Structured Electronic Design

EE3C11

Noise in Electronic Circuits

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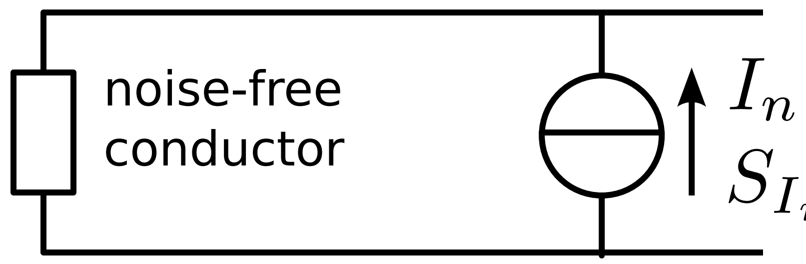
Noise mechanisms

Thermal noise

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

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

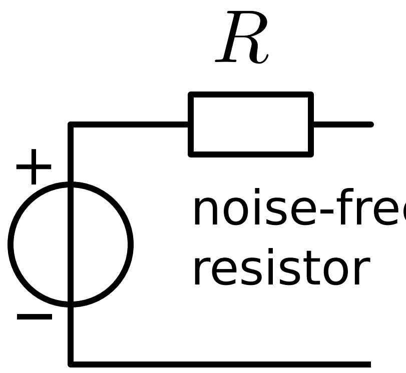


I_n

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

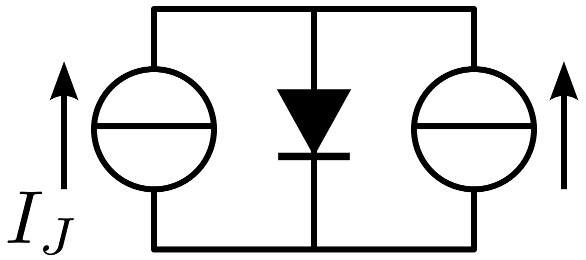
V_n

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



Shot noise

Noise current associated with a DC current through a junction.



I_n

$S_{I_n} = 2qI_J$

Excess noise

Noise current resulting from fluctuations in conduction mechanism.

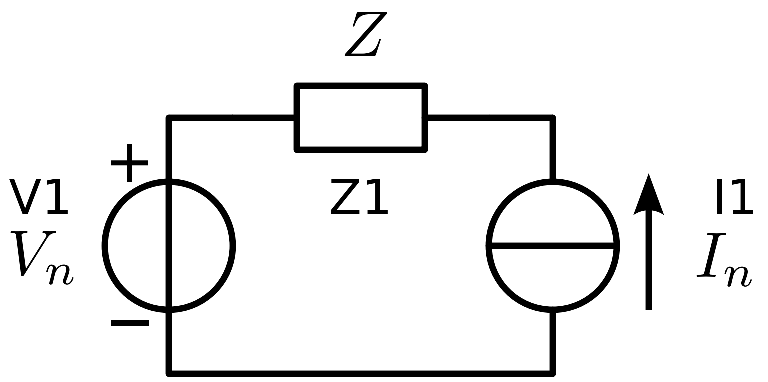
In junctions $S_{I_n} = K\frac{I_J^\alpha}{f}$

