RF Tasarım

Smith Chart, Power ve Linearity

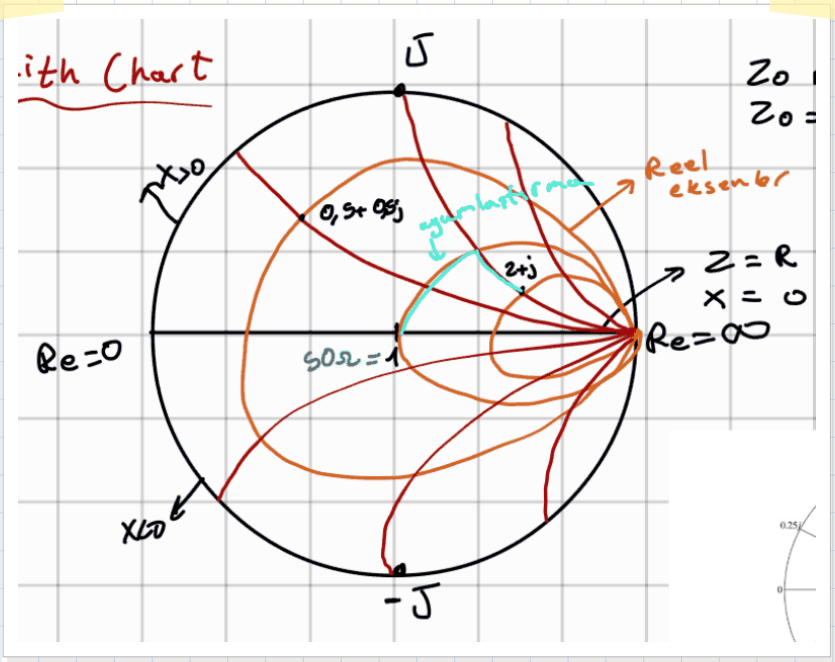
Orijinal not: Ders-4.pdf

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

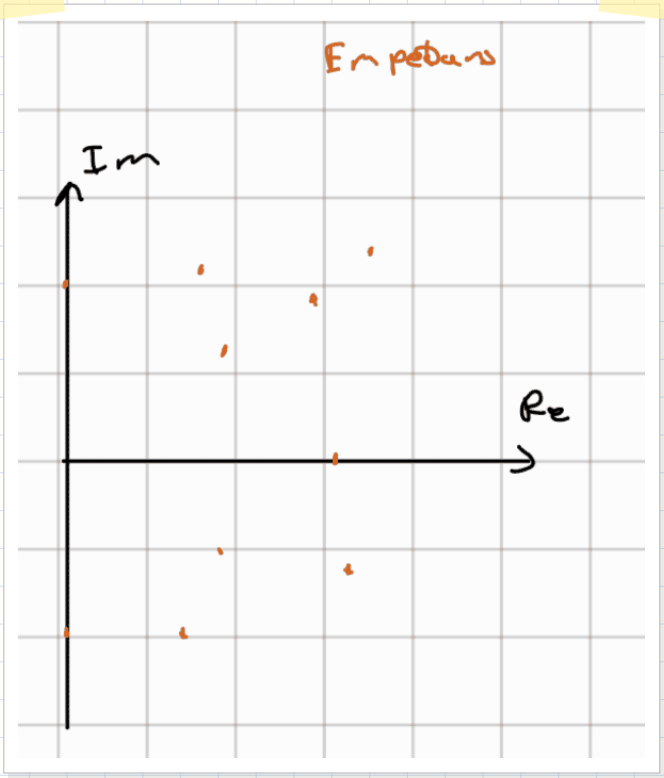
Smith Chart



orijinal çizim, s. 1

$$Z = R + jX$$

Z_0 normalize $Z_0 = 50\,\Omega$



orijinal çizim, s. 1

Şekil: Basılı normalize empedans Smith abağı (Figure 6-42); dijitalleştirilmedi.
(orijinal notta, s. 1)

$$Z_{in} = R + j\underbrace{\omega X_{im}}_{X}$$

- Impedance matching
- Finding transmission line length
- Finding the value of L or C used for matching
- Finding reflection coefficient of both load or source
- Converting Z to admittance Y
- Finding VSWR (Voltage Standing wave ratio)

