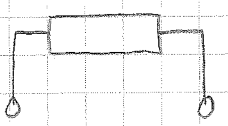
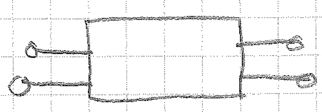
Noise Theory 2 - Noise in two-ports

Noise in circuits





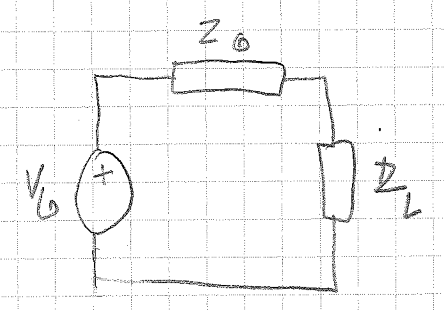
1-port — 2-port

Component — Amplifer

impedance — Transfer function

noise — Noise factor

Power calculations

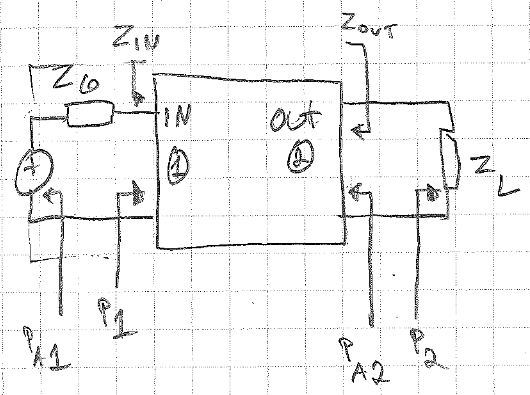


only real parts of impedances produce noise

Available power:

$$P_A = P_{ZL}\Big|_{Z_L = Z_G} = \frac{|V_G|^2}{4 \cdot R\{Z_G\}} \; [W]$$

Power gains



Operating power gain: $G = \frac{P_2}{P_1} \left[\frac{W}{W} = \cdot\right]$ Depends on Z_L and Z_G

Transducer —"— : $G_T = \frac{P_2}{P_{A1}} [\cdot]$

Available power gain: $G_A = \frac{P_{A2}}{P_{A1}}$ [·] Depends on Z_G (not Z_L)

If $Z_G = Z_{IN}^*$ ($P_1 = P_{A1}$) then $G_T = G$

If $Z_L = Z_{OUT}^*$ ($P_2 = P_{A2}$) then $G_T = G_A$

If $(Z_G = Z_{IN}^*) \wedge (Z_L = Z_{OUT}^*)$ then $G_T = G = G_A$

The transducer power gain expresses the advantage of using an amplifer as opposed to matching.

With no amplifier

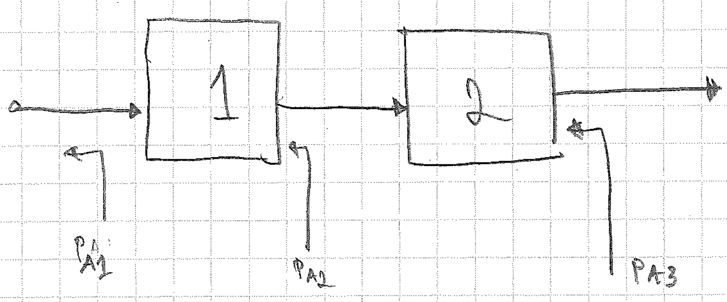
$$P_{ZL} = P_{A1} \quad (\text{for } Z_G = Z_L^*)$$

With amplifier

$$P_{ZL} = P_2 = P_{A1} \cdot G_T \quad (\text{Power in load})$$

More on power gains

Blocks in cascade

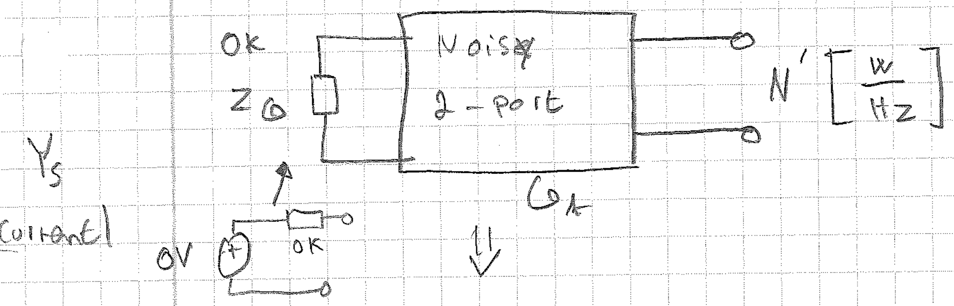


$G_{A1} = \frac{P_{A2}}{P_{A1}}$ $\quad G_2 = \frac{P_{A3}}{P_{A2}}$

$$G_{ARES} = \frac{P_{A3}}{P_{A1}} = \frac{P_{A2}}{P_{A1}} \cdot \frac{P_{A3}}{P_{A2}} = G_{A1} \cdot G_{A2}$$

$$G_{TRES} = \frac{P_3}{P_{A1}} = \frac{P_{A2}}{P_{A1}} \cdot \frac{P_3}{P_{A2}} = G_{A1} \cdot G_{T2}$$

