Lecture Outline

* Reading: Senturia, Chpt. 14
* Lecture Topics:
  - Detection Circuits
    - Velocity Sensing
    - Position Sensing
Velocity-to-Voltage Conversion

* To convert velocity to a voltage, use a resistive load

Consider the mechanical device by itself first, with output shorted. Then, taking $R_L$ into account.

\[ V_o = \frac{\omega_o Q}{k} \cdot V_i \]

Solve the problem @ resonance first, then multiply by $\Theta(s)$.

\[ \text{If this structure has completely symmetrical J0 port:} \]

\[ V_o = \frac{R_o}{R_{x} + R_{o}} V_i \]

- \( \omega_o \) is @ resonance (to simplify the analysis)
- \[ \frac{V_o}{V_i} = \frac{R_o}{R_x + R_o} @ \text{resonance} \]
- Then, generalize to off resonance:
  \[ \frac{V_o}{V_i} = \frac{R_o}{R_x + R_o} @ (\xi, \Omega), \text{where } \Omega = Q \frac{R_x}{R_{x} + R_o} \]
Velocity-to-Voltage Conversion

- To convert velocity to a voltage, use a resistive load

\[
V_o = \frac{R_o}{R_x + \frac{1}{C_x} + \frac{1}{L_x} + \frac{1}{C_y}}
\]

Brute force approach:

\[
N_o(s) = \frac{sL_x}{sL_x + \frac{1}{C_x} + \frac{1}{L_x} + \frac{1}{C_y}}
\]

Velocity Sensing Circuits
Velocity-to-Voltage Conversion

* To convert velocity to a voltage, use a resistive load.

Problems With Purely Resistive Sensing

Now, we get: (approximately)

$$N_v^0 \sim \frac{R_D}{R_x + R_D} \cdot \left( \frac{\omega_d}{\omega_0} \right)$$

Depend on both $R_x + R_D$.

Impact depends on $\omega_d$ relative to $\omega_0$. 

Includes $C_0$, line $C$, bond pad $C$, and next stage $C$.

Not good

Okay
**Problems With Purely Resistive Sensing**

- In general, the sensor output must be connected to the inputs of further signal conditioning circuits → input $R_i$ of these circuits can load $R_D$

These change w/ hook-up → not good.

- Problem: need a sensing circuit that is immune to parasitics or loading.

- Soln: use op amps.

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**The TransR Amplifier Advantage**

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

- The zero output resistance of the (ideal) op amp can drive virtually anything

$\text{Virtual Ground } \Rightarrow 0$ voltage across $C_p$

$C_p$ effectively isn’t there! $\frac{V_0}{R_o} = \frac{R_2(s)N_4}{N_6}$
Position Sensing Circuits

Position-to-Voltage Conversion

To sense position (i.e., displacement), use a capacitive load.
**Position-to-Voltage Conversion**

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

\[
\frac{V_O}{V_i} = \frac{C_D}{C_D + C_b} \frac{(\omega_d)^2}{(1 + \frac{C_b}{C_D})^2 + (\frac{\omega_d}{\omega_c})^2}
\]

- DC Gain
- Low-Pass Biquad

To maximize gain \( \to 1 \), need \( C_b \to 0 \).


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**Problems With Pure-C Position Sensing**

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

\[
\frac{V_O}{V_i} = \frac{C_D C_b}{1 + C_D C_b} \frac{\frac{1}{\omega_c} + \frac{1}{\omega'_c}}{\left(\frac{s}{\omega_c}\right)^2 + \frac{1}{\omega_c^2}}
\]

Integereation yields displacement.

To maximize gain, minimize \( C_b \).

\[
V = C_b \frac{C_D}{C_b + C_D + C_p}
\]

\[
\text{Output will get smaller!}
\]

**Remedy:** Suppress \( C_b \) 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

![Diagram of differential position sensing](image)

\[ V_0 = -V_p + \left( \frac{1}{C_1 + C_2} \right) C_1 V_P\]

- **Suspension Beam in Tension**
- **Proof Mass**
- **Sense Finger**
- **Fixed Electrodes**
- **Capacitive divider**
- **Parasitic Capacitance**

**Buffer-Bootstrapped Position Sensing**

- **Includes capacitance from interconnects, bond pads, and \( C_{gs} \) of the op amp**
- **Unity Gain Buffer**
- **\( +V_p \)**
- **\(-V_p \)**

\[ V_0 = \frac{C_p}{C_gd + C_p} V_P \]

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

**Includes**

- \( C_{gs} \) of the input MOS transistor
Effect of Finite Op Amp Gain

\[ +V_p \quad \text{Total ADXL-50 Sense } C \sim 100 \text{fF} \]

Unity Gain Buffer

\[ \frac{N_v}{V_0} = A_o (N_{i2} - N_{i1}) + A_o (N_{i2} - N_{i1}) \rightarrow \frac{N_v}{V_0} \left( 1 + A_o \right) = \frac{N_v}{V_0} \left( \frac{A_o}{1 + A_o} \right) \]

Get \( Z_s = \frac{N_v}{Z_s} \) as \( Z_s \left( N_{i2} - N_{i1} \right) = \frac{C_f}{1 + A_o} \)

\[ C_{ef} = \frac{C_f}{1 + A_o} \quad \text{No longer poor!} \]

Ex: \( A_o = 100 \), \( C_f = 2 \text{pF} \)

\[ C_{ef} = \frac{2 \text{pF}}{101} = 20 \text{fF} \]

Not negligibly compared with ADXL-50 \( C_f \sim 100 \text{fF} \)

Integrator-Based Diff. Position Sensing

\[ +V_p \quad \text{for biasing} \]

\[ V_0 \quad \text{Can drive next stage's } R_2 \text{ without interference to transfer function!} \]

\[ \frac{N_o}{V_p} = \frac{-C_1 \cdot C_2}{C_F} \quad \Rightarrow \text{A seemingly perfect differential sensor/amplifier output!...but only when the op amp is ideal...} \]