RF Tasarım

Noise, Noise Figure, Cascaded Stages, Noise Floor

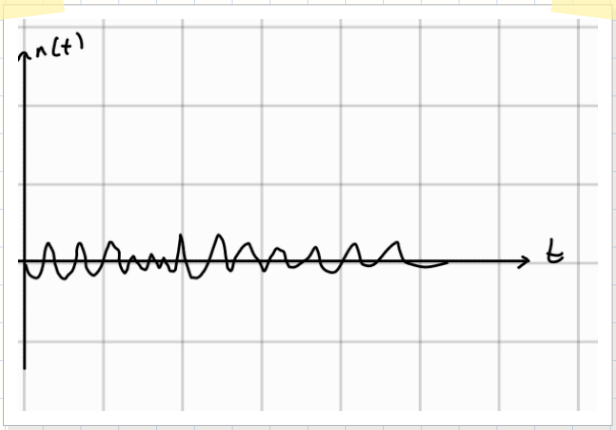
Orijinal not: Ders6.pdf

UYARI Bu belge, el yazısı ders notlarından Claude (Anthropic) yardımıyla dijitale aktarılmıştır. Yardımcı kaynak olarak hazırlanmıştır; hata veya eksik içerebilir. Lütfen orijinal notları ve ders kaynaklarını esas alın.

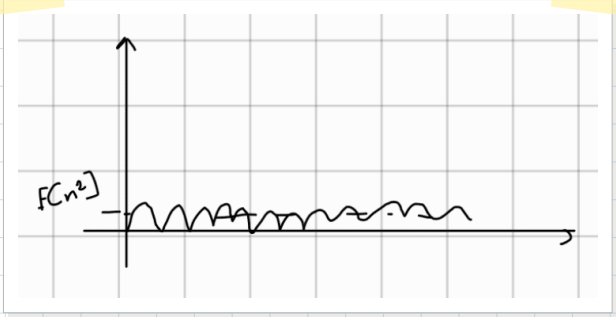
NOTICE *This document was transcribed from handwritten lecture notes with the help of Claude (Anthropic). It is meant as a supplementary resource and may contain errors or omissions. Always check against the original notes and official course material.*

orj. s. 1

Noise



orijinal çizim, s. 1

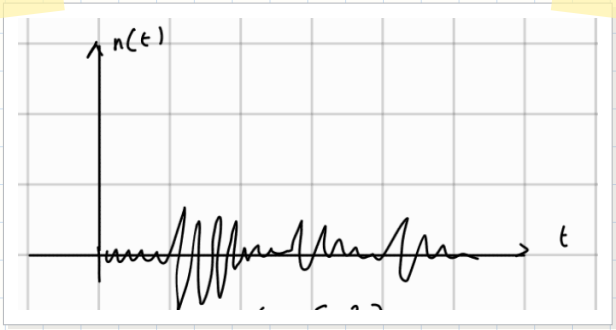


orijinal çizim, s. 1

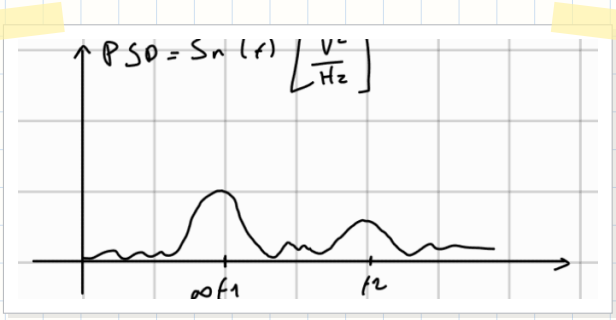
$$P_{ave} = \lim_{T\to\infty} \int_0^T n^2(t)\,dt = E\left[n^2(t)\right]$$

$$\underbrace{\sigma^2}_{P_{AC}} = \underbrace{E\left[n^2\right]}_{P_{ave}} - \underbrace{E^2\left[n\right]}_{P_{DC}}$$

