RF Tasarım

Desensitization, Intermodulation, IIP3, Noise

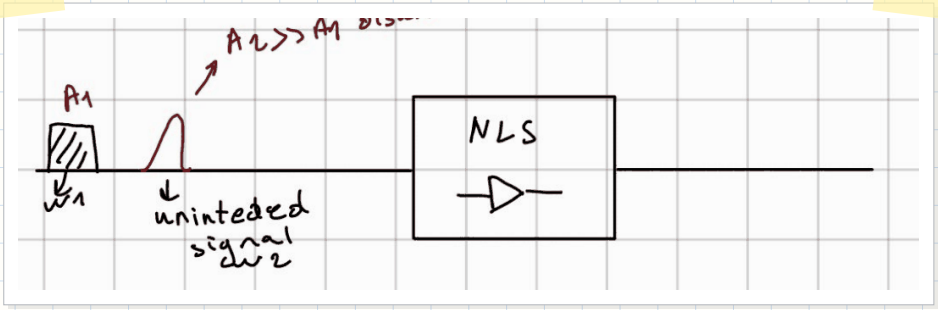
Orijinal not: Ders-5.pdf

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

(3) Desensizitation



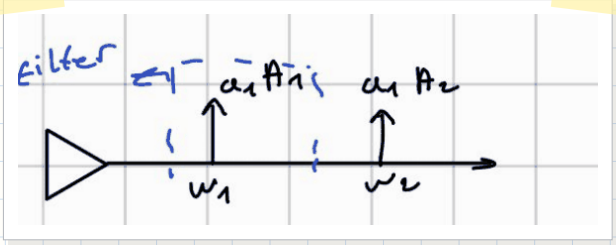
orijinal çizim, s. 1

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

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

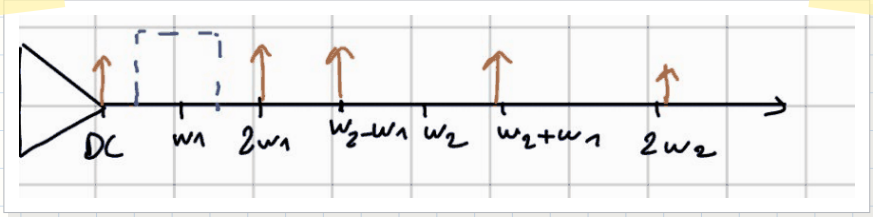
$$y(t) = a_1(A_1 \cos \omega_1 t + A_2 \cos \omega_2 t) + a_2(A_1 \cos \omega_1 t + A_2 \cos \omega_2 t)^2 + a_3(A_1 \cos \omega_1 t + A_2 \cos \omega_2 t)^3$$

$$= a_1 A_1 \cos \omega_1 t + a_1 A_2 \cos \omega_2 t$$



orijinal çizim, s. 1

$$+ a_2\left[A_1^2\cos^2\omega_1 t + A_2^2\cos^2\omega_2 t\right] + 2a_2A_1A_2 \underbrace{(\cos\omega_1 t)(\cos\omega_2 t)}_{\cos(\omega_1+\omega_2)t+\cos(\omega_2-\omega_1)t}$$



orijinal çizim, s. 1

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

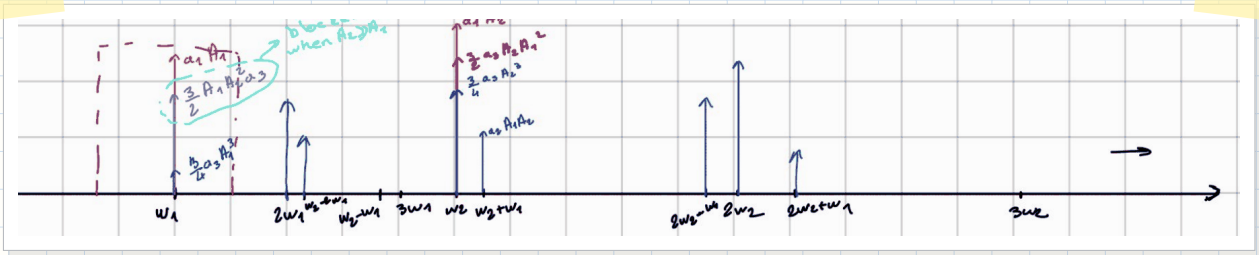
$$\frac{3}{4}a_3A_1^3\cos\omega_1 t + \frac{A_1^3}{4}\cos 3\omega_1 t$$

