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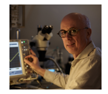
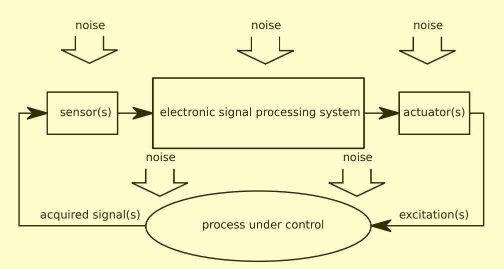
anton@montagne.nl
https://www.analog-electronics.eu



Information processing



Signal
- a physical quantity that contains meaningful data

Data
- properties or details of a signal that represent the information

Noise
- a physical quantity whose data is meaningless

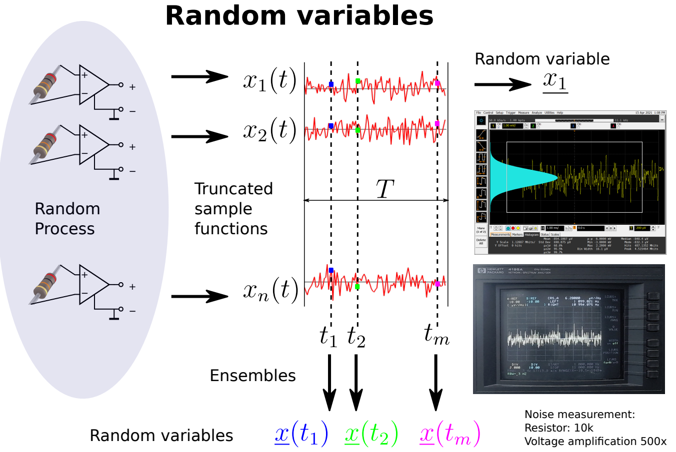
Information
- the meaning of the data

Signal processing
- Perform operations on a signal. Extract or modify the information contained in the signal.

Random signal modeling

A signal is a signal, it is neither random nor deterministic, but we can model it either way.
G.P. Box:
All models are wrong, but some are useful.

Random variables



Stationary process
Statistical properties do not change with time.

Ergodic process
Statistical properties of one sample function equal those of ensembles (the whole process).

Random modeling: use of statistical description methods

Probability Density Function

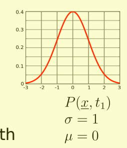
$\int_{-\infty}^{\infty} P(\underline{x},t)dx = 1$

$\Pr(a \le \underline{x} \le b, t) = \int_a^b P(\underline{x},t)dx$

Power Spectral Density

$S(f)$ [W/Hz]

Mean power per unit of bandwidth as a function of frequency.



Ensemble Average First-order expectation	Moment Second-order expectation	Variance Squared standard deviation	
$E(\underline{x}) = \int_{-\infty}^{\infty} xP(\underline{x},t)dx$	$E(\underline{x}^2) = \int_{-\infty}^{\infty} x^2P(\underline{x},t)dx$	$\sigma^2 = E\left(\underline{x} - E(\underline{x})\right)^2$	PDF
$\overline{\underline{x}(t_1)} = \frac{1}{n}\sum_{i=1}^{i=n} x_i(t_1)$	$\overline{\underline{x}(t_1)^2} = \frac{1}{n}\sum_{i=1}^{i=n} x_i(t_1)^2$	$S_{n-1} = \frac{1}{n-1}\sum_{i=1}^{i=n}\left(x_i(t_1) - \overline{\underline{x}(t_1)}\right)^2$	SD
Time Average: DC value	**Mean Square Value:**	**Mean square AC value:**	
$\overline{x(t)} = x_{DC} = \lim_{T\to\infty}\frac{1}{T}\int_0^T x(t)dt$	$\overline{x(t)^2} = \lim_{T\to\infty}\frac{1}{T}\int_0^T x(t)^2dt$	$\overline{x^2_{AC}} = \lim_{T\to\infty}\frac{1}{T}\int_0^T \left(x(t) - x_{DC}\right)^2 dt$	TF

Autocorrelation
The joint power between a signal and its time-shifted copy tells us something about the dependency between signal values.