$$P_{ave} = P_{AC} + P_{DC}$$

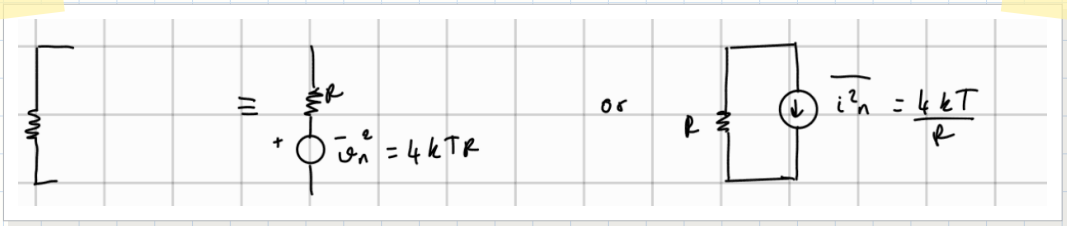


orijinal çizim, s. 1



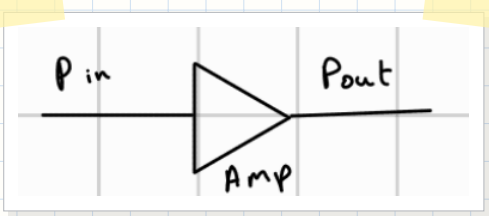
orijinal çizim, s. 1

$$P_{ave} = \int_0^{\infty} S_n(f)\, df$$



orijinal çizim, s. 1

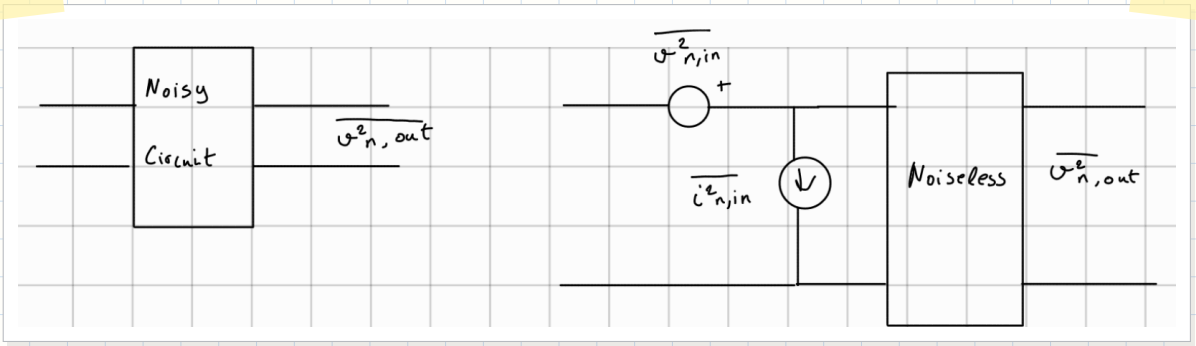
Input referred Noise



orijinal çizim, s. 1

$$\Rightarrow \begin{aligned} P_{out} &= P_{in} \cdot G \\ N_{out} &= N_{in} \cdot G + N_A \end{aligned}$$

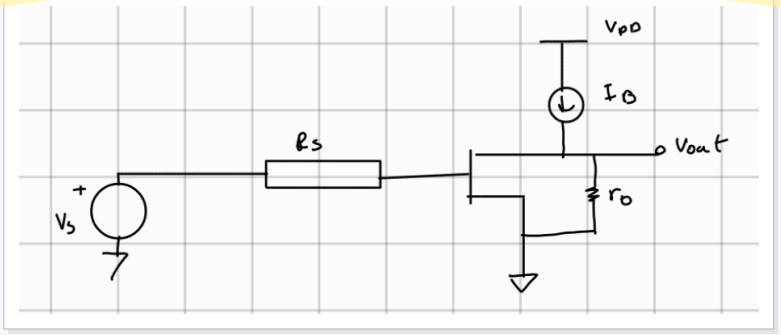
orj. s. 2



orijinal çizim, s. 2

How to find input referred Noise

Örnek



orijinal çizim, s. 2

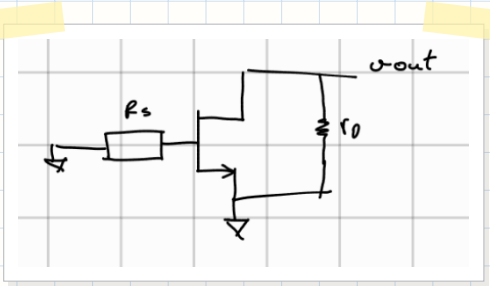
$$\overline{v^2_{n,out1}} + \overline{v^2_{n,out2}} + \overline{v^2_{n,out3}} + \cdots = \overline{v^2_{n,out(total)}}$$

$$\overline{v^2_{n,input}} = \frac{\overline{v^2_{n,out(total)}}}{A^2_{vt}}$$

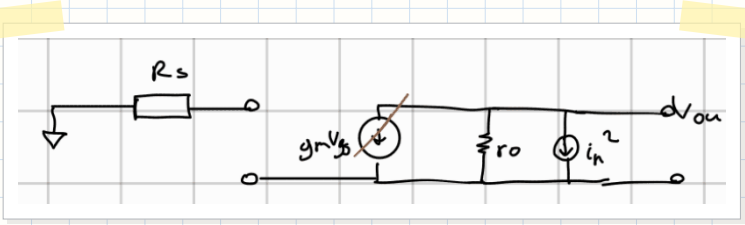
(1) Cancel sources (gerilim kısa devre, akım açık)

$v_s \rightarrow$ short

$I_B \rightarrow$ open



orijinal çizim, s. 2



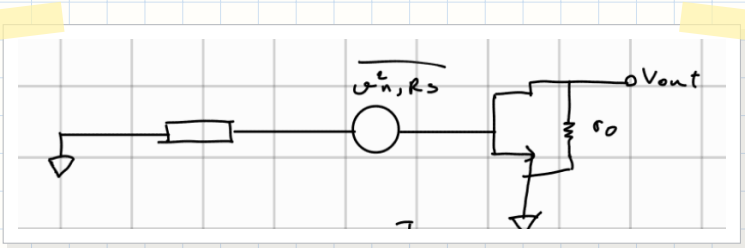
orijinal çizim, s. 2

$$\overline{i_n^2} = 4kT\gamma g_m$$

$$\rightarrow \overline{v_{out,1}^2} = \overline{i_n^2} \cdot r_o^2$$

$$\overline{v_{out,1}^2} = r_o^2\, 4kT\gamma g_m$$

(2)



orijinal çizim, s. 2

$$\overline{v_{n,out2}^2} = \overline{v_{n,R_s}^2} \overbrace{(g_m r_o)^2}^{\text{Transistor gain}} = 4kTR_s (g_m r_o)^2$$

