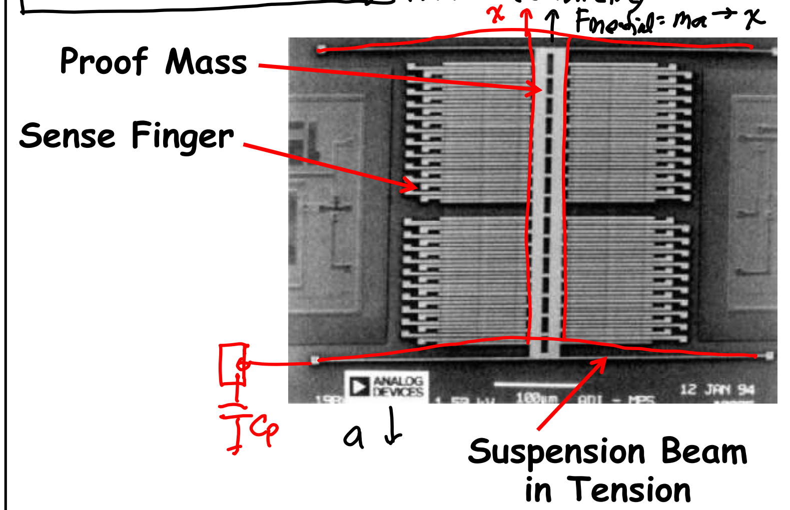
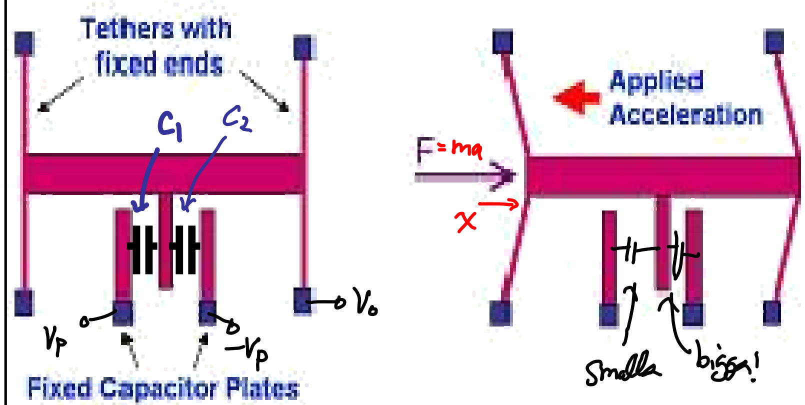
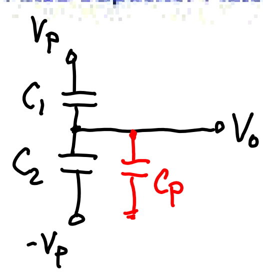
Lecture 25: Sensing Circuits II and Noise

- Announcements:
- HW#6 online and due Thursday, April 27
- Project Slide Set #2 due Friday, April 21
- Module 17 on Noise & MDS online
- --
- Reading: Senturia, Chpt. 14
- Lecture Topics:
  - Detection Circuits
    - Velocity Sensing
    - Position Sensing
- --
- Reading: Senturia Chpt. 16
- Lecture Topics:
  - Minimum Detectable Signal
  - Noise
    - Circuit Noise Calculations
    - Noise Sources
    - Equivalent Input-Referred Noise
  - Gyro MDS
    - Equivalent Noise Circuit
    - Example ARW Determination
- --
- Last Time:
- Single-ended position detection using Module 14
- Now, move to differential sensing …

Differential Position Sensing (of an accelerometer)







$$V_o = -V_p + (2V_p)\frac{C_1}{C_1+C_2} = \frac{-V_pC_1 - V_pC_2 + 2V_pC_1}{C_1+C_2}$$

$$\Rightarrow \boxed{V_o = V_p\left(\frac{C_1-C_2}{C_1+C_2}\right)} \quad \text{(ideal)}$$