$r_x(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_0^T x_T(t)x_T(t+\tau)dt \qquad r_x(0) = \lim_{T\to\infty}\frac{1}{T}\int_0^T x_T(t)^2dt = \overline{x(t)^2}$

Fourier Transform | **Wiener-Khinchin theorem** | **Parseval's theorem**

Joseph Fourier
21-03-1768, France
16-05-1830

Norbert Wiener
26-11-1894, Columbia, Missouri, US
18-03-1964, Stockholm, Sweden

$S_x(\omega) = \mathcal{F}\{r_x(\tau)\}$
$r_x(\tau) = \mathcal{F}^{-1}\{S_x(\omega)\}$

Aleksandr Khinchin
19-07-1894, Kondrovo, Russian Empire
18-11-1959, Moscow, Russian SFSR

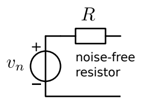
Stationary process:
Autocorrelation function and spectral density form a Fourier pair

Marc-Antoine Parseval
17-04-1755, des Chenes, France
16-08-1836

$\overline{x_1(t)^2} = \int_0^\infty S(f)df$

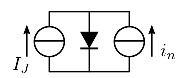
Noise in electronic circuits

Thermal noise
Noise in conductors caused by thermal (Brownian) motion (Brown 1828). Experimentally detected by Johnson (1928) and explained by Nyquist (1928).



$S_{v_n} = 4kTR\ [V^2/\mathrm{Hz}]$

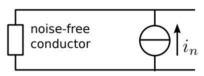
Shot noise
Noise current associated with a DC current through a junction.



$S_{i_n} = 2qI_J\ [\mathrm{A}^2/\mathrm{Hz}]$

Excess noise
Noise current resulting from fluctuations in conduction mechanism.

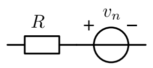
$G = \frac{1}{R}$



$S_{i_n} = 4kTG\ [\mathrm{A}^2/\mathrm{Hz}]$

In resistors

$S_{v_{nf}} = K\frac{V_R^2}{f}$



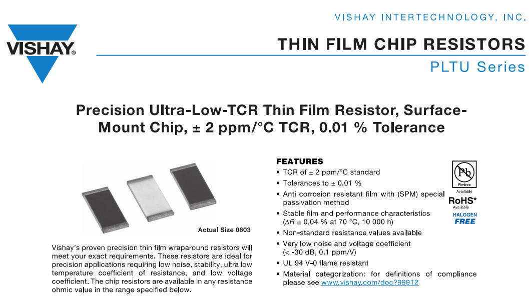
$S_{v_n} = 4kTR\left(1 + \frac{f_\ell}{f}\right)$

$f_\ell = K\frac{P_R}{4kT}$

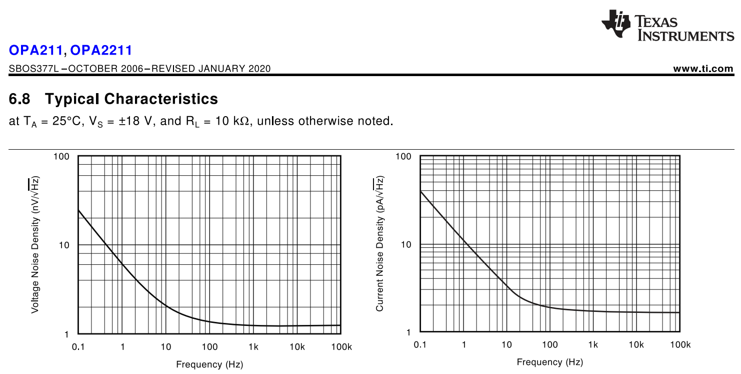
$K = \frac{10^{\frac{N}{10}} \cdot 10^{-12}}{\ln 10}$

In junctions

$S_{i_{nf}} = K\frac{I_J^{\alpha}}{f}\ [\mathrm{A}^2/\mathrm{Hz}]$



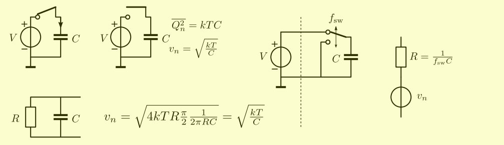
VISHAY INTERTECHNOLOGY, INC.
THIN FILM CHIP RESISTORS
PLTU Series
Precision Ultra-Low-TCR Thin Film Resistor, Surface-Mount Chip, ± 2 ppm/°C TCR, 0.01 % Tolerance



OPA211, OPA2211
SBOS377L – OCTOBER 2006 – REVISED JANUARY 2020
www.ti.com
6.8 Typical Characteristics
at T_A = 25°C, V_S = ±18 V, and R_L = 10 kΩ, unless otherwise noted.