Softwares

1- (Keysight) ADS Advance Design System
EM simulation
2- (Cadence[NI]) AWR (1–2: çip düzeyinde tasarım)
3- CST (Dassault) Özellikle anten tasarımcıları için
4- HFSS (Ansys)

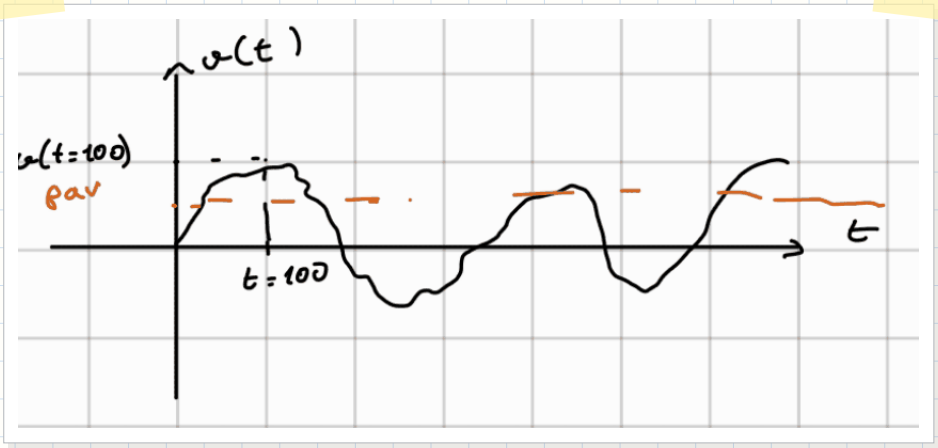
Measurement Devices

1) Spectrum Analyzer: (Frequency Range) (10 Hz–13 GHz) frekans güçlerini ...
2) Signal Analyser:
   Spectrum Analyser'a ilaveten demodulation yapılabilir

orj. s. 2

3) Network Analyzer:
   S param f-domain or Smith chart
4) Signal generater: yüksek frekanslı sinyal üretir
5) Microwave/RF power Meter

Instantaneous Power (anlık güç)



orijinal çizim, s. 2

$$p(t) = v(t)\,i(t) = \frac{v^2(t)}{R}$$

Bizim için ortalama güç önemli

$$P_{ave} = \frac{1}{T}\int_0^T p(t)\,dt = \frac{1}{R}\frac{1}{T}\int_0^T v^2(t)\,dt$$

$$\langle v^2(t)\rangle = \frac{1}{T}\int_0^T v^2(t)\,dt \qquad v^2(t)\text{'nin ortalaması}$$

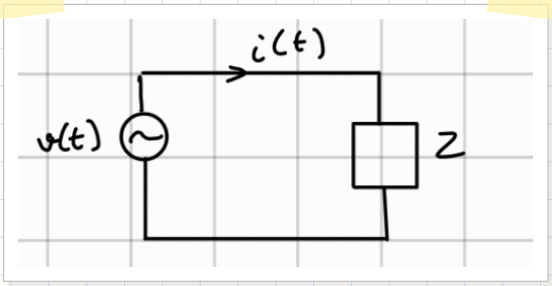
$$\sqrt{\langle v^2(t)\rangle} = V_{rms} \text{ (root mean square)}$$

$$v(t) = \frac{2}{A}\cos(\omega t)$$

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

$$R = 50\,\Omega \Rightarrow P_{avg} = \frac{\langle v^2(t)\rangle}{R} = \frac{A^2}{2\cdot 50} = \frac{1}{25}\,W$$

