RF Tasarım

Vize çalışması: Doğrusal olmama, gürültü, dinamik aralık

Orijinal not: Not.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

$$v = A\cos\omega t$$

$$\frac{A^2}{2} = \frac{1}{T}\int_0^T v^2(t)\,dt = V_{rms}^2$$

$$P = \frac{A^2}{2R}$$

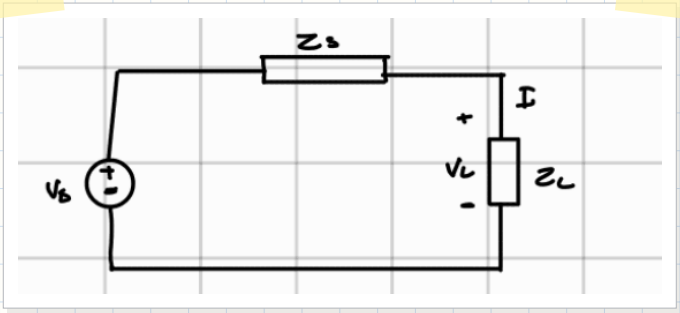
Power and Phasor

$$P_{avg} = \frac{|V|}{\sqrt{2}} \cdot \frac{|I|}{\sqrt{2}} \cos(\phi) \qquad \phi = \theta_V - \theta_I$$
$$= V_{rms} \cdot I_{rms} \cos(\phi)$$

Complex power

$$S = \underbrace{P}_{\text{aktif güç (W)}} + j \underbrace{Q}_{\text{reaktif güç (VAR)}}$$
$$= \frac{1}{2}(V \cdot I^*) = V_{rms} I_{rms}^*$$
$$|S| = \text{görünür güç}$$

Maximum power

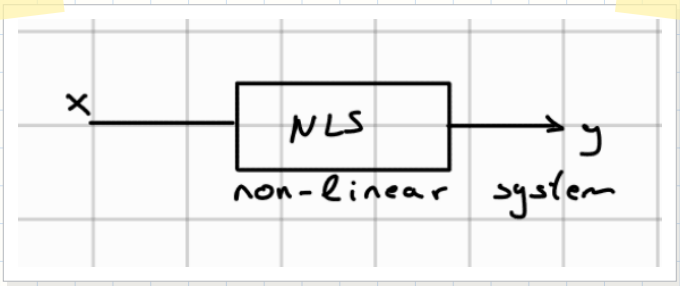


orijinal çizim, s. 1

$$Z_s = Z_L^* \Rightarrow P_L = \frac{1}{8}\frac{|V_s|^2}{R_s}$$

① Harmonic distortion

$$y = a_1x + a_2x^2 + a_3x^3$$



orijinal çizim, s. 1

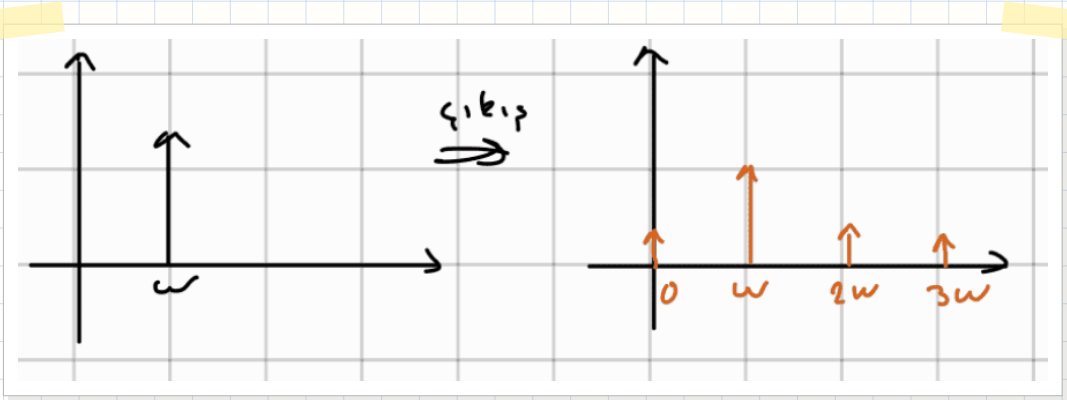
$$x(t) = A\cos\omega t$$

$$y(t) = a_1A\cos\omega t + a_2(A\cos\omega t)^2 + a_3(A\cos\omega t)^3$$

$$(A\cos\omega t)^2 = \frac{A^2}{2}(1+\cos 2\omega t)$$

$$(A\cos\omega t)^3 = \frac{A^3}{4}(3\cos\omega t + \cos 3\omega t)$$

$$y(t) = a_1A\cos\omega t + a_2\frac{A^2}{2}(1+\cos(2\omega t)) + a_3\frac{A^3}{4}(3\cos\omega t + \cos 3\omega t)$$



orijinal çizim, s. 1

$$y(t) = \frac{a_2 A^2}{2} + \left(a_1 A + \frac{3a_3 A^3}{4}\right)\cos\omega t + \frac{a_2 A^2}{2}\cos 2\omega t + \frac{a_3 A^3}{4}\cos 3\omega t$$

orj. s. 2

BPF $a_1 A + \frac{3a_3}{4}A^3$ geçer

② Gain compression

$$V_{out} = \underbrace{-\sqrt{2k\frac{W}{L}I_B}R_D}_{a_1} V_{in} + \underbrace{\frac{2k^{3/2}}{8\sqrt{I_B}}R_D}_{\frac{3a_3}{4}} V_{in}^3$$

a_1, a_3 have different signs

Most of the time $a_1 \cdot a_3 < 0$

$$\text{Gain} = \frac{V_{out}(\text{fundamental})}{V_{in}} = \frac{a_1 A + \frac{3a_3}{4}A^3}{A}$$

$$V_{out} = a_1 V_{in} + \frac{3a_3}{4}V_{in}^3$$

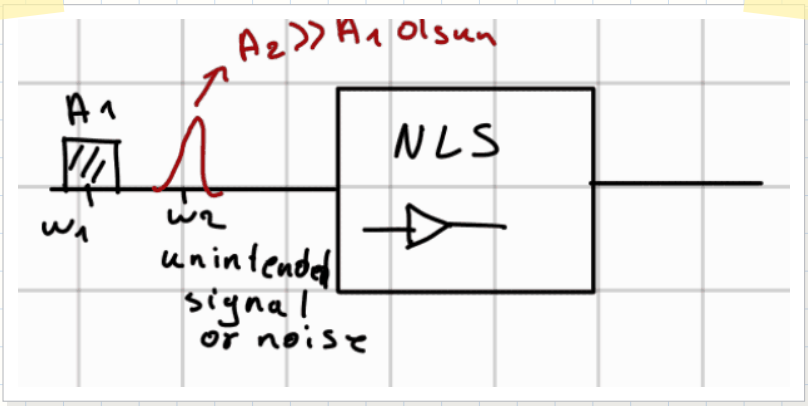
$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{a_1 A + \frac{3a_3}{4}A^3}{A}$$

$$\Rightarrow \text{gain} = a_1 + \frac{3}{4}a_3 A^2$$

1) $a_1 > 0$, $a_3 < 0 \rightarrow \text{Gain} = a_1 - \frac{3}{4}|a_3|A^2 \rightarrow v_{in}$ gain girişe bağlı.
2) $\text{Gain} \propto A^2$

girişin genliği çok yükselirse kazanç düşer

③ Desensitization

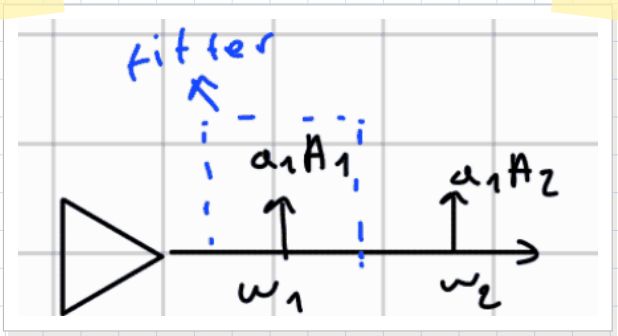


orijinal çizim, s. 2

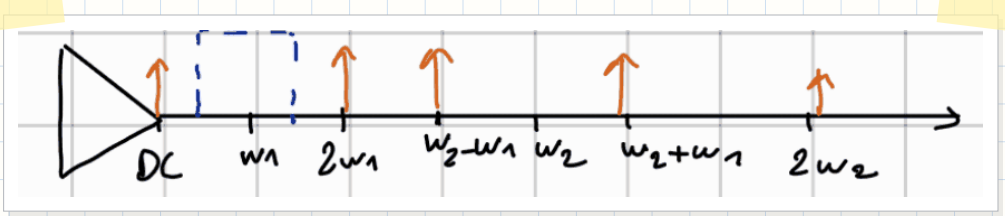
$$x_i(t) = \underbrace{A_1 \cos \omega_1 t}_{\text{desired input signal}} + \underbrace{A_2 \cos \omega_2 t}_{\text{unwanted signal}}$$

$$y = a_1 x + a_2 x^2 + a_3 x^3$$

$$y(t) = a_1 A_1 \cos \omega_1 t + a_1 A_2 \cos \omega_2 t + a_2 \left[A_1^2 \cos^2 \omega_1 t + A_2^2 \cos^2 \omega_2 t \right] + 2 a_2 A_1 A_2 \underbrace{(\cos \omega_1 t)(\cos \omega_2 t)}_{\cos(\omega_1+\omega_2)t + \cos(\omega_2-\omega_1)t}$$



orijinal çizim, s. 2



orijinal çizim, s. 2

orj. s. 3

$$+ a_3\Big[A_1^3\cos^3\omega_1 t + A_2^3\cos^3\omega_2 t + 3A_1\cos\omega_1 t\cdot\underbrace{A_2^2\cos^2\omega_2 t}_{1+\cos 2\omega_2 t}$$