(3) Sum of squares

$$\overline{v_{n,out(total)}^2} = \overline{v_{n,out1}^2} + \overline{v_{n,out2}^2}$$

$$= r_o^2\, 4kT\gamma g_m + (g_m r_o)^2\, 4kTR_s$$

orj. s. 3

(4) $$\overline{v_{in,n}^2} = \frac{\overline{v_{n,out(total)}^2}}{A_{vt}^2}$$

$$= \frac{r_o^2\, 4kT\gamma g_m + (g_m r_o)^2\, 4kTR_s}{(g_m r_o)^2}$$

$$\overline{v_{in,n}^2} = \underbrace{\frac{4kT\gamma}{g_m}}_{\text{amplifikatörden girişe yansıyan gürültü}} + \underbrace{4kTR_s}_{\text{kaynağın gürültüsü}}$$

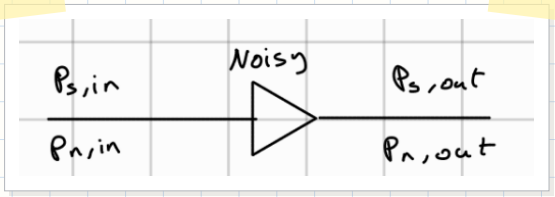
to decrease $\overline{v_{in,n}^2}$, increase g_m

genellikle amplifierlar 10,15 dB üstü tasarlanır ki gürültüsü az olsun.

Noise Figure $(NF)^{dB}$

Noise Factor (F)

$$NF = 10\log(F)$$



orijinal çizim, s. 3

$$SNR_{in} = \frac{P_{s,in}}{P_{n,in}}$$

$$SNR_{out} = \frac{P_{s,out}}{P_{n,out}} = \frac{P_{s,out}}{P_{n,in} \cdot G + P_{n,A}}$$

$$SNR_{in} > SNR_{out}$$

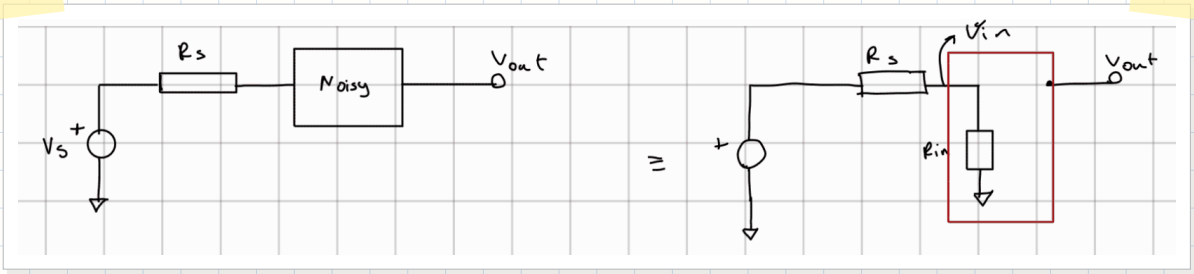
$$F = \frac{SNR_{in}}{SNR_{out}} > 1$$

$$NF = 10\log\left[\frac{SNR_{in}}{SNR_{out}}\right]$$

$$NF = SNR_{in,dB} - SNR_{out,dB} > 0\ dB$$

⋆ good LNA → NF: 0 ~ 2 dB

orj. s. 4

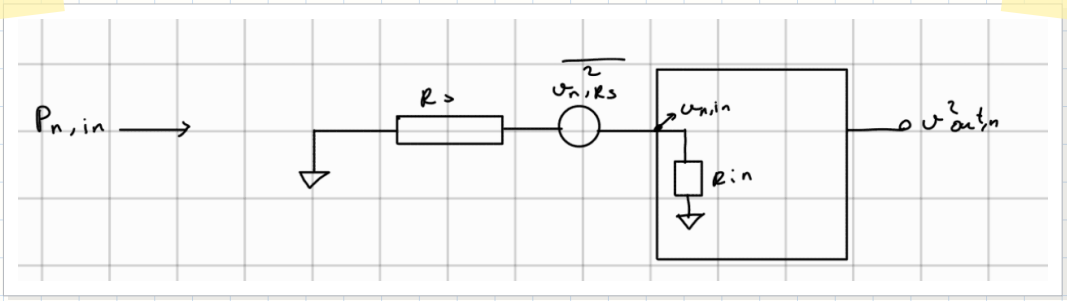


orijinal çizim, s. 4

$$SNR_{in} = \frac{P_{s,in}}{P_{n,in}}$$

$$P_{s,in} \rightarrow v_{in} = \frac{R_{in}}{R_{in} + R_s} v_s$$

$$P_{s,in} = \frac{v_{in}^2}{R_{in}} = \frac{\left(\frac{R_{in}}{R_{in}+R_s}\right)^2 \cdot v_s^2}{R_{in}}$$