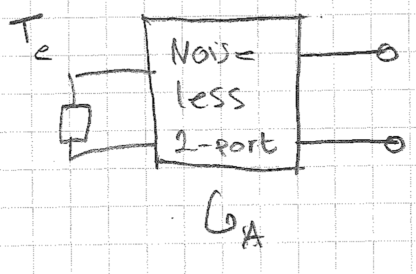
Effective Noise Temperature



Z_G is neccasary to calc Available power

0 K = noisless

T_e = effective noise temp [K]



Noise at the output:

$$N' = kT_e G_A \ [W/Hz]$$

$$N = kT_e B G_A \ [W]$$

Here G_A is constant with respect to frequency

Equivalent noise bandwidth

For G_A not being constant, we write

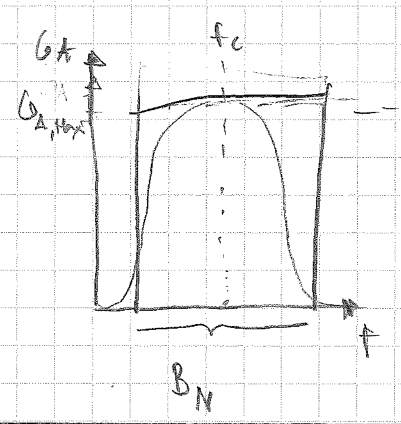
$$N = kT_e B_N \cdot G_A' = kT_e \int G_A \cdot df$$

We have:

$$B_N \cdot G_A' = \int_{-\infty}^{\infty} |H(f)|^2 \, df$$

$$B_N = \frac{\int |H(f)|^2 \, df}{G_A'}$$

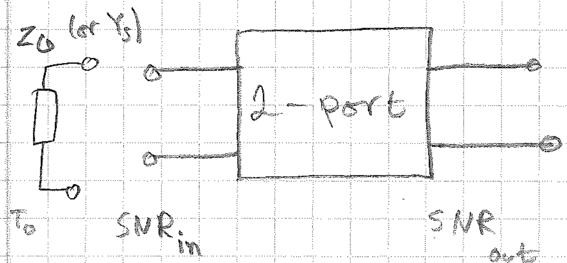
G_A' normally would be $G_{A,MAX}$



f_c should be specified

sometimes G_T is used

Noise factor



The noise factor F expresses the degradation of SNR:

$$F = \frac{SNR_{in}}{SNR_{out}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} = \frac{S_{in}}{S_{out}} \cdot \frac{N_{out}}{N_{in}}$$

$$= \frac{1}{G_A} \cdot \frac{N_{out}'}{N_{in}'}$$ same bandwidth

use G_A because of noise signals

where $n = N$!

$$G_A = \frac{S_{out}}{S_{in}} \quad [\cdot]$$

$$N_{in} = kT_o$$

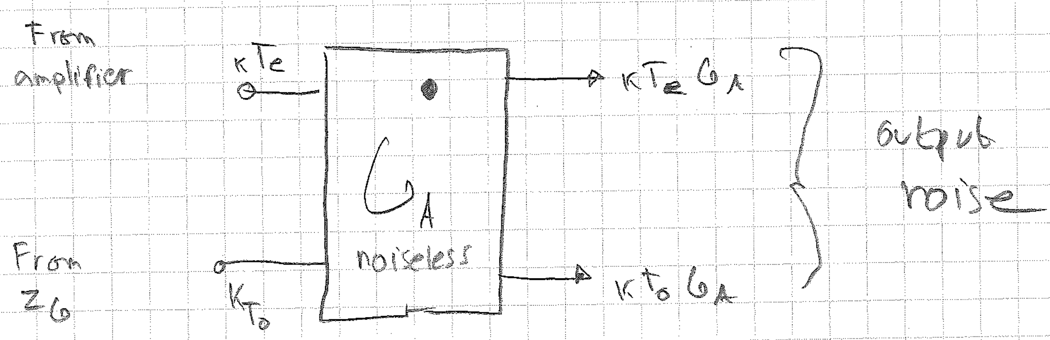
$$N_{out}' = kT_o G_A + kT_e G_A$$

We get:

$$F = \frac{1}{G_A} \cdot \frac{kT_o G_A + kT_e G_A}{kT_o}$$

$$= 1 + \frac{T_e}{T_o} \quad [\cdot]$$

Ilustration



Noise factor cont.

