$$u_{OD} = \alpha I R_C \left(\frac{1}{1+e^{-u_{ID}/V_T}} - \frac{1}{1+e^{u_{ID}/V_T}} \right)$$

$$\frac{1}{1+e^{-a}} - \frac{1}{1+e^{a}} = \frac{e^{a/2}}{e^{a/2}+e^{-a/2}} - \frac{e^{-a/2}}{e^{a/2}+e^{-a/2}} = \frac{e^{a/2}-e^{-a/2}}{e^{a/2}+e^{-a/2}} = \tanh\left(\frac{a}{2}\right) \quad \text{οπότε:}$$

$$\rightarrow \boxed{u_{OD} = u_{C_2} - u_{C_1} = \alpha I R_C \tanh\left(\frac{u_{ID}}{2V_T}\right)} \qquad (u_{ID} = u_{B_1} - u_{B_2})$$

$$\hookrightarrow \tanh(x) = x - \frac{1}{3}x^3 + \left|\frac{2}{15}x^5 - \frac{17}{315}x^7 + \ldots\right.$$

Γραμμική προσέγγιση:

$$u_{OD} \simeq \frac{\alpha I R_C}{2V_T} u_{ID} \qquad \text{και αφού } \frac{\alpha I}{2}\cdot\frac{1}{V_T} = \frac{I_C}{V_T} = g_m \rightarrow \boxed{u_{OD} \simeq \frac{R_C}{g_m} u_{ID}}$$

Αρμονική παραμόρφωση σε μη γραμμικά κυκλώματα

π.χ. MOS διαφ. ζεύγος, $i_{OD} \simeq g_m u_{ID} - \frac{g_m}{8(V_{GS}-V_T)^2} u_{ID}^3$

$$\left.\begin{aligned} i_{OD} &= b_1 u_{ID} + b_3 u_{ID}^3 \\ u_{ID} &= a\cos\omega t \end{aligned}\right\} \rightarrow i_{OD} = b_1 a\cos\omega t + b_3 a^3 \cos^3\omega t = b_1 a\cos\omega t + b_3 a^3\left[\frac{3}{4}\cos\omega t + \frac{1}{4}\cos 3\omega t\right] =$$

$$= \left(b_1 a + \frac{3}{4}b_3 a^3\right)\cos\omega t + \left(\frac{1}{4}b_3 a^3\right)\cos 3\omega t$$

Γενικά: $i_O = \sum_{n=0}^{\infty} C_n \cdot \cos(n\omega t + \varphi_n)$

$HD_n = \frac{C_n}{C_1}$ (harmonic distortion)

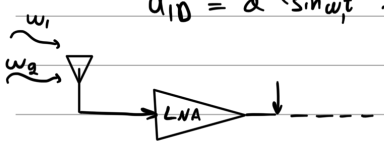
$THD = \frac{\sqrt{\sum_{n=2}^{\infty} C_n^2}}{C_1}$ (total HD) → %, → dB

$$THD \simeq HD_3 = \frac{\frac{1}{4}b_3 a^3}{b_1 a + \frac{3}{4}b_3 a^3} \simeq \frac{\frac{1}{4}b_3 a^3}{b_1 a} = \frac{a^2}{(V_{GS}-V_T)^2}$$

ΜΗ Αρμονική παραμόρφωση σε μη γραμμικά κυκλώματα

- Παράδειγμα: παραμόρφωση ενδοδιαμόρφωσης (Intermodulation Distortion (IM))

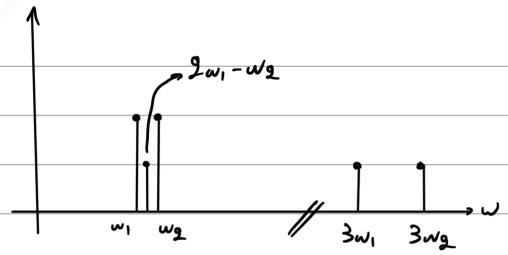
$u_{ID} = a(\sin\omega_1 t + \sin\omega_2 t)$



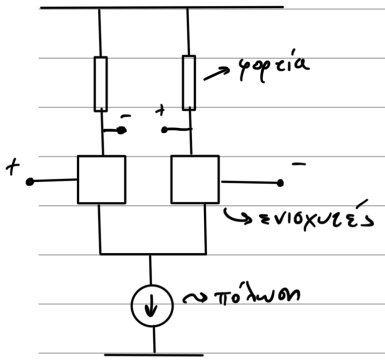
$$i_{OD} \simeq b_1 u_{ID} + b_3 u_{ID}^3 = b_1 a(\sin\omega_1 t + \sin\omega_2 t) + b_3 a^3(\sin\omega_1 t + \sin\omega_2 t)^3 =$$

