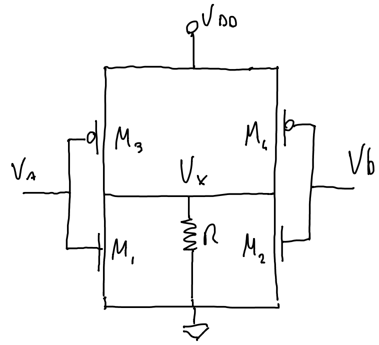
ES. 1



$V_{TN} = 0.5\,V$ $\quad \beta_N = \beta_P = 500\,\mu A/V^2 = \beta$

$V_{TP} = -0.5\,V$

$V_{DD} = 5\,V$

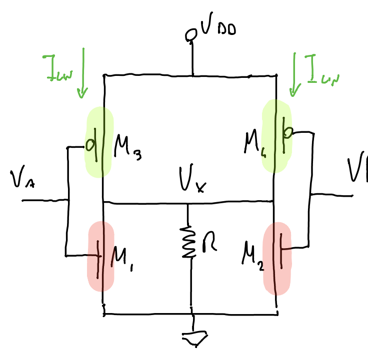
$R = 10\,k\Omega$

→ imponendo $V_b = 0$ calcolare V_x per diversi valori di V_A

→ potenza dissipata ...

→ poi di nuovo tutto con $V_b = V_{DD}$

$V_b = 0V$, $V_A = 0V$



→ condizione per cui PMOS SATURO?

$V_{SD} < V_{GS} - V_{TP} \Rightarrow LIN$

→ supponiamo che PMOS LINEARE

$$I_{LIN} = \frac{\beta_P}{2} \cdot \left[2\left(V_{SG} + V_{TP}\right) \cdot V_{SD} - \underbrace{V_{SD}^2}_{V_{DD}-V_x} \right]$$

$$V_x = R \cdot I_R = R \cdot 2\, I_{LIN}$$

$$= 10 \cdot 10^3 \cdot \cancel{2} \cdot \frac{0.5 \cdot 10^{-3}}{\cancel{2}} \cdot \left[2 \cdot (5-0.5) \cdot (5-V_x) - (5-V_x)^2 \right] =$$

$$\Rightarrow V_x = \left\{ 4.89 \,,\, \cancel{-4.09} \right\}$$

non accett.

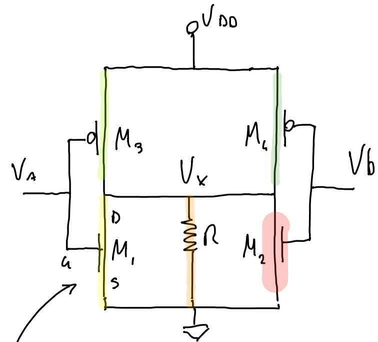
$\Rightarrow V_{SD} = 5 - 4.89$

è minore di $V_{SG} - V_{TP}$? sì

→ LINEARE

PMOS TRIODO (≡LIN) $\quad V_x = 4.89$

$V_B = 0V$, $V_A = V_{TN}$ → si accendono NMOS



$$\frac{V_x}{R_1} + \underbrace{I_{M1}}_{\approx 0} = I_{M3} + I_{M4} = 2\, I_{LIN}$$

→ siamo poco lontani da condizioni di prima, sono stesse condizioni

$I_{SAT} = \frac{\beta}{2}\left(V_{GS} - V_T\right)^2 \approx 0$

$\uparrow$ 0.5 - 0.5

IPOTESI: $M_{3,4}$ TRIODO M_1 SATURO

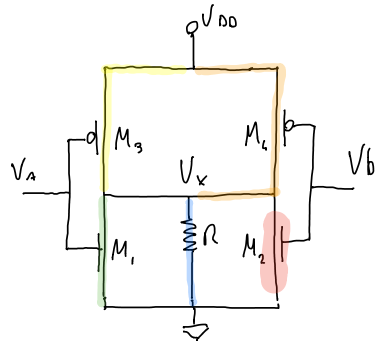
$$V_x = R \cdot \frac{\beta}{2}\, 2\left[2\cdot\left(5 - 0.5 - \overset{V_{TP}}{0.5}\right)\left(5 - V_x\right)\left(5 - V_x\right)^2\right]$$

$$= 75 + 10V_x - 5V_x^2$$

$V_x = 4.88$ → circa uguale a prima
HA SENSO

EFFETTI TRASCURABILI

$V_B = 0$, $V_A = V_x$



IPOTESI PER M_1, M_3 = SAT ← osservando grafico?