Power & Phasor



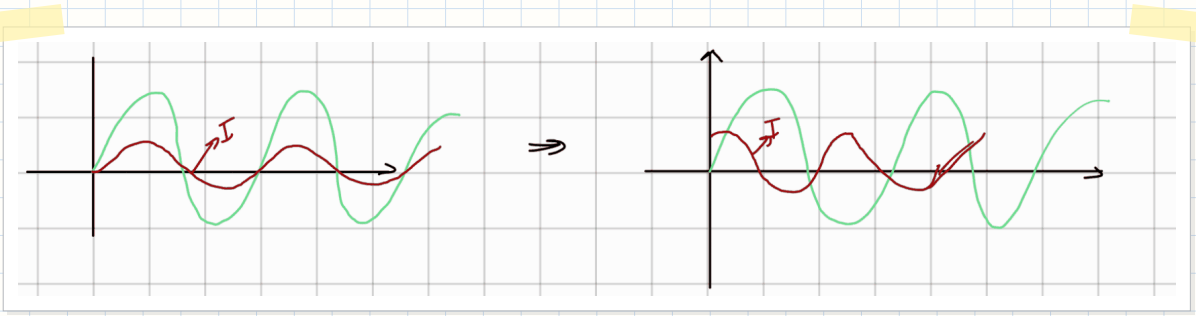
orijinal çizim, s. 2

$$V = |V|e^{j\theta_V} \rightarrow v(t) = |V|\cos(\omega t + \theta_V)$$
$$I = |I|e^{j\theta_I} \rightarrow i(t) = |I|\cos(\omega t + \theta_I)$$
$$Z = \frac{V}{I} = \frac{|V|e^{j\theta_V}}{|I|e^{j\theta_I}} = \frac{|V|}{|I|}e^{j(\theta_V - \theta_I)}$$

orj. s. 3

$$Z = R \Rightarrow I = \frac{V}{Z} = \frac{|V|e^{j\theta_V}}{R} = \frac{|V|}{R}e^{j\theta_V}$$
$$Z = j\omega L = \omega L \cdot e^{j90^\circ} \Rightarrow I = \frac{V}{Z} = \frac{|V|e^{j\theta_V}}{\omega L\, e^{j90^\circ}}$$
$$= \frac{|V|}{\omega L}e^{j(\theta_V - 90^\circ)}$$

akım, gerilime göre 90° derece geridedir



orijinal çizim, s. 3

$$p(t) = v(t)\,i(t)$$
$$= |V||I|\cos(\omega t + \theta_V)\cos(\omega t + \theta_I)$$
$$= \frac{|V||I|}{2}\left\{\cos(2\omega t + \theta_V + \theta_I) + \cos(\theta_V - \theta_I)\right\}$$

$$P_{avg} = \frac{1}{T}\int_0^T p(t)\,dt = \frac{|V||I|}{2}\cos(\theta_V - \theta_I)$$
$$= \frac{|V|}{\sqrt{2}}\frac{|I|}{\sqrt{2}}\cos(\phi) \qquad \phi \equiv \theta_V - \theta_I$$

$$P_{ave} = V_{rms} I_{rms} \cdot \cos(\phi)$$

$Z = L \rightarrow P_{ave} = 0 \longrightarrow$? Nasıl olabilir (reaktif güç var)

$Z = R \rightarrow P_{ave} = V_{RMS} \cdot I_{RMS}$

Complex Power

$$V = |V| e^{j\theta_V} \qquad V_{rms} = \frac{|V|}{\sqrt{2}} e^{j\theta_V}$$

$$I = |I| e^{j\theta_I} \qquad I_{rms} = \frac{|I|}{\sqrt{2}} e^{j\theta_I}$$

$$S = P + jQ$$

$$\begin{aligned} S &= \frac{1}{2}(V \cdot I^*) \text{ or } (V_{rms} \cdot I^*_{rms}) \\ &= \frac{1}{2}\left(|V| e^{j\theta_V} |I| e^{-j\theta_I}\right) = \frac{1}{2}|V||I| e^{j(\theta_V - \theta_I)} \\ &= \underbrace{\frac{1}{2}|V||I|\cos(\theta_V - \theta_I)}_{P} + j \underbrace{\frac{1}{2}|V||I|\sin(\theta_V - \theta_I)}_{Q} \end{aligned}$$

orj. s. 4

P: average power or active Power $P = \text{Real}\{S\}$ [watt – W]

