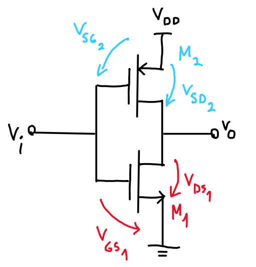
1)



$\rightarrow V_i = 0$

$V_i = V_{GS_1} = 0 < V_{Th}^m \Rightarrow M_1$ ao corte $\Rightarrow i_{D_1} = 0$ ($i_{D_1} = i_{D_2}$)

$M_2 \rightarrow$ Tríodo $\Rightarrow i_{D_2} = k_p\left[2(V_{SG_2} - V_{Th}^p)V_{SD_2} - V_{SD_2}^2\right] = 0 \Leftrightarrow$

$\Leftrightarrow \left(2(V_{SG_2} - V_{Th}^p) - V_{SD_2}\right)V_{SD_2} = 0 \Leftrightarrow \begin{cases} V_{SD_2} = 0 \\ V_{SD_2} = 2(V_{SG_2} - V_{Th}^p) = 2(V_{DD} - V_{Th}^p) = 6{,}6\,V \end{cases}$

$V_{SD_2} = 0 \rightsquigarrow V_{SD_2} < V_{SG_2} - V_{Th}^p \Leftrightarrow 0 < 5 - 1.7 = 3.3\,V$

$\hookrightarrow$ Confirma tríodo $\Rightarrow V_o = V_{DD} - V_{SD_2} = 5\,V$

$\rightarrow V_i = V_{DD}$

$V_{SG_2} = V_{DD} - V_i = 0 < V_{Th}^p \Rightarrow M_2$ ao corte $\Rightarrow i_{D_2} = 0$ ($i_{D_1} = i_{D_2}$)

$M_1 \rightarrow$ Tríodo $\Rightarrow i_{D_1} = k_m\left[2(V_{GS_1} - V_{Th}^m)V_{DS_1} - V_{DS_1}^2\right] = 0 \Leftrightarrow$

$\Leftrightarrow \left(2(V_{GS_1} - V_{Th}^m) - V_{DS_1}\right)V_{DS_1} = 0 \Leftrightarrow \begin{cases} V_{DS_1} = 0 \\ V_{DS_1} = 2(V_{GS_1} - V_{Th}^m) = 2(V_{DD} - V_{Th}^m) = 6.2\,V \end{cases}$

$V_{DS_1} = 0 \rightsquigarrow V_{DS_1} < V_{GS_1} - V_{Th}^m \Leftrightarrow 0 < 5 - 1.9 = 3.1\,V$

$\hookrightarrow$ confirma o tríodo $\Rightarrow V_o = V_{DS_1} = 0$

$\rightarrow V_i = \frac{V_{DD}}{2}$ Vamos supor M_1 e M_2 na saturação

$i_{D_1} = k_m(V_{GS_1} - V_{Th}^m)^2 = 105\,\mu A$

$i_{D_2} = k_p(V_{SG_2} - V_{Th}^p)^2 = 154\,\mu A$

$\Rightarrow i_{D_2} \neq i_{D_1}$ Não temos os 2 em saturação!

i_{D_2} pode baixar se M_2 estiver no tríodo:

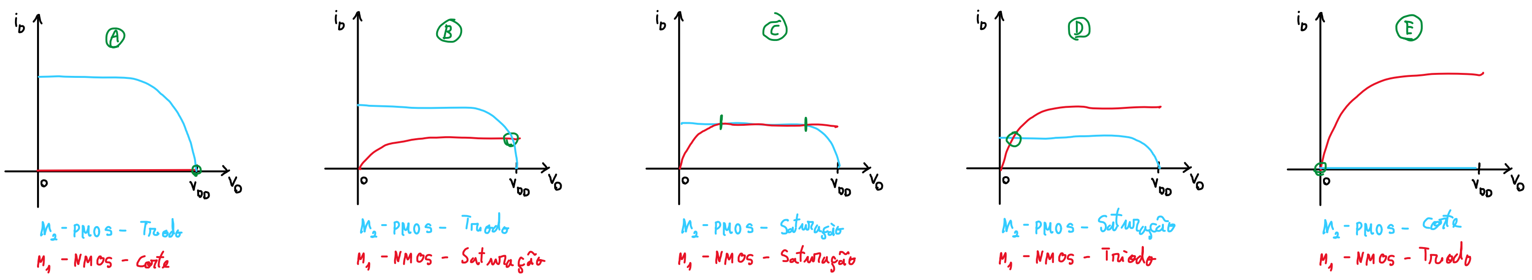
$i_{D_1} = k_p\left[2(V_{SG_2} - V_{Th}^p)V_{SD_2} - V_{SD_2}^2\right] \Leftrightarrow k_p \cdot V_{SD_2}^2 - 2k_p(V_{SG_2} - V_{Th}^p)\cdot V_{SD_2} + i_{D_1} = 0 \Leftrightarrow$