$\cos\omega_2 t$
$\cos 3\omega_2 t$

$$\begin{cases}\cos\omega_1 t\\ +\cos(2\omega_2-\omega_1)t\\ +\cos(2\omega_2+\omega_1)t\end{cases}\qquad\begin{cases}\cos\omega_2 t\\ +\cos(2\omega_1-\omega_2)t\\ +\cos(2\omega_1+\omega_2)t\end{cases}$$

$$\boxed{n\omega_1 \pm m\omega_2,\quad n+|m|=3}$$

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



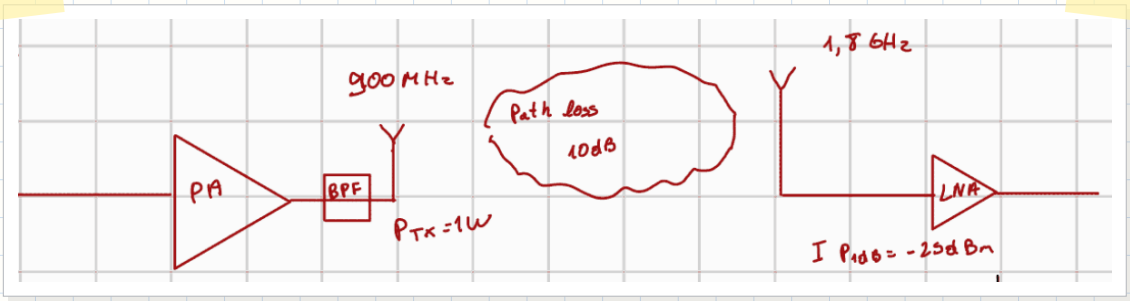
orijinal çizim, s. 1

orj. s. 2

Gain: $\dfrac{\left(a_1A_1 - \frac{3}{2}a_3A_1A_2^2\right)\cos\omega_1 t}{A_1\cos\omega_1 t}$ } $A_2 \uparrow\uparrow$

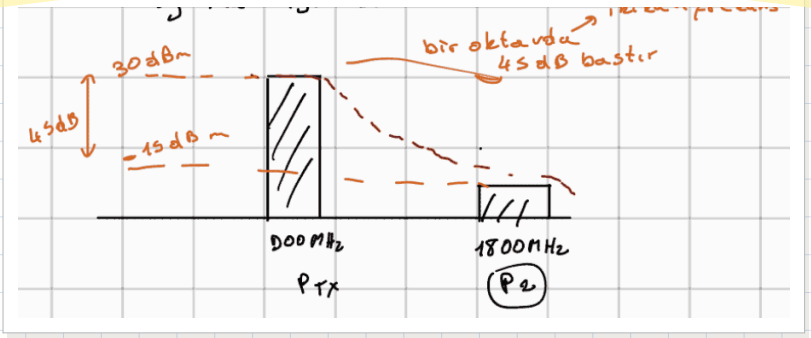
No signal appears at the output

Ex



orijinal çizim, s. 2

Vericinin ikinci harmoniğine kadar bastırılmalıdır ki bu alıcı doyma ?olmaması



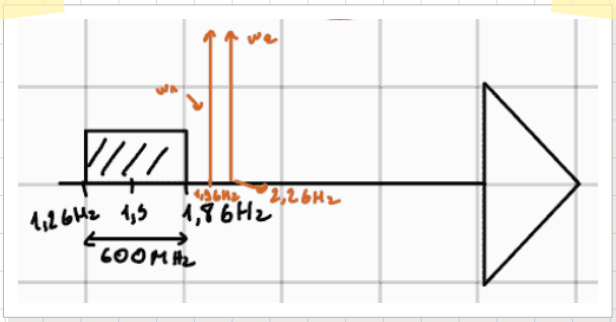
orijinal çizim, s. 2

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

en az 45 dB bastırılmalıdır.