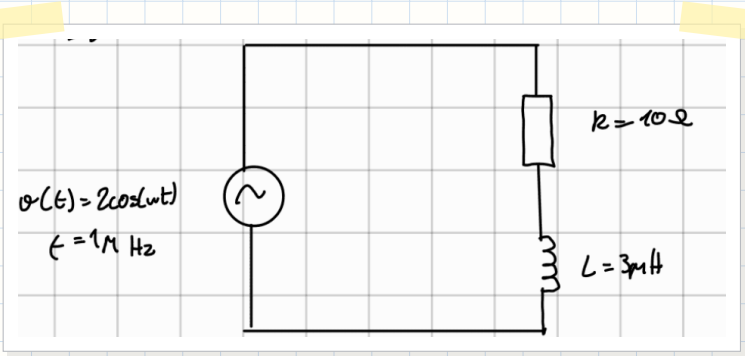
Q: reactive power $Q = \text{Imag}\{S\}$ [VAR] Voltage Amper Reactive

	Z	P	Q
Resistor	R $\theta_V = \theta_I = 0$	$P = \frac{\|V\|^2}{R} > 0$ absorbs power	0
Inductor	$j\omega L$ $\theta_V - \theta_I = 90°$	0	$\frac{j\|V\|^2}{\omega L} > 0$ absorbs power (VAR)
Capacitor	$\frac{1}{j\omega C}$ $\theta_V - \theta_I = -90°$	0	$-j\|V\|^2 \omega C < 0$ generate VAR

HW (1)

1) $v(t) = 2\cos(\omega t + 30)$
   $Z = 5 + j10$
   Find I and P_{ave}

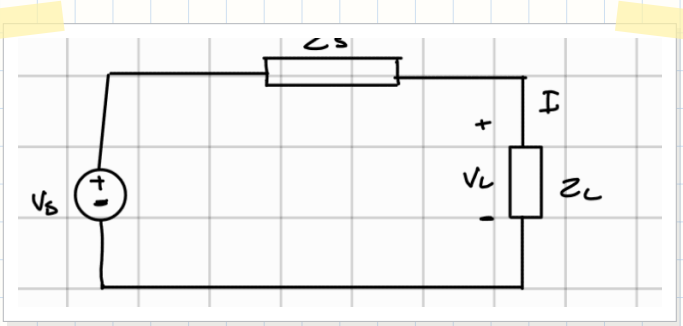
2)



orijinal çizim, s. 4

Find S =?

Maximum Power



orijinal çizim, s. 4

$$P_{ave}(load) = P_L = \frac{1}{2}Re\{V_L I^*\}$$

$$= \frac{1}{2}Re\left\{\overbrace{\frac{Z_L}{Z_s+Z_L}V_s}^{V_L}\left(\frac{V_s}{Z_s+Z_L}\right)^*\right\}$$

$$= \frac{1}{2}Re\left\{V_s \cdot V_s^* \cdot \frac{Z_L}{Z_s+Z_L}\cdot\frac{1}{Z_s^*+Z_L^*}\right\}$$

orj. s. 5

$$= \frac{1}{2}\frac{|V_s|^2}{|Z_s+Z_L|^2}\cdot Re\{Z_L\}$$

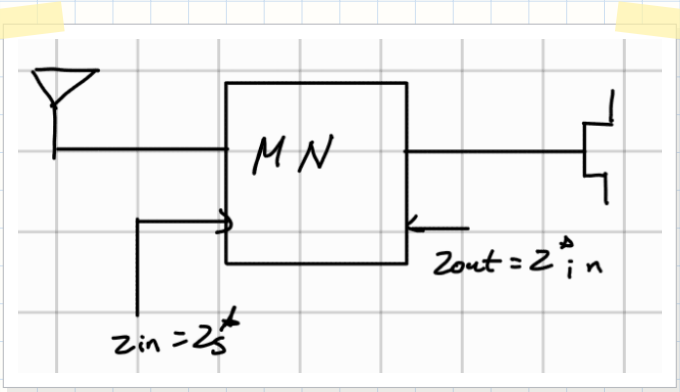
$$P_L = \frac{1}{2}\frac{|V_s|^2}{|R_s+jX_s+R_L+jX_L|^2}\cdot R_L$$

