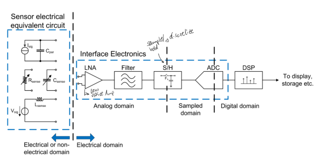
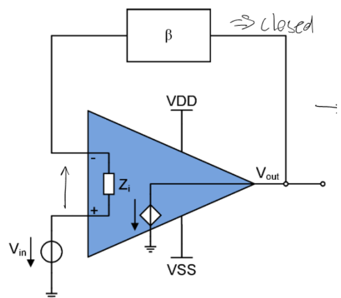
# Sensor Principles

## A generic sensor interface




## OPAMP Basics

## Opamps in feedback



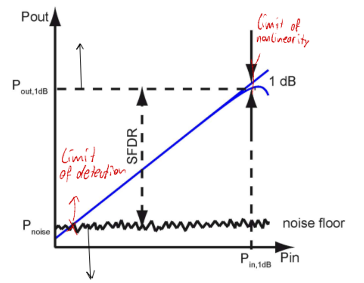

Gain : $T(\omega)=\beta\cdot A_0(\omega)$
Phase Margin:
$PM=180^\circ+\angle(T(\omega_1)|_{|T(\omega_1)|=1}$
Gain margin:$GM=$
$20\cdot log_{10}(\frac{1}{T(\omega_2)})|_{\angle(T(\omega_2)=-180^\circ}$

**Generic Transfer function**
$V_x=\beta\cdot V_{\text{out}}=$
$\beta\cdot A(\omega)\cdot(V_{\text{in}}-V_x)=$
$\beta\cdot A(\omega)\cdot(V_{\text{in}}-\beta\cdot V_{\text{out}})$
$\frac{V_{\text{out}}}{V_{\text{in}}}=\frac{A(\omega)}{1+\beta\cdot A(\omega)}\overset{A(\omega)]\gg1}{\approx}\frac{1}{\beta}$

**Negative Feedback and linear operation**
$A(\omega)\gg1\Rightarrow$ virtual short at the input $\Delta V\approx0$
$Z_i\rightarrow\infty\Rightarrow i_{oa}\approx0$
Voltage Drive → negative feedback
Current drive → positive feedback

## Errors and Noise

**Limit of detection(LOD):** minimum measurable input amplitude ($SNR\approx0$)
**Dynamic range()DR:** ratio of max and min amplitude within inaccuracy levels.




**Errortypes**:
Deterministic: source loading, offset, gain error
Random: thermal noise, 1/f noise

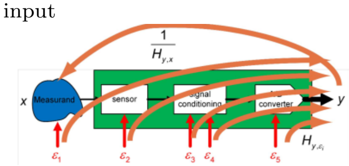
**Quantification**:
Absolute : $\Delta x=|\hat{x}-x_0|$
Relative: $\left|\frac{\Delta x}{x_0}\right|=\left|\frac{\hat{x}-x_0}{\hat{x}}\right|$
Max inaccuracy:
$\Delta x_{max}|x\in[\hat{x}-\Delta x_{\max},\hat{x}+\Delta x_{\max}]$

**Error Propagation**
$y=f(x_1,x_2,\ldots,x_N)$
Deterministic fluctuations of $x_i\rightarrow$ total error:
$\Delta y\approx\sum_{i=1}^N\frac{\partial f}{\partial x_i}\cdot\Delta x_i$
Partial derivative $\frac{\delta f}{\delta x_i}$ is called **sensitivity**
Additive errors are best specified absolute and multiplicative errors are best specified relative

**Interference:**
Unwanted coupling of external signal
Noise: random fluctuations from setup → can be modeled as error sources

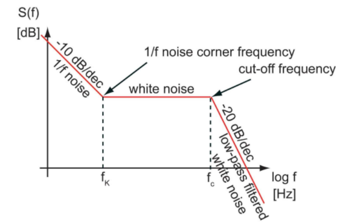
## Combining Error sources

**Output referred noise**
Effect of an error-source on the output
**Input referred noise** Equivalent effect of the error-source on the input




Find TF from ES to output
$y:H_{y,ES}\Rightarrow y_{\text{out}},_{\epsilon_2}=H_{y,\epsilon_2}\cdot\epsilon_2$
Refer result back to input wit
$H_{y,x}:x_{\epsilon_2}=\frac{y_{\text{out}},_{\epsilon_2}}{H_{y,x}}=H_{y,\epsilon_2}\cdot\frac{\epsilon_2}{H_{y,x}}$
**Lin. System noise:**

$PSD=S_y(f)=|H(f)|^2\cdot S_x(f)$




## Noise Types

**Thermal noise:** excitation of charge carriers(white)
**Shot noise:** carriers randomly crossing the barrier, dependent on DC bias and white
**Flicker Noise:**, due to traps in semiconduct. 1/f spectral density. MOS trans at low freq.
**Thermalnoise Theorem:** Every closed system at temp. T has average. Energy of $kT/2\rightarrow$
$S_u(f)=2kTR($ double-sided $)$ math
$S_u(f)=4kTR($ single-sided $)$ physics

## Langevin Approach kt/C noise

PSD noise voltage of $V_n$
$=S_{v_n}(f)=4kT\cdot\Re\{Z(j2\pi f)$
$\rightarrow\overline{V_n^2}=kT\left[\frac{1}{C_\infty}-\frac{1}{C_0}\right]=\frac{kT}{C}$

**MOS IRN**
$S_{\Delta V^2_{\text{nG-tot}}}=4kT\cdot$
$R_{\text{nG-tot}},\quad R_{\text{nG-tot}}=\frac{\rho}{W\cdot L\cdot f}+\frac{\gamma_{nD}}{G_m}$
with GateExcess Noise factor
$:\gamma_{nD}=(n=1.3)\cdot[0.5WI;2/3SI]$
**Bipolar Trans IRN:**
$S_{\Delta V^2_{nR}}=4kT\cdot R_B$

## Noise Aanalysis

small-signal-equivalent is valid.
Total ORN:
$S_{n,\text{ out}}(f)=\sum_{k=1}^N|H_k(f)|^2\cdot S_{nk}(f)$
N uncorrelated NS.
$H_k(f)$ TF from NS to output. IRN:
$S_{V_{\text{neq}}}(f)=\frac{S_{V_{\text{nout}}}(f)}{|A(f)|^2}$ with $A(f)$ is TF