$\Leftrightarrow V_{SD_2} = \dfrac{2k_p(V_{SG_2} - V_{Th}^p) \pm \sqrt{2k_p(V_{SG_2} - V_{Th}^p)^2 - 4k_p i_{D_1}}}{2k_p} = \begin{cases} V_{SD_2} = 1{,}25\,V \\ V_{SD_2} = 0{,}35\,V \end{cases}$

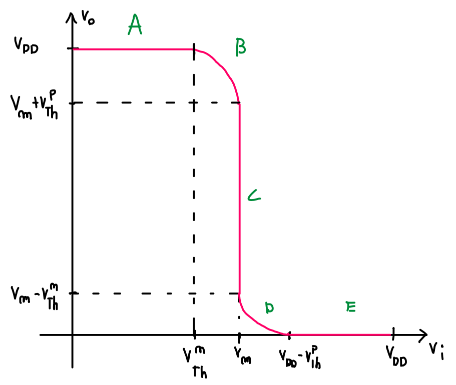
$V_{SD_2} = 0.35\,V \rightsquigarrow V_{SD_2} < V_{SG_2} - V_{Th}^p \Leftrightarrow 0.35 < 2.5 - 1.7 \Leftrightarrow 0.35 < 0.8 \Rightarrow$ Confirma M_2 a tríodo!

Logo $V_o = V_{DD} - V_{DS_2} = 4{,}65\,V$ e $i_D = i_{D_1} = i_{D_2} = 105\,\mu A$

3.2)



	A	B	C	D	E
NMOS	C	S	S	T	T
PMOS	T	T	S	S	C



$V_{Th}^m = 1.9\,V$

$V_{DD} - V_{Th}^p = 3.3\,V$

$V_m = 2.57\,V$

$V_m + V_{Th}^p = 4.27\,V$

$V_m - V_{Th}^m = 0.67\,V$

$V_m = ?$ $\quad i_{D_1} = k_m(V_{GS_1} - V_{Th}^m)^2$, $\quad i_{D_2} = k_p(V_{SG_2} - V_{Th}^p)^2$ $\Rightarrow k_m(V_i - V_{Th}^m)^2 = k_p(V_{DD} - V_i - V_{Th}^p)^2 \Rightarrow V_m = V_i = \dfrac{\sqrt{k_m}\,V_{Th}^m + \sqrt{k_p}\,(V_{DD} - V_{Th}^p)}{\sqrt{k_m} + \sqrt{k_p}} = 2.57\,V$

3.3) i_D Max $\Rightarrow$ saturação

$V_i = V_m \Rightarrow i_D = k_m(V_m - V_{Th}^m)^2 = 130\,\mu A$ //

3.4) $V_{OH} = V_{DD} = 5\,V$

$V_{OL} = V_{SS} = 0\,V$

$V_{IL} = 2.73\,V$

$V_{IH} = 2.38\,V$

$NM_L = V_{IL} - V_{OL} = 2.38\,V$

$NM_H = V_{OH} - V_{IH} = 2{,}27\,V$

$V_{IL} \rightarrow$ Zona (B)

$i_{D_1} = i_{D_2} \Rightarrow k_m(V_i - V_{Th}^m)^2 = k_p\left[2(V_{DD} - V_i - V_{Th}^p)(V_{DD} - V_o) - (V_{DD} - V_o)^2\right]$ $\Rightarrow \begin{cases} V_{IL} = -11.5\,V \\ V_{IL} = 2.38\,V \end{cases}$

Derivar em ordem a V_i:

$2k_m(V_i - V_{Th}^m) = 2k_p\left[V_o - V_{DD} + (V_{DD} - V_i - V_{Th}^p)\left(-\frac{dV_o}{dV_i}\right) - (V_{DD} - V_o)\left(-\frac{dV_o}{dV_i}\right)\right]$

Com $\frac{dV_o}{dV_i} = -1$ e $V_i = V_{IL}$:

$k_m(V_i - V_{Th}^m) = k_p(2V_o - V_{IL} - V_{Th}^p - V_{DD}) \Leftrightarrow \boxed{V_o = \frac{1}{2}\left(1 + \frac{k_m}{k_p}\right)V_{IL} + \frac{1}{2}\left(V_{DD} - \frac{k_m}{k_p}V_{Th}^m + V_{Th}^p\right)}$

Temos que ter $V_{GS_1} = V_{IL} > V_{Th}^m \Rightarrow V_{IL} = 2.38\,V$ //

$V_{IH} \rightarrow$ Zona (D)

$i_{D_1} = i_{D_2} \Rightarrow k_m\left[2(V_i - V_{Th}^m)V_o - V_o^2\right] = k_p(V_{DD} - V_i - V_{Th}^p)^2$ $\Rightarrow \begin{cases} V_{IH} = -11.85\,V \\ V_{IH} = 2{,}73\,V \end{cases}$

Derivar em ordem a V_i:

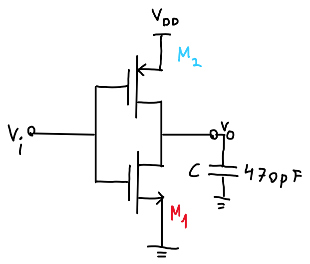
$2k_m\left[V_o + (V_{Th}^m - V_i)\left(-\frac{dV_o}{dV_i}\right) + V_o\left(-\frac{dV_o}{dV_i}\right)\right] = -2k_p(V_{DD} - V_i - V_{Th}^p)$

Com $\frac{dV_o}{dV_i} = -1$ e $V_i = V_{IH}$:

$k_m(2V_o - V_{IH} + V_{Th}^m) = -k_p(V_{DD} - V_{IH} - V_{Th}^p) \Rightarrow \boxed{V_o = \frac{1}{2}\left(1 + \frac{k_p}{k_m}\right)V_{IH} + \frac{1}{2}\left(\frac{k_p}{k_m}V_{Th}^p - V_{Th}^m - \frac{k_p}{k_m}V_{DD}\right)}$

Temos que ter $V_{GS_1} = V_{IH} > V_{Th}^m \Rightarrow V_{IH} = 2{,}73\,V$

3.5)



$$i_c = C\frac{dV_o}{dt} \Rightarrow \bar{i} \approx C\frac{\Delta V_o}{\Delta t} \Rightarrow \Delta t = \frac{C}{\bar{i}}\Delta V_o$$

$$\frac{d\,i_c}{dt} \approx 0 \Rightarrow i_c = \bar{i}$$

$$\Delta V_o = V_o(t_f) - V_o(t_i)$$

$$\bar{i} = \frac{i_c(t_f) + i_c(t_i)}{2}$$

t_{pHL} → M_1 conduz, M_2 corta

Descarrega!

Em t_i: $\begin{cases} V_o(t_i) = V_{OH} = 5\,V \quad (V_{DS_1} > V_{GS_1} - V_{Th}^n) \\ i_{D_1}(t_i) = K_n(V_{OH} - V_{Th}^n)^2 = 2.806\,mA \quad (M_1 \text{ Sat}) \end{cases}$

Em t_f: $\begin{cases} V_o(t_f) = \frac{V_{OL} + V_{OH}}{2} = 2.5\,V \\ i_{D_1}(t_f) = K_n\left[2(V_{OH} - V_{Th}^n)\left(\frac{V_{OH}+V_{OL}}{2}\right) - \left(\frac{V_{OH}+V_{OL}}{2}\right)^2\right] = 2{,}701\,mA \quad M_1 \text{ Triodo} \end{cases}$

$\Rightarrow$ $\Delta V_o = -2.5\,V$, $\bar{i} = -2.754\,mA$ $\Rightarrow$ $t_{pHL} = 427\,ns$

t_{pLH} → M_1 corta, M_2 conduz

Carrega!

Em t_i: $\begin{cases} V_o(t_i) = V_{OL} = 0 \quad (V_{SD_2} > V_{SG_2} - V_{Th}^p) \\ i_{D_2}(t_i) = K_p(V_{SG_2} - V_{Th}^p)^2 = K_p(V_{DD} - V_{OL} - V_{Th}^p)^2 = 2.614\,mA \quad (M_2 \text{ Sat}) \end{cases}$

Em t_f: $\begin{cases} V_o(t_f) = \frac{V_{OL} + V_{OH}}{2} = 2.5\,V \\ i_{D_2} = K_p\left[2(V_{SG_2} - V_{Th}^n)V_{SD_2} - V_{SD_2}^2\right] = K_p\left[2(V_{DD} - V_{Th}^p)\left(V_{DD} - \frac{V_{OH}+V_{OL}}{2}\right) - \left(V_{DD} - \frac{V_{OH}+V_{OL}}{2}\right)^2\right] = 2.460\,mA \quad (M_2 \text{ Triodo}) \end{cases}$

$\Rightarrow$ $\Delta V_o = 2.5\,V$, $\bar{i} = 2.537\,mA$ $\Rightarrow$ $t_{pHL} = 463\,ns$

$$t_p = \frac{t_{pHL} + t_{pLH}}{2} = 445\,ns$$

Equações exatas

$$t_{pHL} = \frac{C V_{Th}^n}{K_n(V_{DD} - V_{Th}^n)^2} + \frac{C}{2K_n(V_{DD} - V_{Th}^n)}\ln\left(\frac{3V_{DD} - 4V_{Th}^n}{V_{DD}}\right) = 420\,ns$$

$$t_{pLH} = \frac{C V_{Th}^p}{K_p(V_{DD} - V_{Th}^p)^2} + \frac{C}{2K_p(V_{DD} - V_{Th}^p)}\ln\left(\frac{3V_{DD} - 4V_{Th}^p}{V_{DD}}\right) = 453\,ns$$

$\Rightarrow t_p = 436\,ns$