M_4 = LIN

$$\frac{V_x}{R} + I_{SAT1} = I_{SAT3} + I_{LIN4}$$

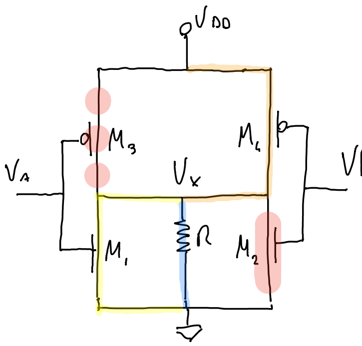
$$\frac{V_x}{R} = \frac{\beta}{2}\left(V_{DD} - V_x - V_T\right)^2 + \frac{\beta}{2}\left[2\left(V_{DD} - V_T\right)\cdot \left(V_{DD} - V_x\right) - \left(V_{DD} - V_x\right)^2\right] - \frac{\beta}{2}\left(V_x - V_T\right)^2 =$$

$$= \frac{\beta}{2}\left\{\left(4.5 - V_x\right)^2 + \left[9\left(5 - V_x\right) - \left(25 + V_x^2 - 10V_x\right)\right] - \left(V_x^2 + 0.25 - V_x\right)\right\} =$$

$$= \frac{\beta}{2}\left\{-V_x^2 - 7V_x + 40\right\}$$

$$\to V_x = \frac{\beta}{2}\left\{-V_x^2 - 7V_x + 40\right\}\cdot R = 3.63$$

$V_B = 0 \quad V_A = V_{DD} - V_T$ → soglia spegnimento pmos



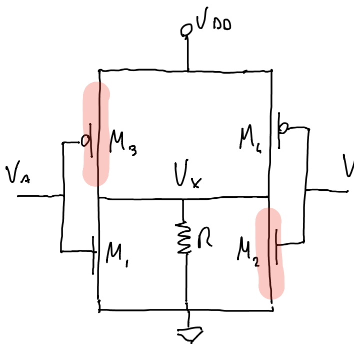
M_3 va in pinch-off → IPOTESI SATURO

$$V_X = R\left(\cancel{I_{M3}} + I_{M4\,LIN} - I_{M1\,LIN}\right)$$

$$= \frac{R\beta}{2}\left\{\left[2(V_{DD}-V_T)(V_{DD}-V_X)-(V_{DD}-V_X)^2\right]-\left[2(V_{DD}-V_T-V_T)\cdot V_X - V_X^2\right]\right\} = \dots$$

$$V_X = 2.7$$

$V_B = 0, \; V_A = V_{DD}$

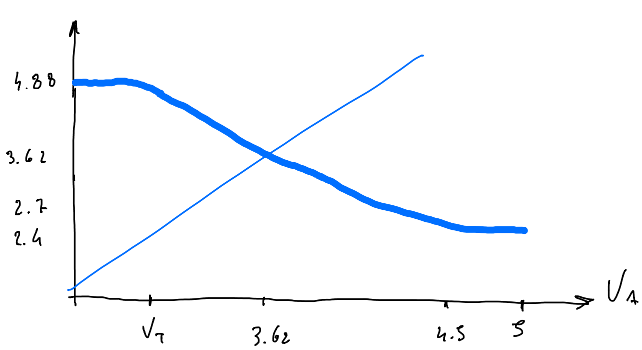


→ simile a condizione precedente

$$V_X = \frac{R\beta}{2}\left\{\left[2(V_{DD}-V_T)(V_{DD}-V_X)-(V_{DD}-V_X)^2\right]-\left[2(V_{DD}-V_T-\cancel{V_T})\cdot V_X - V_X^2\right]\right\}$$

$$V_X = 2.38$$

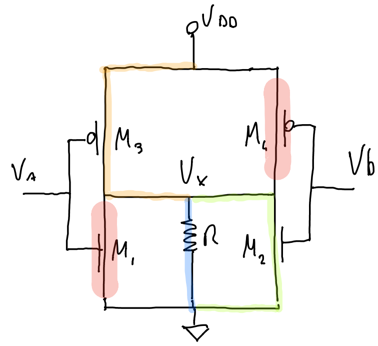
GRAFICO



→ non è un buon invertitore
fa solo calcoli.

