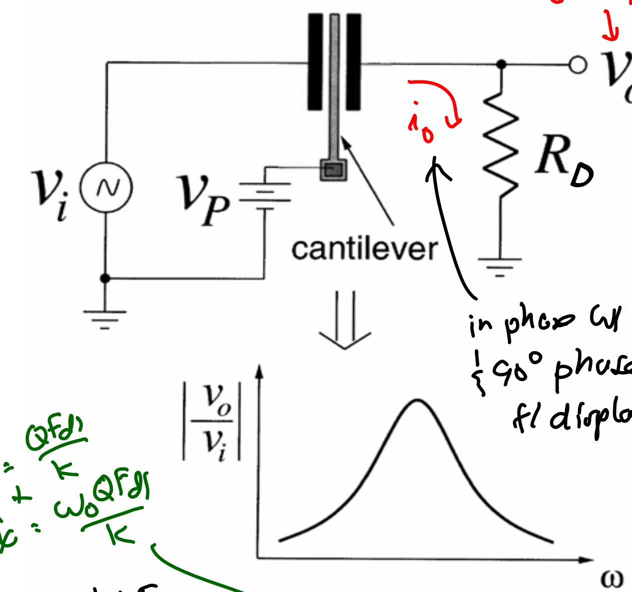
## Lecture 26: Sensing Circuits I

- Announcements:
- Module 14 & 15 online
- HW#7 online since Friday last week
  - Due Friday, May 9
- Project Slide 3 due this Friday
- Project Outbrief Signups:
  - Now up on my door; sign up!
- ------------------------------------
- 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:
- Going through Module 15 on Gyros
- Continue with this … go through slides 11-16

over

## Velocity-to-Voltage Conversion

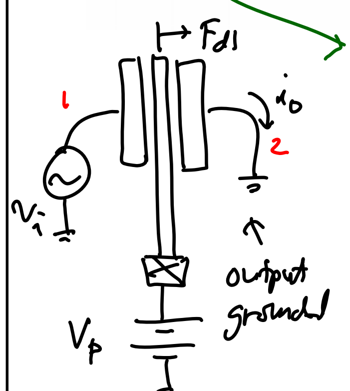
represent velocity




in phase w/ velocity
{ 90° phase shift f/ displacement

$x = \frac{QF_{d1}}{k}$

$\dot{x} = \frac{\omega_0 Q F_{d1}}{k}$



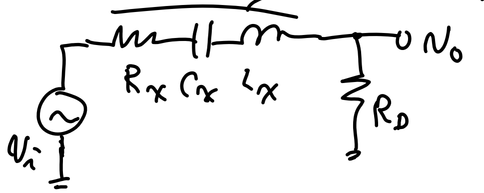

$$\frac{\dot{x}}{F_{d1}}(s) = \frac{\omega_0 Q}{k} H(s)$$

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

$$\frac{\dot{x}}{v_i}(s) = \eta_{e1}\frac{\omega_0 Q}{k} H(s)$$

$$[i_o = \eta_{e2}\dot{x}] \Rightarrow \frac{i_o}{v_i}(s) = \eta_{e1}\eta_{e2}\frac{\omega_0 Q}{k} H(s) = \underbrace{\frac{\eta_{e1}\eta_{e2} Q}{m\omega_0}}_{\frac{1}{R_{x12}}} H(s)$$

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




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

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

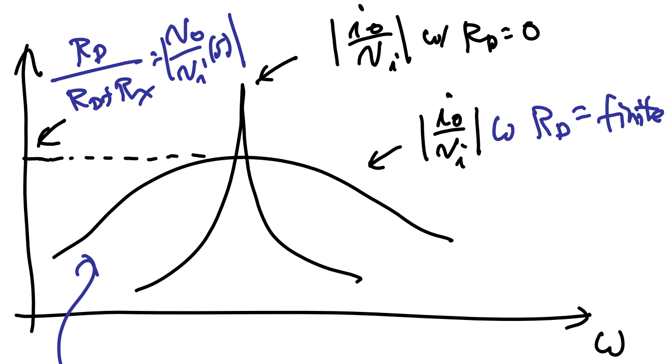
$$\left[Q = \frac{\omega_o L_x}{R_x} \rightarrow Q' = \frac{\omega_o L_x}{R_x+R_D} \rightarrow \frac{R_x+R_D}{L_x} = \frac{\omega_o}{Q'}\right]$$