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

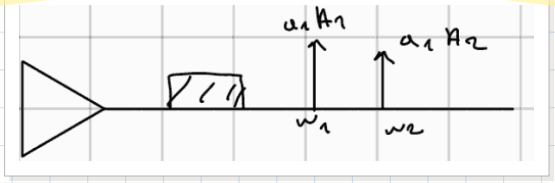
(4) Intermodulation



orijinal çizim, s. 2

$$x_1(t) = A_1 \cos \omega_1 t$$
$$x_2(t) = A_2 \cos \omega_2 t$$
$$x(t) = x_1(t) + x_2(t) = A_1 \cos \omega_1 t + A_2 \cos \omega_2 t$$

$$y(t) = a_1 x + a_2 x^2 + a_3 x^3$$
$$y(t) = a_1 (\underbrace{A_1 \cos \omega_1 t}_{\omega_1} + A_2 \cos \omega_2 t)$$



orijinal çizim, s. 2

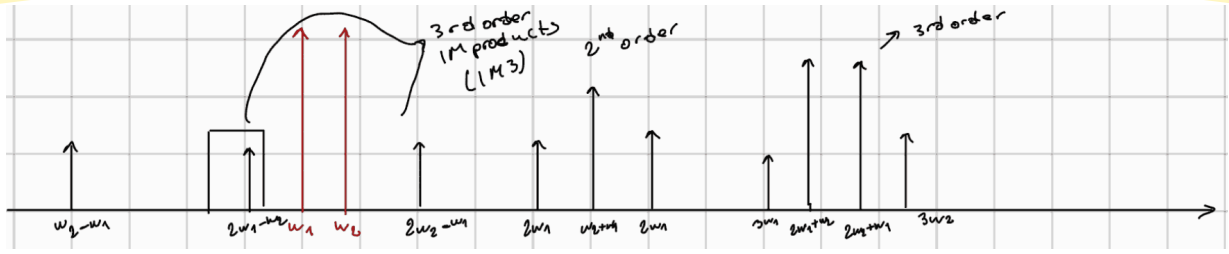
$$+ a_2 \left[\underbrace{A_1^2 \cos^2 \omega_1 t}_{\substack{DC \\ 2\omega_1}} + \underbrace{A_2^2 \cos^2 \omega_2 t}_{\substack{DC \\ 2\omega_2}} + \underbrace{2A_1 A_2 \cos \omega_1 t \cos \omega_2 t}_{\substack{\omega_2 - \omega_1 \\ \omega_2 + \omega_1}} \right]$$

$$+ a_3 \left[\underbrace{A_1^3 \cos^3 \omega_1 t}_{\substack{\omega_1 \\ 3\omega_1}} + \underbrace{A_2^3 \cos^3 \omega_2 t}_{\substack{\omega_2 \\ 3\omega_2}} \right.$$
$$\left. + \underbrace{3A_1 \cos \omega_1 t A_2^2 \cos^2 \omega_2 t}_{\substack{\omega_1 \\ 2\omega_2 - \omega_1 \\ 2\omega_2 + \omega_1}} + \underbrace{3A_2 \cos \omega_2 t A_1^2 \cos^2 \omega_1 t}_{\substack{\omega_2 \\ 2\omega_1 + \omega_2 \\ 2\omega_1 - \omega_2}} \right]$$

orj. s. 3

$2\omega_2 - \omega_1 = 2 \cdot (2{,}1\,G) - 1{,}9\,G = 2{,}3\,G$ düşmüyor

$2\omega_1 - \omega_2 = 2 \cdot (1{,}9\,G) - 2{,}1 = 1{,}7\,G \rightarrow$ In band



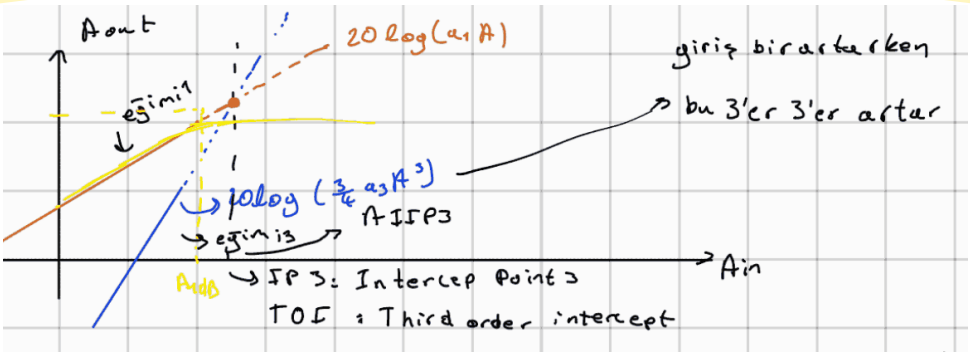
orijinal çizim, s. 3

$$A_{IM3} = \frac{3}{4} a_3 A_1^2 A_2 \left[\cos(2\omega_1 - \omega_2)t\right]$$

$$A_1 = A_2 = A \rightarrow A_{IM3} = \frac{3}{4} a_3 A^3$$

if system linear $\rightarrow a_1 A$
Intermodulation product $\rightarrow \frac{3}{4} a_3 A^3$