orijinal çizim, s. 4

$$\rightarrow v_{n,in} = \frac{R_{in}}{R_{in} + R_s} \cdot v_{n,R_s}$$

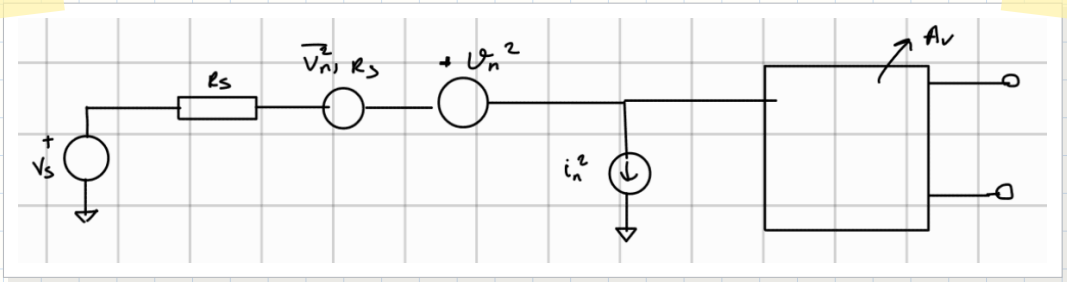
$$P_{n,in} = \frac{\overline{v_{n,in}^2}}{R_{in}} = \frac{\left(\frac{R_{in}}{R_{in}+R_s}\right)^2 \overline{v_{n,R_s}^2}}{R_{in}}$$

$$SNR_{in} = \frac{\frac{\left(\frac{R_{in}}{R_{in}+R_s}\right)^2 \cdot v_s^2}{R_{in}}}{\frac{\left(\frac{R_{in}}{R_{in}+R_s}\right)^1 \overline{v_{n,R_s}^2}}{R_{in}}} = \frac{v_s^2}{v_{n,R_s}^2} \quad \leftarrow \text{sadece kaynağa bağlı}$$

$$SNR_{in} = \frac{v_s^2}{v_{n,R_s}^2}$$

[1] Claude notu: paydadaki $\left(\frac{R_{in}}{R_{in}+R_s}\right)$ çarpanının karesi alınmamış; muhtemelen $(\cdots)^2$ olmalı.

$$SNR_{out} = \frac{P_{s,out}}{P_{n,out}}$$



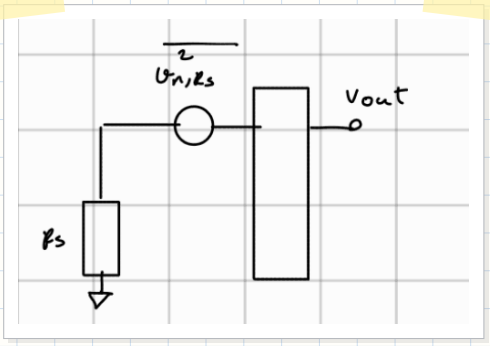
orijinal çizim, s. 4

$$P_{s,out} = \left[v_s \left(\frac{R_{in}}{R_{in}+R_s}\right)\right]^2 \cdot A_v^2 = v_s^2 \left(\frac{R_{in}}{R_{in}+R_s}\right)^2 \cdot A_v^2$$

orj. s. 5

$P_{n,out}$

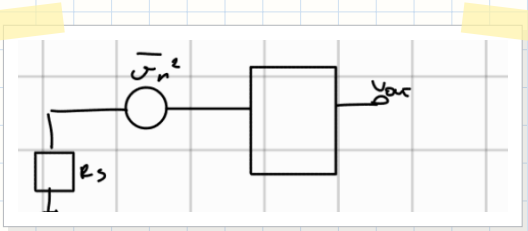
(1) Noise coming from R_s $(\overline{v_n^2} = 0,\ \overline{i_n^2} \to \infty)$



orijinal çizim, s. 5

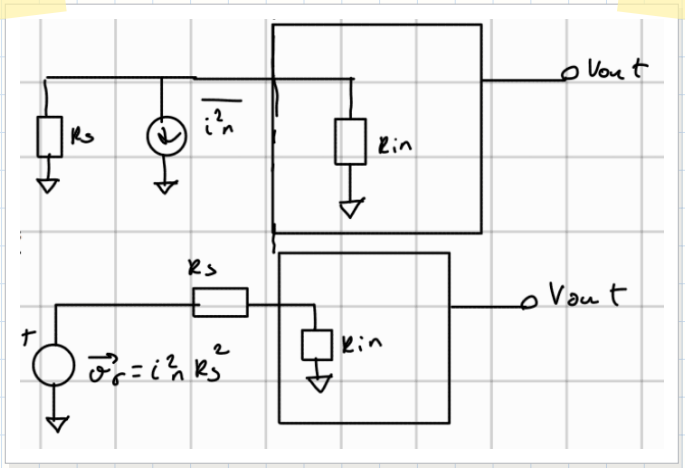
$$\overline{v_{n,out1}^2} = \overline{v_{n,R_s}^2} \cdot \left(\frac{R_{in}}{R_{in}+R_s}\right)^2 \cdot A_v^2$$

