Lecture 23: Gyroscopes & Sensing Circuits I

- Announcements:
- Project Slide Set #2 due Friday, April 19
- HW#6 due Tuesday, 4/23, at 9 a.m.
- Module 14 on Sensing Circuits online
- Module 15 on Gyros, Noise, & MDS online (actually with last lecture)
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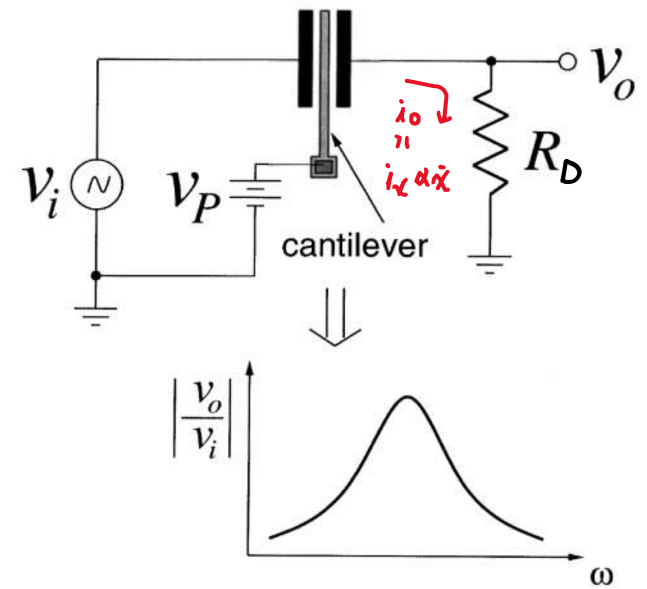
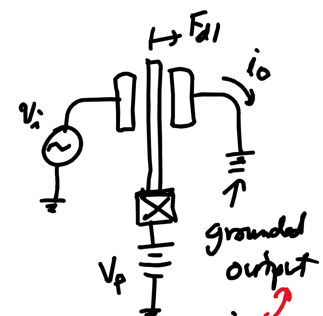
- Reading: Senturia, Chpt. 14, Chpt. 16, Chpt. 21
- Lecture Topics:
  - Gyroscopes
- Reading: Senturia, Chpt. 14
- Lecture Topics:
  - Detection Circuits
    - —Velocity Sensing
    - —Position Sensing
- -----------------------------------
- Last Time:
- Started gyroscopes by going through slides 1-6 in Module 15
- Now, continue with this …

Velocity-to-Voltage Conversion





$$\frac{\dot{x}}{F_{d1}}(s) = \frac{\omega_o Q}{k} H(s)$$

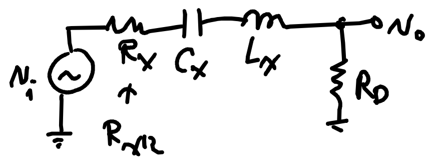
$$\left[F_{d1} = \eta_{e1} v_i\right]$$

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

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

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

Now, include R_D: (detection resistor)



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

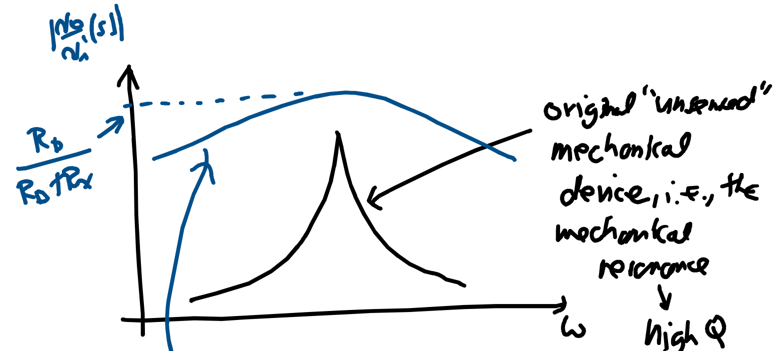
$$= \underbrace{\frac{R_D}{R_x+R_D}}_{\text{Gain Term}} \; \frac{s\left(\frac{R_x+R_D}{L_x}\right)}{\underbrace{s^2 + s\left(\frac{R_x+R_D}{L_x}\right) + \frac{1}{L_x C_x}}_{\text{Freq. Shaping Term}}}$$