In resistors $S_{V_n} = K\frac{V_R^2}{f}$

Drawing conventions

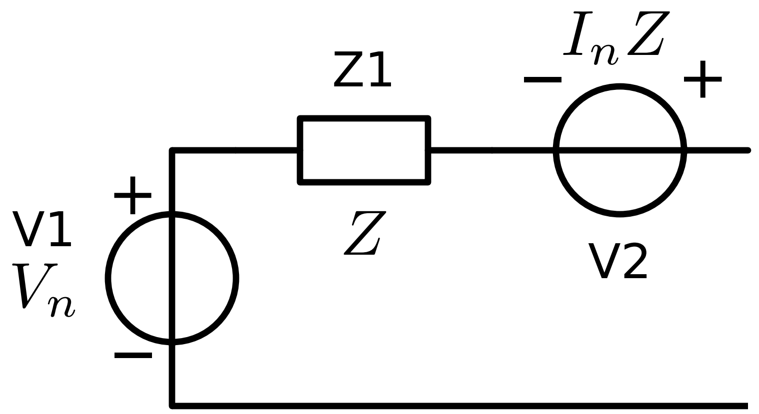
Complex impedance of Z1

Fourier Transform of noise voltage of V1



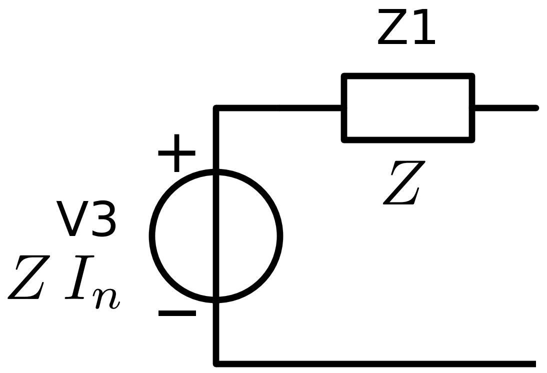
Fourier Transform of noise current of I1

Equivalent circuit after Norton-Thevenin Transformation



Equivalent circuit in which the voltage of V3 represents the total noise voltage

$$V_{n,tot} = V_n + Z\, I_n$$



Noise parameters

Equivalent noise bandwidth of a system

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

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

Noise temperature

Apparent temperature of a noise source with available noise power P over bandwidth B:

$$T_n = \frac{P}{kB}$$

Signal-to-noise ratio

dB ratio of (weighted) signal power and (weighted) noise power:

$$SNR = 10\log_{10}\left(\frac{P_{signal}}{P_{noise}}\right)$$

Noise figure

dB measure for deterioration of the signal-to-noise ratio by a system:

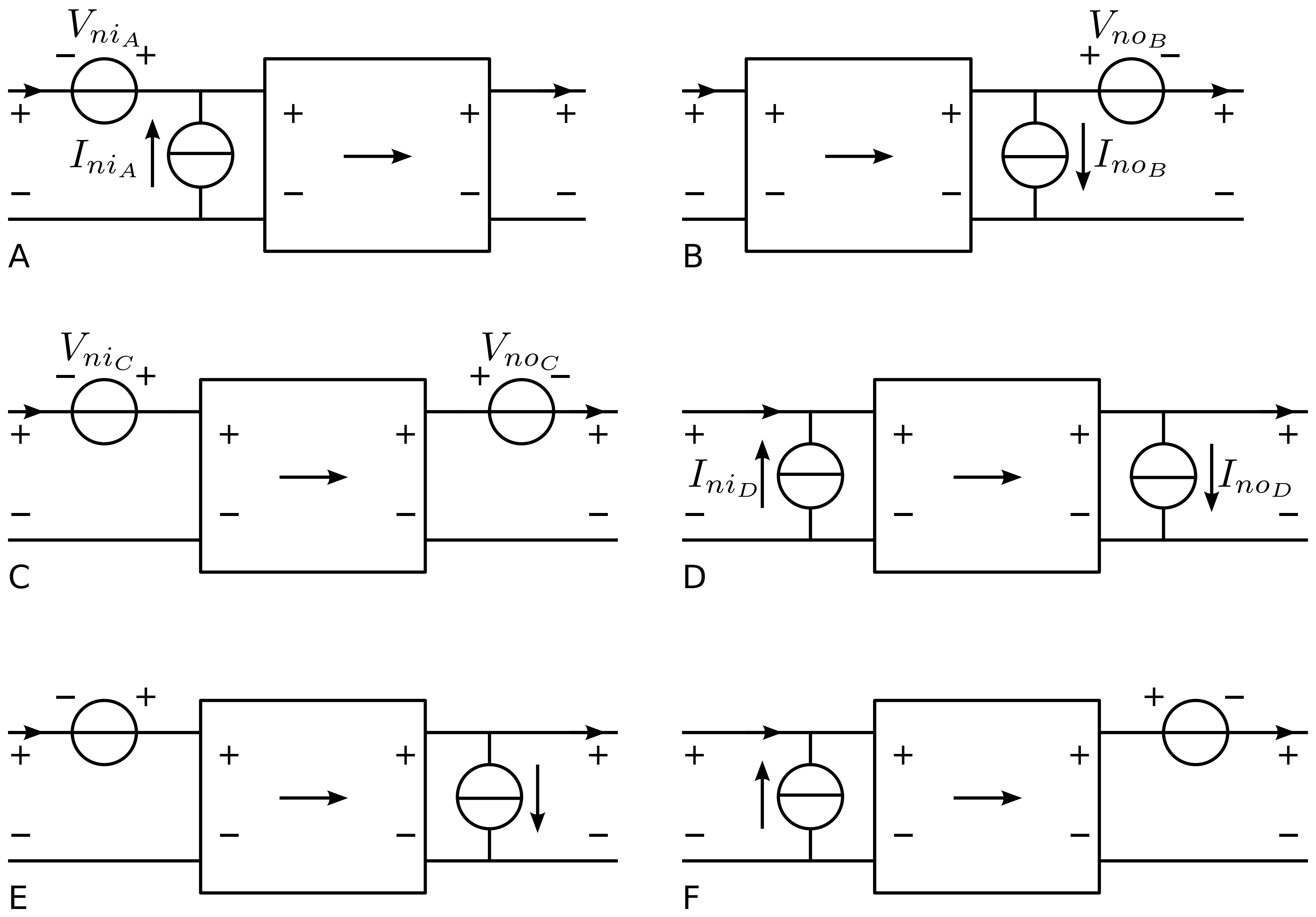
$$F = SNR_{\mathrm{input}} - SNR_{\mathrm{output}}$$