Noise figure:

$$NF = 10\log F \quad [dB]$$

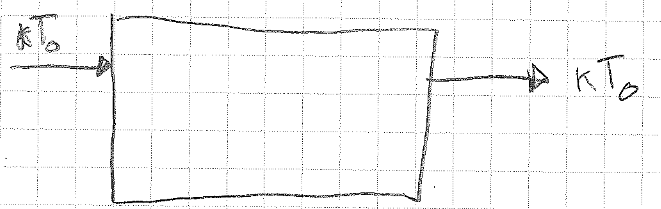
Excess noise ratio (ENR):

$$ENR = F - 1 = \frac{T_e}{T_0} \quad [\cdot]$$

leading to:

$$T_e = T_0 \cdot ENR = 290 \cdot ENR \quad [K]$$

Resistive attenuator



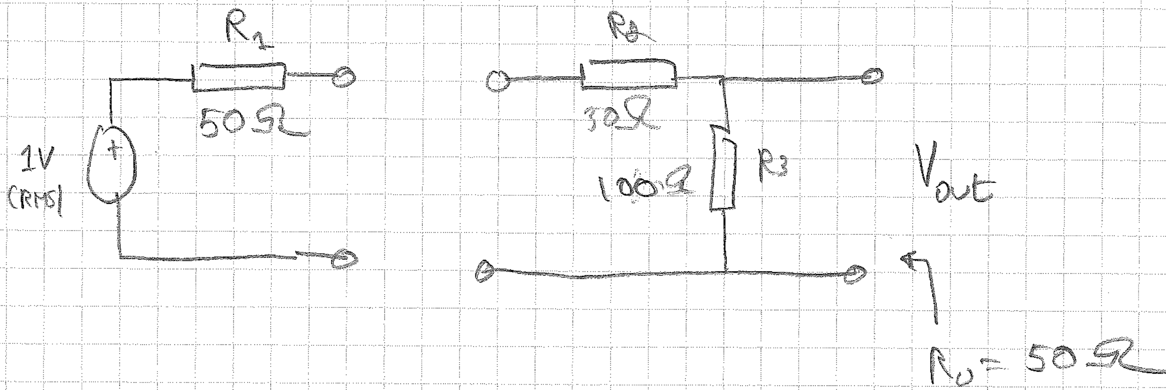
Noise factor:

$$F = \frac{1}{G_A} \cdot \frac{N_{out}'}{N_{in}} = \frac{1}{G_A} = \underset{\text{insertion loss}}{L}$$

$$T_e = T_0 \cdot (L - 1)$$

Ex

Resistive attenuator



$$V_{out} = 0.5\,V$$

$$P_{A1} = \frac{V_G^2}{4 \cdot R_1} = \frac{1}{200} = 5\,mW$$

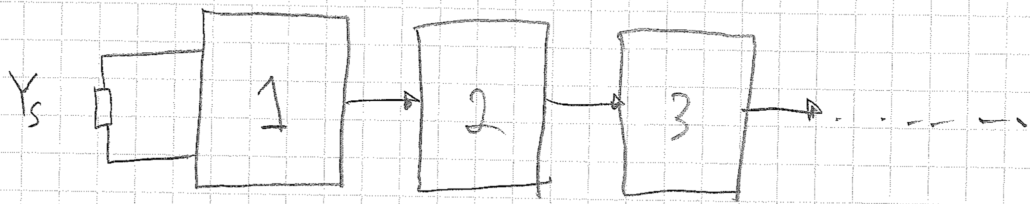
$$P_{A2} = \frac{V_{out}^2}{4 \cdot R_0} = \frac{1}{2} \cdot \frac{1}{200} = \frac{5}{4}\,mW$$

$$G_A = \frac{P_{A2}}{P_{A1}} = \frac{1}{4} \Rightarrow L = \frac{1}{G_A} = 4$$

$$F = 4$$

$$NF = 6\,dB$$

Friss cascade formula



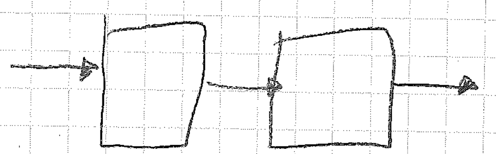
The resulting noise factor:

smallest noise factor place

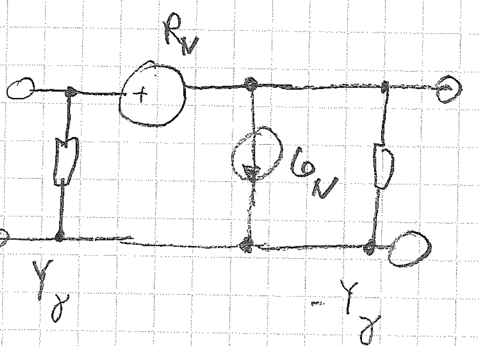
$$F_{RES} = F_1 + \frac{F_2 - 1}{G_{A1}} + \frac{F_3 - 1}{G_{A1} G_{A2}} + \frac{F_4 - 1}{G_{A1} G_{A2} G_{A3}}$$

$+ \ldots$

Noise parameters



Noise model   amplifier (noiseless)



4 values:

R_N, G_N, Y_γ
(Re+Im)