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

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

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

$$\hookrightarrow Q' = Q\left(\frac{R_x}{R_x+R_D}\right)$$

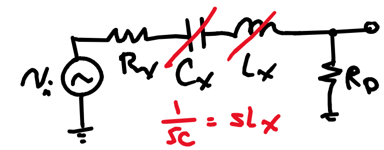


Q' lower than original Q

$\hookrightarrow Q' = \left(\frac{R_x}{R_x+R_D}\right)$ } Big Problem!

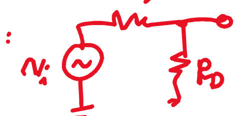
$\frac{R_x}{R_x+R_D} < 1$

Analysis @ Resonance:



$\frac{1}{sC} = sL_x$

↳ cancel:



$v_o = \frac{R_D}{R_x+R_D} v_i$

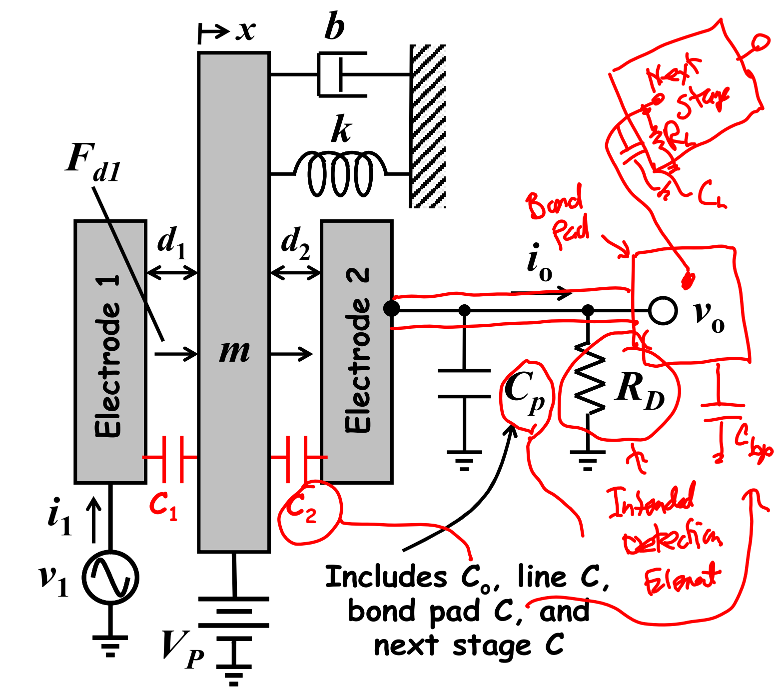
↑ @ resonance

Convert to general freqs. by $\times H(s, Q')$

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

(a fast way to solve R_D-loaded LCR problems)

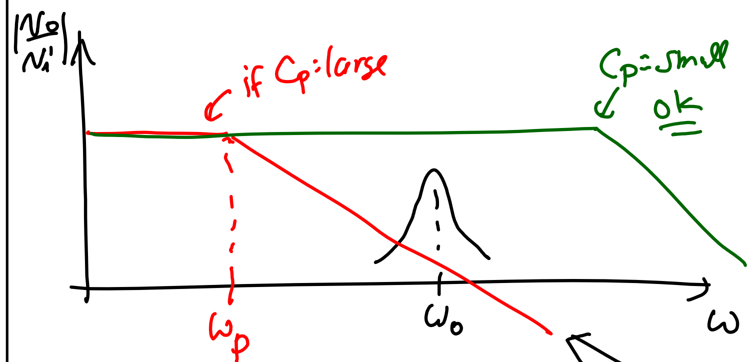
The Problem is Actually Bigger!