Dynamic range

dB ratio of maximum signal power and the noise power in the absence of a signal:

$$D = 10\log_{10}\left(\frac{P_{s,max}}{P_{n,min}}\right)$$

Noisy two-ports



Noise representation

- A noise-free two-port with two noise sources
- Six representations:
  4 port variables:
  * two independent variables
  * two dependent variables

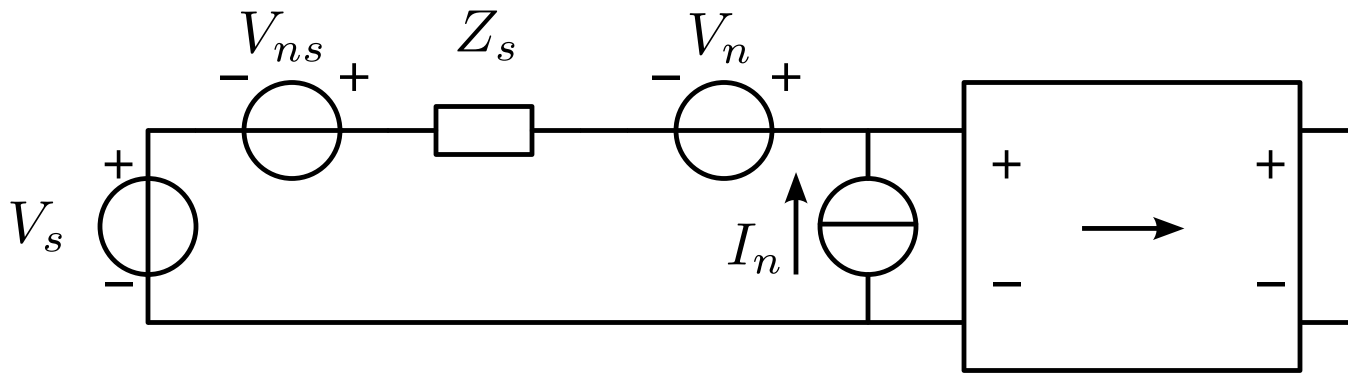
Can be translated into each other

- Example 2.9
- Example 19.2

Amplifier noise design

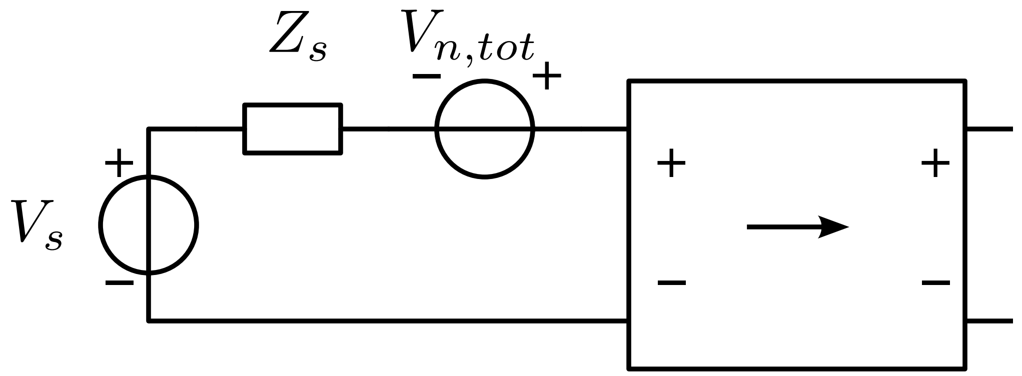
Equivalent-input noise description is convenient at early stages of the design.

