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EE C247B - ME C218 Introduction to MEMS Design Fall 2016

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Module 17: Noise & MDS

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Lecture Outline

- 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

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Determining Sensor Resolution

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Minimum Detectable Signal (MDS)

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

The diagram shows a signal flow from left to right. It starts with an input labeled 'Sensed Signal' entering a box labeled 'Sensor'. Inside the 'Sensor' box, the signal passes through a 'Sensor Scale Factor' block and is then summed with 'Sensor Noise' at a junction marked with a plus sign (+). The output of the sensor then enters a second box labeled 'Signal Conditioning Circuit'. Inside this box, the signal passes through a 'Circuit Gain' block and is then summed with 'Circuit Output Noise' at another junction marked with a plus sign (+). The final output is labeled 'Output' and is noted to 'Include desired output plus noise'.

- 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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Noise

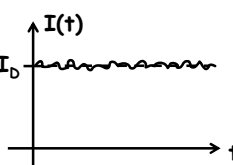
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Noise

- **Noise:** Random fluctuation of a given parameter $I(t)$
- In addition, a noise waveform has a zero average value

Avg. value
(e.g. could be
DC current)



- We can't handle noise at instantaneous times
- But we can handle some of the averaged effects of random fluctuations by giving noise a power spectral density representation
- Thus, represent noise by its mean-square value:

Let $i(t) = I(t) - I_D$

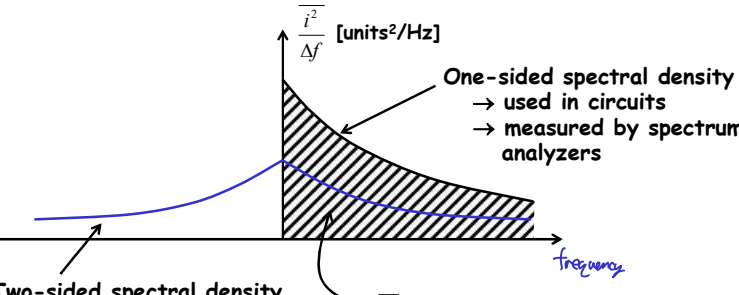
Then $\overline{i^2} = \overline{(I - I_D)^2} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T |I - I_D|^2 dt$

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Noise Spectral Density

- We can plot the spectral density of this mean-square value:



One-sided spectral density
 → used in circuits
 → measured by spectrum analyzers

Two-sided spectral density
 (1/2 the one-sided)
 Often used in systems courses

$\overline{i^2}$ = integrated mean-square noise spectral density over all frequencies (area under the curve)

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Noise Sources

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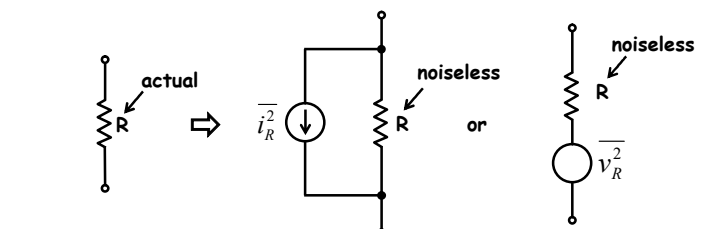
Thermal Noise

- Thermal Noise in Electronics:** (Johnson noise, Nyquist noise)
 - ↳ Produced as a result of the thermally excited random motion of free e^- 's in a conducting medium
 - ↳ Path of e^- 's randomly oriented due to collisions
- Thermal Noise in Mechanics:** (Brownian motion noise)
 - ↳ Thermal noise is associated with all dissipative processes that couple to the thermal domain
 - ↳ Any damping generates thermal noise, including gas damping, internal losses, etc.
- Properties:**
 - ↳ Thermal noise is white (i.e., constant w/ frequency)
 - ↳ Proportional to temperature
 - ↳ Not associated with current
 - ↳ Present in any real physical resistor

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Circuit Representation of Thermal Noise

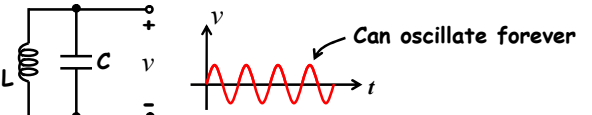
- Thermal Noise can be shown to be represented by a series voltage generator $\overline{v_R^2}$ or a shunt current generator $\overline{i_R^2}$



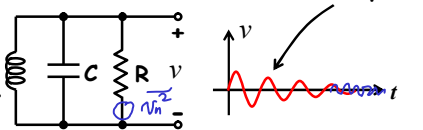
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Noise in Capacitors and Inductors?

- Resistors generate thermal noise
- Capacitors and inductors are noiseless → why?



- Now, add a resistor:
 - Decays to zero
 - But this violates the laws of thermodynamics, which require that things be in constant motion at finite temperature



Need to add a forcing function, like a noise voltage $\overline{v_R^2}$ to keep the motion going → and this noise source is associated with R

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