$$+ 3A_2\cos\omega_2 t\cdot A_1^2\cos^2\omega_1 t\Big]$$

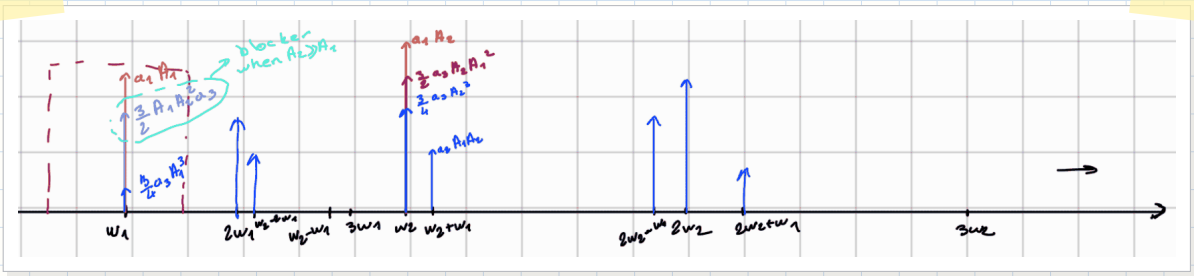
$$\frac{3}{4}a_3A_1^3\cos\omega_1 t + \frac{A_1^3}{4}\cos 3\omega_1 t$$

$$\begin{array}{ccc} & \cos\omega_1 t & \cos\omega_2 t \\ \cos\omega_2 t & + & + \\ + & \cos(2\omega_2-\omega_1)t & \cos(2\omega_1-\omega_2)t \\ \cos 3\omega_2 t & + & + \\ & \cos(2\omega_2+\omega_1)t & \cos(2\omega_1+\omega_2)t \end{array}$$

$$n\omega_1 + m\omega_2$$
$$n + |m| = 3$$

gelen sinyal

$$\frac{3}{4}a_3A_1^3\cos\omega_1 t + \frac{3A_1A_2^2}{2}a_3\cos\omega_1 t$$



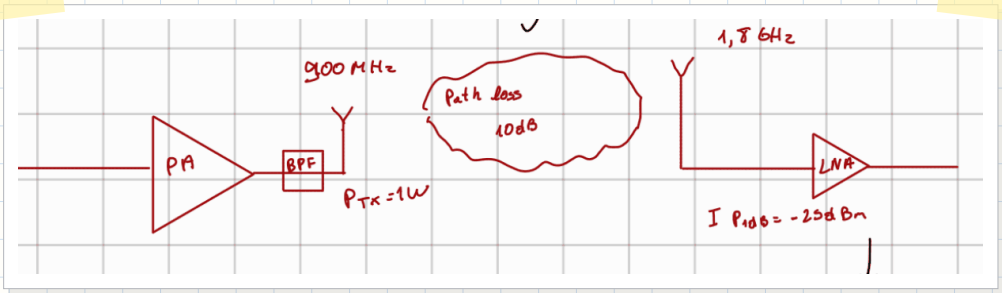
orijinal çizim, s. 3

ω_1 frekansında olan sinyal:

$$a_1A_1\cos\omega t + \frac{3}{4}a_3A_1^3\cos\omega_1 t + \frac{3A_1A_2^2}{2}a_3\cos\omega_1 t$$

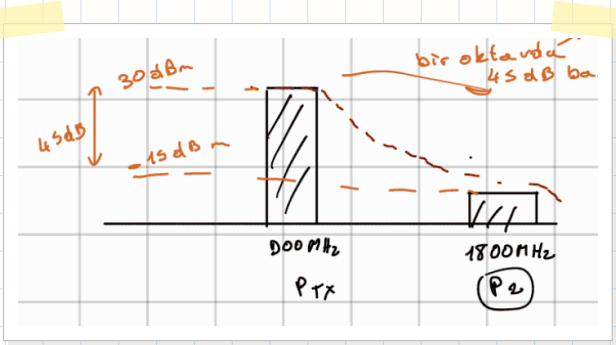
Gain: $\dfrac{\left(a_1A_1 - \frac{3}{2}|a_3|A_1A_2^2\right)\cos\omega_1 t}{A_1\cos\omega t}$ } $A_2\uparrow\uparrow$ No signal appears at the output

Ex



orijinal çizim, s. 3

Vericinin ikinci harmoniğine kadar bastırılmalıdır ki bu alıcı ?doyuma uğramasın



orijinal çizim, s. 3

$$P_2 - 10\,\text{dB} < P_{1dB}$$
$$P_2 - 10 < -25\,\text{dB}$$
$$P_2 < -15\,\text{dBm}$$

en az 45 dB bastırılmalıdır.

0 dBm 1 mWatt
10 dBm 10 mWatt
$$10\log\left(\frac{1\,W}{10^{-3}}\right) = 30\,\text{dBm}$$

orj. s. 4

④ Intermodulation

$$A_{IM3} = \frac{3}{4}a_3 A_1^2 A_2 \cos(2\omega_1 - \omega_2)t$$
$$A_1 = A_2 = A \Rightarrow A_{IM3} = \frac{3}{4}a_3 A^3$$

if system linear $\Rightarrow a_1 A$

Intermodulation products $\Rightarrow \frac{3}{4}a_3A^3$

$$IM3 = \frac{\frac{3}{4}a_3A^3}{a_1A} = \frac{3}{4}\left|\frac{a_3}{a_1}\right|A^2$$

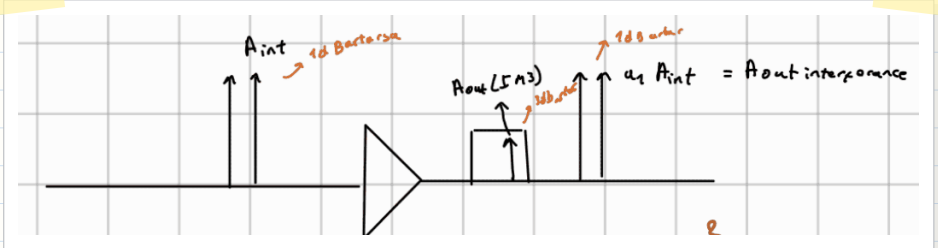
$$A_{IIP3} \Rightarrow 20\log(|a_1|A_{IIP3}) = 20\log\left(\frac{3}{4}|a_3|A_{IIP3}^3\right)$$

$$\boxed{A_{IIP3} = \sqrt{\frac{4}{3}\left|\frac{a_1}{a_3}\right|}}$$

$$A_{1dB} = \sqrt{0{,}145\left|\frac{a_1}{a_3}\right|}$$

$$A_{IIP3}(dB) - A_1(dB) = 9{,}6\ dB$$

if A_{IIP3} ↑ more linear system



orijinal çizim, s. 4

$$\frac{A_{out,int}(\omega_1,\omega_2)}{A_{out}(IM3)} = \frac{a_1A_{int}}{\frac{3}{4}a_3A_{int}^3} = \frac{a_1{}^1}{\frac{3}{4}a_3A_{int}^2} = \frac{A_{IIP3}^2}{A_{int}^2}$$

$$A_{IIP3}^2 = \frac{A_{out,int}(\omega_1,\omega_2)}{A_{out}(IM3)}A_{int}^2$$

$$20\log(A_{IIP3}) = 20\log(A_{int}) + \frac{1}{2}\left[20\log A_{out,int}(\omega_1,\omega_2) - 20\log A_{out}(IM3)\right]$$

Ex

$$P = \frac{V^2}{R}$$

$$10\log\left(\frac{P_{IIP3}}{\underbrace{10^{-3}}_{W}}\right) = -10\ dBm$$

$$\underbrace{}_{-1}$$

$$\Rightarrow P_{IIP3} = 10^{-4}\ W = 0{,}1\ mW$$

$$P_{IIP3} = \frac{A_{IIP3}^2}{2} \qquad \sqrt{A_{IIP3}^2} = \sqrt{10^{-4}\cdot 50}$$

[1] Kırmızı kalemle a_1 üzerine A_{IIP3}^2 yazılmış.

$$A_{IIP3} = 70\ \text{mV}$$

orj. s. 5

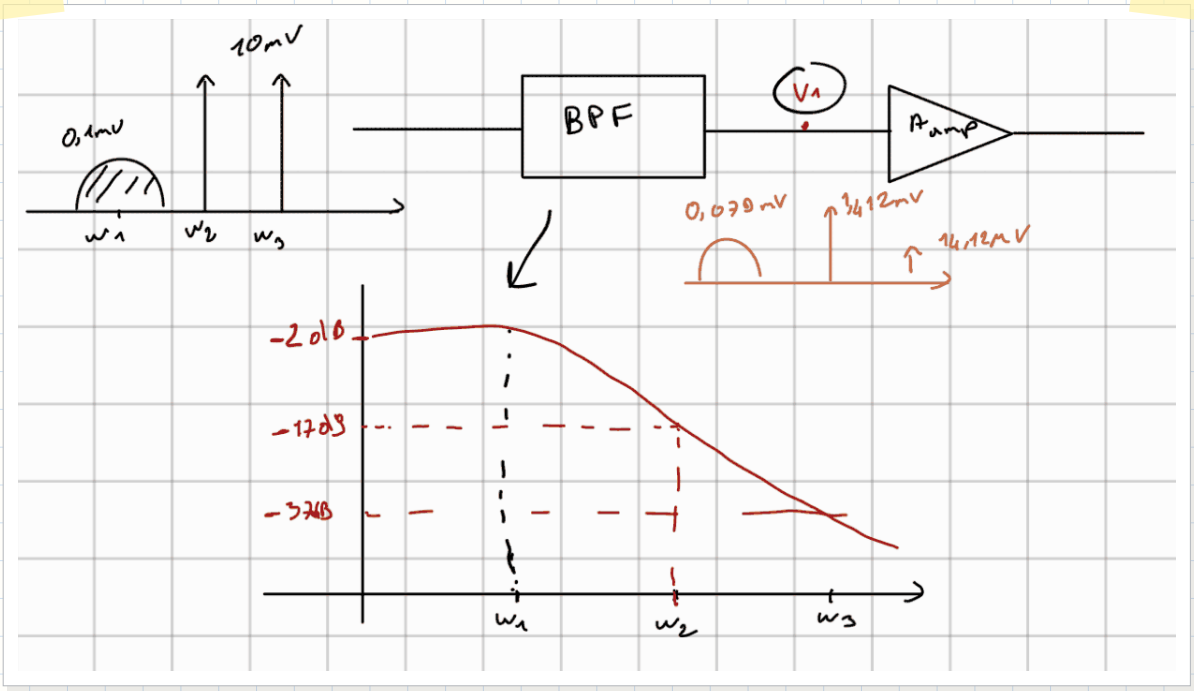
$$A_{IIP3}^2 = \frac{A_{out,int}(\omega_1, \omega_2)}{A_{o,IM3}} \cdot A_{in,int}^2$$

