F)
v_o/v_P = -(C_1 - C_2)/C_F
⇒ A seemingly perfect differential sensor/amplifier output! . . . but only when the op amp is ideal . . .
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