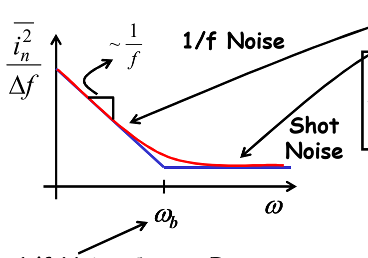
Flicker (1/f) Noise

- In general, associated w/ random trapping & release of carriers from "slow" states
- Time constant associated with this process gives rise to a noise signal w/ energy concentrated at low frequencies
- Often, get a mean-square noise spectral density that looks like this:



$$\frac{\overline{i_n^2}}{\Delta f} = 2qI_D + K\left(\frac{I_D^a}{f^b}\right)$$

I_D = DC current
K = const. for a particular device
a = 0.5 → 2
b ~ 1

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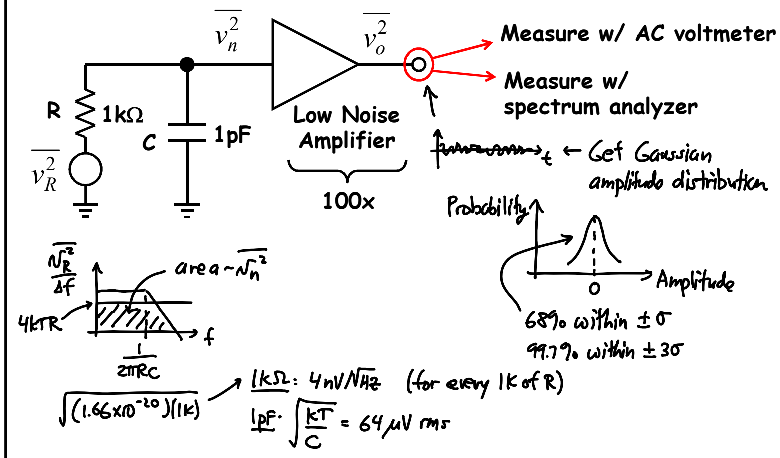
Example: Typical Noise Numbers

- Hookup the circuit below and make some measurements



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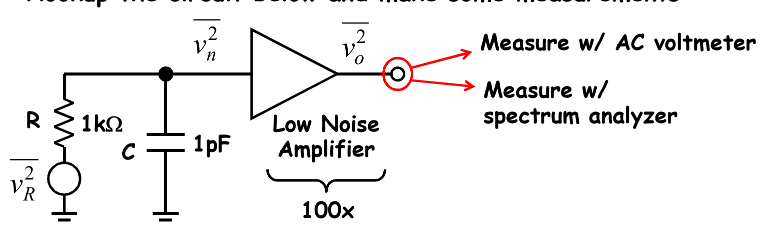
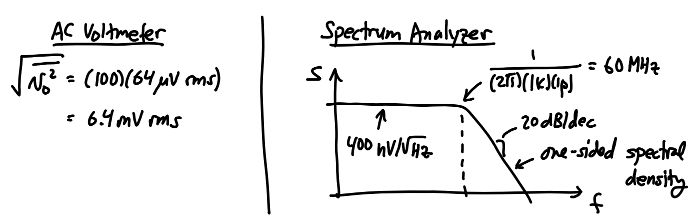
Example: Typical Noise Numbers

- Hookup the circuit below and make some measurements





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Back to Determining Sensor Resolution