$$A_{IIP3}^2 = \frac{a_1 A_{in,int}}{A_{o,IM3}} \cdot A_{in,int}^2 = \frac{a_1 A_{in,int}^3}{A_{o,IM3}}$$

$$A_{IIP3}^2 = \overbrace{\frac{a_1 A_{in,int}^3}{A_{o,IM3}} \cdot \frac{A_{in,s}}{A_{in,s}}}^{A_{o,s}} = \boxed{\frac{A_{o,s}}{A_{o,IM}}} \cdot \frac{A_{in,int}^3}{A_{in,s}}$$

$$\frac{A_{o,s}}{A_{o,IM3}} = A_{IIP3}^2 \cdot \frac{A_{in,s}}{A_{in,int}^3} = (70\ \text{mV})^2 \cdot \frac{1\ \text{mV}}{(1\ \text{mV})^3} = 4{,}9 \longrightarrow \simeq 13{,}8\ \text{dB}$$

Ex



orijinal çizim, s. 5

Compute IIP3 of the amplifier such that IM3 product falling at ω_3 is 20 dB below the desired signal ? ($\rightarrow A_{o,IM3}$??, $\rightarrow A_{o,s}$)

$$\frac{A_{o,s\text{dB}}}{A_{o,IM3\text{dB}}} = 20\ \text{dB} \Rightarrow \frac{A_{o,s}}{A_{o,IM3}} = 10$$

$$20 \log A_{sig}(\omega_1) - 2\ \text{dB} = 20 \log A_{sig_{BPF}}(\omega_1)$$

$$20 \log \frac{A_{sig}}{A_{sig_{BPF}}} = 2 \Rightarrow \frac{A_{sig}}{A_{sig_{BPF}}} = 10^{1/10} = \frac{0{,}1 \cdot 10^{-3}\ \text{V}}{A_{sig_{BPF}}}$$

$$A_{sig_{BPF}}(\omega_1) = 0{,}079\ \text{mV} = \textcircled{V_1}$$

$$20\log\frac{A_{int}(\omega_2)}{10\,\text{mV}} - 17\,\text{dB} = 20\log A_{int_{BPF}}(\omega_2)$$

$$\Rightarrow A_{int_{BPF}}(\omega_2) = 1{,}412\ \text{mV}\ \checkmark_2$$

$$\ldots\ A_{int_{BPF}}(\omega_3) = 0{,}141\ \text{mV}\ \checkmark_3$$

orj. s. 6

$$\underset{(\text{dB})}{A_{o,sig}} - \underset{(\text{dB})}{A_{o,IM3}} = 20\ \text{dB}$$

$$A_{o,s} = a_1 V_1$$

$$A_{o,IM3} = \frac{4}{3}a_3 A_2^2 A_3{}^2 = \frac{3}{4}a_3 V_2^2 V_3$$

$$\Rightarrow 20\log(a_1 V_1) - 20\log\left|\frac{3}{4}a_3 V_2^2 V_3\right| = 20\log 10$$

$$\frac{a_1 V_1}{\frac{3}{4}a_3 V_2^2 V_3} = 10 \Rightarrow \frac{a_1}{a_3} = 26{,}6\cdot 10^{-6}$$

$$A_{IIP3} = \sqrt{\frac{4}{3}\left|\frac{a_1}{a_3}\right|} = \sqrt{\frac{4}{3}\left|26{,}6\cdot 10^{-6}\right|} = 5{,}95\ \text{mV} \approx 15{,}5\ \text{dBm}$$

Ex:

$$\left.\begin{aligned} a_1 &= 10 \\ A_{in,int} &= 10\ \text{mV} \\ A_{IIP3} &= 80\ \text{mV} \end{aligned}\right\} \quad \begin{aligned} IM3 &= ? \\ A_{o,IM3} &= ? \end{aligned}$$

$$A_{IIP3} = \sqrt{\frac{4}{3}\left|\frac{a_1}{a_3}\right|}$$

$$80\cdot 10^{-3} = \sqrt{\frac{4}{3}\cdot\frac{10}{a_3}}$$

$$a_3 = \frac{4\cdot 10}{3\cdot(80\cdot 10^{-3})^2} = \boxed{2083}$$

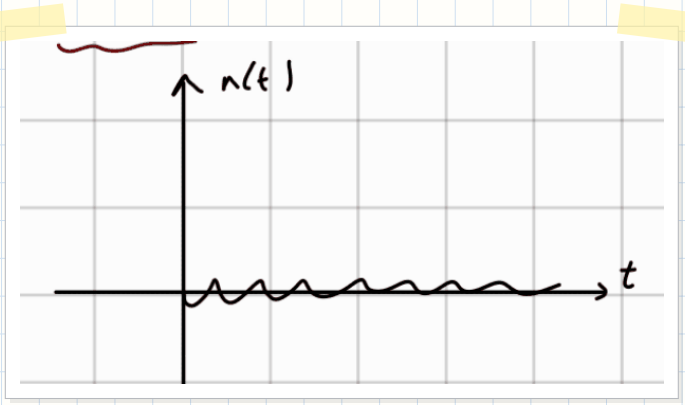
$$IM3 = \frac{\frac{3}{4}a_3 A^3}{a_1 A} = \frac{\frac{3}{4}(2083)(10\cdot 10^{-3})^2}{10} = \boxed{0{,}0156}$$

$$A_{o,IM3} = \frac{3}{4}a_3 A^3 = 0{,}001562\ \text{V}$$
$$= 1{,}562\ \text{mV}$$

orj. s. 7

[2] Claude notu: muhtemelen $\frac{3}{4}$ olmalı.

Noise

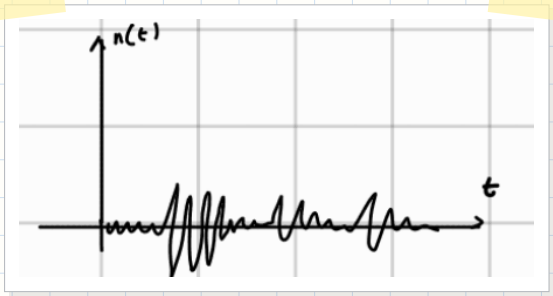


orijinal çizim, s. 7

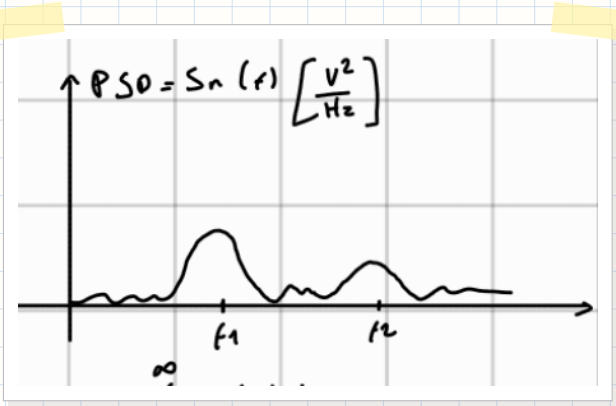
$$P_{ave} = \lim_{T\to\infty} \int_0^T n^2(t)\,dt = E\left[n^2(t)\right]$$ [3]

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

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



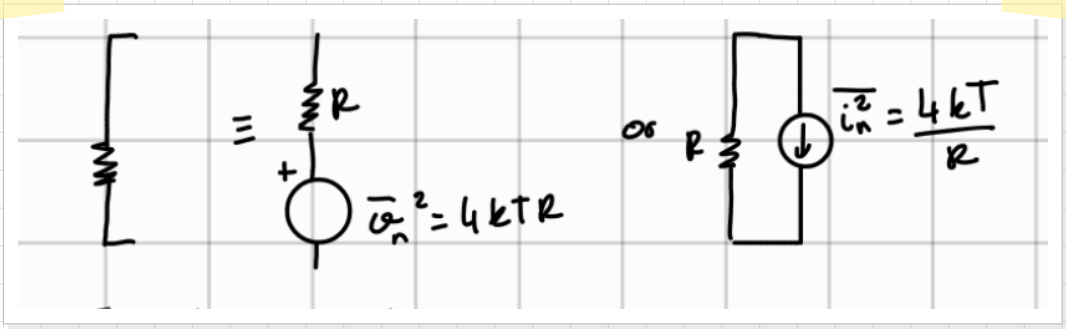
orijinal çizim, s. 7



orijinal çizim, s. 7

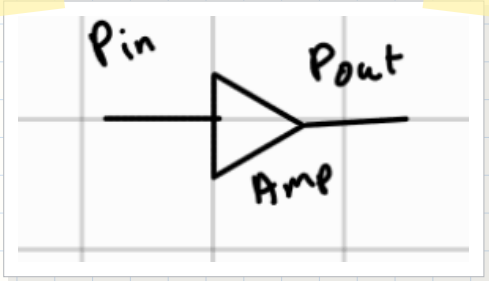
$$P_{ave} = \int_0^\infty S_n(f)\,df$$

[3] Claude notu: muhtemelen integralin önünde $\frac{1}{T}$ çarpanı olmalı.