(2) Noise coming from $\overline{v_n^2}$ $(\overline{v_{n,R_s}} = 0,\ \overline{i_n^2} \to \infty)$



orijinal çizim, s. 5

(3) Noise coming from i_n^2 $(\overline{v_n^2} = 0,\ \overline{v_{n,R_s}^2} = 0)$



orijinal çizim, s. 5

$$\overline{v_{n,out3}^2} = \overline{i_n^2} R_s^2 \left(\frac{R_{in}}{R_{in}+R_s}\right)^2 \cdot A_v^2$$

$$SNR_{out} = \frac{P_{s,out}}{P_{n,out}} = \frac{v_s^2 \left(\frac{R_{in}}{R_{in}+R_s}\right)^2 \cdot A_v^2}{\left[\overline{v_{n,R_s}^2} + \overline{v_n^2} + \overline{i_n^2} R_s^2\right] \left(\frac{R_{in}}{R_{in}+R_s}\right)^2 A_v^2}$$

$$SNR_{out} = \frac{v_s^2}{\overline{v_{n,R_s}^2} + \overline{v_n^2} + \overline{i_n^2} \cdot R_s^2}$$

$$F = \frac{SNR_{in}}{SNR_{out}} = \frac{v_s^2 / \overline{v_{n,R_s}^2}}{v_s^2 / \left(\overline{v_{n,R_s}^2} + \overline{v_n^2} + \overline{i_n^2} \cdot R_s^2\right)}$$

$$F = \frac{\overline{v_{n,R_s}^2} + \overline{v_n^2} + \overline{i_n^2} R_s^2}{\overline{v_{n,R_s}^2}}$$

$$F = 1 + \frac{\overbrace{\overline{v_n^2} + \overline{i_n^2} R_s^2}^{\text{input referred noise}}}{\underbrace{\overline{v_{n,R_s}^2}}_{\text{source noise}}}$$

$$A_v = \frac{v_{out}}{v_{in}}$$

$$A_{vt} = \frac{v_{out}}{v_s} = \overbrace{\frac{v_{out}}{v_{in}}}^{A_v} \cdot \frac{v_{in}}{v_s}$$

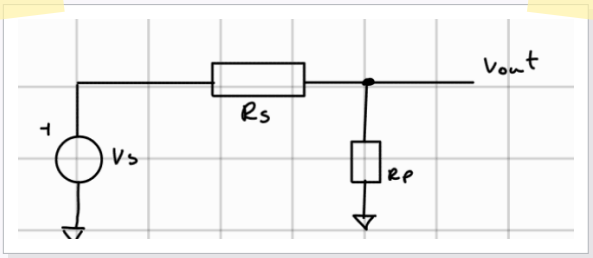
$$F = \frac{A_{vt}^2}{A_{vt}^2}\left(\frac{\overline{v_{n,R_s}^2} + \overline{v_n^2} + \overline{i_n^2}\cdot R_s^2}{\overline{v_{n,R_s}^2}}\right)$$

$$= \frac{\overline{v_{n,out}^2}}{A_{vt}^2}\cdot\frac{1}{\overline{v_{n,R_s}^2}}$$

$$\Rightarrow F = \frac{\overline{v_{n,out}^2}}{A_{vt}^2}\cdot\frac{1}{4kTR_s}$$

orj. s. 6

Örnek

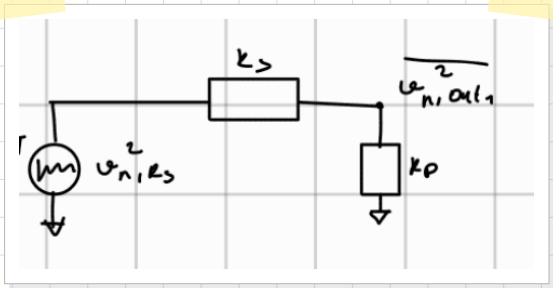


orijinal çizim, s. 6

$$F = \frac{\overline{v_{n,out}^2}}{A_{vt}^2}\cdot\frac{1}{4kTR_s}$$

$$A_{vt} = \frac{R_p}{R_s + R_p}$$

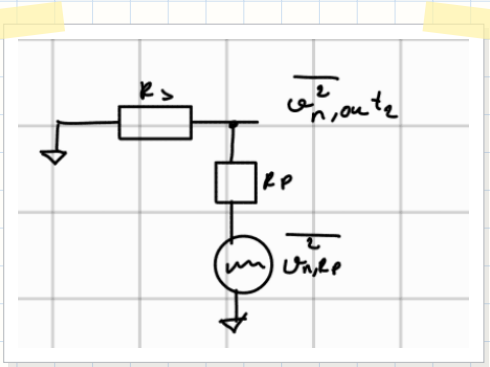
$\overline{v_{n,out(total)}^2} \rightarrow$ R_s $(v_s=0)$ $\longrightarrow$



orijinal çizim, s. 6

$$\overline{v_{n,out1}^2} = \left(\frac{R_p}{R_p + R_s}\right)^2 \overline{v_{n,R_s}^2}$$