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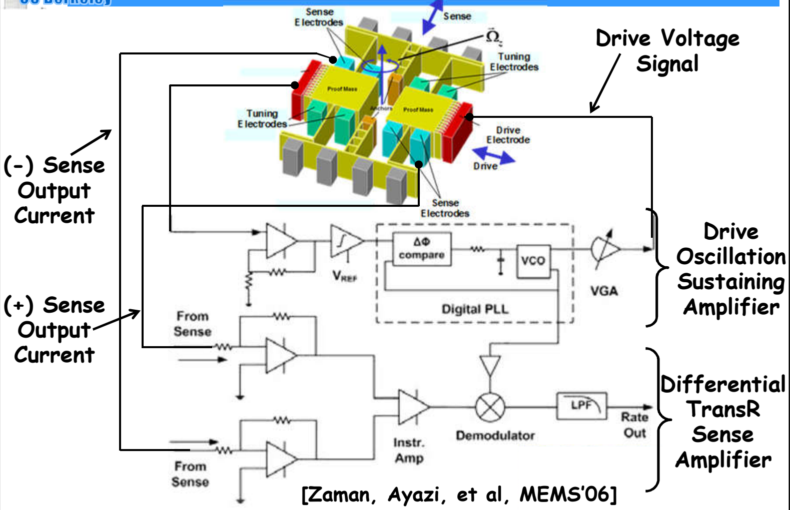
MEMS-Based Tuning Fork Gyroscope



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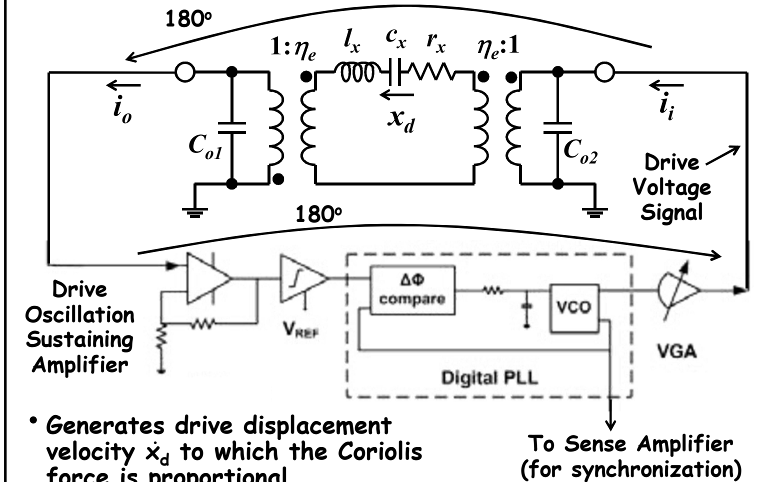
Drive Axis Equivalent Circuit



- Generates drive displacement velocity $\dot{x}_d$ to which the Coriolis force is proportional

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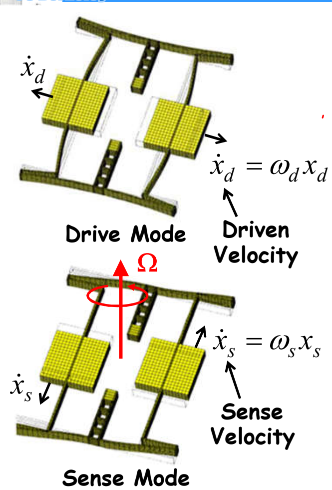
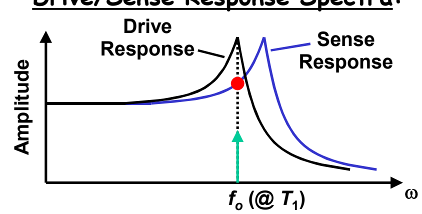
Drive-to-Sense Transfer Function



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

$a_s = 2\omega_d x_d \Omega \sin 90°$

$a_s = 2\omega_d x_d \Omega$

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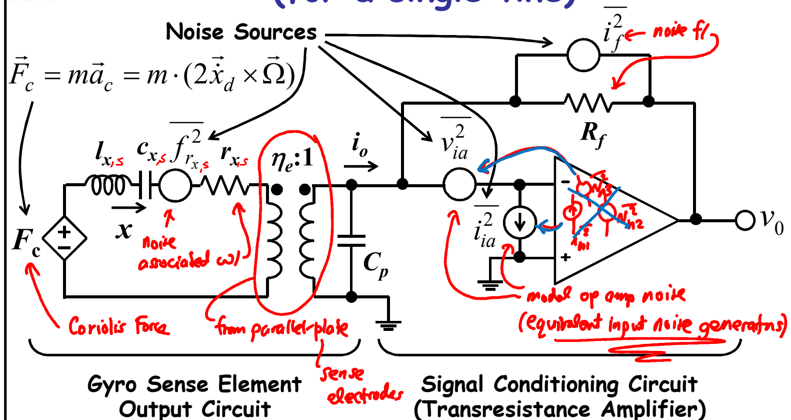
Gyro Readout Equivalent Circuit (for a single tine)



