**Position-to-Voltage Conversion**

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

\[ V_o = \frac{C_D}{C_D + C_x} V_i \]

**Problems With Pure-C Position Sensing**

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

\[ V_o = \frac{C_D}{C_D + C_x} \frac{V_i}{V_P} \]

**The Op Amp Integrator Advantage**

- The virtual ground provided by the ideal op amp eliminates the parasitic capacitance \( C_p \) allowing \( C_o \) to dominate

\[ V_o = \frac{1}{R_2} \left( -\frac{C_o}{C_p} \right) V_i \]
Differential Position Sensing

Example: ADXL-50

Suspension Beam in Tension

Proof Mass

Sense Finger

Tethers with fixed ends

Fixed Electrodes

$V_p$, $V_o$ $V_P$, $V_P - V_P$

$C_1$, $C_2$, $C_{gd}$

$V_P (C_1 + C_2) = V_o$

$V_P (C_1 + C_2) = V_o$

$V_P (C_1 + C_2) = V_o$

$C_{gd}$ = gate-to-drain capacitance of the input MOS transistor

Includes capacitance from interconnects, bond pads, and $C_{gs}$ of the op amp

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

Total ADXL-50 Sense C ~ 100fF

Unity Gain Buffer

$N_i = n_{i1} \cdot n_{i2} \cdot n_{i3} \cdot (N_i - N_i) + N_i (1 + N_i) \cdot A_{op} \cdot N_i$

$N_{gd} = A_{op} \cdot N_i + N_i (1 + N_i) \cdot A_{op} \cdot N_i$

$C_{eff} = \frac{C_p}{1 + A_{op}}$

$N_{gd} = \frac{N_{gd}}{A_{op} \cdot N_i}$

$C_{eff} = \frac{C_p}{1 + A_{op}}$

No longer core!
Integrator-Based Diff. Position Sensing

\[ i_0, i_1, i_k = \frac{V_P}{sC_0} + \frac{V_P}{sC_2} \]

\[ v_0 = -\frac{V_P}{sC_0} \left( \frac{1}{sC_2} \right) = -\frac{V_P}{sC} \left( \frac{C_1 - C_2}{C_F} \right) \]

\[ \Rightarrow A \text{ seemingly perfect differential sensor/amplifier output!...but only when the op amp is ideal...} \]