$R_p \rightarrow$ $(v_s=0)$



orijinal çizim, s. 6

$$\overline{v_{n,out2}^2} = \left(\frac{R_s}{R_s + R_p}\right)^2 \cdot \overline{v_{n,R_p}^2}$$

$$\overline{v_{n,out(total)}^2} = \left(\frac{R_s}{R_p + R_s}\right)^2 \cdot \underbrace{\overline{v_{n,R_p}^2}}_{4kTR_p} + \left(\frac{R_p}{R_p + R_s}\right)^2 \cdot \underbrace{\overline{v_{n,R_s}^2}}_{4kTR_s}$$

$$= 4kT\frac{R_sR_p^2 + R_pR_s^2}{(R_p + R_s)^2} = 4kT\frac{R_sR_p(R_s + R_p)}{(R_s + R_p)^2}$$

$$\overline{v_{n,out(total)}^2} = 4kT\underbrace{\frac{R_sR_p}{R_s + R_p}}_{R_s \| R_p}$$

$$F = \frac{\overbrace{4kT\left(\frac{R_sR_p}{R_s + R_p}\right)}^{\overline{v_{n,out}^2}}}{\underbrace{\frac{R_p^2}{(R_s + R_p)^2}}_{A_{vt}^2}} \cdot \frac{1}{4kTR_s}$$

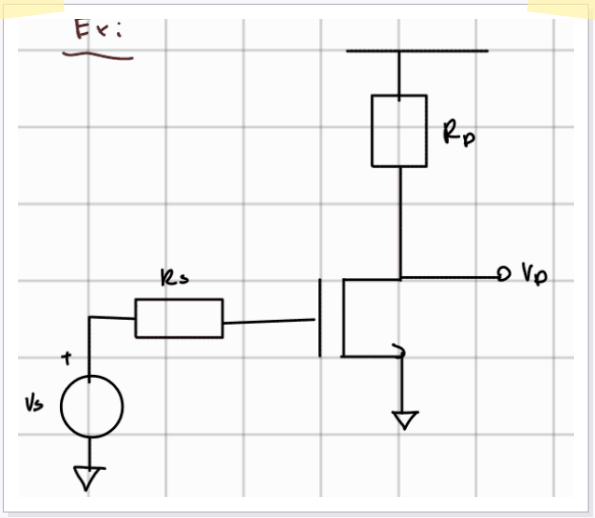
$$F = \frac{R_s + R_p}{R_p} = 1 + \frac{R_s}{R_p}$$

$R_p \uparrow\uparrow \longrightarrow F \approx 1$ görültüsüz

$R_p \gg R_s \rightarrow$ No noise effect coming from R_p

orj. s. 7

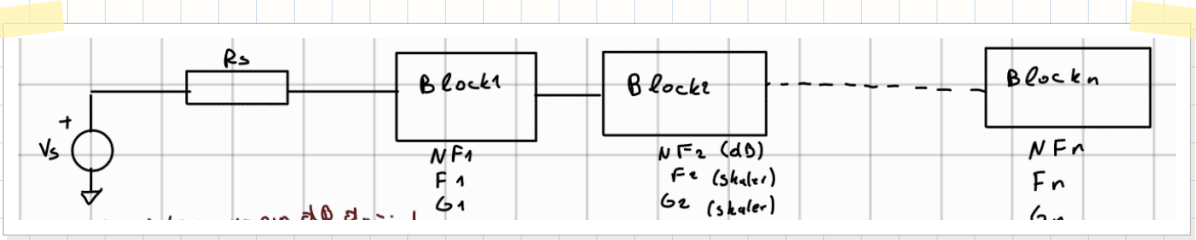
Örnek



orijinal çizim, s. 7

$$F = \frac{\overline{v_{n,out}^2}}{A_{vt}^2} \cdot \frac{1}{4kTR_s} = ?$$

Noise in Cascaded Stages



orijinal çizim, s. 7

→ skaler işlem yapın dB değil!

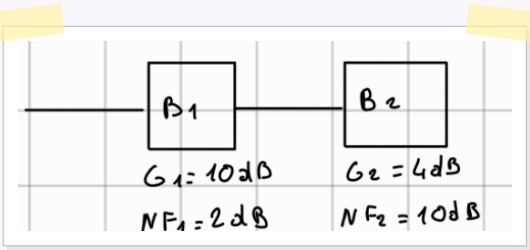
Friis' Formula

$$F_{(total)} = 1 + (F_1 - 1) + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \cdots + \frac{F_n - 1}{G_1 G_2 \cdots G_{n-1}}$$

$$F_{(total)} = \underbrace{F_1}_{\text{Dominant } F} + \frac{F_2 - 1}{\underbrace{G_1}_{\approx >10\text{ dB}}} + \frac{F_3 - 1}{G_1 G_2}$$

mutlaka girişte düşük gürültülü ve NF düşük olan amplifier seçilmeli

Örnek



orijinal çizim, s. 7

NF_t =?

$$F_t = F_1 + \frac{F_2 - 1}{G_1} = 1{,}58 + \frac{10-1}{10} = 1{,}58 + 0{,}9 = 2{,}48$$

