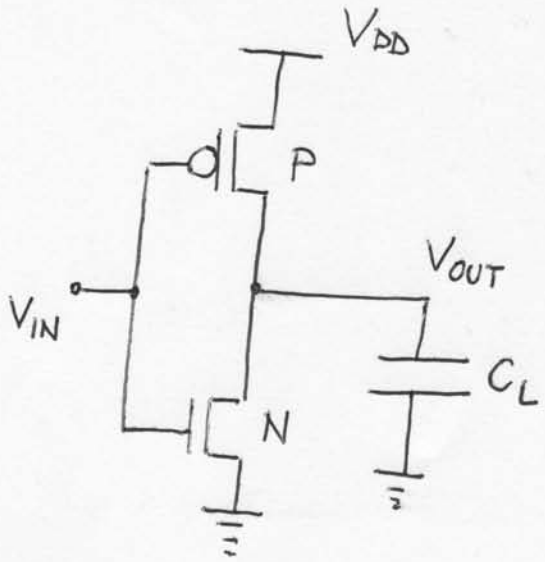
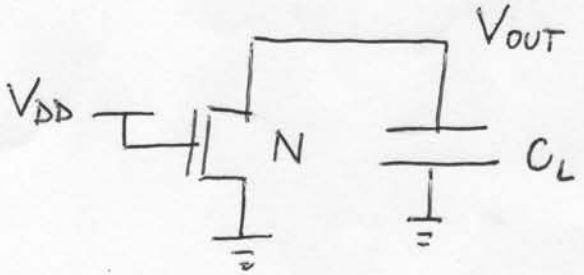
INVERTITORE CMOS : TRANSITORIO



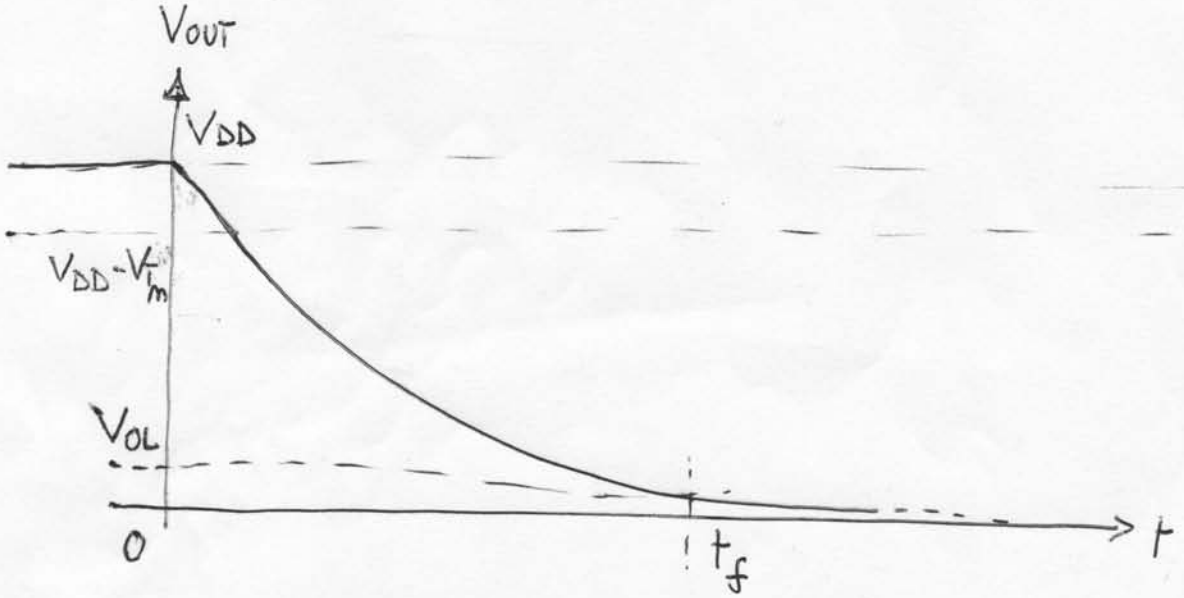
A) TRANSITORIO DI DISCESA (t_f)