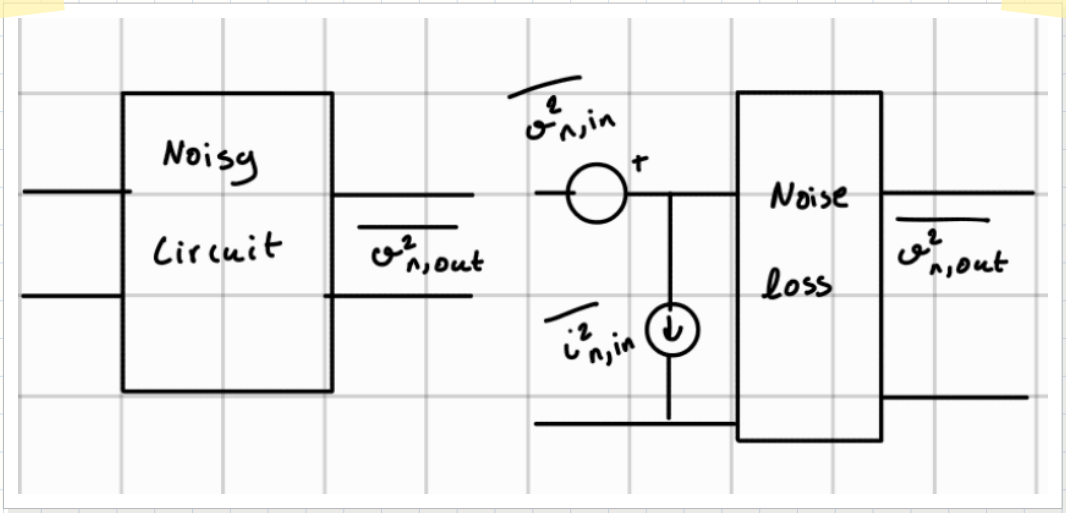
orijinal çizim, s. 7

Input referred Noise



orijinal çizim, s. 7

$$\Rightarrow P_{out} = P_{in} \cdot G$$
$$N_{out} = N_{in} \cdot G + N_A$$



orijinal çizim, s. 7

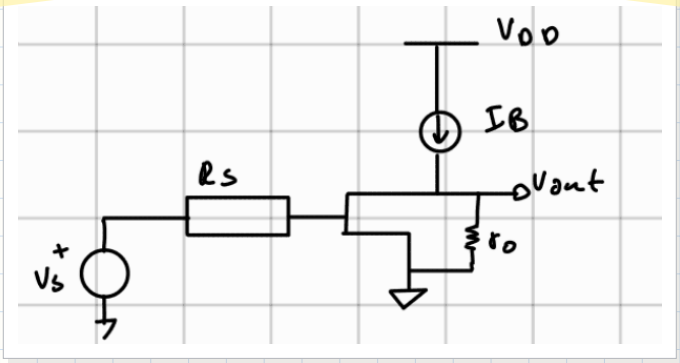
$$A_v = \frac{v_{out}}{v_{in}}$$

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

← önemli

How to find input referred Noise

Ex:



orijinal çizim, s. 7

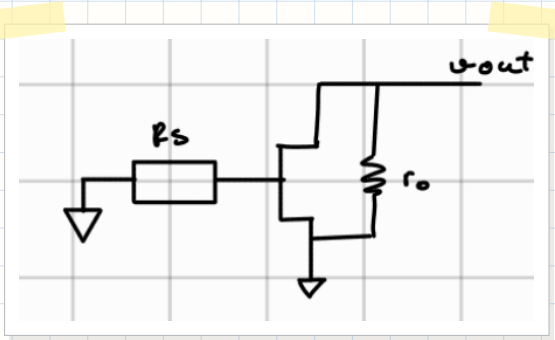
$$\overline{v_{n,out_1}^2} + \overline{v_{n,out_2}^2} + \overline{v_{n,out_3}^2} + \cdots = \overline{v_{n,out_{total}}^2}$$

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

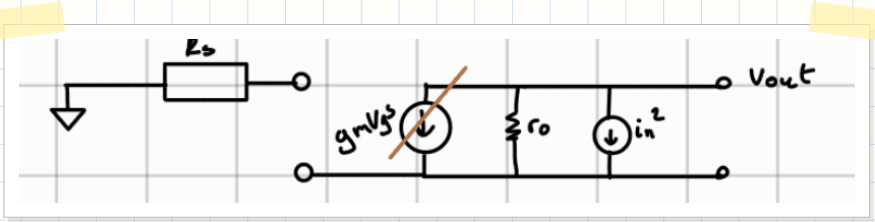
① Cancel sources (gerilim kaynağı kısa, akım kaynağı açık devre)

$v_s \rightarrow$ short

$I_B \rightarrow$ open



orijinal çizim, s. 7

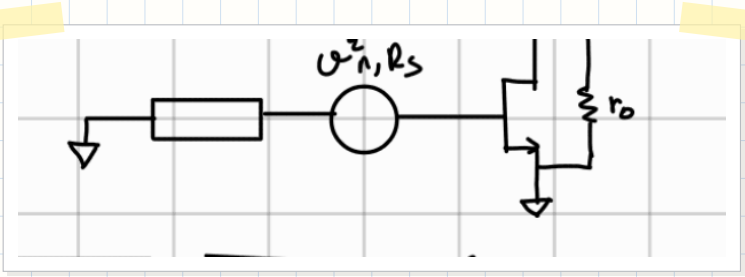


orijinal çizim, s. 7

$$\Rightarrow \overline{v_{n,out,1}^2} = \overline{i_n^2} \cdot r_o^2 \qquad \overline{i_n^2} = 4kT\gamma g_m$$

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

②



orijinal çizim, s. 7

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

③ Sum of squares

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

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

④ $$\overline{v_{in,n}^2} = \frac{\overline{v_{n,out(total)}^2}}{A_{vt}^2} = \frac{r_o^2\, 4kT\gamma g_m + (g_m r_o)^2\, 4kTR_s}{(g_m r_o)^2}$$

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

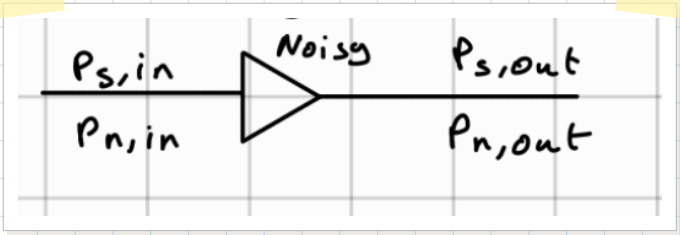
To decrease $\overline{v_{in,n}^2}$, increase g_m

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

orj. s. 8

Noise Figure (NF) / Noise Factor (F)

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



orijinal çizim, s. 8

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

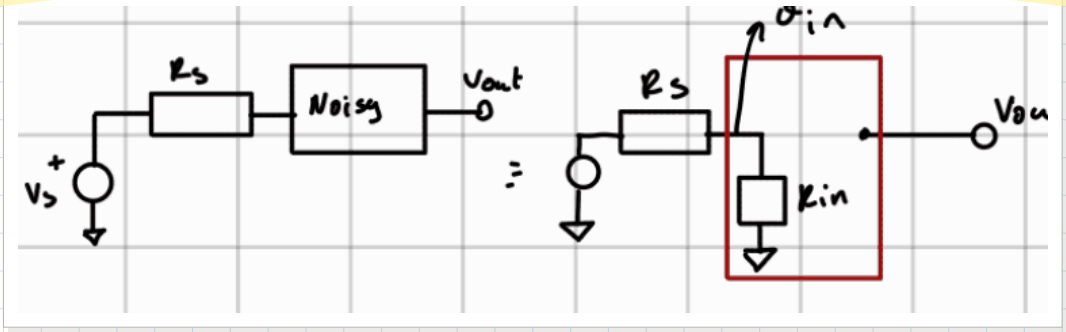
$$SNR_{out} = \frac{P_{s,out}}{P_{n,out}} = \frac{P_{s,out}}{P_{n,in}\cdot G + P_{n,A}}$$

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

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

$$NF = 10\log F = \underset{dB}{SNR_{in}} - \underset{dB}{SNR_{out}} > 0\ dB$$ ← önemli

good LNA → NF : 0 ~ 2 dB ← önemli

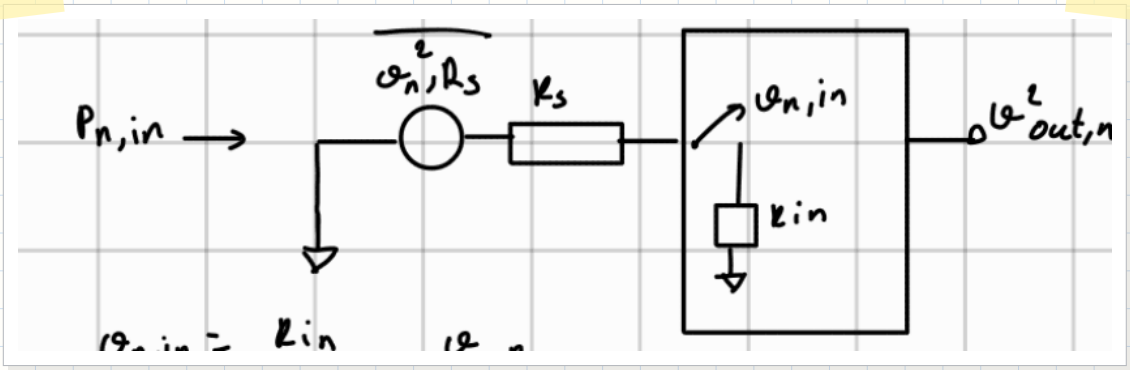


orijinal çizim, s. 8

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

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

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



orijinal çizim, s. 8

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

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

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

sadece kaynağa bağlı

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

$$\text{What is } SNR_{out} =? = \frac{P_{s,out}}{P_{n,out}}$$

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

Şekil: Basılı gürültü modeli şeması (V_s, R_s, $\overline{v_n^2}$, $\overline{i_n^2}$, gürültüsüz A_v kutusu, R_{in}); el yazısıyla $\overline{v_{n,R_s}^2}$ kaynağı eklenmiş *(orijinal notta, s. 8)*