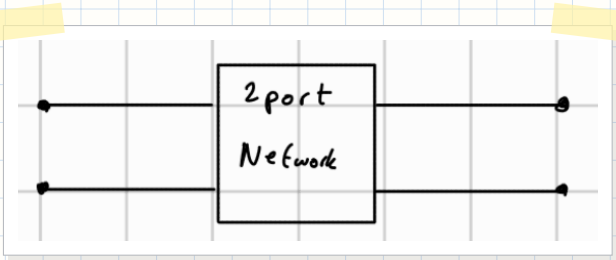
$$F_1 = 10^{\frac{NF_1}{10}} = 1{,}58$$
$$F_2 = 10^{\frac{NF_2}{10}} = 10$$
$$G_1 = 10^{10/10} = 10$$

$$\longrightarrow NF_t = 10 \log F_t = 10 \log(2{,}48) = 3{,}95 \text{ dB}$$

orj. s. 8

Noise in Passive Reciprocal Circuit

Reciprocity



orijinal çizim, s. 8

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

S_{11} → Return loss

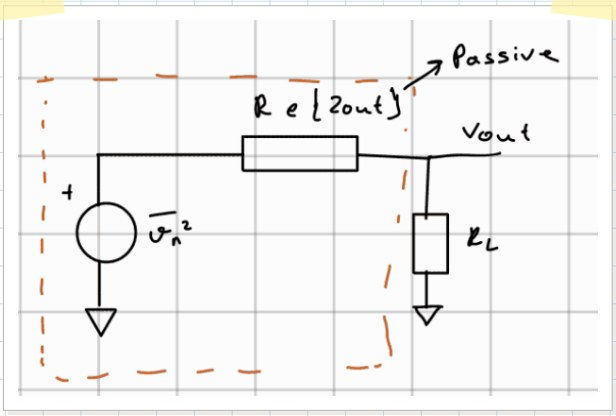
S_{22} → Output Return loss

S_{21} → Gain

S_{12} → Isolation

Reciprocity ← pasif devrelerde olabiliyor

$$S_{12} = S_{21}$$

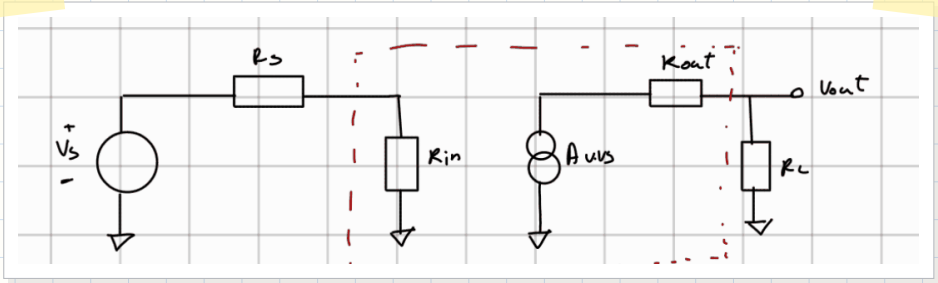


orijinal çizim, s. 8

$$\overline{v_n^2} = 4kT \underbrace{\mathrm{Re}\{Z_{out}\}}_{R_{out}}$$

$$\overline{v_{n,out}^2} = \overline{v_n^2} \left(\frac{R_L}{R_L + R_{out}} \right)^2$$

$$\overline{v_{n,out}^2} = 4kTR_{out} \left(\frac{R_L}{R_L + R_{out}} \right)^2$$



orijinal çizim, s. 8

$R_s = R_{in}$ Input matched $R_L = R_{out}$ output matched

$$\frac{R_{in}}{R_s + R_{in}} = \frac{1}{2}$$

$$P_{in} = \frac{V_{in}^2}{R_{in}} = \frac{V_s^2}{4R_{in}}$$

orj. s. 9

$$P_{out} = \frac{(A_v \cdot V_s)^2}{4R_L}$$

$$\frac{P_{out}}{P_{in}} = G$$

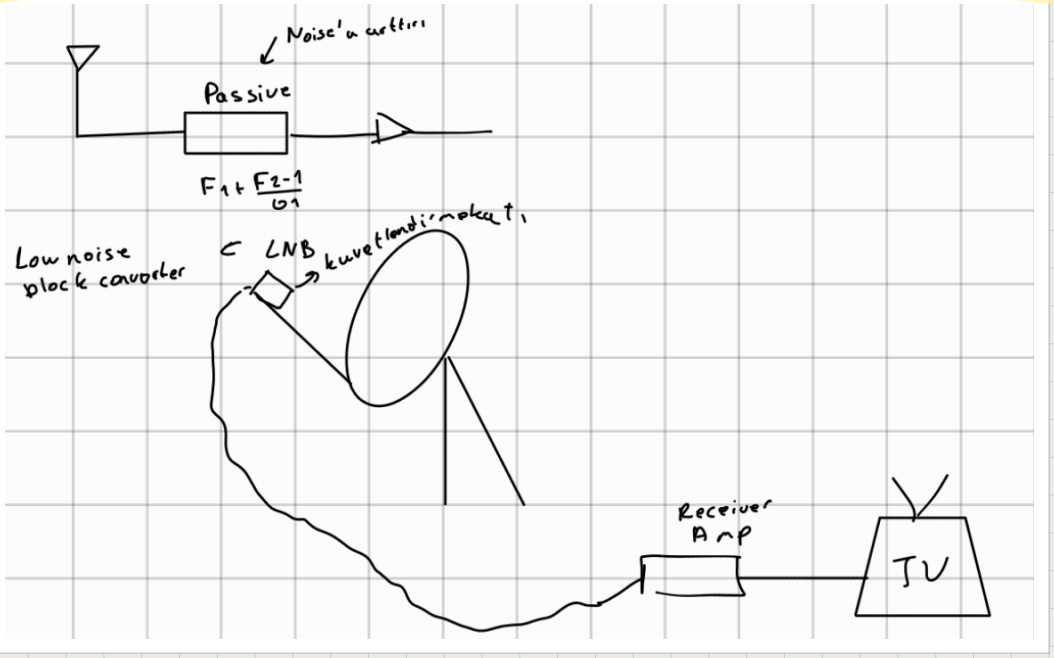
$$G = \frac{\frac{(A_v \cdot V_s)^2}{4R_L}}{\frac{V_s^2}{4R_{in}}} = \boxed{A_v^2 \cdot \frac{R_s}{R_L} = G}$$