Switched capacitor noise

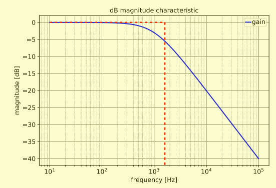
- Thermal noise current
- Opening the switch fixes charge
- Periodic switching yields noisy resistor



Noise parameters

Equivalent noise bandwidth
Bandwidth of a brickwall filter with a pass-band gain equal to the maximum magnitude of the system transfer that would produce the same output noise power as the system:

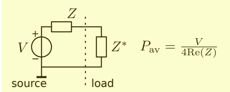
$B_n = \frac{1}{2\pi}\int_0^\infty \left|\frac{H(j\omega)}{H_{\max}}\right|^2 d\omega\,[\mathrm{Hz}]$



First-order low-pass:
$B_n = \frac{\pi}{2}B_{-3\mathrm{dB}}$

Noise temperature
Apparent temperature of a noise source with available noise power P over a bandwidth B: $T_n = \frac{P}{kB}$

Available power
Maximum power that can be delivered by a source:



Signal-to-noise ratio
Ratio of (weighted) signal power and (weighted) noise power:
$SNR = \frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}} \qquad SNR_{dB} = 10\log_{10}\left(\frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}}\right)$

Noise figure
Measure for deterioration of the signal-to-noise ratio by a system:
$F = \frac{SNR \text{ at the input of a system}}{SNR \text{ at the output of a system}} \qquad F_{dB} = 10\log_{10}F$

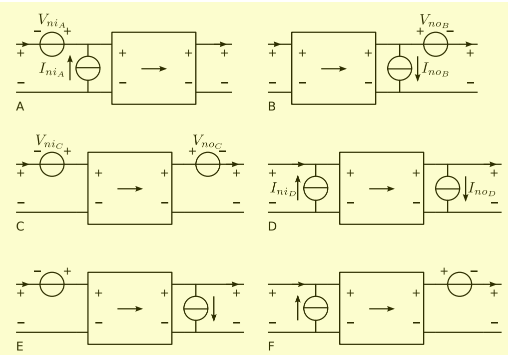
Dynamic range
Ratio of maximum signal power and the noise power in the absence of a signal:
$D = \frac{P_{s,max}}{P_{n,min}} \qquad D_{dB} = 10\log_{10}\left(\frac{P_{s,max}}{P_{n,min}}\right)$

Effective number of bits
In mixed signal (analog-digital systems) Log (base 2) of the ratio of the maximum number of counts and the standard deviation in counts in the absence of a signal:
$ENOB_n = \log_2\frac{2^n}{\sigma}$
Other definitions are also in use

Two-ports

Two-port: amplifier model used at an early stage of the design

- Two ports
- Two port variables (V, I)
- Six representation methods (Chapter 18)



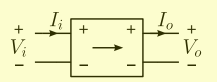
Noisy two-ports
- Two independent variabes
- Two dependent variables
- Six representation methods

Can be translated into each other:
- Example 2.9
- Example 19.2

Noise performance modeled correctly for aribitrary port termination impedances

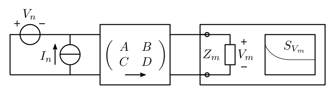
Transmission-1 matrix two-port representation

Anti-causal representation
Output port quantities as independent variables
Input port quantities as dependent variables

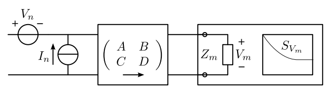


$\begin{pmatrix} V_i \\ I_i \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix}\begin{pmatrix} V_o \\ I_o \end{pmatrix}$

Measurement of input-referred noise sources



Shorted input: Voltage noise

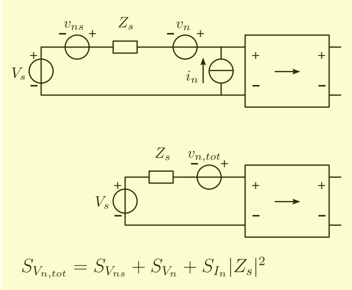


Open input: Current noise

Amplifier noise design

Equivalent-input noise description is convenient at early stages of the design.

Budgets for equivalent input noise sources can be determined without knowledge of the amplifier circuit.