maximize etmek için $Z_s = Z_L^*$

$$Z_s = Z_L^* \Rightarrow P_L = \frac{1}{2}\frac{|V_s|^2}{|R_s+jX_s+R_s-jX_s|^2}\cdot R_s$$

$$= \frac{1}{2}\frac{|V_s|^2}{|2R_s|^2}\cdot R_s$$

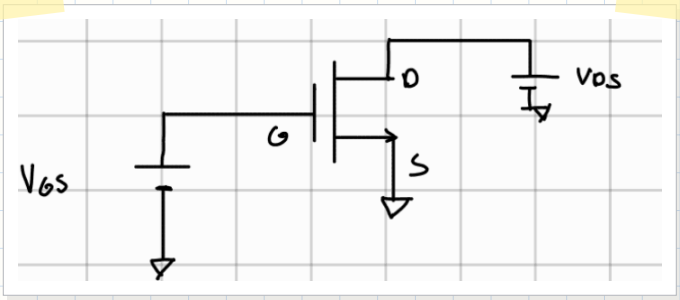
$P_L = \frac{1}{8}\frac{|V_s|^2}{R_s}$ yükteki max power kaynağa bağlı



orijinal çizim, s. 5

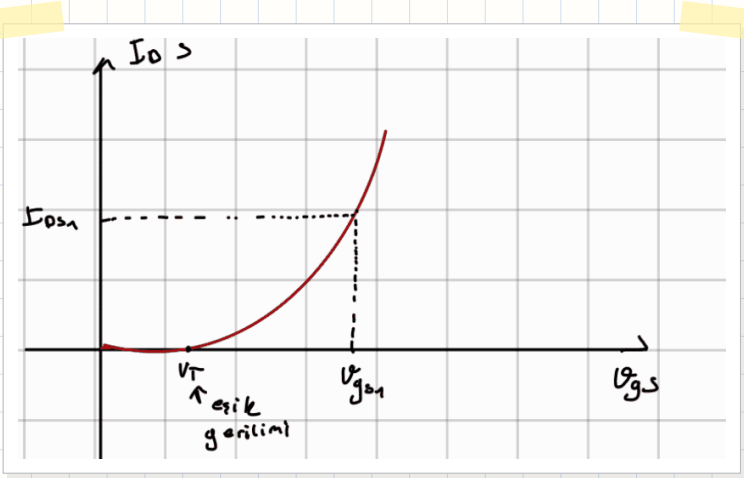
Kuvvetlendiriciler

MOS transistörler

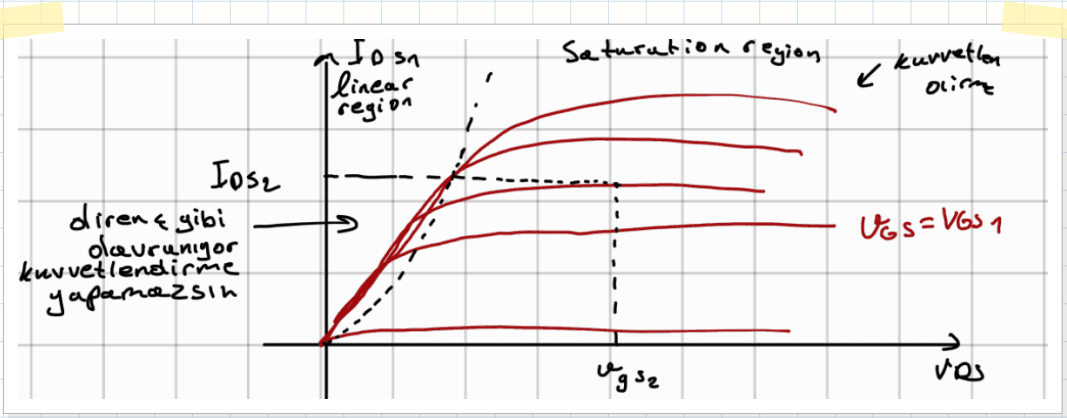


orijinal çizim, s. 5

$$I_D = k\frac{W}{L}(V_{GS} - V_T)^2$$ sat mı (lineer mi?)