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

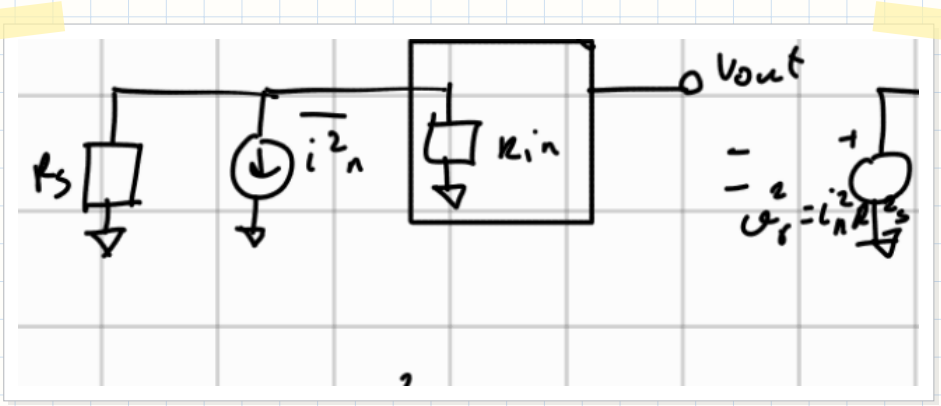
$$\overline{v_{n,out_1}^2} = \overline{v_{n,R_s}^2} \left(\frac{R_{in}}{R_s + R_{in}} \right)^2 A_v^2$$

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

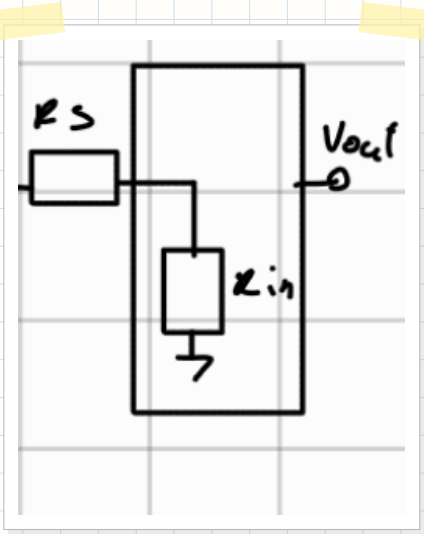
$$\overline{v_{n,out_2}^2} = \overline{v_n^2} \left(\frac{R_{in}}{R_s + R_{in}} \right)^2 A_v^2$$

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

$$\overline{v_{n,out_3}^2} = \overline{i_n^2} R_s^2 \left(\frac{R_{in}}{R_{in} + R_s} \right)^2 A_v^2$$



orijinal çizim, s. 8



orijinal çizim, s. 8

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

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

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

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

← önemli

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

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

← önemli

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

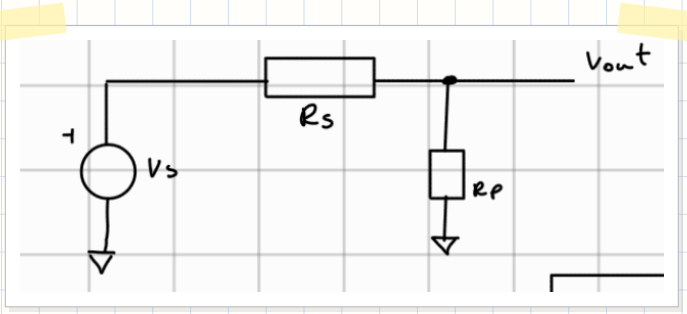
$$= \frac{\overline{v_{n,out}^2}}{A_{vt}^2} \cdot \frac{1}{\overline{v_{n,R_s}^2}}$$

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

← önemli

orj. s. 9

Ex:

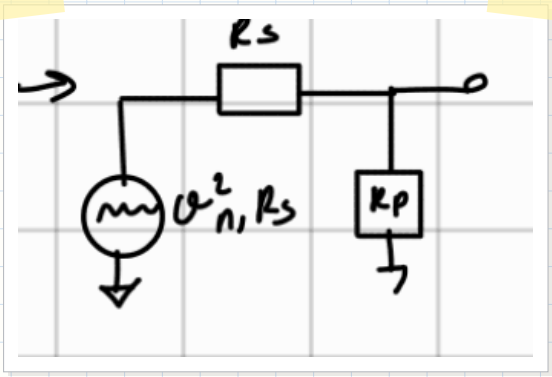


orijinal çizim, s. 9

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

$$A_{vt} = \frac{R_P}{R_S + R_P}$$

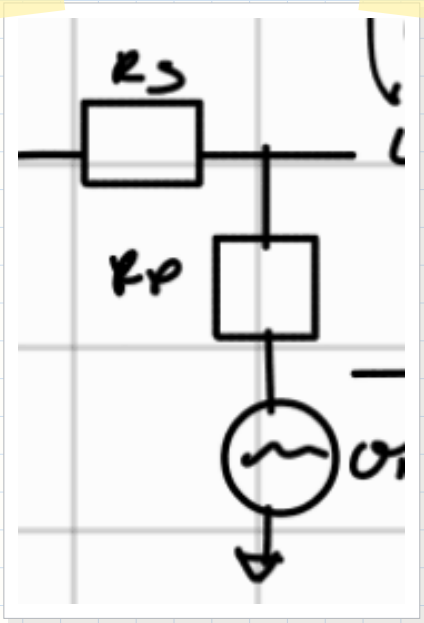
$\overline{v^2_{n,out(total)}} \rightarrow R_S \ (V_s = 0)$



orijinal çizim, s. 9

$$\overline{v^2_{n,out_1}} = \left(\frac{R_P}{R_P + R_S}\right)^2 \overline{v^2_{n,R_S}}$$

$R_P \ (V_s = 0) \rightarrow$



orijinal çizim, s. 9

$$\overline{v^2_{n,out_2}} = \left(\frac{R_S}{R_S + R_P}\right)^2 \overline{v^2_{n,R_P}}$$

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

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

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

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

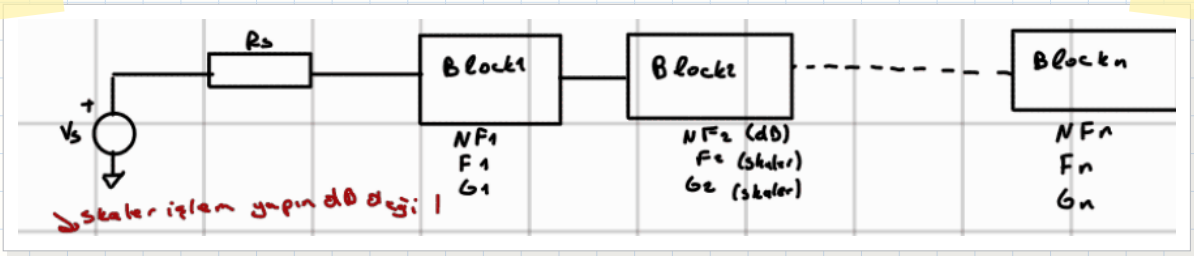
$$= \frac{R_s + R_p}{R_p} = 1 + \frac{R_s}{R_p}$$

$R_p \uparrow\uparrow \rightarrow F \approx 1$ gürültüsüz

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

Çalışma sorusuna bak
Ders 6

Noise in Cascaded Stages



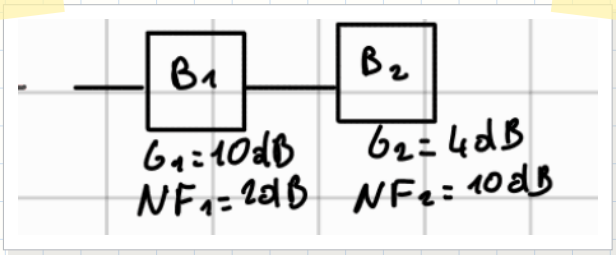
orijinal çizim, s. 9

$$F_{total} = 1 + (F_1 - 1) + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1G_2}$$
$$+ \frac{F_4 - 1}{G_1G_2G_3} + \cdots + \frac{F_n - 1}{G_1G_2 \cdots G_{n-1}}$$

$$F_{total} = \underbrace{F_1}_{\text{Dominant } F} + \underbrace{\frac{F_2 - 1}{G_1}}_{\approx >10\text{ dB}} + \frac{F_3 - 1}{G_1G_2}$$

mutlaka girişte düşük gürültülü ve NF düşük olan amplifier seçilmeli

Ex:



orijinal çizim, s. 9

$$NF_t = ??$$

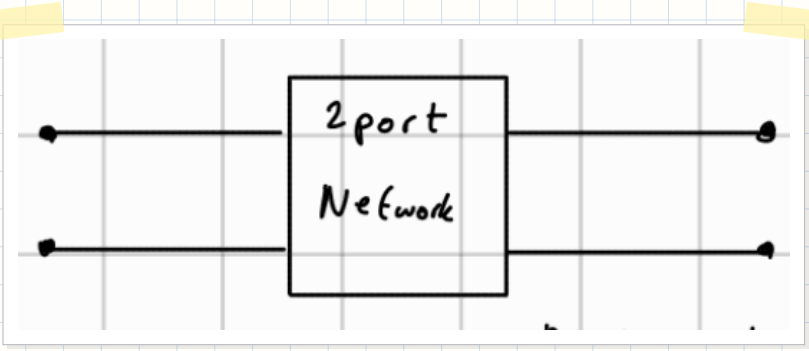
$$F_1 = 10^{\frac{2}{10}} = 1{,}58 \qquad F_2 = 10^{\frac{10}{10}} = 10 \qquad G_1 = 10$$