SECONDA PARTE

$V_B = V_{DD}\ ,\ V_A = 0$



IPOTESI M3 LINEARE
M2 LINEARE

$$0 = \frac{V_x}{R} + I_{2\,LIN} - I_{3\,LIN}$$

$$= \frac{V_x}{R} + \frac{\beta}{2}\left\{\left[2(V_{DD}-V_T)V_x - V_x^2\right] - \left[2(V_{DD}-V_T)(V_{DD}-V_x) - (V_{DD}-V_x)^2\right]\right\}$$

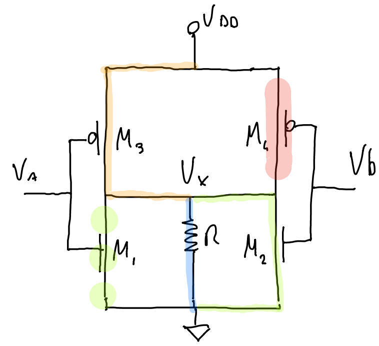
$$= V_x + 2.5\left\{9V_x - V_x^2 - 45 + 9V_x + 25 + V_x^2 - 10V_x\right\} =$$

→ FAI MACINARE A SOLVE( ) $V_x = 2.38$

$V_B = V_{DD}\ ,\ V_A = V_T$

→ soglia accensione, corrente trascurabile

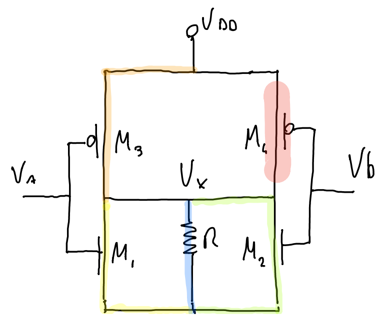
→ UGUALE A PRIMA AGGIUNGENDO NUMERO CHE MANCA



$V_x = 2.02$

$V_B = V_{DD}\ ,\ V_A = V_x$

$M_1 \quad M_3 \quad M_2$
SAT, SAT, LIN



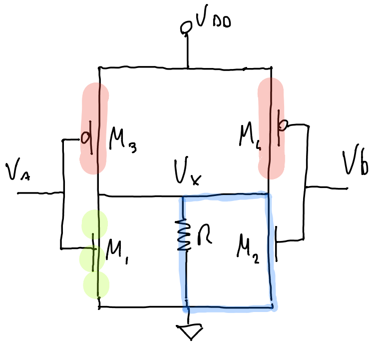
$$0 = \frac{V_x}{R} + I_{M1\,SAT} + I_{M2\,SAT} - I_{M3SAT}$$

$$= \frac{V_x}{R} + \frac{\beta}{2}(V_x - V_T)^2 - \frac{\beta}{2}(4.5 - V_x)^2 + \frac{\beta}{2}\left[2(4.5)\cdot V_x - V_x^2\right] =$$

$$= V_x + 2.5\left[\left(V_x - 2.5\right)^2 - 20.25 - V_x^2 + 9V_x + 9V_x - V_x^2\right] =$$

$V_x = 1.23$

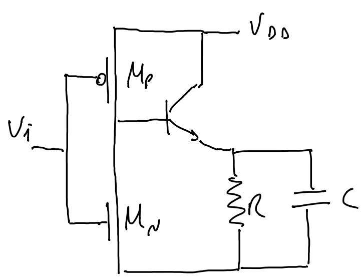
$V_B = V_{DD}$, $V_A = V_{DD} - V_T$



→ QUELLI SOPRA SONO SPENTI!