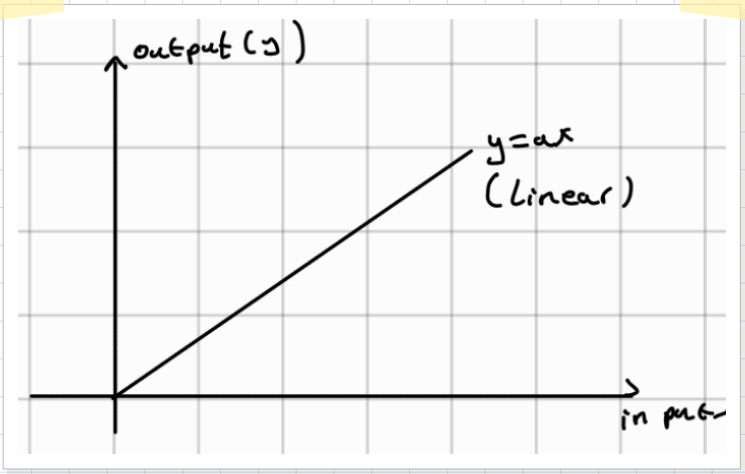
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orj. s. 6

Linearity

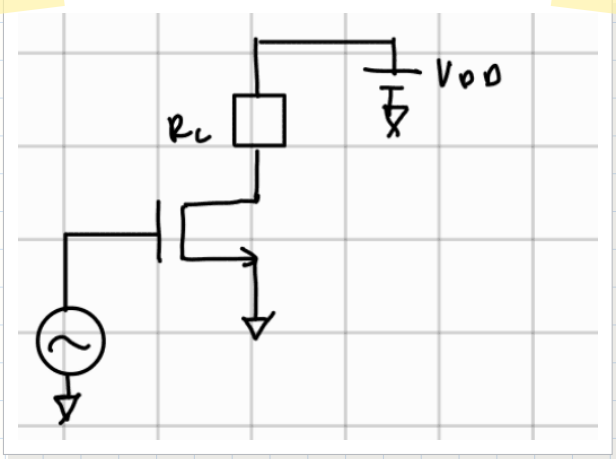


orijinal çizim, s. 6

$$y = ax + bx^2 + cx^3 + \cdots \qquad \text{(non linear)}$$

$$x \ll \text{(çok küçük)} \Rightarrow bx^2 + cx^3 \approx 0$$

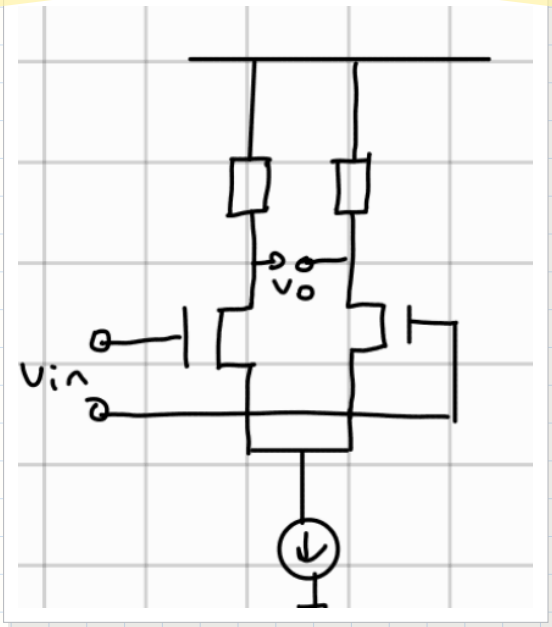
Ex



orijinal çizim, s. 6

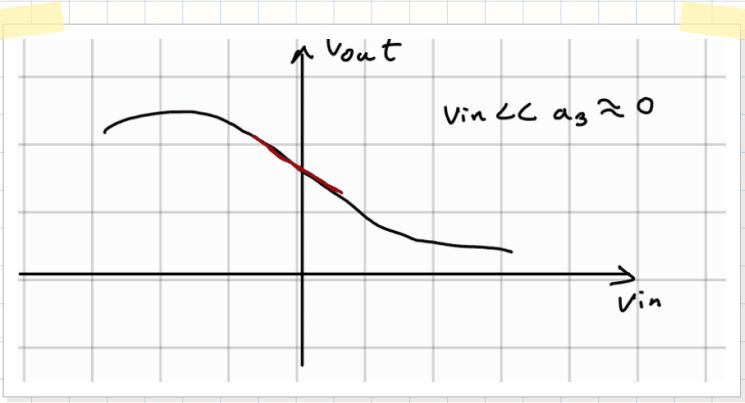
$$V_{out} = V_{DD} - k\frac{W}{L}(V_{GS} - V_T)^2 \cdot R_L$$
$$= DC + a_2 V_{gs}^2$$

Differential Pair



orijinal çizim, s. 6