Now, we got:

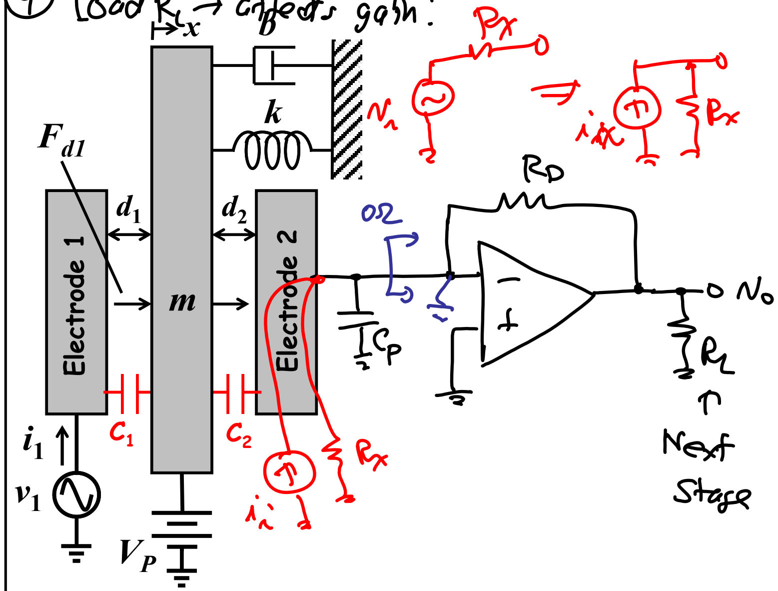
$$\frac{v_o}{v_1}(s) \sim \frac{R_D}{R_x+R_D}\cdot\frac{1}{1+\frac{s}{\omega_p}}\cdot H(s,\omega_o',Q')$$

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



Problems w/ Purely Resistive Detection

1. Need large R_D for large gain ... but..
2. $R_D\uparrow \rightarrow Q\downarrow$ ✗
3. $R_D\uparrow \rightarrow \omega_p \sim \frac{1}{R_D C_p}\downarrow \rightarrow$ get undesirable LPF cut-off ✗
4. Load $R_L \rightarrow$ affects gain!

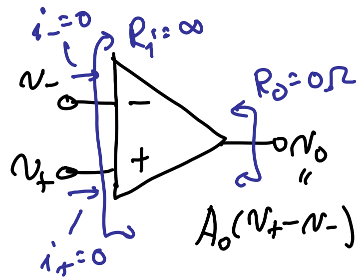


Ideal Op Amp Laws:

① $R_i = \infty \rightarrow i_- = 0,\ i_+ = 0$

② $R_o = 0$

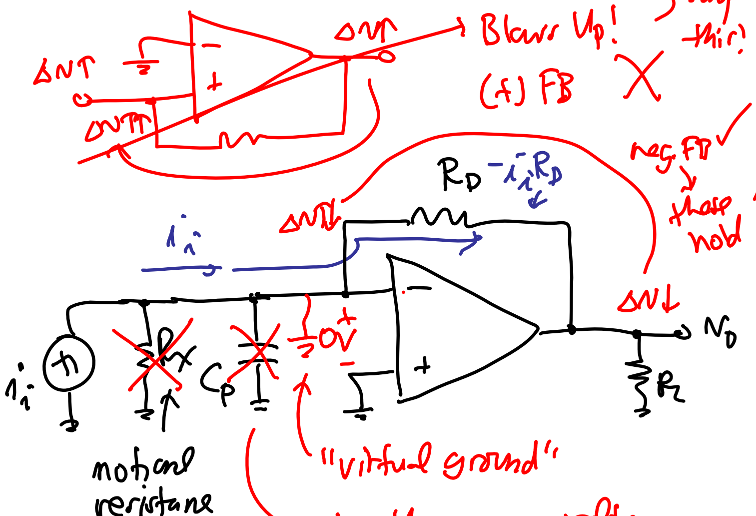
③ Gain $= A_o = \infty$



neg. FB

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

can't say this!



"virtual ground"

since there are no voltage variations across C_p!

$v_o = -i_i R_D$

$\Downarrow$

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

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

no Q degradation