Per $t < 0$ $\quad V_{IN} = 0 \longrightarrow V_{OUT} = V_{DD}$

Per $t = 0$ $\quad V_{IN} : 0 \longrightarrow V_{DD}$ $\quad$ P OFF, N ON $\quad$ C_L si scarica a massa



$V_{OUT}(t=0) = V_{DD}$



$$t_f = \frac{2 C_L}{\beta_m} F_m$$

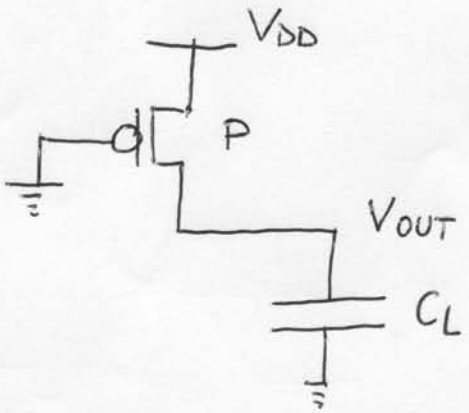
con

$$F_m = \frac{V_{Tm}}{(V_{DD} - V_{Tm})^2} + \frac{1}{2 (V_{DD} - V_{Tm})} \ln \frac{2 (V_{DD} - V_{Tm}) - V_{OL}}{V_{OL}}$$

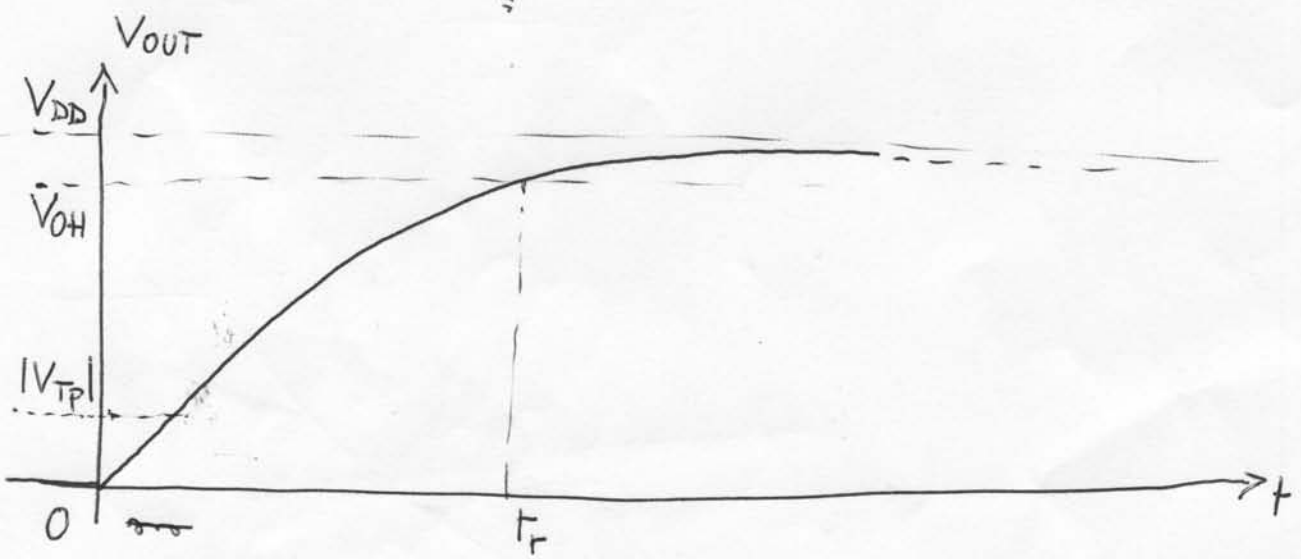
B) TRANSITORIO DI SALITA t_r

Per $t < 0$ $\quad V_{IN} = V_{DD} \longrightarrow V_{OUT} = 0$

Per $t = 0$ $\quad V_{IN} : V_{DD} \longrightarrow 0$ quindi: N_{OFF}, P_{ON} $\quad C_L$ si carica