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



Noise figure

equivalent-input notation:



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

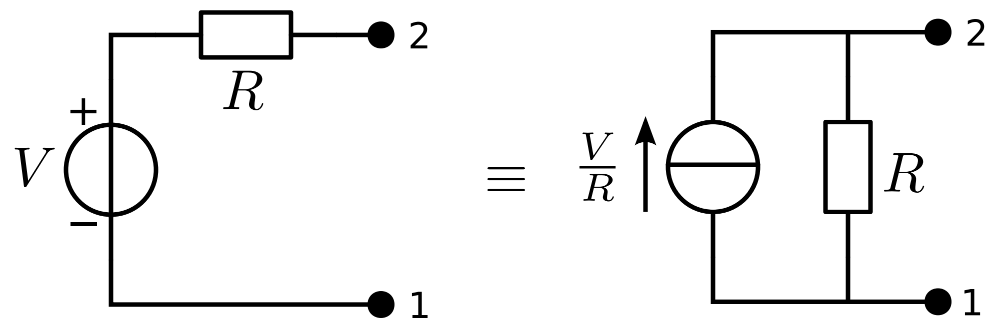
$$F = \frac{\int_0^\infty S_{V_{n,tot}} |W(f)|^2 df}{\int_0^\infty S_{V_{ns}} |W(f)|^2 df}$$

$|W(f)|^2$

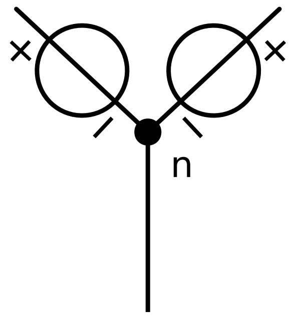
Squared magnitude of weighting function that models the sensitivity of the observer as a function of frequency