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

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

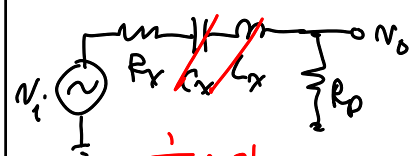
$$Q' = Q\left(\frac{R_x}{R_x+R_D}\right)$$

proportional to velocity

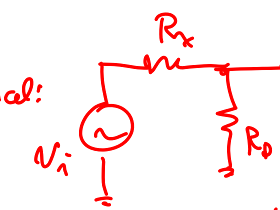



$\left|\frac{v_o}{v_i}(s)\right| \Rightarrow Q'$ ~ lower than $Q$ $= Q\underbrace{\left(\frac{R_x}{R_x+R_D}\right)}_{<1}$ } Big Problem!

Analysis @ Resonance:




$\frac{1}{sC_x} = sL_x$ → cancel!

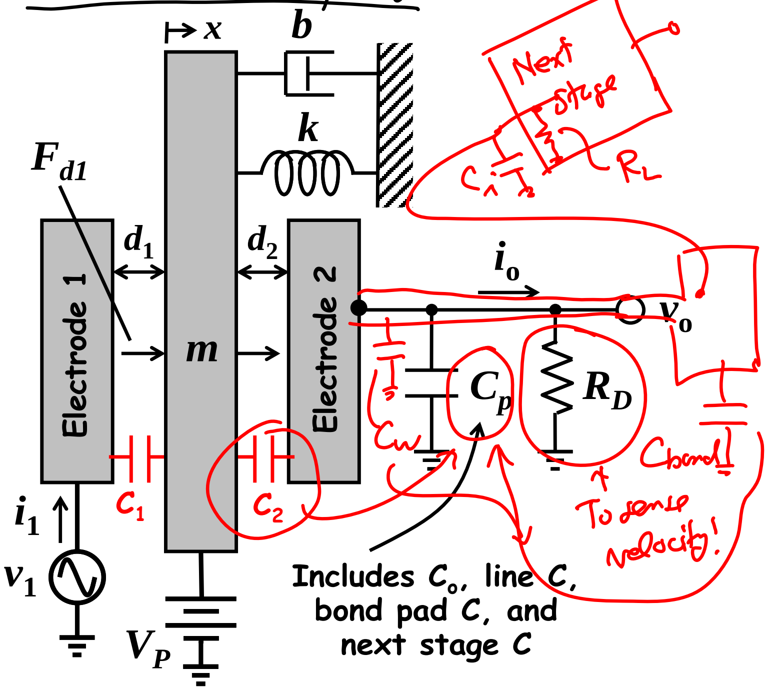



$v_o = \left(\frac{R_D}{R_D+R_x}\right)v_i$ ← @ resonance

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

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

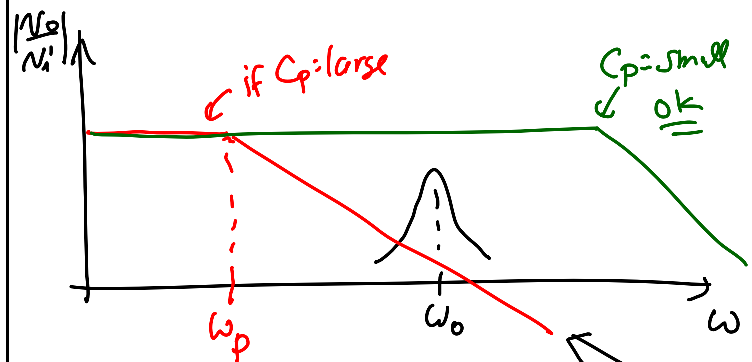
The Problem is actually bigger:




Now, we get:

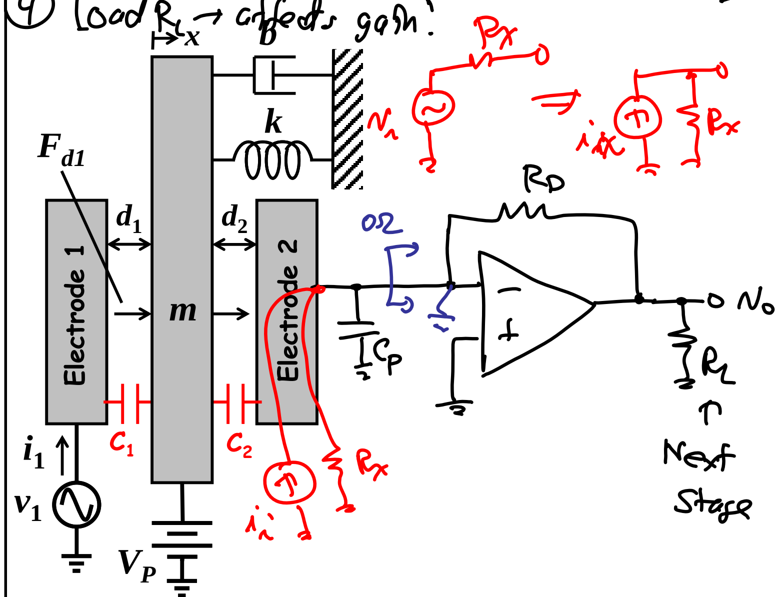
$$\frac{v_o}{v_1}(s) \sim \frac{R_D}{R_D + R_x} \cdot \frac{1}{1+\frac{s}{\omega_p}} \cdot H(s, \omega_o', Q')$$

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




Problems w/ Purely Resistive Detection

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

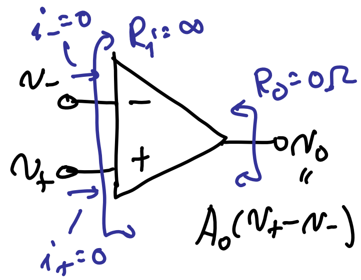


## Ideal Op Amp Laws:

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

② $R_o = 0$

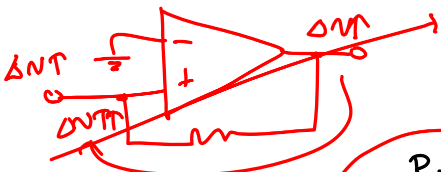
③ Gain $= A_o = \infty$



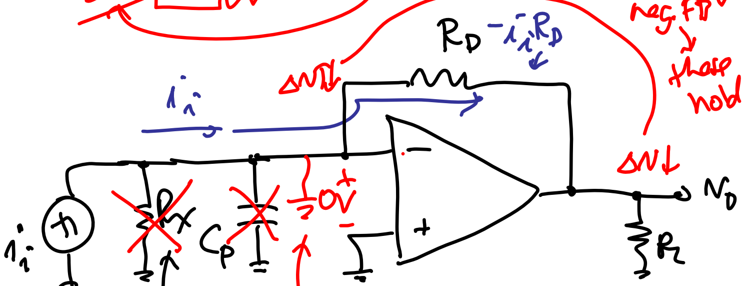

neg. FB

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

can't say this!




neg FB ✓ → these hold




notional resistance

"virtual ground"

since there are no voltage variations across $C_p$!

$v_o = -i_i R_D$

$\Downarrow$

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

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

$(v_i = i_i R_x)$

no Q degradation