$V_{OUT}(0) = 0$



$$t_r = \frac{2 C_L}{\beta_P} F_P$$

com

$$F_P = \frac{|V_{TP}|}{(V_{DD} - |V_{TP}|)^2} + \frac{1}{2(V_{DD} - |V_{TP}|)} \ln \frac{2(V_{DD} - |V_{TP}|) - (V_{DD} - V_{OH})}{V_{DD} - V_{OH}}$$

- TECNOLOGIA A

$V_{DD} = 3,3\,V$ $\quad V_{Tm} = |V_{TP}| = 0,7\,V$ $\quad \beta'_m = 100\,\mu A/V^2$ $\quad \beta'_P = 50\,\mu A/V^2$

$L_{min} = 0,35\,\mu m$ $\quad C_{ox} = 3,45\,fF/\mu m^2$

- TEMPI DI TRANSITO AL 90%

$V_{OL} = \frac{V_{DD}}{10} = 0,33\,V$

$V_{OH} = \frac{9}{10} V_{DD} = 2,97\,V$ $\qquad V_{DD} - V_{OH} = 0,33\,V$

$$F_{m_{90\%}} = F_{P_{90\%}} = \frac{0,7}{6,76} + \frac{1}{5,2} \ln \frac{5,2 - 0,33}{0,33} =$$

$$= 0,10355 + 0,51764 = 0,6212 \quad V^{-1}$$

- TEMPI DI TRANSITO AL 50% $\qquad V_{OL} = \frac{V_{DD}}{2} = 1,65\,V = V_{OH}$

$$F_{m_{50\%}} = F_{P_{50\%}} = \frac{0,7}{6,76} + \frac{1}{5,2} \ln \frac{5,2 - 1,65}{1,65} =$$

$$= 0,10355 + 0,14734 = 0,2509 \quad V^{-1}$$

$C_L = n\, C_{in_{gate}} = n\left(W_p L_p^{W_m L_m} C_{ox}\right) = n\, L_{min}^2 (S_m + S_p) C_{ox}$

Sia $C_L = 120$ fF

$n(S_m + S_p) = \frac{C_L}{L_{min}^2 C_{ox}} = \frac{120 \cdot 10^{-15}}{0,1225 \cdot 10^{-12} \cdot 3,45 \cdot \frac{10^{-15}}{10^{-12}}} = \frac{120}{0,4226} \simeq 284$

- $S_m = 2 \qquad S_p = 2\, S_m = 4$

$\beta_m = \beta'_m \cdot S_m = 200 \frac{\mu A}{V^2} \qquad \beta_p = \beta'_p S_p = 200 \frac{\mu A}{V^2}$

$t_{f_{90\%}} = t_{r_{90\%}} = \frac{2 \cdot 120 \cdot 10^{-15}}{200 \cdot 10^{-6}} \cdot 0,6212 = 0,7454 \cdot 10^{-9} = 745,4$ ps

$t_{f_{50\%}} = t_{r_{50\%}} = \frac{2 \cdot 120 \cdot 10^{-15}}{200 \cdot 10^{-6}} \cdot 0,2509 = 0,301 \cdot 10^{-9} = 301$ ps

- $S_m = 1 \qquad S_p = 4$

$\beta_m = \beta'_m S_m = 100\ \mu A/V^2 \qquad \beta_p = \beta'_p S_p = 200 \frac{\mu A}{V^2}$

$t_{r_{90\%}} = 745,4$ ps $\qquad t_{f_{90\%}} = 2\, t_{r_{90\%}} = 1490,8$ ps $\simeq 1,49$ ms