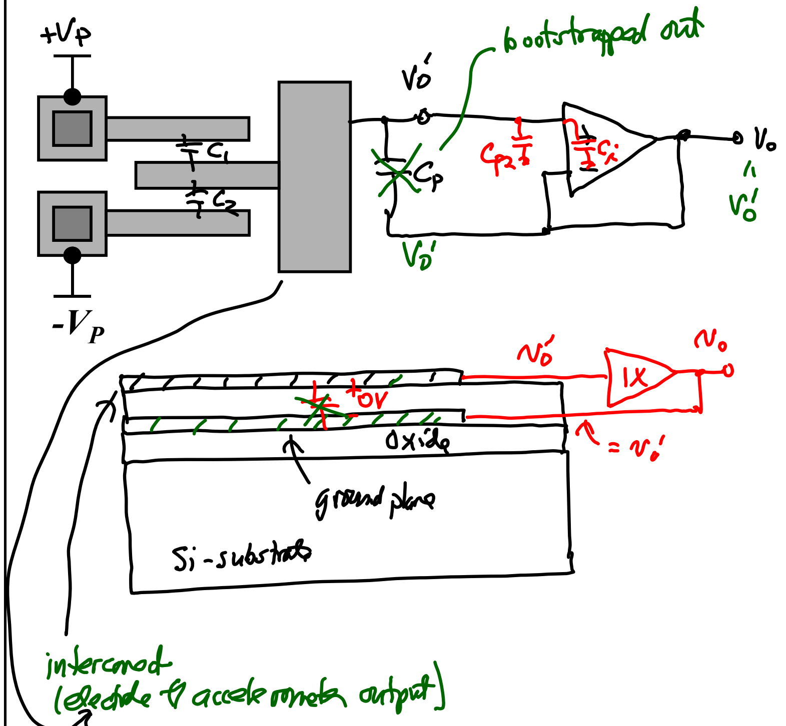
Issue: parasitic C_p!

$$V_o = \left(\frac{C_1 - C_2}{C_1 + C_2 + C_p}\right) V_P$$

↳ if $C_p >> C_1$ or C_2 → degrade sensitivity!

Problem!

Solution: use an op amp!

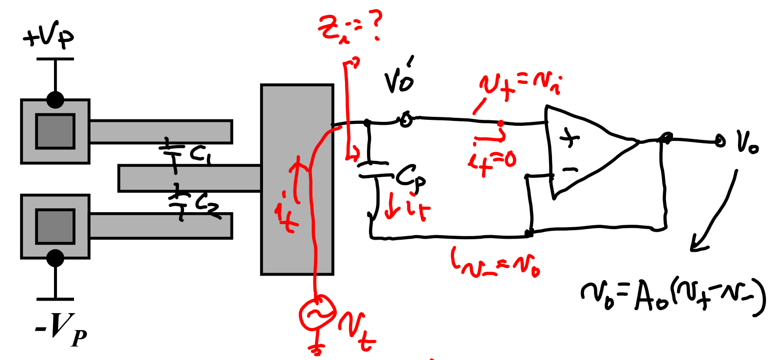


Remarks. ① Works best if op amp is ideal and we access to all C terminals.

② Any shunt C to ground avoids cancellation

③ Finite op amp gain reduces the C_p cancellation.

Case: Finite Op Amp Gain (an op amp non-ideality)



$$v_o = A_o(v_+ - v_-) = A_o(v_i - v_o)$$

$$v_o(1 + A_o) = A_o v_i \rightarrow \boxed{\frac{v_o}{v_i} = \frac{A_o}{1 + A_o}} \rightarrow A_o = \text{large} \rightarrow \text{unity gain buffer!}$$

Get $Z_i = \frac{v_t}{i_t}$:

$$i_t = (v_i - v_o)sC_p = v_i\left(1 - \frac{A_o}{1 + A_o}\right)sC_p$$

$$= v_i \frac{1}{1 + A_o} sC_p$$

$$\therefore Z_i = \frac{v_t}{i_t} = \frac{v_i}{i_t} = \frac{1}{s\left[\frac{C_p}{1 + A_o}\right]} \rightarrow \boxed{C_{eff} = \frac{C_p}{1 + A_o}}$$

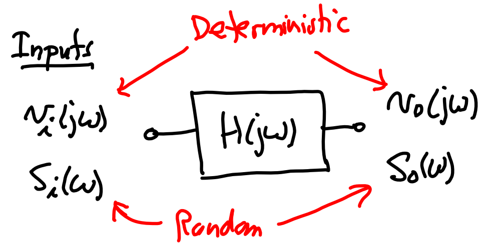
Ex. $A_o = 100$, $C_p = 2pF$

$$\Rightarrow C_{eff} = \frac{2p}{101} = 20fF$$ ← not negligible!

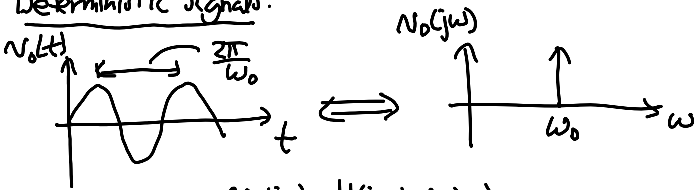
↳ would like high A_o!