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



orijinal çizim, s. 3

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

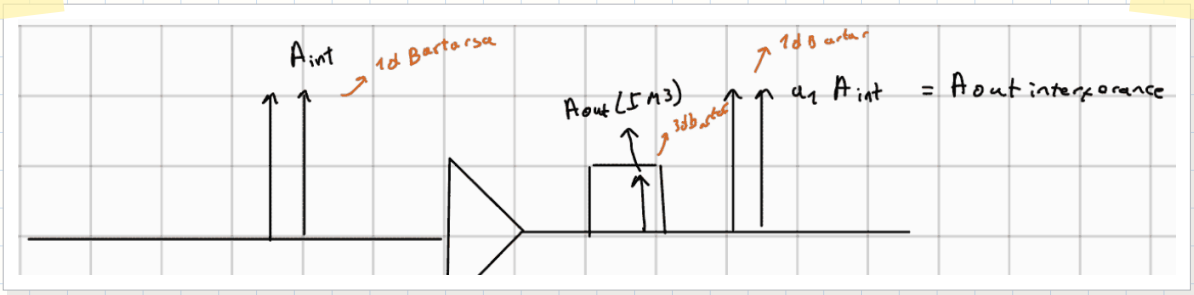
$$\boxed{A_{IIP3} = \sqrt{\frac{4}{3}\left|\frac{a_1}{a_3}\right|}}$$

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

$$A_{IIP3}(\text{dB}) - A_{1dB}(\text{dB}) = 9{,}6 \text{ dB}$$

if $A_{IIP3} \uparrow \rightarrow$ more linear System.

orj. s. 4



orijinal çizim, s. 4

$$\frac{A_{out,int}(\omega_1,\omega_2)}{A_{out}(IM3)} = \frac{a_1 A_{int}}{\frac{3}{4}a_3 A_{int}^3} = \underbrace{\frac{a_1}{\frac{3}{4}a_3}}_{A_{IIP3}^2} \cdot \frac{1}{A_{int}^2}$$

$$= \frac{A_{IIP3}^2}{A_{int}^2}$$

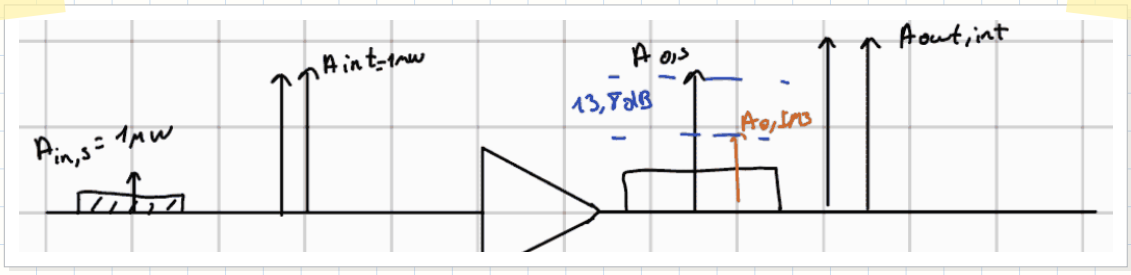
$$A_{IIP3}^2 = \frac{A_{out,int}(\omega_1,\omega_2)}{A_{out}(IM3)} A_{int}^2$$

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

Ex:

$$\left.\begin{aligned} A_{in,S} &= 1\,\mu V \\ A_{in,int} &= 1\,mV \\ P_{IIP3} &= -10\,dBm \end{aligned}\right\} \quad \text{Find} \quad \frac{A_{o,S}}{A_{o,IM3}} = ?$$

