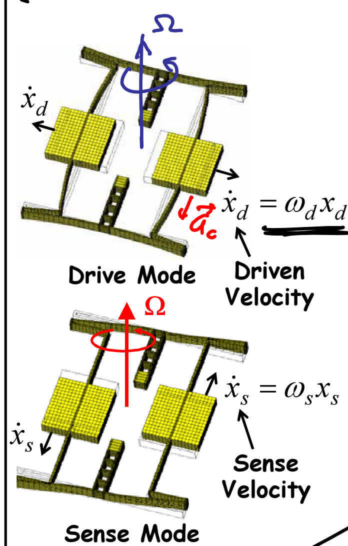
Lecture 25: Equivalent Input-Referred Noise

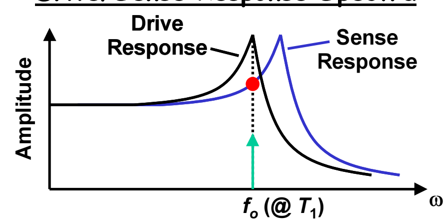
- Announcements:
- HW#7 online next week and due Friday morning, May 8
- Project slide #3 due Friday, May 1
- You should be sending me these slides to get feedback
- Project Outbrief Sign-up: → Tu, W
- This is our last lecture
- ------------------------------------
- Reading: Senturia Chpt. 16
- Lecture Topics:
  - Minimum Detectable Signal
  - Noise
    - Circuit Noise Calculations
    - Noise Sources
    - Equivalent Input-Referred Noise
  - Gyro MDS
    - Equivalent Noise Circuit
    - Example ARW Determination
- Course Wrap Up
- Final Exam Info
- Course evaluations
- ------------------------------------
- Last Time:
- Input referred noise

over

Gyroscope Drive-to-Sense Xfer Fcn

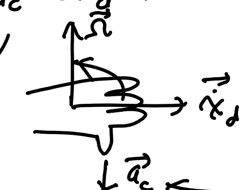


Drive/Sense Response Spectra:



Rotation-Induced Coriolis Force:

$\vec{a}_c = 2\dot{\vec{x}}_d \times \vec{\Omega}$



$= 2\omega_d \vec{x}_d \times \vec{\Omega}$ → acts in the sense mode direction

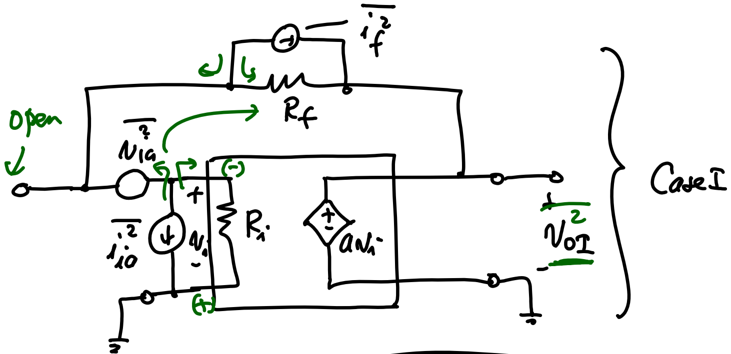
$a_s = a_c = 2\omega_d x_d \Omega \sin 90°$

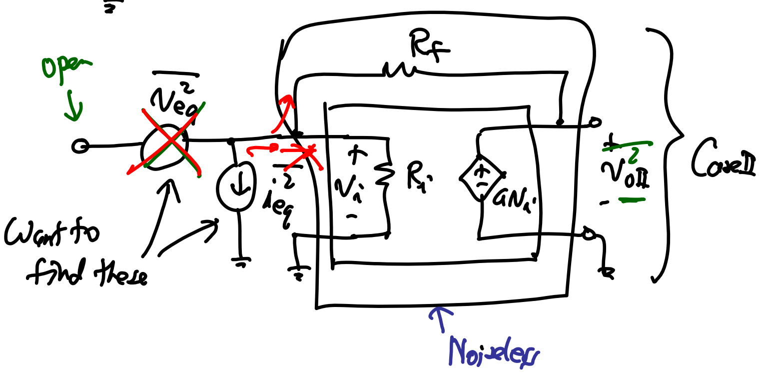
$$\boxed{a_s = 2\omega_d x_d \Omega}$$

rotation rate (Ω); drive radian frequency (ω_d); drive displacement amplitude (x_d)