- Easiest to analyze if all noise sources are summed at a common node

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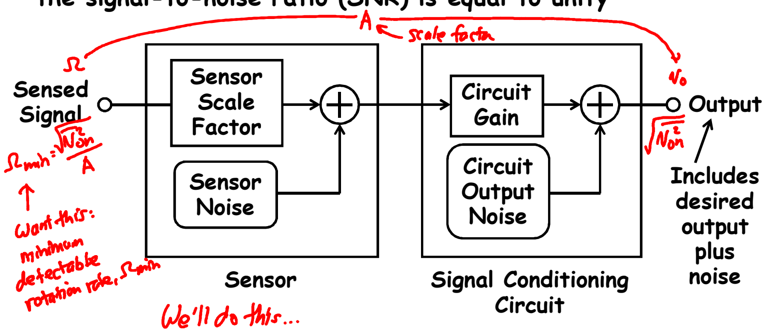
Minimum Detectable Signal (MDS)

UC Berkeley

- Minimum Detectable Signal (MDS): Input signal level when the signal-to-noise ratio (SNR) is equal to unity



- The sensor scale factor is governed by the sensor type
- The effect of noise is best determined via analysis of the equivalent circuit for the system

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Move Noise Sources to a Common Point

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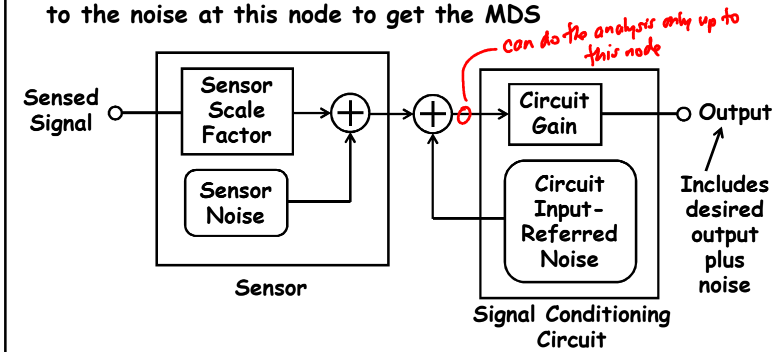
- Move noise sources so that all sum at the input to the amplifier circuit (i.e., at the output of the sense element)
- Then, can compare the output of the sensed signal directly to the noise at this node to get the MDS



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Equivalent Input-Referred Voltage and Current Noise Sources

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Equivalent Input v, i Noise Generators

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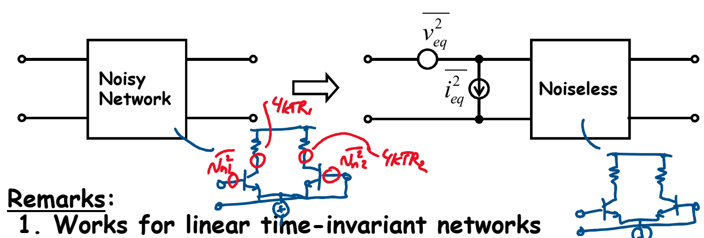
- Take a noisy 2-port network and represent it by a noiseless network with input *v* and *i* noise generators that generate the same total output noise



- **Remarks**:
  1. Works for linear time-invariant networks
  2. v_{eq} and i_{eq} are generally correlated (since they are derived from the same sources)
  3. In many practical circuits, one of v_{eq} and i_{eq} dominates, which removes the need to address correlation
  4. If correlation is important → easier to return to original network with internal noise sources

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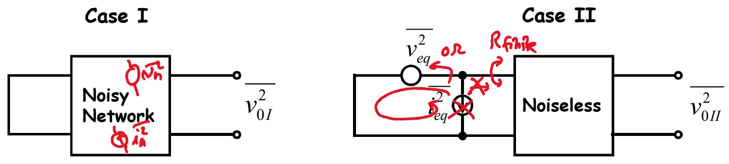
Calculation of $\overline{v_{eq}^2}$ and $\overline{i_{eq}^2}$

a) To get $\overline{v_{eq}^2}$ for a two-port:



1) Short input, find $\overline{v_{0I}^2}$ (or $\overline{i_{0I}^2}$)

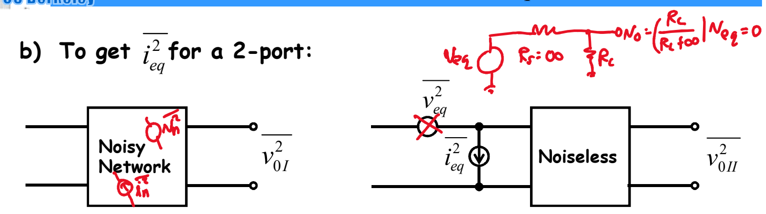
2) For eq. network, short input, find $\overline{v_{0II}^2}$ (or $\overline{i_{0II}^2}$)

$\overline{v_{0II}^2} = f\left(\overline{v_{eq}^2}\right)$, $\overline{i_{0II}^2} = f\left(\overline{v_{eq}^2}\right)$

3) Set $\overline{v_{0I}^2} = \overline{v_{0II}^2}$ → solve for $\overline{v_{eq}^2}$ (or $\overline{i_{0I}^2} = \overline{i_{0II}^2}$)

Calculation of $\overline{v_{eq}^2}$ and $\overline{i_{eq}^2}$ (cont)

b) To get $\overline{i_{eq}^2}$ for a 2-port:



1) Open input, find $\overline{v_{0I}^2}$ (or $\overline{i_{0I}^2}$)

2) Open input for eq. circuit, find $\overline{v_{0II}^2}$ (or $\overline{i_{0II}^2}$)

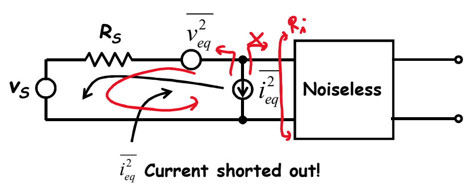
3) Set $\overline{v_{0I}^2} = \overline{v_{0II}^2}\left(\overline{i_{eq}^2}\right)$ → solve for $\overline{i_{eq}^2}$ (or $\overline{i_{0I}^2} = \overline{i_{0II}^2}\left(\overline{i_{eq}^2}\right)$)

- Once the equivalent input-referred noise generators are found, noise calculations become straightforward as long as the noise generators can be treated as uncorrelated

Cases Where Correlation Is Not Important

- There are two common cases where correlation can be ignored:
  1. Source resistance R_s is small compared to input resistance R_i → i.e., voltage source input
  2. Source resistance R_s is large compared to input resistance R_i → i.e., current source input

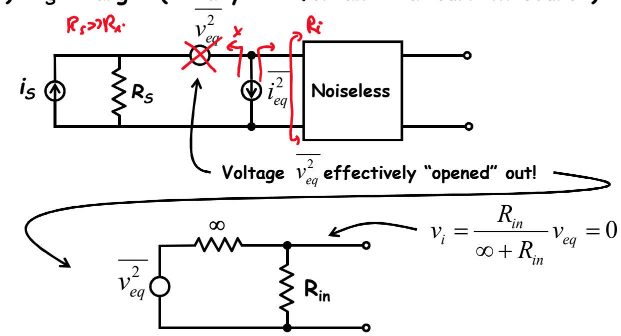
1) R_S = small (ideally = 0 for an ideal voltage source):



∴ For R_S= small, $\overline{i_{eq}^2}$ can be neglected → only $\overline{v_{eq}^2}$ is important!
(Thus, we need not deal with correlation)

Cases Where Correlation Is Not Important

2) R_S = large (Ideally = ∞ for an ideal current source)



∴ For R_S= large, $\overline{v_{eq}^2}$ can be neglected!
→ only $\overline{i_{eq}^2}$ is important!

(… and again, we need not deal with correlation)

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