$$V_{out} = -\sqrt{2k\frac{W}{L}I_D} \cdot R_D \cdot V_{in} + \frac{2k^{3/2}}{8\sqrt{I_D}} R_D V_{in}^3$$
$$= a_1 \cdot V_{in} + a_3 V_{in}^3$$



orijinal çizim, s. 6

Drawbacks of Nonlinearity

(1) Harmonic Distortion

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



orijinal çizim, s. 6

orj. s. 7

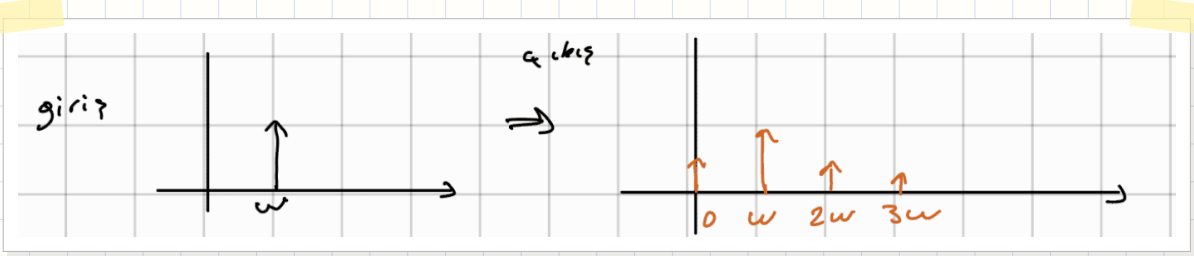
$$x(t) = A\cos\omega t$$

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

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

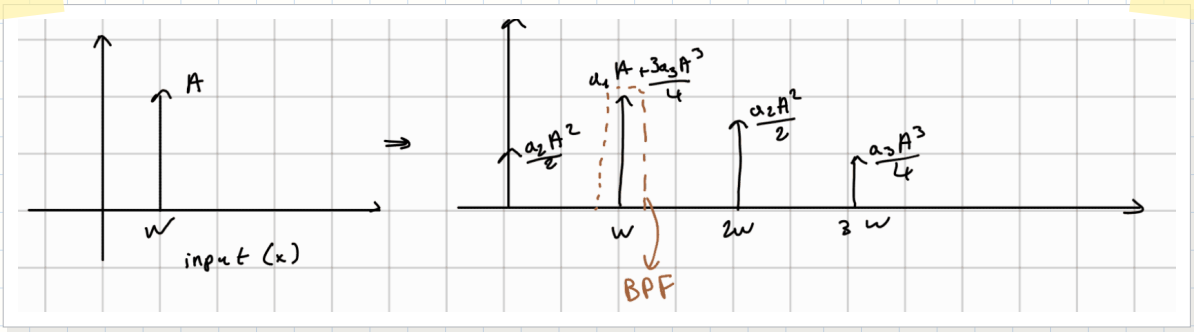
$$(A\cos\omega t)^3 = \frac{A^3}{4}(3\cos\omega t + \cos 3\omega t)$$