$t_{r_{50\%}} = 301$ ps $\qquad t_{f_{50\%}} = 2\, t_{r_{50\%}} = 602$ ps

- $S_m = 2 \qquad S_p = 2$

$\beta_m = \beta'_m S_m = 200 \frac{\mu A}{V^2} \qquad \beta_p = \beta'_p S_p = 100 \frac{\mu A}{V^2}$

$t_{f_{90\%}} = 745,4$ ps $\qquad t_{r_{90\%}} = 2\, t_{f_{90\%}} = 1490,8$ ps $\simeq 1,49$ ms

$t_{f_{50\%}} = 301$ ps $\qquad t_{r_{50\%}} = 2\, t_{f_{50\%}} = 602$ ps

- TECNOLOGIA B

$V_{DD} = 1V \qquad \beta'_n = 200 \frac{\mu A}{V^2} \qquad \beta'_p = 100 \frac{\mu A}{V^2} \qquad V_{T_n} = |V_{T_p}| = 0,25V$

$L_{min} = 0,09 \mu m = 90 nm \qquad C_{ox} = \frac{23 fF}{\mu m^2}$

- TEMPI DI TRANSITO AL 90%

$V_{OL} = \frac{V_{DD}}{10} = 0,1V$

$V_{OH} = 0,9V \qquad V_{DD} - V_{OH} = 0,1V$

$$F_{m_{90\%}} = F_{p_{90\%}} = \frac{0,25}{0,5625} + \frac{1}{1,5} \ln \frac{1,5 - 0,1}{0,1} =$$

$$= 0,4444 + 1,7593 = 2,203\ V^{-1}$$

- TEMPI DI TRANSITO AL 50%

$V_{OL} = V_{OH} = \frac{V_{DD}}{2} = 0,5V$

$$F_{m_{50\%}} = F_{p_{50\%}} = \frac{0,25}{0,5625} + \frac{1}{1,5} \ln \frac{1,5 - 0,5}{0,5} =$$

$$= 0,4444 + 0,4621 = 0,906\ V^{-1}$$

$$\frac{F_{m\,90\%\,B}}{F_{m\,90\%\,A}} = \frac{F_{p\,90\%\,B}}{F_{p\,90\%\,A}} = 3,546$$

$$\frac{F_{m\,50\%\,B}}{F_{m\,50\%\,A}} = \frac{F_{p\,50\%\,B}}{F_{p\,50\%\,A}} = 3,611$$

$$C_L = m\, L_{min}^2\, (S_m + S_p)\, C_{ox} = 284 \cdot 8{,}1 \cdot 10^{-3} \cdot \cancel{10^{-12}} \cdot 23 \cdot \frac{10^{-15}}{\cancel{10^{-12}}} =$$

$$= 52{,}9 \text{ fF}$$

- $S_m = 2 \qquad S_p = 4$

$$\beta_m = \beta'_m S_m = 400 \frac{\mu A}{V^2} \qquad \beta_p = \beta'_p S_p = 400 \frac{\mu A}{V^2}$$

$$t_{fgox} = t_{rgox} = \frac{2 \cdot 52{,}9 \cdot 10^{-15}}{400 \cdot 10^{-6}} \cdot 2{,}203 = 0{,}5827 \text{ ns} = 582{,}7 \text{ ps}$$

$$t_{fsox} = t_{rsox} = \frac{2 \cdot 52{,}9 \cdot 10^{-15}}{400 \cdot 10^{-6}} \cdot 0{,}906 = 239{,}6 \text{ ps}$$

- $S_m = 1 \qquad S_p = 4$

$$\beta_m = \beta'_m S_m = 200 \frac{\mu A}{V^2} \qquad \beta_p = \beta'_p S_p = 400 \frac{\mu A}{V^2}$$