$Z = 50\,\Omega$



orijinal çizim, s. 4

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

$$P_{IIP3} = \frac{A_{IIP3}^2}{Z}$$

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

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

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

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

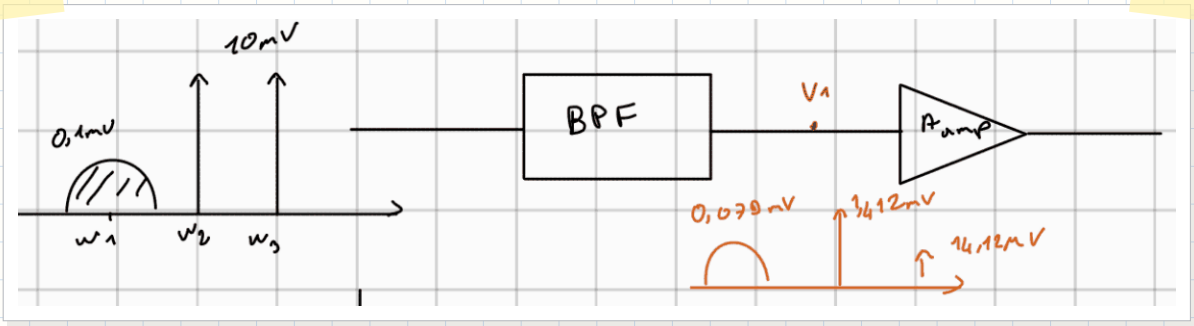
$$A_{IIP3}^2 = \frac{a_1 A_{in,int}^3}{A_{o,IM3}} \cdot \frac{A_{in,S}}{A_{in,S}} = \boxed{\frac{A_{o,S}}{A_{o,IM3}}} \cdot \frac{A_{in,int}^3}{A_{in,S}}$$

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

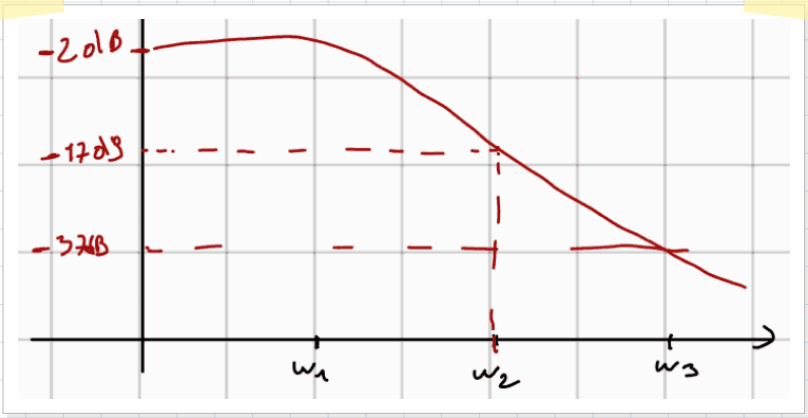
$$= (70\,\text{mV})^2 \cdot \frac{1\,\mu\text{V}}{(1\,\text{mV})^3} = 4{,}9 \rightarrow \approx 13{,}8\,\text{dB}$$

orj. s. 5

Ex



orijinal çizim, s. 5



orijinal çizim, s. 5

Compute IIP3 of the amplifier such that IM3 product falling at ω_1 ($\rightarrow A_{o,IM3}$??) is 20 dB below the desired signal ? ($\rightarrow A_{o,S}$)

$$\frac{\overbrace{A_{o,S}}^{\text{sorulan}}}{A_{o,IM3}} \Rightarrow 20\,\text{dB} \Rightarrow \frac{A_{o,S}}{A_{o,IM3}} = 10$$

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

$$20\log\frac{A_{sig}(\omega_1)}{A_{sig_{BPF}}(\omega_1)} = 2 \Rightarrow$$

$$\frac{A_{sig}(\omega_1)}{A_{sig_{BPF}}(\omega_1)} = \frac{0{,}1\,\text{mV}}{A_{sig_{BPF}}(\omega_1)} = 10^{2/20}$$

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

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

$$\rightarrow A_{int_{BPF}}(\omega_2) = 1{,}412\,\text{mV} \quad (V_2)$$

$$20\log A_{int}(\omega_3) - 37\,\text{dB} = 20\log A_{int_{BPF}}$$

$$\rightarrow A_{int_{BPF}}(\omega_3) = \underset{0{,}141\,\text{mV}}{14{,}12\,\mu\text{V}} \quad (V_3)$$

$$A_{o,S} = a_1 \cdot V_1 \qquad A_3(\omega_3) = A_2(\omega_2) = A$$

$$A_{o,IM3} = \frac{3}{4}a_3A^3 \qquad = \frac{3}{4}a_3A_2^2A_3 = \frac{3}{4}a_3V_2^2V_3$$

but $A_2(\omega_2) \neq A_3(\omega_3)$
$V_2 \neq V_3$

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

$$20\log|a_1V_1| - 20\log\left|\frac{3}{4}a_3V_2^2V_3\right| = 20\log 10$$

orj. s. 6

$$\frac{a_1V_1}{\frac{3}{4}a_3V_2^2V_3} = 10 \Rightarrow \frac{a_1}{a_3} = 26{,}6\cdot10^{-6}$$

$$A_{IIP3} = \sqrt{\frac{4}{3}\left|\frac{a_1}{a_3}\right|} = \sqrt{\frac{4}{3}\left|26{,}6\times10^{-6}\right|}$$