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

$$NF_t = 10 \log F_t = 3{,}95 \text{ dB}$$

Noise in passive Reciprocal Circuit

Reciprocity



orijinal çizim, s. 9

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

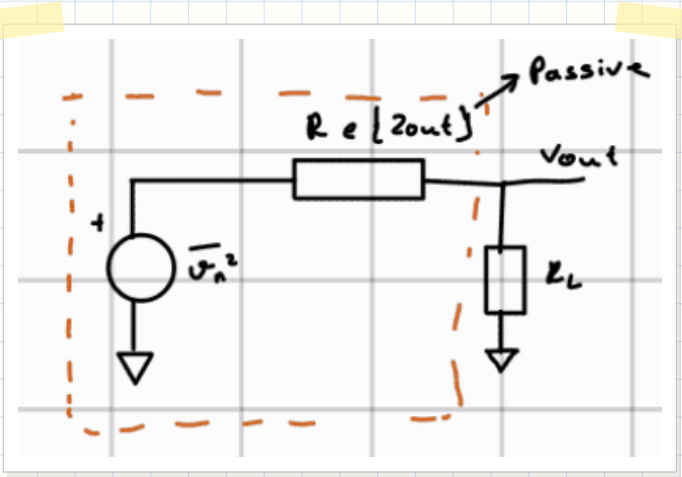
← pasif devrelerde olabiliyor

$S_{11} \rightarrow$ Return loss

$S_{22} \rightarrow$ Output Return loss

$S_{21} \rightarrow$ Gain

$S_{12} \rightarrow$ Isolation

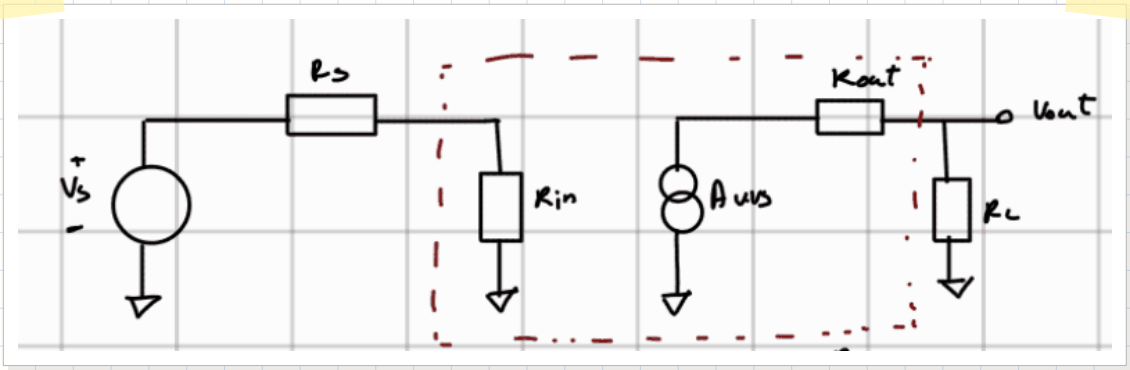


orijinal çizim, s. 9

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

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

orj. s. 10



orijinal çizim, s. 10

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

Input matched

$$P_{in} = \frac{v_{in}^2}{R_{in}} = \frac{v_s^2}{4R_{in}}$$

$$v_{in} = V_s\left(\frac{R_{in}}{R_s + R_{in}}\right)$$

$R_L = R_{out}$

Output matched

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

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

[4] Claude notu: muhtemelen ikinci terimden önceki işaret – değil = olmalı.

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

$$\boxed{\text{zayıflama } L = \frac{1}{G} = \frac{1}{A_v^2} \cdot \frac{R_L}{R_s}} \leftarrow \textbf{önemli}$$

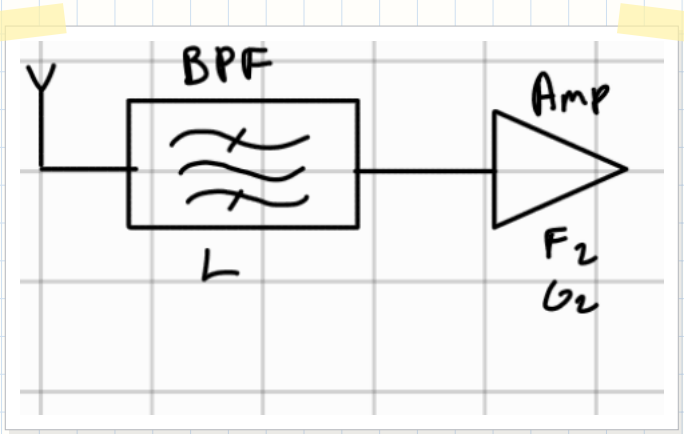
$$F = \frac{\overline{v_{n,out}^2}}{A_{vt}^2} \cdot \frac{1}{4kTR_s}$$

$$= \frac{4kTR_{out}\left(\frac{R_L}{R_L+R_{out}}\right)^2}{\left(\frac{A_v}{2}\right)^2} \cdot \frac{1}{4kTR_s}$$

$$= \frac{\frac{4kTR_L}{4}}{\left(\frac{A_v}{2}\right)^2} \cdot \frac{1}{4kTR_s} \Rightarrow \boxed{\frac{1}{A_v^2} \cdot \frac{R_L}{R_s} = F}$$

$$A_{vt} = \overbrace{\frac{V_o}{V_{in}}}^{A_v} \overbrace{\frac{V_{in}}{V_s}}^{1/2} = \frac{A_v}{2}$$

Ex:



orijinal çizim, s. 10

$$F_t = ?$$

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

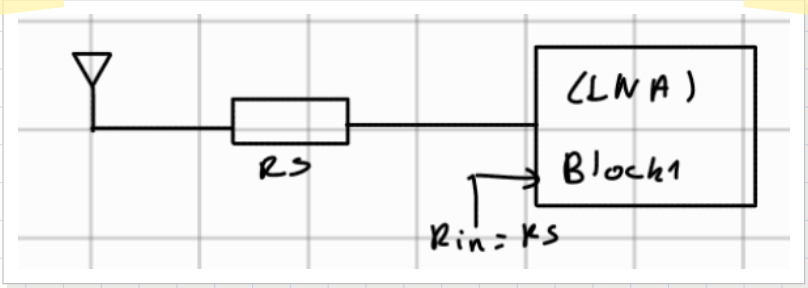
$$= L + LF_2 - L = LF_2 = F_{total}$$

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

$$NF_t = L_{dB} + NF_2$$

Noise figure artırır

Noise power in Rx input



orijinal çizim, s. 10

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

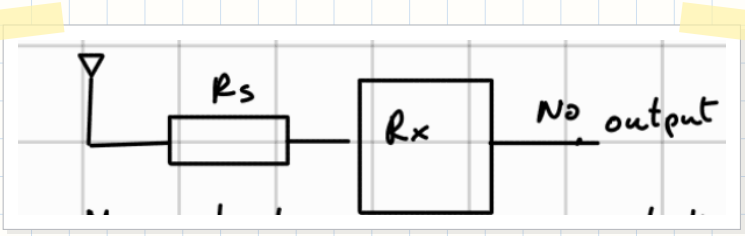
$$\frac{\overline{v_{n,in}^2}}{R_{in}} = \frac{kTR_s}{\underbrace{R_{in}}_{R_{in}=R_s}} = kT \qquad (1\,\text{Hz BW})$$

1Hz'lik bantta kT kadar gürültü gücü bulunur

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

Receive Noise Floor

Noise floor = Receiver input equivalent noise



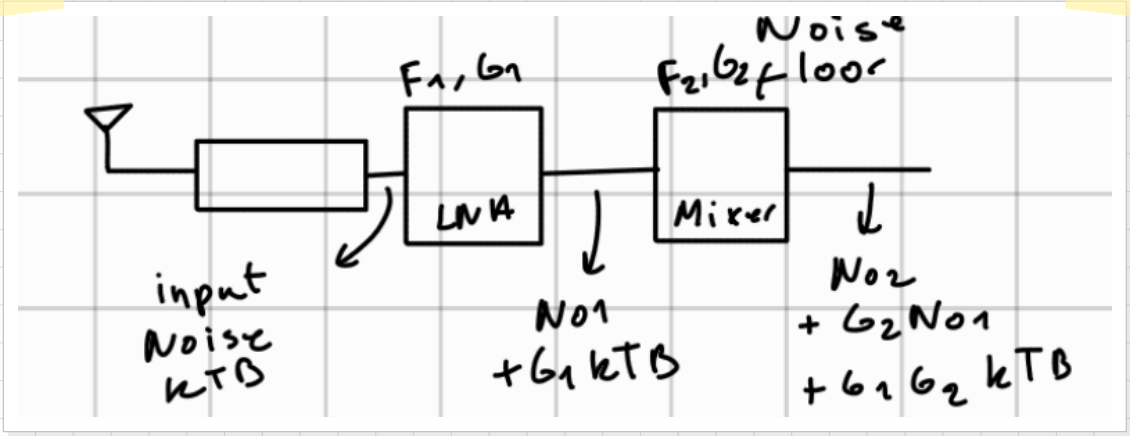
orijinal çizim, s. 10

N_o: output noise power excluding R_s kaynak gürültü düşünülmediğinde

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

$$F = \frac{\text{Total output noise power including } R_s}{G\,(\text{Noise power from } R_s \text{ only})}$$
$$= \frac{N_o + GkTB}{GkTB} = F$$