$t_{rgox} = 582{,}7$ ps $\qquad t_{fgox} = 2\, t_{rgox} = 1165{,}4$ ps $= 1{,}165$ ns

$t_{rsox} = 239{,}6$ ps $\qquad t_{fsox} = 2\, t_{rsox} = 479{,}2$ ps

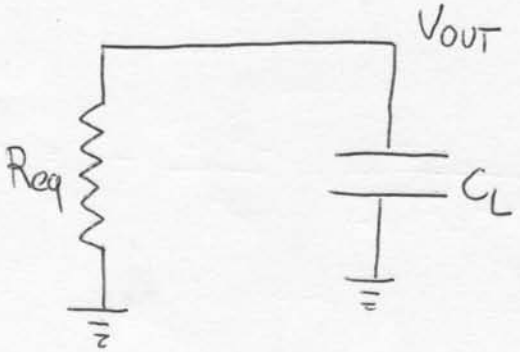
- $S_m = 2 \qquad S_p = 2$

$$\beta_m = \beta'_m S_m = 400 \frac{\mu A}{V^2} \qquad \beta_p = \beta'_p S_p = 200 \frac{\mu A}{V^2}$$

$t_{fgox} = 582{,}7$ ps $\qquad t_{rgox} = 2\, t_{fgox} = 1165{,}4$ ps $= 1{,}165$ ns

$t_{fsox} = 239{,}6$ ps $\qquad t_{rsox} = 2\, t_{fsox} = 479{,}2$ ps

- MODELLO RESISTENZA EQUIVALENTE



$$V_{OUT}(0) = V_{DD}$$

$$\frac{V_{OUT}}{R_{eq}} = -C_L \frac{dV_{OUT}}{dt}$$

$$\frac{dV_{OUT}}{V_{OUT}} = -\frac{dt}{R_{eq} C_L}$$

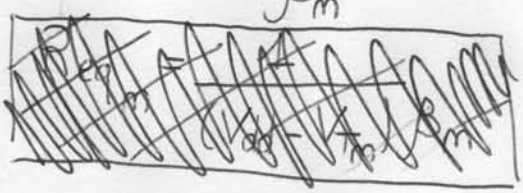
$$R_{eq} = \frac{2}{\beta_n} \cdot F_n \cdot \frac{1}{\ln \frac{V_{DD}}{V_{OL}}}$$

$$= \frac{2}{\beta_n'} F_n \cdot \frac{1}{\ln \frac{V_{DD}}{V_{OL}}} \cdot \frac{1}{S_n}$$

$$\left[\ln V_{OUT} \right]_{V_{DD}}^{V_{OL}} = -\frac{t_f}{R_{eq} C_L}$$

$$t_f = R_{eq} C_L \ln \frac{V_{DD}}{V_{OL}}$$

$$R_{eq} \propto \frac{1}{\beta_n} \qquad R_{eq_{tgt}, S_n = 1}$$



$$t_{f\,90\%} = R_{eq_{n90}} C_L \ln(10)$$

$$t_{f\,50\%} = R_{eq_{n90}} C_L \ln(2)$$

$$V_{OUT}(0) = 0$$

$$\frac{V_{DD} - V_{OUT}}{R_{eq}} = C_L \frac{dV_{OUT}}{dt}$$

$$t_{r\,90\%} = R_{eq_{p90}} C_L \ln(10)$$

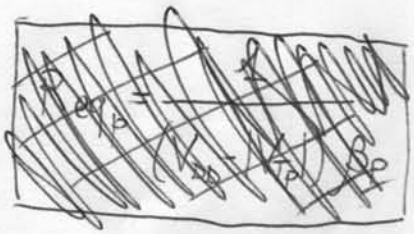
$$t_{r\,50\%} = R_{eq_{p50}} C_L \ln(2)$$