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

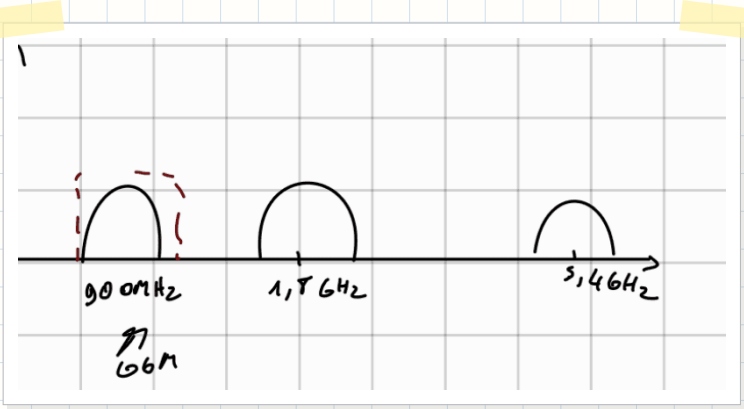


orijinal çizim, s. 7

$$y(t) = \frac{a_2 A^2}{2} + \left(a_1 A + \frac{3a_3 A^3}{4}\right)\cos\omega t + \underbrace{\frac{a_2 A^2}{2}\cos 2\omega t}_{\text{2nd harmonic}} + \underbrace{\frac{a_3 A^3}{4}\cos 3\omega t}_{\text{3rd}}$$



orijinal çizim, s. 7



orijinal çizim, s. 7

(2) Gain compression

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

a_1, a_3 have different signs
Most of the time $\boxed{a_1 \cdot a_3 < 0}$

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

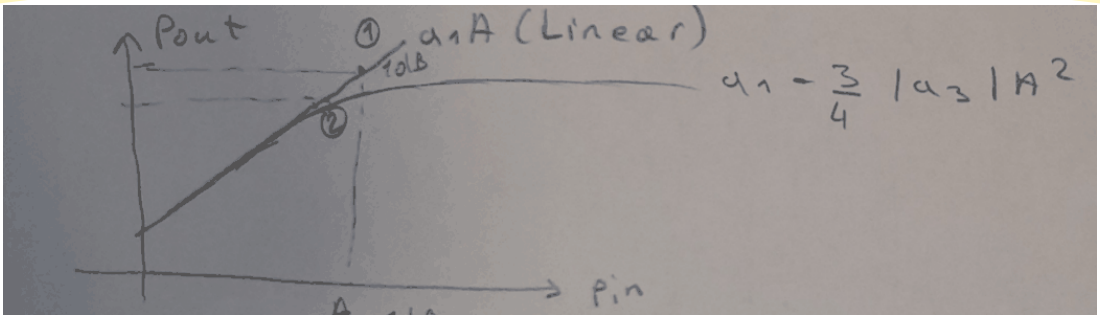
orj. s. 8

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

1) $a_1 > 0, a_3 < 0 \Rightarrow \text{Gain} = a_1 - \frac{3}{4}|a_3|A^2$
2) $\text{Gain} \propto A^2$

girişin genliği çok yükselirse kazanç düşer.

(2) Gain Compression



orijinal çizim, s. 8

A_{-1dB} or P_{1dB} ← sistemin linear davranışından 1db düştüğü nokta

$$\begin{array}{rl} (1) & 10\log|a_1 P_{1dB}| \\ -\,(2) & 10\log\left|a_1 P_{1dB} + \frac{3}{4}a_3 P_{1dB}^3\right| \\ \hline & 1\,dB \end{array} \rightarrow 20\log|a_1 A_{-1dB}|$$

$$P_{1dB} = \sqrt{0{,}145\left|\frac{a_1}{a_3}\right|} \quad \rightarrow a_3 = 0 \rightarrow P_{1dB} \rightarrow \infty$$

$$P_{1dB} \quad \frac{|a_1|\cancel{P_1}}{\left|a_1 + \frac{3}{4}a_3 P_1^2\right|\cancel{P_1}} = 1 \;?? \qquad 1\,dB = 10^1$$

$$\frac{a_1}{a_1 + \frac{3}{4}a_3 P_1^2} = 10$$

$$a_1 = 10a_1 + \frac{15}{2}a_3 P_1^2$$

$$\frac{-18a_1}{15a_3} = P_1^2 \qquad P_1$$