$$\text{Input noise} \overset{???}{=} kTB + \frac{N_o}{G} = \underbrace{FkTB}_{\text{Noise floor}}$$



orijinal çizim, s. 10

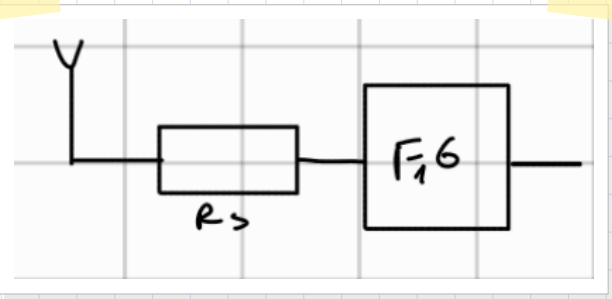
orj. s. 11

Receiver noise Floor

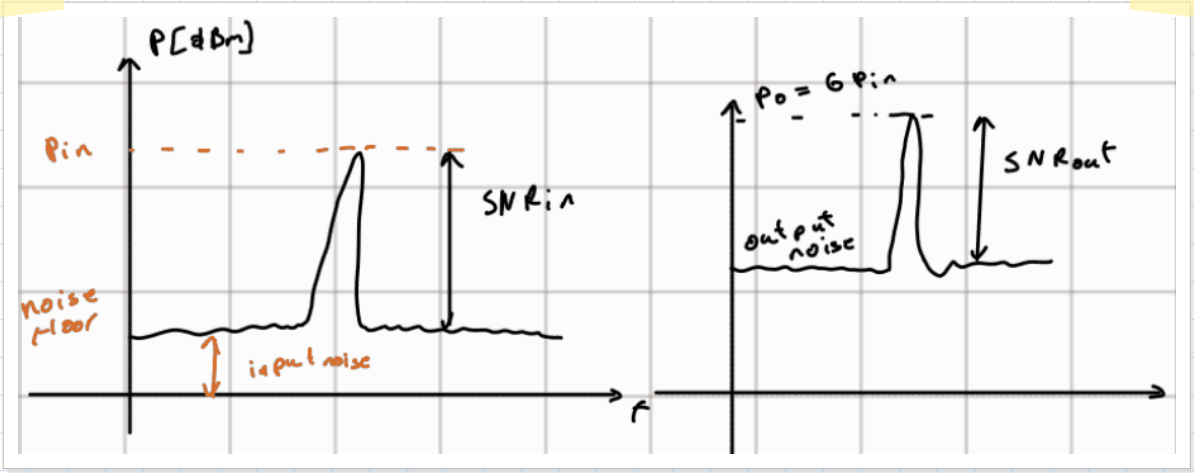
$$F = \frac{N_o + GkTB}{G} \cdot \frac{1}{kTB}$$

$$\text{Noise floor} = FkTB = \frac{N_o}{G} + kTB$$

Receiver SNR & Noise



orijinal çizim, s. 11



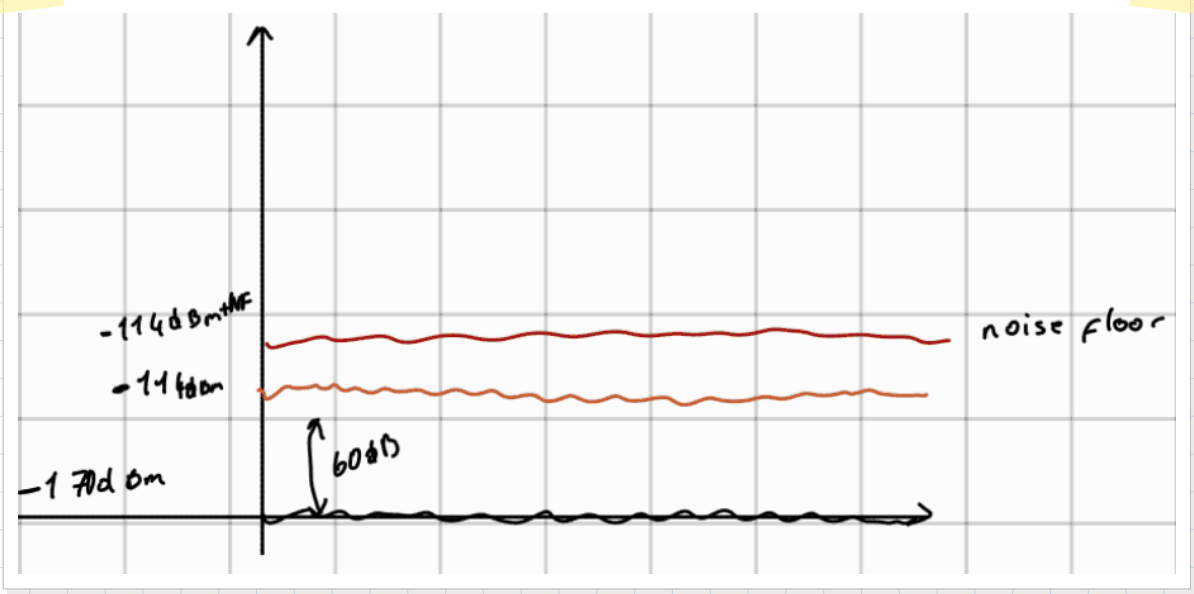
orijinal çizim, s. 11

$$SNR_{out} < SNR_{in}$$

output noise = input noise + N_A

$$\text{Noise floor} = FkTB = \underbrace{10\log F}_{NF} + \underbrace{10\log kT}_{-174\ \text{dBm/Hz}} + 10\log B$$

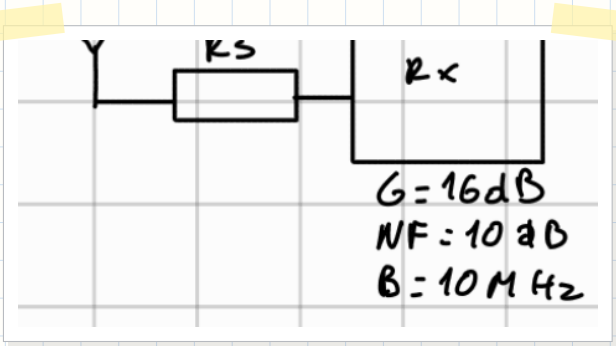
$$\underset{(\text{dB})}{\text{Noise floor}} = -174\ \frac{\text{dBm}}{\text{Hz}} + 10\log B + NF$$



orijinal çizim, s. 11

$$\underset{\text{total noise}}{\text{Output referred}} = FkTBG = NF - 174 + 10\log B + 10\log G$$

Ex:

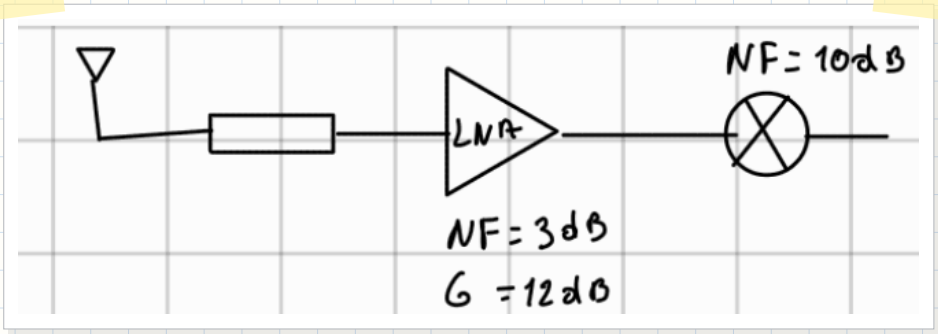


orijinal çizim, s. 11

$$\text{noise floor} = FkTB = -174\,\frac{\text{dBm}}{\text{Hz}} + 10\log(10 \cdot 10^6) + 10$$
$$= -174 + 70 + 10 = -94\ \text{dBm}$$

$$N_{out,t} = -94 + 16 = -78\ \text{dBm}$$

Ex:



orijinal çizim, s. 11

Calculate NF total

$$F = F_1 + \frac{F_2 - 1}{G_1} \qquad \text{Skaler almalı}$$
$$= 10^{3/10} + \frac{10^{12/10} - 1^{5}}{10^{12/10}} = 2{,}57$$

$$NF = 10\log(F) = 10\log(2{,}57) = 4{,}1\ \text{dB}$$

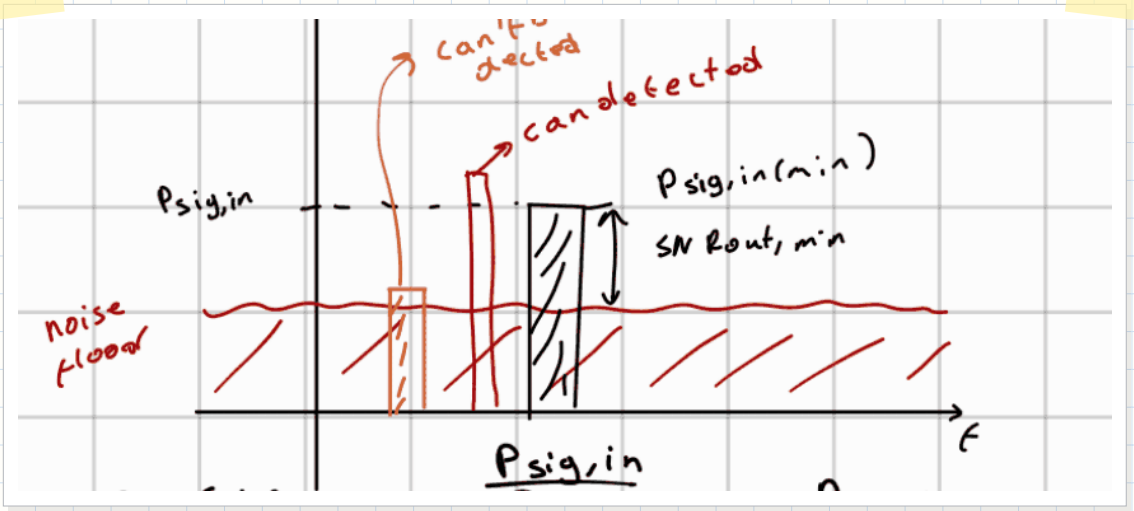
Calculate Noise floor $B = 5\,\text{MHz}$

$$\text{Noise floor} = -174\,\frac{\text{dBm}}{\text{Hz}} + 10\log(5 \cdot 10^6) + 4{,}1$$
$$= -102{,}9\ \text{dBm}$$

[5] Claude notu: muhtemelen paydaki üs 10/10 olmalı ($F_2 = 10$).