$$\underbrace{L}_{\text{Zayıflatma}} = \frac{1}{G} = \frac{1}{A_v^2} \cdot \frac{R_L}{R_s}$$ ← Pasif devrelerde

$$NF = \frac{\overline{v_{n,out}^2}}{A_{vt}^2} \cdot \frac{1}{4kTR_s} = \frac{\frac{4kTR_L}{4}}{\left(\frac{A_v}{2}\right)^2} \cdot \frac{1}{4kTR_s}$$

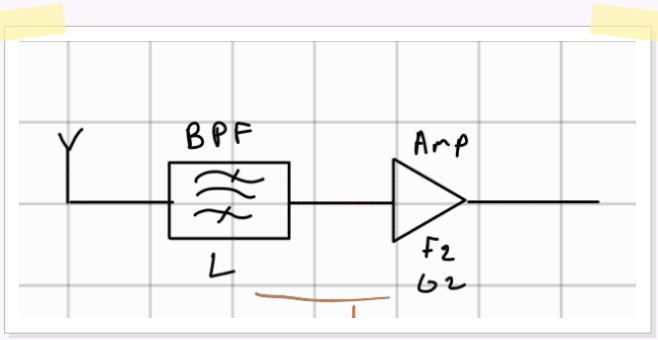
$$\Rightarrow \boxed{NF = \frac{1}{A_v^2} \cdot \frac{R_L}{R_s}}$$

$$A_{vt} = \overbrace{\left(\frac{v_o}{v_{in}}\right)}^{A_v} \overbrace{\left(\frac{v_{in}}{v_s}\right)}^{1/2} = \frac{A_v}{2}$$



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Örnek



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F_t =?

$$F_t = F_1 + \frac{F_2 - 1}{G_1} = L + \frac{F_2 - 1}{\frac{1}{L}}$$
$$= L + LF_2 - L = LF_2 = F_{total}$$

$$\left.\begin{aligned} F_1 &= L \\ G_1 &= \frac{1}{L} \end{aligned}\right\}$$

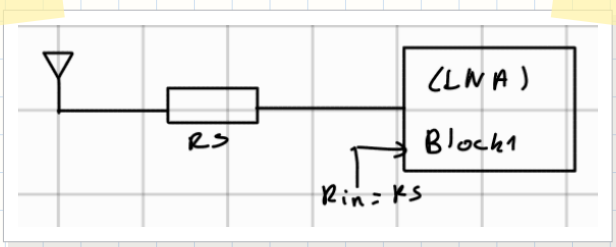
$$NF_t = L_{dB} + NF_2$$ ← Noise figürü arttırır

ters olması daha iyi

Onun yerine dar bantlı amfi ? seç

orj. s. 10

Noise power in Rx input



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$$\overline{v_{in,n}^2} = \underbrace{\left(\frac{R_{in}}{R_{in} + R_s}\right)^2}_{1/4} \cdot \underbrace{\overline{v_s^2}}_{4kTR_s} = kTR_s$$

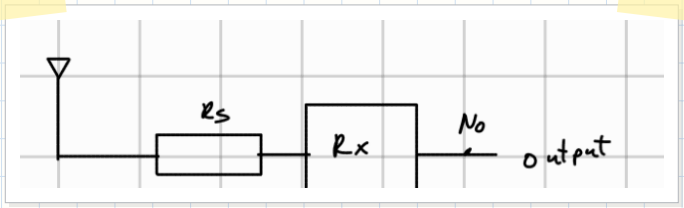
$$\frac{\overline{v_{n,in}^2}}{R_{in}} = \frac{kTR_s}{\underbrace{R_{in}}_{R_{in}=R_s}} = kT \quad (1\,\text{Hz},\ BW)$$

1Hz'lik bantta kT kadar power bulunur

$$P_{in} = kTB \quad \text{(Input noise power in bandwith } B\text{)}$$

Receive Noise Floor

Noise floor = Receiver input equivalent noise



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N_o : output noise power exluding R_s.

kaynak ?düşünülmediğindeki gürültü

$$F = \frac{\overline{v_{n,input}^2}}{A_{vt}^2} \cdot \frac{1}{4kTR_s} = \frac{\text{Total output noise power including } R_s}{G \cdot (\text{Noise power from } R_s \text{ only})}$$

$$= \frac{N_o + G(kTB)}{G \cdot kTB} = F$$

$$\Rightarrow \text{Input noise} = kTB + \frac{N_o}{G} = \underbrace{FkTB}_{\text{Noise Floor}}$$