Lecture 24: Sensing Circuits I

- **Announcements:**
- Module 14 on Sensing Circuits online
- Module 15 on Gyros, Noise, & MDS online
- HW#6 online and due Thursday, April 27
- Responded to emails on Slide Set#1
- Project Slide Set #2 due Friday, April 21
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- Reading: Senturia, Chpt. 14
- Lecture Topics:
  - Detection Circuits
    - Velocity Sensing
    - Position Sensing
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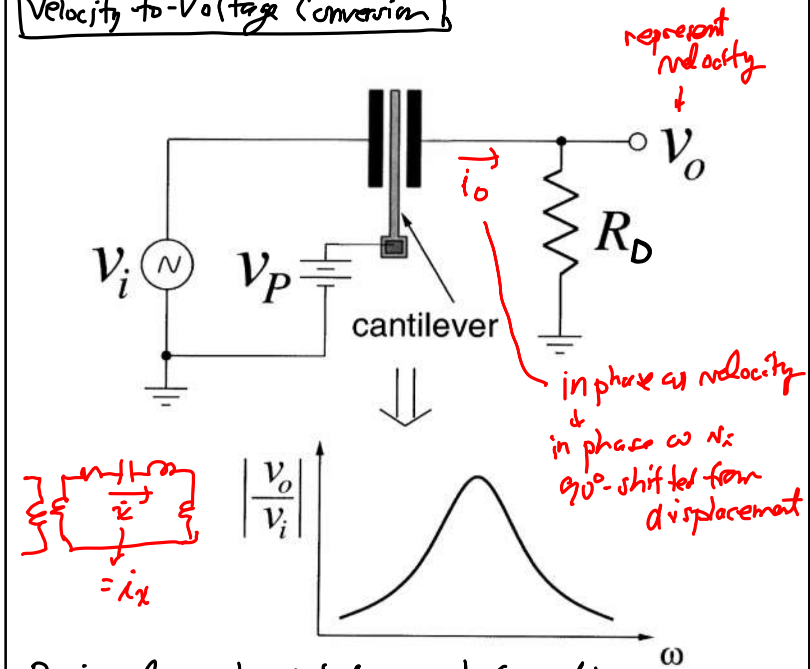
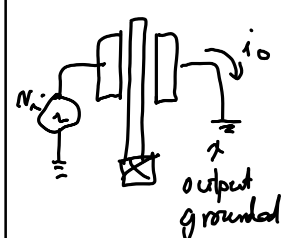
- **Last Time:**
- Went through Module 15 parts that introduce gyroscopes

over

Velocity-to-Voltage Conversion



Review Case when Output goes to Ground



$$\frac{\dot{x}}{F_{d1}}(s) = \frac{\omega_o Q}{k} \Theta(s), \quad \Theta(s) = \frac{s(\omega_o/Q)}{s^2 + s(\omega_o/Q) + \omega_o^2}$$

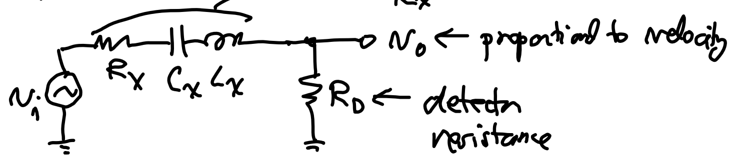
$[F_{d1} = \eta_{e1} v_i]$

$$\frac{\dot{x}}{v_i}(s) = \eta_{e1} \frac{\omega_o Q}{k} \Theta(s)$$

$$[i_o = \eta_{e2} \dot{x}] \Rightarrow \frac{i_o}{v_i}(s) = \eta_{e1}\eta_{e2} \frac{\omega_o Q}{k} \Theta(s) = \frac{\eta_{e1}\eta_{e2} Q}{m\omega_o} \Theta(s)$$

$\frac{1}{R_{x12}}$

Now, include R_D: $Q = \frac{\omega_o L_x}{R_x}$



$$\frac{v_o}{v_i}(s) = \frac{R_D}{R_x + \frac{1}{sC_x} + sL_x + R_D} = \cdots \text{math} \cdots$$

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

$$\left[Q = \frac{\omega_o L_x}{R_x} \rightarrow Q' = \frac{\omega_o L_x}{R_x+R_D} \rightarrow \frac{R_x+R_D}{L_x} = \frac{\omega_o}{Q'} \right]$$

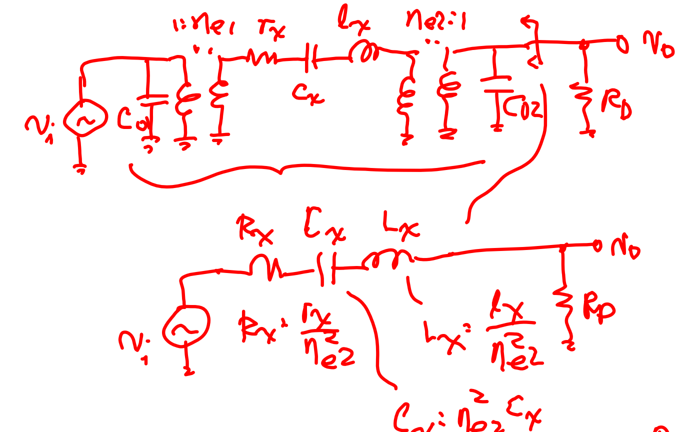
$$\frac{v_o}{v_i}(s) = \frac{R_D}{R_x+R_D} \frac{s(\omega_o/Q')}{s^2 + s(\omega_o/Q') + \omega_o^2}$$