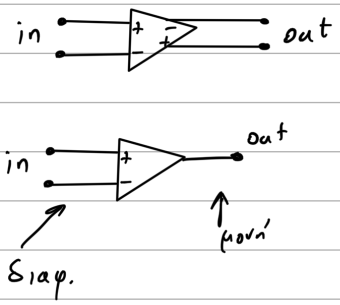
$$= \alpha(\sin\omega_1 t + \sin\omega_2 t) + \beta(\sin 3\omega_1 t + \sin 3\omega_2 t) +$$

$$+ \gamma\left[\sin(2\omega_1 - \omega_2)t - \sin(\omega_1 - 2\omega_2)t + \sin(2\omega_1 + \omega_2)t + \sin(\omega_1 + 2\omega_2)t\right]$$

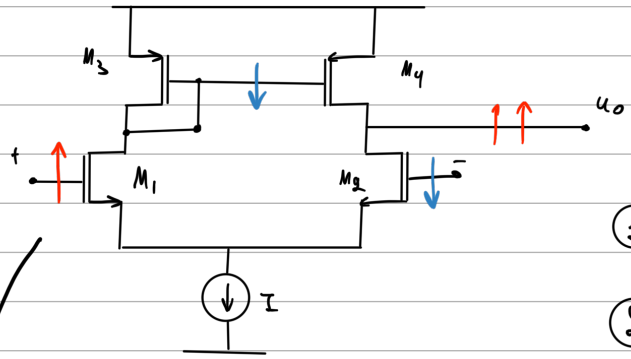


- $a' = b_1 a + \frac{9}{4} b_3 a^3$
- $\gamma = \frac{3}{4} b_3 a^4$
- $\beta = \frac{1}{4} b_3 a^3$
- $IM_3 = \frac{\gamma}{a'} \simeq \frac{3}{32} \frac{a^2}{(V_{GS} - V_T)^2}$





Διαφ. ενισχυτής με μετατροπή διαφ. σήματος σε μονό

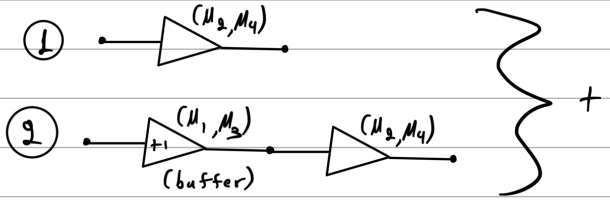


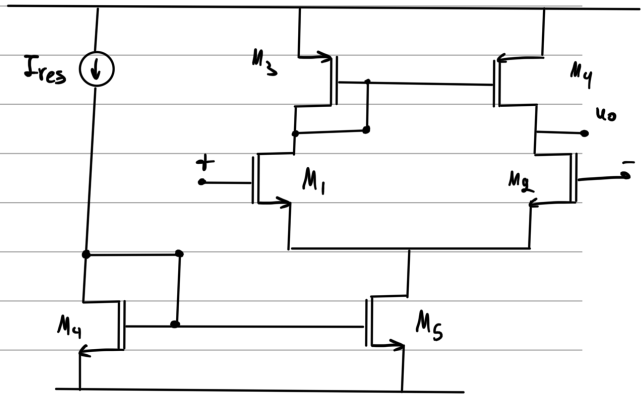
M_2, M_4: analog CMOS inverter

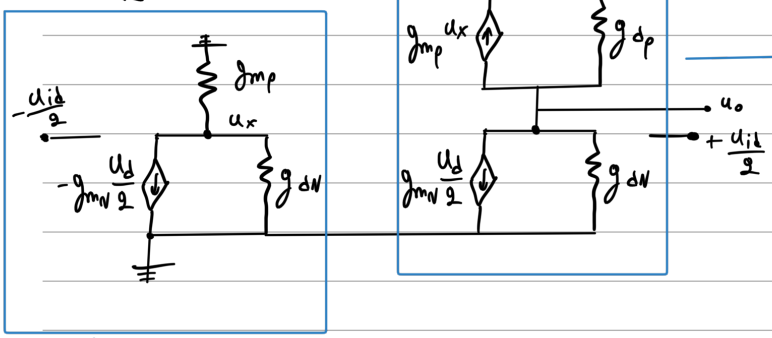
Σταδία ενίσχυσης:

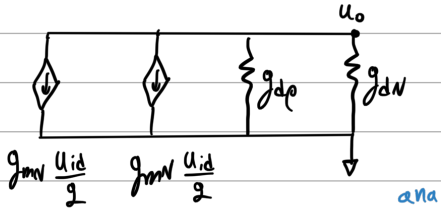
① M_1, M_3: ενισχυτής CS με διοδικό φορτίο (M_3)

② M_4, M_2: analog CMOS inverter με είσοδο στο pmos (M_4)



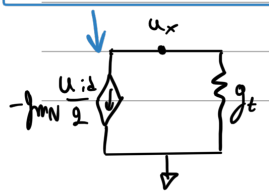






analog CMOS inverter

$$u_o = -\frac{g_{mN}}{g_{dp} + g_{dN}} u_{id}$$



- $g_t = g_{dN} + g_{mp} \simeq g_{mp}$
- $u_x = \frac{-g_{mN}\left(-\frac{u_{id}}{2}\right)}{g_{mp}} \simeq +\frac{u_{id}}{2}$

(ενίσχυση 1ου σταδίου $\simeq 1$)