ADXL-50 $C_i \approx 100fF$

Circuit Noise Calculations

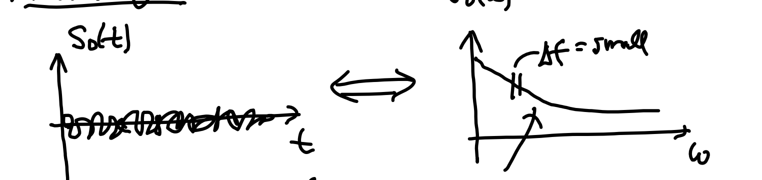


Deterministic Signals:



$$v_o(j\omega) = H(j\omega) v_i(j\omega)$$

Random Signal:



Mean-Square Spectral Density

mean-square value

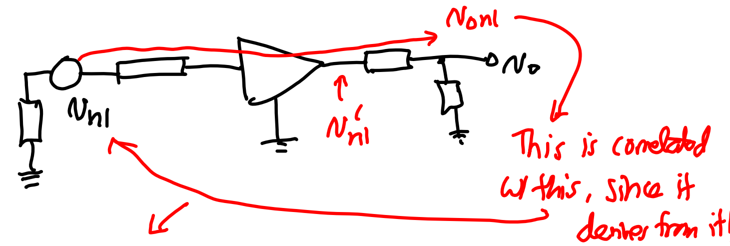
$$S_o(\omega) = [H(j\omega) H^*(j\omega)] S_i(\omega) = |H(j\omega)|^2 S_i(\omega)$$

$$\sqrt{S_o(\omega)} = |H(j\omega)| \sqrt{S_i(\omega)}$$

root mean-square amplitude

Noise Source Correlation

Case ①: Single Noise Source

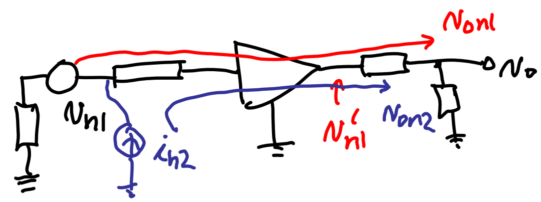


Thus, can write:

$v_{on1} = H_1(j\omega) v_{n1}$ (can work w/ the actual signal as usual)

Case ②: Multiple Noise Sources

⇒ in general, the noise sources are not correlated



Can write: $v_{on1} = H_1(j\omega) v_{n1}$
$v_{on2} = H_2(j\omega) i_{n2}$

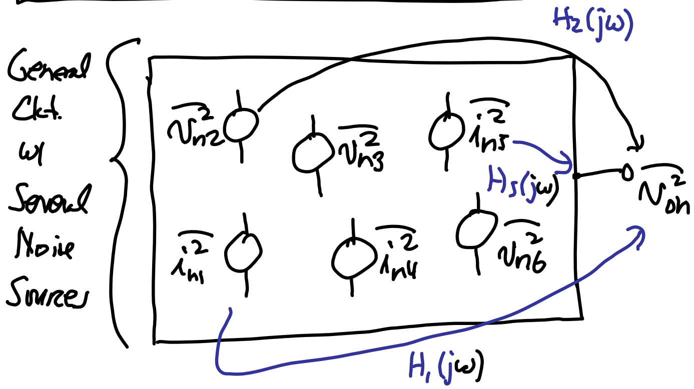
these are not correlated ∴ cannot write

$v_{oT} \neq v_{on1} + v_{on2}$

Rather: $\overline{v_{oT}^2} = \overline{v_{on1}^2} + \overline{v_{on2}^2}$

(must add powers!)

Systematic Noise Calculation Procedure



Assume noise sources are correlated.

① For $\overline{i_{n1}^2}$, replace w/ a source i_{n1}.

② Calculate $v_{on1}(\omega) = i_{n1}(\omega) H_1(j\omega)$
(treating it like a deterministic signal)

③ Determine $\overline{v_{on1}^2} = \overline{i_{n1}^2} \cdot |H_1(j\omega)|^2$

④ Repeat for each noise source:
$\overline{v_{on2}^2} = f(\overline{v_{n2}^2})$, $\overline{v_{o3}^2} = f(\overline{v_{n3}^2})$, ...

⑤ Add noise <u>power</u> (mean-square values)

$$\overline{v_{onTOT}^2} = \overline{v_{on1}^2} + \overline{v_{on2}^2} + \overline{v_{on3}^2} + \overline{v_{on4}^2} + \cdots$$

$$v_{onTOT} = \sqrt{\overline{v_{on1}^2} + \overline{v_{on2}^2} + \overline{v_{on3}^2} + \overline{v_{on4}^2} + \cdots}$$

↑ total rms value