Source transformation techniques

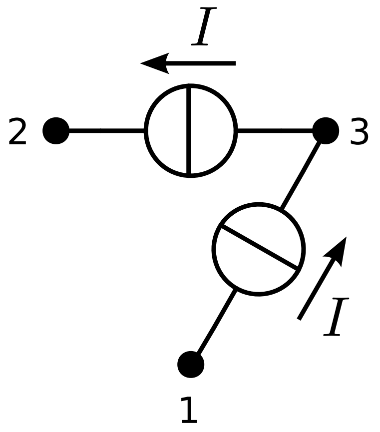
Thévenin / Norton
equivalent networks



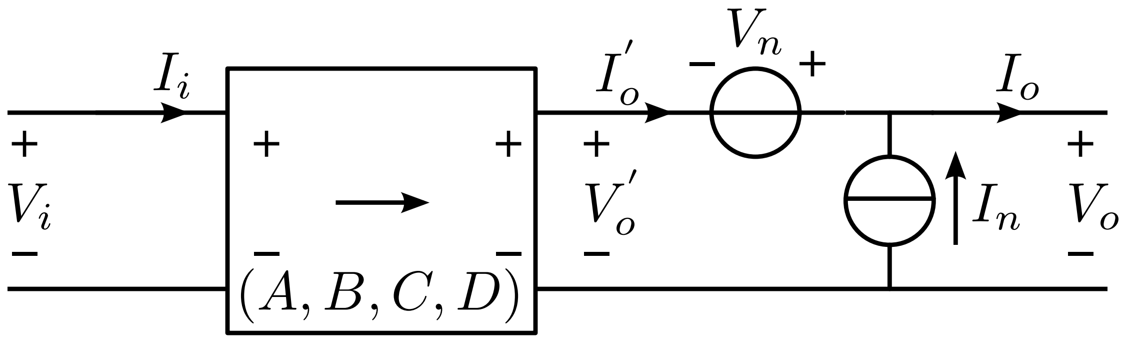
Blakesley voltage shift

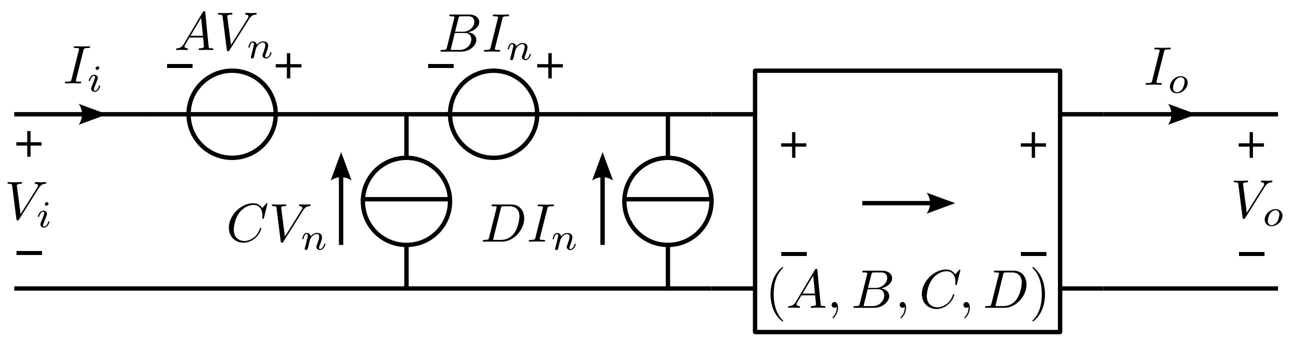


Current split / redirect

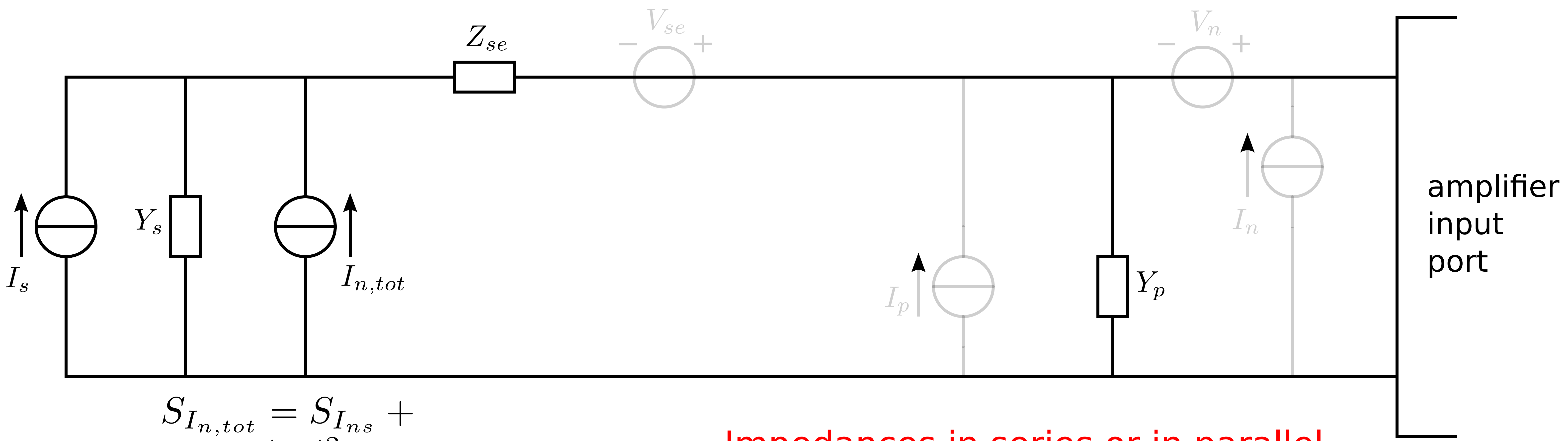


Equivalent two-port representations





Impedances in the signal path



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

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

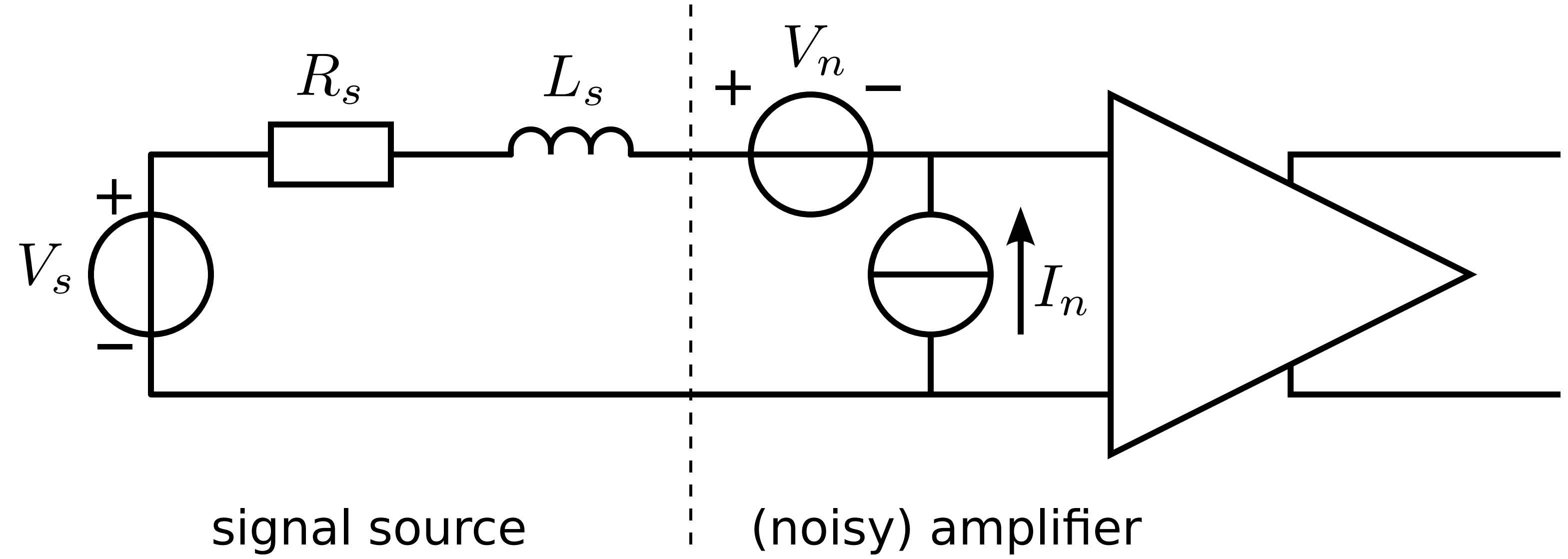
Design conclusions