$F_c = m a_s = m a_c$

Example: TransR Amplifier Input-Referred Noise





Input-referred Current Noise:

Open inputs; equate output voltage noise for Case I & II:

Case I:

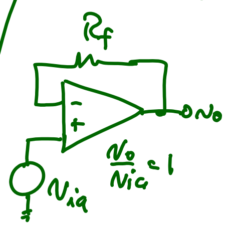
$\overline{i_{ia}^2}$: $v_{oI1} = i_{ia} R_f \rightarrow \overline{v_{oI1}^2} = \overline{i_{io}^2} R_f^2$

$\overline{i_f^2}$: $v_{oI2} = i_f R_f \rightarrow \overline{v_{oI2}^2} = \overline{i_f^2} R_f^2$

$\overline{v_{ia}^2}$: $v_{oI3} = v_{ia} \rightarrow \overline{v_{oI3}^2} = \overline{v_{ia}^2}$

→ power @ output generated by noise sources

$\therefore \overline{v_{oI}^2} = \overline{i_{ia}^2} R_f^2 + \overline{i_f^2} R_f^2 + \overline{v_{ia}^2}$

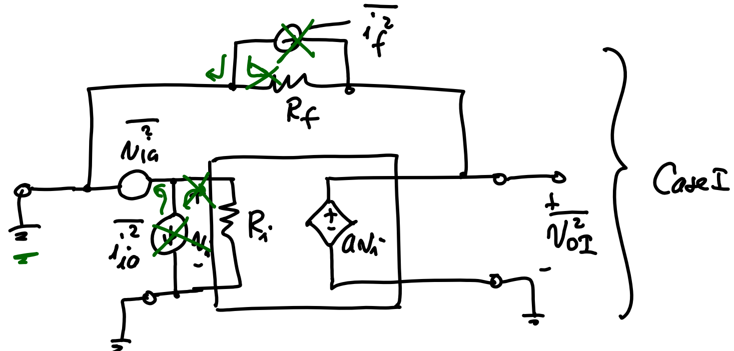


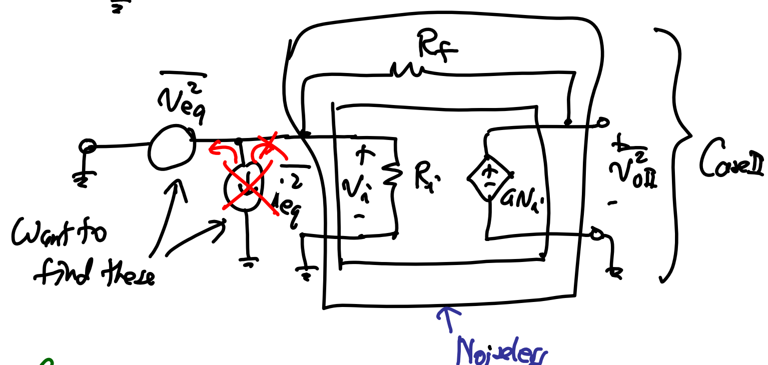
Case II: $\overline{v_{oII}^2} = \overline{i_{eq}^2} R_f^2$

Now, set $\overline{v_{oI}^2} = \overline{v_{oII}^2}$: $\boxed{\overline{i_{eq}^2} = \overline{i_{ia}^2} + \overline{i_f^2} + \frac{\overline{v_{ia}^2}}{R_f^2}}$

Now, get the input-referred voltage-noise:

Short inputs; equate output voltage noise.



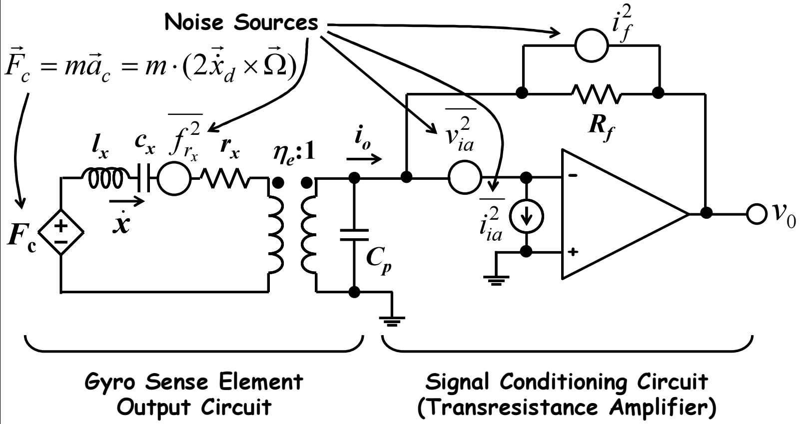


Case I: $v_{oI} = a v_{ia} \rightarrow \overline{v_{oI}^2} = a^2 \overline{v_{ia}^2}$