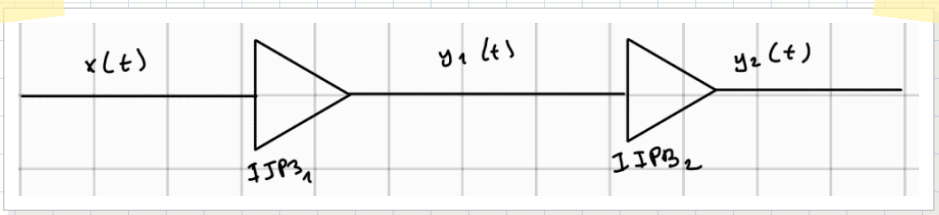
$$= 5{,}95\ \text{mV} \approx 15{,}5\ \text{dBm}$$

Ex:

Çalışma sorusu

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

Cascaded Nonlinear Stages



orijinal çizim, s. 6

$$y_1(t) = a_1x(t) + a_2x^2(t) + a_3x^3(t)$$
$$y_2(t) = b_1y_1(t) + b_2y_1^2(t) + b_3y_1^3(t)$$

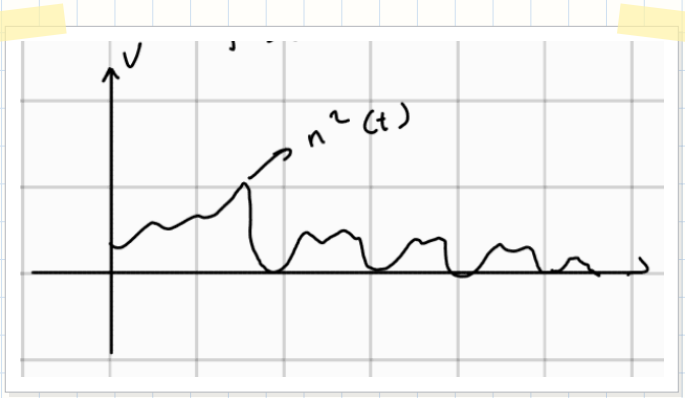
$$\frac{1}{A^2_{IIP3\,(total)}} = \frac{1}{A^2_{IIP3,1}} + \frac{a_1^2}{A^2_{IIP3,2}} \qquad (a_1^2 \rightarrow \text{gain of the first stage})$$

$\star$ $A_{IIP3,2} > A_{IIP3,1} \rightarrow$ More linear system

2. amplifier linearlığının ilkinden daha iyi olmalıdır.

Noise

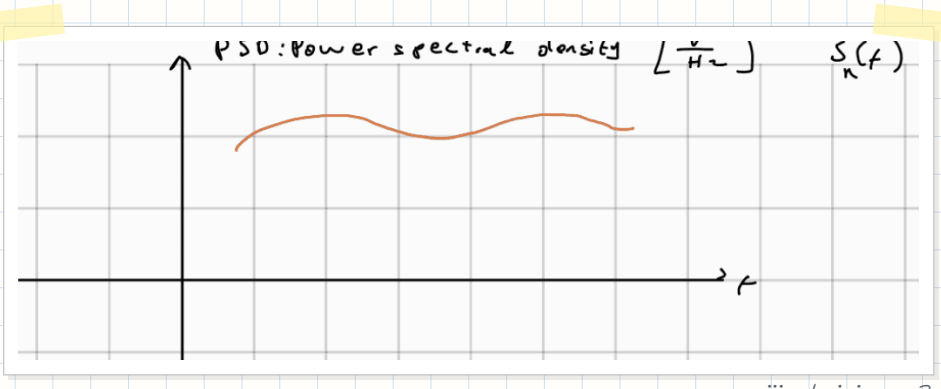
$$P_{ave,n} = \lim_{T\to\infty} \frac{1}{T}\int_0^T n^2(t)\,dt$$