$$\frac{dV_{OUT}}{V_{DD} - V_{OUT}} = \frac{dt}{R_{eq} C_L}$$

$$-\ln\left(\frac{V_{DD} - V_{OH}}{V_{DD}}\right) = \frac{t_r}{R_{eq} C_L}$$

$V_{DD} - V_{OH}$

$$t_r = R_{eq} C_L \ln\left(\frac{V_{DD}}{V_{DD} - V_{OH}}\right)$$



$$t_{f\,90\%} = \frac{2\,C_L}{\beta_m} F_{m\,90\%} = \frac{2\,C_L}{\beta'_m\,S_m} F_{m\,90\%} = \frac{1}{S_m}\left(\frac{2\,F_{m\,90\%}}{\beta'_m}\right) C_L$$

$$t_{f\,90\%} = R_{m\,eq_{90\%}}\, C_L\, \ln(10)$$

$$R_{m\,eq_{90\%}}\, \ln(10) = \frac{1}{S_m}\left(\frac{2\,F_{m\,90\%}}{\beta'_m}\right)$$

$$R_{m\,eq\,90\%} = \frac{1}{S_m}\left(\frac{2\,F_{m\,90\%}}{\beta'_m\,\ln(10)}\right) = \frac{R_{m\,eq\,90\%,\,S=1}}{S_m}.$$

Quindi:

$$R_{m\,eq\,90\%,\,S=1} = \frac{2\,F_{m\,90\%}}{\beta'_m\,\ln(10)}$$

$$R_{p\,eq\,90\%,\,S=1} = \frac{2\,F_{p\,90\%}}{\beta'_p\,\ln(10)}$$

$$R_{m\,eq\,50\%,\,S=1} = \frac{2\,F_{m\,50\%}}{\beta'_m\,\ln(2)}$$

$$R_{p\,eq\,50\%,\,S=1} = \frac{2\,F_{p\,50\%}}{\beta'_p\,\ln(2)}$$

- TECNOLOGIA A

$$R_{m\,eq\,90\%,\,S=1} = \frac{2 \cdot 0,6212}{100 \cdot 10^{-6} \cdot 2,3026} = 5,395\ k\Omega$$

$$R_{P\,eq\,90\%,\,S=1} = 10,79\ k\Omega$$

$$R_{m\,eq\,50\%,\,S=1} = \frac{2 \cdot 0,2509}{100 \cdot 10^{-6} \cdot 0,6931} = 7,24\ k\Omega$$

$$R_{P\,eq\,50\%,\,S=1} = 14,48\ k\Omega$$

- TECNOLOGIA B

$$R_{m\,eq\,90\%,\,S=1} = \frac{2 \cdot 2,203}{200 \cdot 10^{-6} \cdot 2,3026} = 9,567\ k\Omega$$

$$R_{P\,eq\,90\%,\,S=1} = 19,134\ k\Omega$$

$$R_{m\,eq\,50\%,\,S=1} = \frac{2 \cdot 0,906}{200 \cdot 10^{-6} \cdot 0,6931} = 13,071\ k\Omega$$