Insertion of impedances in series or in parallel with the signal path should be avoided

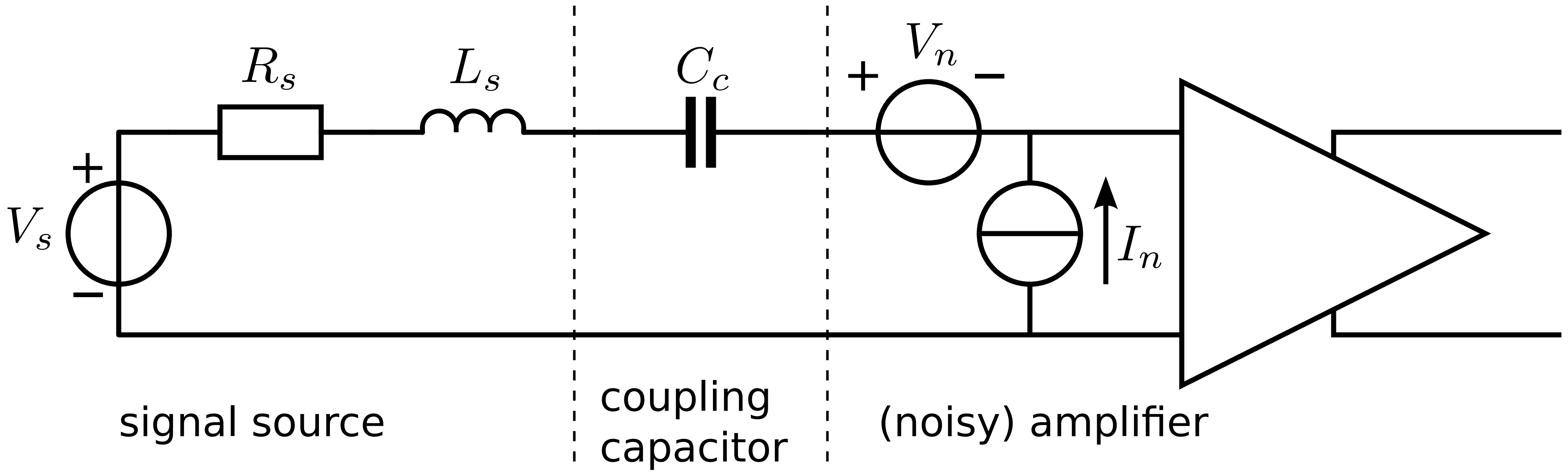
Gererally, they increase the influence of existing noise sources

If these impedances have a nonzero real part they contribute noise themselves

Only in narrow-band applications they may improve the noise performance:



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



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

Strong reduction of contribution of I_n
to the total source-referred noise if $\omega L_s \approx \frac{1}{\omega C_c}$