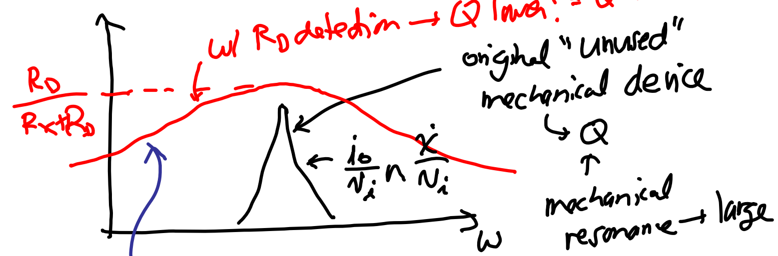
$$\boxed{\frac{v_o}{v_i}(s) = \frac{R_D}{R_x+R_D} \cdot H(s, Q') \qquad Q' = Q\underbrace{\left(\frac{R_x}{R_x+R_D}\right)}_{<1 \;\therefore\; Q' < Q}}$$

Transfer Fcn for Resistive Detection of Velocity

Bad!

Transformer-Based Ckt:

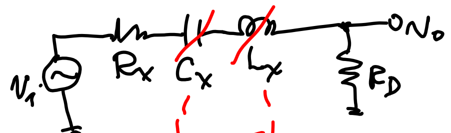




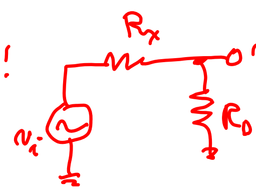
$\left|\frac{v_o}{v_i}(s)\right| \rightarrow Q'$ ~ lower than Q

$$= Q\underbrace{\left(\frac{R_x}{R_x+R_D}\right)}_{<1}$$ Big Problem!

Analysis @ Resonance:



$\frac{1}{sC_x} = sL_x$ ← cancel!

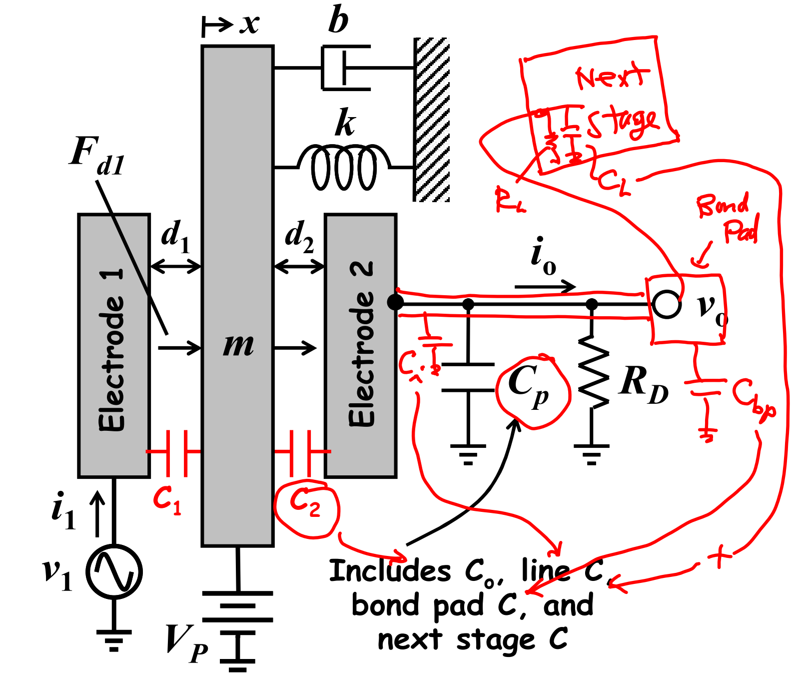


$v_o = \frac{R_D}{R_x+R_D} v_i$ ← @ resonance

convert to general freqs: $\times H(s,Q')$

$$\frac{v_o}{v_i}(s) = \frac{R_D}{R_x+R_D} H(s,Q'), \text{ where } Q' = Q\left(\frac{R_x}{R_x+R_D}\right)$$

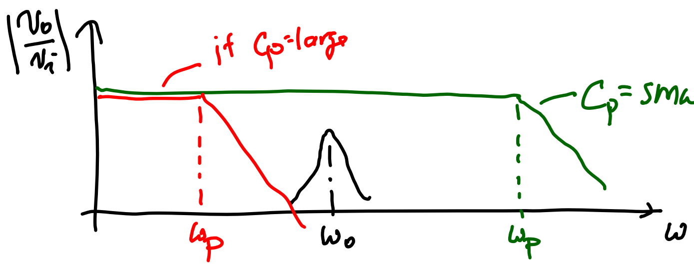
The Problem is actually bigger:



Now, we get:

$$\frac{v_o}{v_i}(s) \sim \frac{R_D\|R_L}{R_x+R_D\|R_L} \cdot \frac{1}{1+\frac{s}{\omega_p}} \cdot H(s,\omega_o',Q')$$

$$\omega_p = \frac{1}{(R_x\|R_D\|R_L)C_p}$$



Problems w/ Purely Resistive Detection

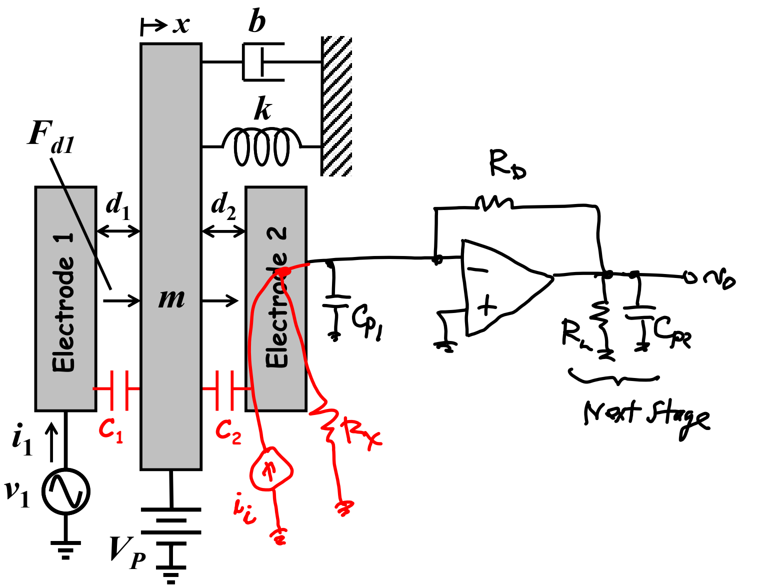
① Need large R_D for large gain ... but ...

② $R_D \uparrow \rightarrow Q' \downarrow$

③ $R_D \uparrow \longrightarrow \frac{1}{R_D C_p} \downarrow \rightarrow$ get undesirable LPF cut-off

④ Load $R_L \rightarrow$ affects gain!

Solution: Use an Op Amp

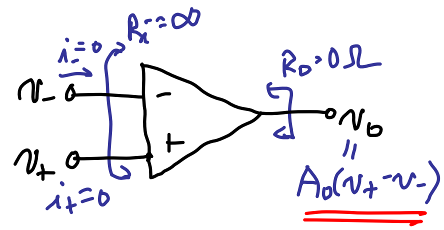


Ideal Op Amp Laws:

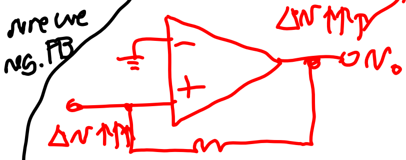
① $R_i = \infty$

② $R_o = 0$

③ Gain $= A_o = \infty$

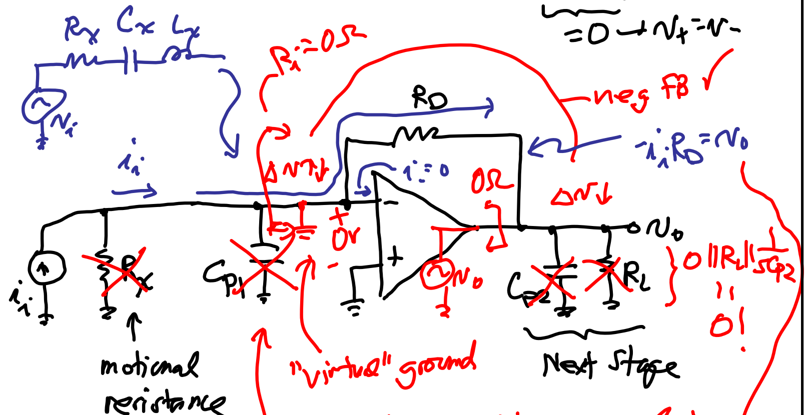


Make sure we have neg. FB



Blows Up!
w/ positive FB!
(Don't like this!)

$v_o = A_o(v_+ - v_-) \longrightarrow$ finite $= \infty \underbrace{(v_+ - v_-)}_{= 0 \,\rightarrow\, v_+ = v_-}$



No voltage variation across C_p!
$\therefore$ C_p gone!

$$\boxed{\frac{v_o}{i_i} = -R_D \text{ @ resonance}}$$

$$\boxed{\frac{v_o}{v_i}(s) = -\frac{R_D}{R_x} H(s)}$$

no Q degradation!
since $R_i = 0\,\Omega$ for the total FB ckt!