orijinal çizim, s. 6

orj. s. 7

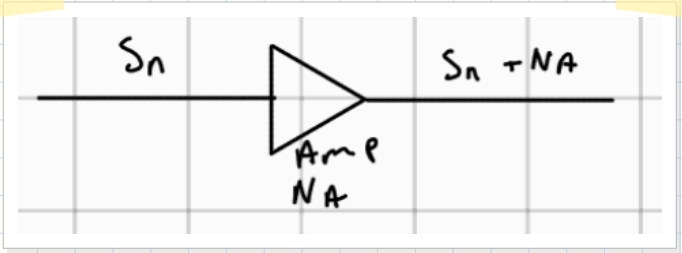
PSD: Power spectral density $[V^2/Hz]$ $S_n(f)$



orijinal çizim, s. 7

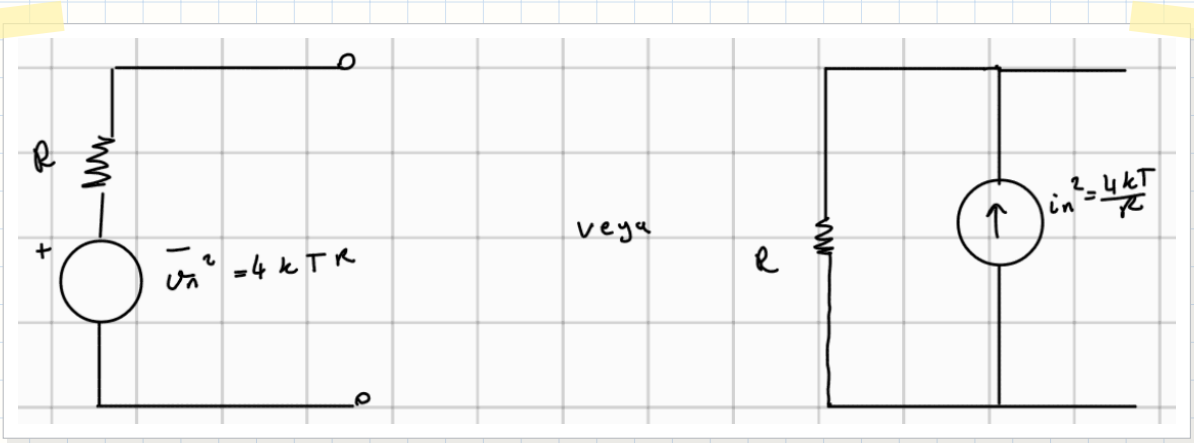
$$P_{ave} = \int_0^\infty S_n(f)\,df$$

Device Noise



orijinal çizim, s. 7

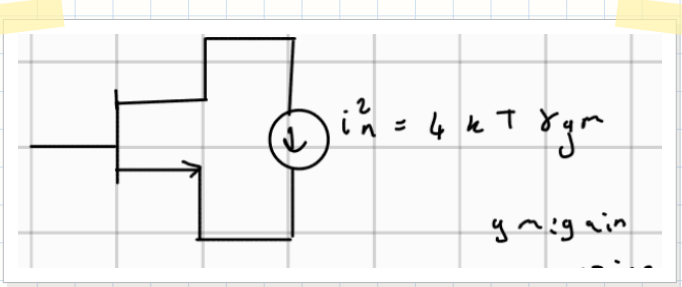
Resistor Noise:



orijinal çizim, s. 7

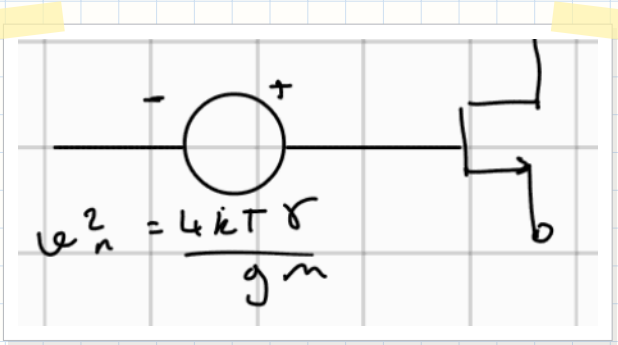
$1{,}38 \times 10^{-23}$ J/K
k: Boltzmann sabiti
T = (kelvin) sıcaklık

MOS Transistor Noise



orijinal çizim, s. 7

γ : noise coefficient



orijinal çizim, s. 7