$V_x = 0$

ES. 2



$V_{DD} = 3.3$ $V_T = 0.4$ $V_\gamma = 0.75$ $\beta_F = 50$

$\beta = 1.2 \cdot 10^{-3}$ $R = 500$ $C = 1 \cdot 10^{-12}$

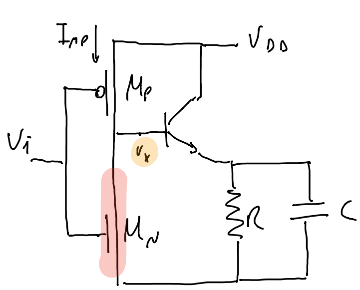
MODELLO A SOGLIA $V_{CE\,sat} = 0$

V_i ⊓⊓ 100 MHz 50%

→ potenza media dissipata senza componente dinamica

→ tempo propagazione HL, quando uscita passa da basso ad alto

$V_i = 0$ M_N OFF



V_x ALTO

REGIONE NORMALE O SAT?

→ COLLETTORE A VDD → SPOR FORZA LINEARE

$$I_{MP} = \beta\left\{(V_{DD} - V_T)(V_{DD} - V_x) - \frac{(V_{DD} - V_x)^2}{2}\right\}$$

→ difficile che tutto ricada su condizione e già saturo

→ base non si può accendere con potenziale più alto di VDD → <u>NO</u> SAT

→ Z_{MP} è incognita

$$I_E = \frac{V_u}{R} \qquad I_P = I_B = \frac{I_E}{\beta_F + 1} \quad \Rightarrow I_P = \frac{V_u}{R(\beta_F+1)} = \frac{V_x - V_\gamma}{R(\beta_F+1)}$$

→ non si guarda componente dinamica, come se condensatore non ci fosse

$$V_u = V_x - V_\gamma \qquad V_x = V_u + V_\gamma$$

$$I_P = \beta\left\{(3.5-0.4)(3.5-0.75-V_u) - \frac{(3.5-0.75-V_u)^2}{2}\right\} =$$

$$= \beta\left\{8.52 - 3.1V_u - 3.78 - \frac{V_u^2}{2} + 2.75V_u\right\} = \qquad I_P = \frac{V_u}{R(\beta_F+1)}$$

$$= \beta_P\left\{4.74 - 0.35V_u - 0.5V_u^2\right\} \Rightarrow V_x = V_u + V_\gamma$$

$$V_u = 2.72 \qquad V_x = 3.47$$

→ POTENZA STATICA

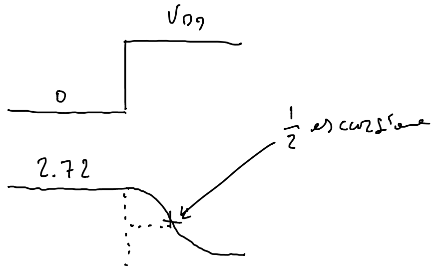
$$P = V \cdot I \qquad I = I_R \qquad I = \frac{V_u}{R}$$

$P = 19\,mW$ quando $V_i = 0$

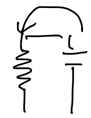
se ingresso alto, uscita $= 0$ → $P = 0$

... 0 | 19mW | 0 | 19 ... → QUINDI POT MEDIA $= \frac{P}{2}$

→ TEMPO PROPAGAZIONE



→ condensatore si scarica solo tramite resistenza



$$I_C = -I_R$$

$$\underbrace{C\frac{dV_M}{dt} = -\frac{V_M}{R}}$$

$$dt = -\frac{RC}{V_M}\,dV_M$$

↓

INTEGRO

$$t_{pHL} = \int_{V_M}^{\frac{V_M}{2}} -\frac{RC}{V_M}\,dV_M$$

$$t_{pHL} = RC\left[\ln|V_M| - \ln\frac{|V_M|}{2}\right] =$$

da capacità pF

$$= 500 \cdot \left[\ln(2.8) - \ln(1.4)\right] = 346 \text{ ps}$$