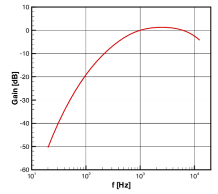
$S_{V_{n,tot}} = S_{V_{ns}} + S_{V_n} + S_{I_n}|Z_s|^2$

Noise figure
Source-referred defenition:

Ratio of total (weighted) source-referred noise and the total (weighted) noise associated with the signal source:

$F = \frac{\int_0^\infty S_{v_{n,tot}}|W(f)|^2df}{\int_0^\infty S_{v_{ns}}|W(f)|^2df}$

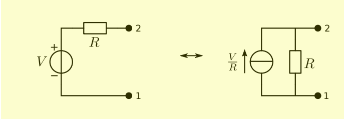
$|W(f)|^2$ Squared magnitude of a weighting function that models the sensitivity of the observer as a function of frequency



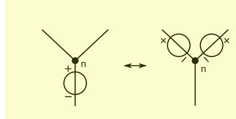
DIN A weighting curve (audio)

Determination of source-referred noise

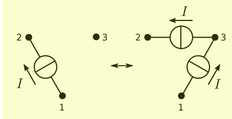
Thévenin / Norton transformation



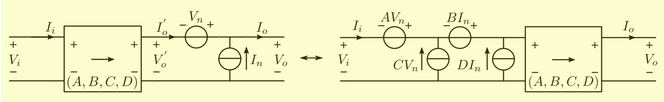
Blakesley voltage shift



Current redirect

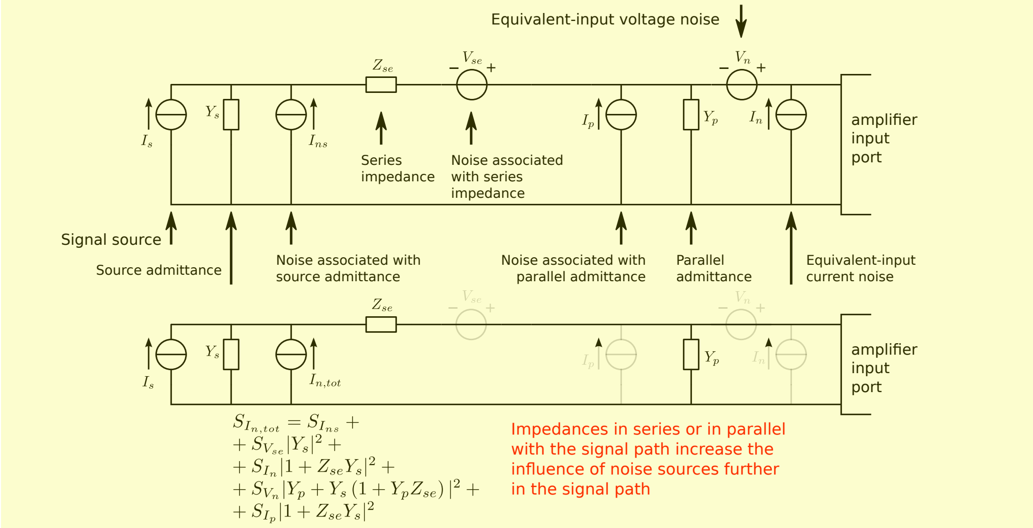


Equivalent two-port representations



SPICE / SLiCAP / MNA
Determination of output (detector-referred) noise:
- Summ all noise contributions at detector
Determination of input (source-referred) noise
- Divide result by source-to-load transfer

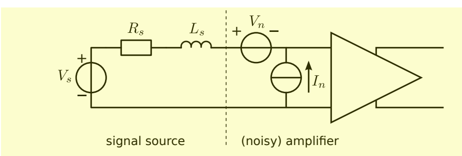
Thou shalt not insert impedances in series or in parallel with the signal path



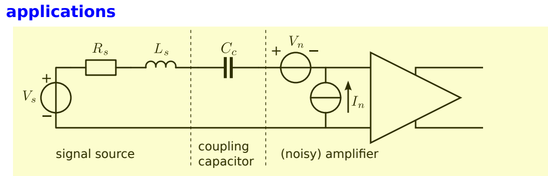
$S_{I_{n,tot}} = S_{I_{ns}} +$
$+ S_{V_{sc}}|Y_s|^2 +$
$+ S_{I_n}|1 + Z_{sc}Y_s|^2 +$
$+ S_{V_n}|Y_p + Y_s(1 + Y_pZ_{sc})|^2 +$
$+ S_{I_p}|1 + Z_{sc}Y_s|^2$

Impedances in series or in parallel with the signal path increase the influence of noise sources further in the signal path

Narrow-band applications



$S_{V_{n_{tot}}} = 4kTR_s + S_{V_n} + S_{I_n}\left(R_s^2 + (\omega L_s)^2\right)$



$S_{V_{n_{tot}}} = 4kTR_s + S_{V_n} + S_{I_n}\left(R_s^2 + \left(\omega L_s - \frac{1}{\omega C_c}\right)^2\right)$

Single-loop passive feedback configurations and their equivalent noise models