$$R_{P\,eq\,50\%,\,S=1} = 26,142\ k\Omega$$

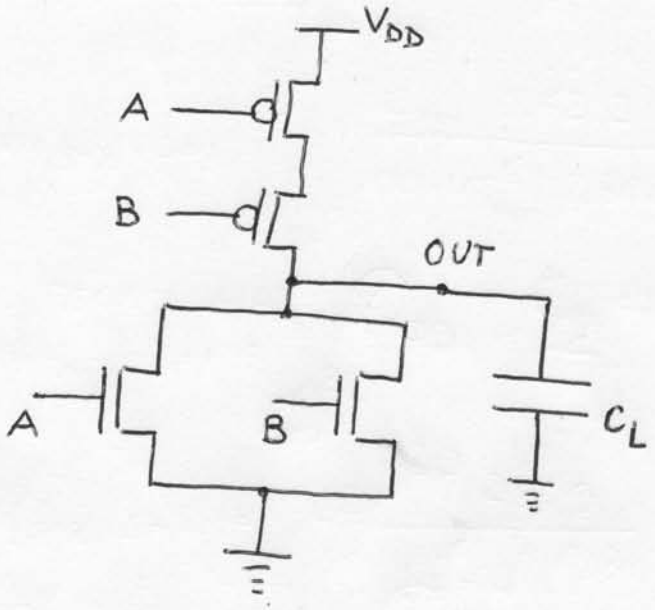
Se TECNOLOGIA (A) $S_p = 4$

$$t_{r_{50\%}} = \frac{14{,}48 \cdot 10^3}{4} \cdot 120 \cdot 10^{-15} \cdot 0{,}6931 = 301 \text{ ps}$$

Se TECNOLOGIA (B) $S_m = 2$

$$t_{f_{90\%}} = \frac{9{,}567 \cdot 10^3}{2} \cdot 52{,}9 \cdot 10^{-15} \cdot 2{,}3026 = 582{,}6 \text{ ps}$$

NOR CMOS



A	B	OUT
0	0	1
0	1	0
1	0	0
1	1	0

n MOS con fattore di forma S_n
p MOS con fattore di forma S_p

- tempo di salita t_r

$$S_{PU} = \frac{S_P}{2}$$

$$t_r = \frac{2\,C_L}{\beta'_p\, S_{PU}}\, F_p = \frac{2\,C_L}{\beta'_p\, \frac{S_P}{2}}\, F_p = \frac{4\,C_L}{\beta'_p\, S_P}\, F_p$$

- tempo di discesa t_f

(a) A B : 00 $\longrightarrow$ 01
10

$$S_{PD} = S_n$$

$$t_f = \frac{2\,C_L}{\beta'_n\, S_N}\, F_n$$

(CASO PEGGIORE)

(b) A B : 00 $\longrightarrow$ 11

$$S_{PD} = 2\,S_N$$

$$t_f = \frac{2\,C_L}{\beta'_n\, 2S_N}\, F_n = \frac{C_L}{\beta'_n\, S_N}\, F_n$$

Se vogliamo $t_r = t_{f\,(caso\ peggiore)}$

$$\frac{4 C_L}{\beta'_p S_p} F_p = \frac{2 C_L}{\beta'_m S_m} F_m$$

$$\frac{S_p}{S_m} = 2 \frac{F_p}{F_m} \cdot \frac{\beta'_m}{\beta'_p} = 2 \cdot \frac{1}{1} = 2 = 4$$

- TECNOLOGIA A ($C_L = 120\,fF$)

- $S_m = 2 \qquad S_p = 4\,S_m = 8$

$$t_{r_{gox}} = \frac{4 C_L F_{m_{gox}}}{\beta'_p S_p} = \frac{4 \cdot 120 \cdot 10^{-15}}{50 \cdot 10^{-6} \cdot 8} \cdot 0{,}6212 = 745{,}44\ ps$$

$$t_{f_{gox\ peggiore}} = 745{,}44\ ps$$

$$t_{r_{sox}} = t_{f_{sox\ peggiore}} = \frac{4 \cdot 120 \cdot 10^{-15}}{50 \cdot 10^{-6} \cdot 8} \cdot 0{,}2509 = 301\ ps$$

- $S_m = 2 \qquad S_p = 2$

$$t_{f_{gox\ peggiore}} = 745{,}44\ ps$$

$$t_{r_{gox}} = 2{,}98\ ns = 4 \cdot t_{f_{gox\ peggiore}}$$

$$t_{f_{sox\ peggiore}} = 301\ ps \qquad t_{r_{sox}} = 4\, t_{f_{sox\ peggiore}} = 1{,}204\ ns$$

- $S_m = 8 \qquad S_p = 8$

$$t_{r_{gox}} = 745{,}44\ ps \qquad t_{f_{gox\ peggiore}} = \frac{t_{r_{gox}}}{4} = 186{,}36\ ps$$

$$t_{r_{sox}} = 301\ ps \qquad t_{f_{sox\ peggiore}} = \frac{t_{r_{sox}}}{4} = 75{,}25\ ps$$