Sensitivity and Dynamic Range

Sensitivity is the minimum which can be detected at output P[dBm]



orijinal çizim, s. 11

$$F = \frac{SNR_{in}}{SNR_{out}} = \frac{\frac{P_{sig,in}}{P_{n,in}}}{SNR_{out}} = \frac{P_{sig,in}}{P_{n,in} \cdot SNR_{out}}$$

$$P_{sig,in} = \underbrace{P_{n,in}}_{\substack{kTB \\ \text{if } R_s = R_{in}}} \cdot F \cdot SNR_{out}$$

$$P_{sig,in} = \underbrace{kTB \cdot F}_{\text{Noise floor}} \cdot SNR_{out}$$

$$P_{sig,in(min)}\Big|_{dB} = \text{noise floor}_{dB} + SNR_{out,dB}$$

$$\underbrace{P_{sig,in(min)}\Big|_{dB}}_{\text{sensitivity}} = -174\ \frac{dBm}{Hz} + 10\log B + NF + SNR_{out}\Big|_{dB}$$

orj. s. 12

Ex:

A GSM receiver has $SNR_{out(min)} = 12$ dB

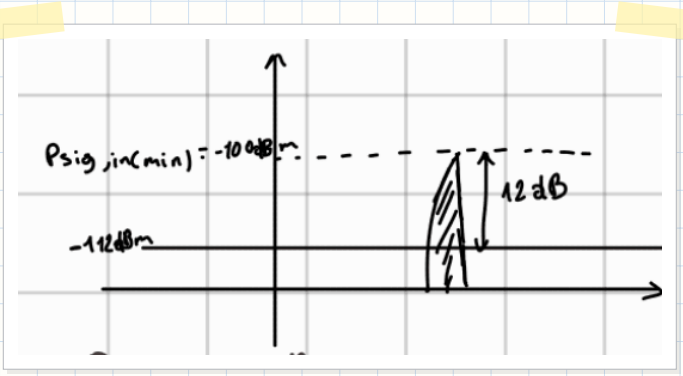
channel BW = 200 kHz

NF = 9 dB

what is the minimum acceptable signal power ?

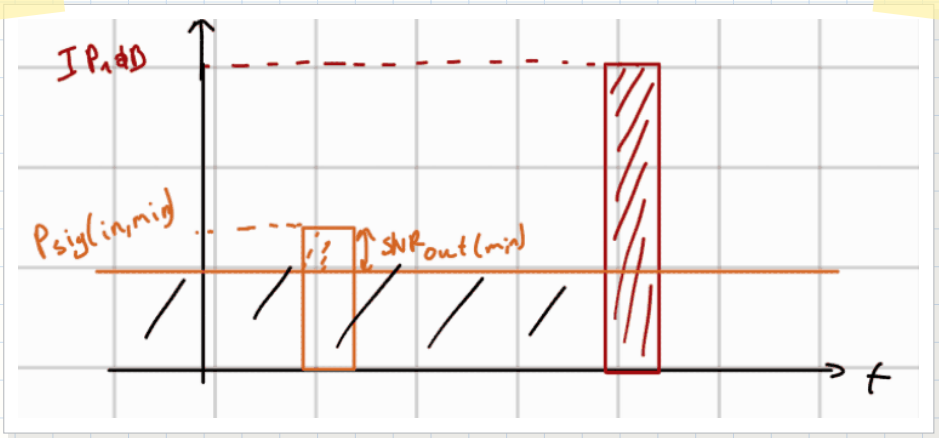
$$P_{sig,in(min)} = -174\ \frac{dBm}{Hz} + \underbrace{10\log(200 \cdot 10^3)}_{53} + 9 + 12$$

$$= -112 + 12 = -100\ \text{dBm}$$



orijinal çizim, s. 12

Dynamic Range

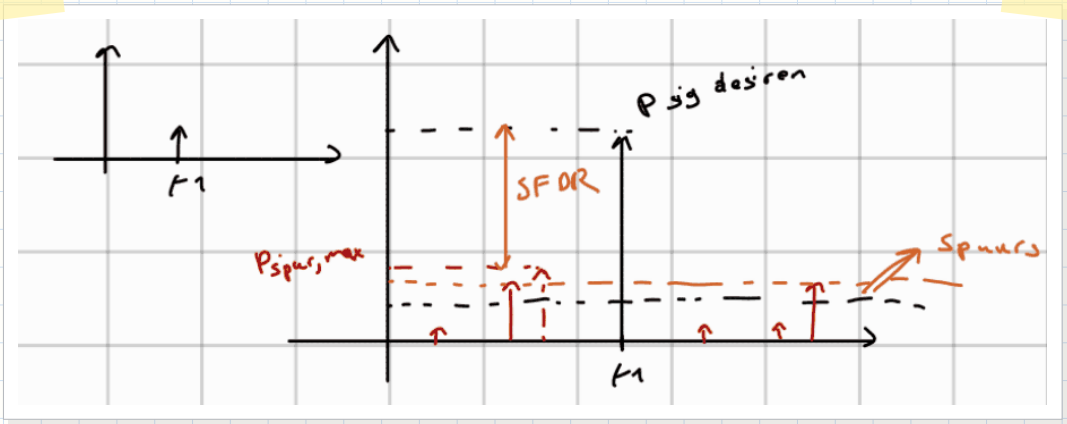


orijinal çizim, s. 12

$$DR = IP_{1dB} - \underbrace{P_{sig,in(min)}\big|_{dB}}_{\substack{MDS \\ \text{Minimum detectable signal}}} = IP_{1dB} - MDS$$

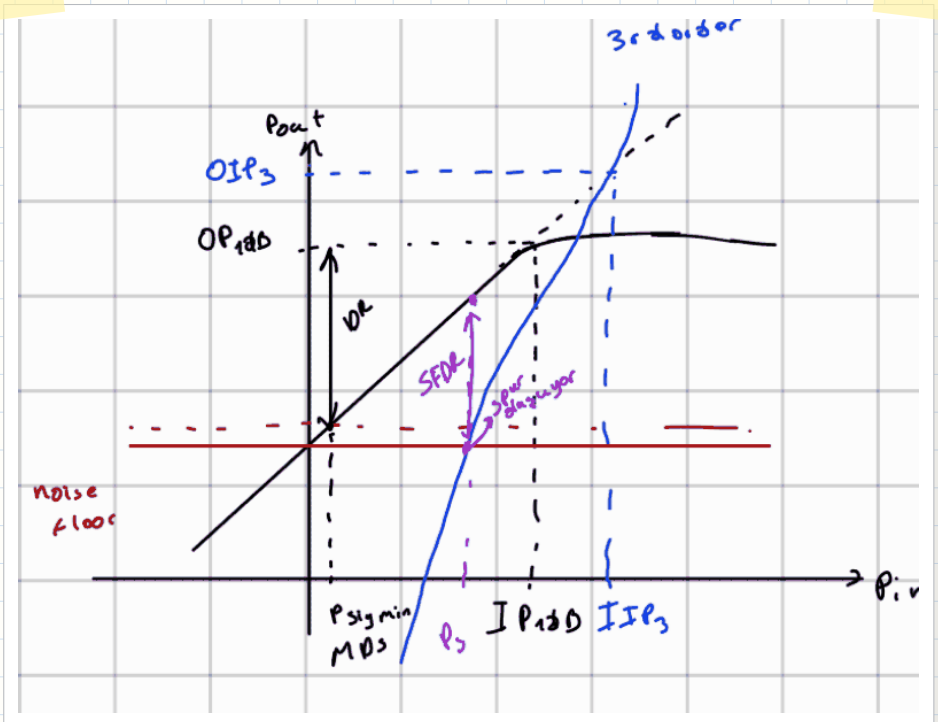
SFDR

Spur-free Dynamic Range

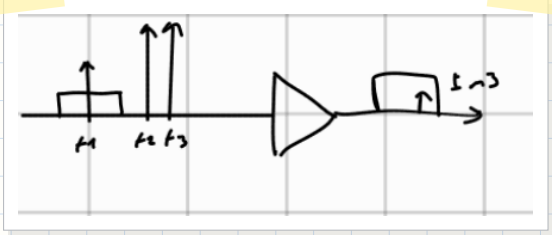


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$$SFDR = P_{sig,desired} - P_{spur}(\max)$$



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orijinal çizim, s. 12

$$SFDR = \frac{2\left(P_{IIP3} + 174 - NF - 10\log B\right)}{3} - SNR_{out}(\min)$$