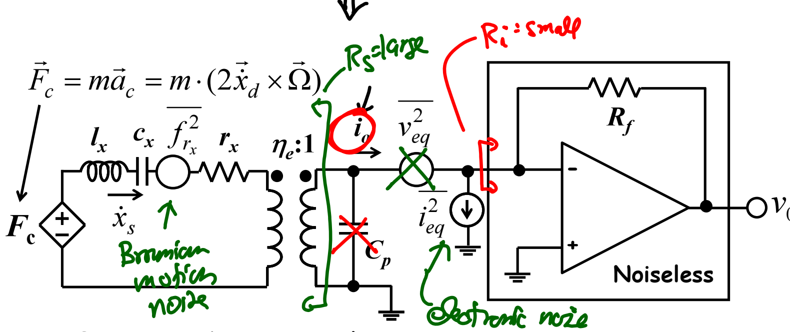
Case II: $v_{oII} = a v_{eq} \rightarrow \overline{v_{oII}^2} = a^2 \overline{v_{eq}^2}$

$\overline{v_{oI}^2} = \overline{v_{oII}^2}$: $\boxed{\overline{v_{eq}^2} = \overline{v_{ia}^2}}$

Gyro Sensing Ckt → Want MDS



⇓



⇒ Find the rotation-to-i_o transfer function:

$$\dot{x}_s = F_c\left(\frac{\omega_s Q_s}{k_s}\,Ⓗ_s(j\omega_d)\right) = \frac{\omega_s Q_s}{k_s}\cdot 2\omega_d x_d \Omega m \cdot Ⓗ_s(j\omega_d)$$

$[F_c = ma_c = 2\omega_d x_d \Omega m]$

$\frac{m}{k_s} = \frac{1}{\omega_s^2}$

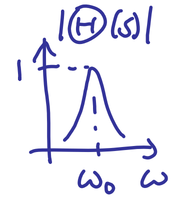
$$\dot{x}_s = 2\frac{\omega_d}{\omega_s} Q_s x_d\, Ⓗ_s(j\omega_d)\cdot\Omega$$

$$Ⓗ(s) = \frac{s(\omega_o/Q)}{s^2 + s(\omega_o/Q) + \omega_o^2}$$

$s=0$: $Ⓗ(0) = 0$

$s=j\omega_o$: $Ⓗ(j\omega_o) = 1$

$s=\infty$: $Ⓗ(\infty) = 0$



$$i_o = \eta_e \dot{x}_s = 2\frac{\omega_d}{\omega_s} Q_s x_d \eta_e Ⓗ_s(j\omega_d)\cdot\Omega$$

A ≙ scale factor

$$\Rightarrow\ i_o = A\Omega,\ \text{where } A = 2\frac{\omega_d}{\omega_s} Q_s x_d \eta_e Ⓗ_s(j\omega_d)$$

↑ input rotation

When $\Omega = \Omega_{min}$ ≙ MDS → $i_o = i_{eqTOT}$

input-referred noise current entering the same amplifier (in pA/√Hz)

∴ $i_{eqTOT} = A\Omega_{min}$

$$\Omega_{min} = \frac{i_{eqTOT}}{A}\left(\frac{3600s}{hr}\right)\left(\frac{180°}{\pi}\right)\ [(°/hr)/\sqrt{Hz}]$$

$$\text{Angle Random Walk} = ARW = \frac{1}{60}\Omega_{min}\ [°/\sqrt{hr}]$$

↳ Easier to determine directional error as a function of elapsed time.

- Related courses at UC Berkeley:
  - EE 143: Microfabrication Technology
  - EE 147/247A: Introduction to MEMS
  - ME 119: Introduction to MEMS (mainly fabrication)
  - BioEng 121: Introduction to Micro and Nano Biotechnology and BioMEMS
  - ME C219 – EE C246: MEMS Design
  - EE 290M?