- TECNOLOGIA B ($C_L = 52,9\ fF$)

- $S_m = 2 \qquad S_p = 4 S_m = 8$

$$t_{r_{90\%}} = \frac{4 C_L}{\beta'_p S_p} F_{P_{90\%}} = \frac{4 \cdot 52,9 \cdot 10^{-15}}{100 \cdot 10^{-6} \cdot 8} \cdot 2,203 = 582,7\ ps = t_{f_{90\% \text{ peggiore}}}$$

$$t_{r_{50\%}} = \frac{4 \cdot 52,9 \cdot 10^{-15}}{100 \cdot 10^{-6} \cdot 8} \cdot 0,906 = 239,6\ ps = t_{f_{50\% \text{ peggiore}}}$$

- $S_m = 2 \qquad S_p = 2$

$t_{f_{90\% \text{ PEGGIORE}}} = 582,7\ ps \qquad t_{r_{90\%}} = 4 \cdot t_{f_{90\% \text{ PEGGIORE}}} = 2,33\ ms$

$t_{f_{50\% \text{ PEGGIORE}}} = 239,6\ ps \qquad t_{r_{90\%}} = 4 \cdot t_{f_{50\% \text{ PEGGIORE}}} = 958,4\ ps$

- $S_m = 8 \qquad S_p = 8$

$t_{r_{90\%}} = 582,7\ ps \qquad t_{f_{90\% \text{ PEGGIORE}}} = \frac{t_{r_{90\%}}}{4} = 145,67\ ps$

$t_{r_{50\%}} = 239,6\ ps \qquad t_{f_{50\% \text{ PEGGIORE}}} = \frac{t_{r_{50\%}}}{4} = 59,9\ ps$

METODO DELLA RESISTENZA EQUIVALENTE

- TECNOLOGIA A $\qquad C_L = 120\ fF \qquad S_m = 8 \qquad t_{f_{90\%}} = ?$

$$S_{PD_{\text{PEGGIORE}}} = S_m = 8$$

$$R_{\underset{PD}{m}\ eq\ 90\%} = \frac{R_{m\ eq\ 90\%,\ S=1}}{8} = 674,37\ \Omega$$

$$t_{f_{90\%}} = R_{PD_{eq\ 90\%}} \cdot C_L \cdot \ln(10) = 674,37 \cdot 120 \cdot 10^{-15} \cdot 2,3025 = 186,32\ ps$$

- TECNOLOGIA B $C_L = 52{,}9\ fF$ $S_P = 2$ $t_{r_{50\%}} = ?$

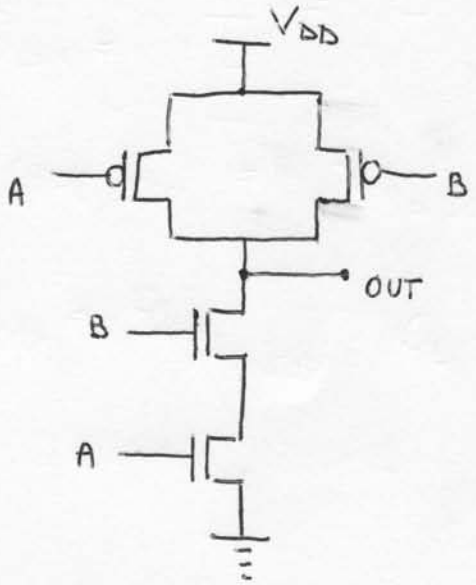
$$S_{PU} = \frac{S_P}{2} = 1$$

$$R_{eq_{PU,50\%}} = R_{eq_{P\,50\%,\,S=1}} = 26{,}142\ k\Omega$$

$$t_{r_{50\%}} = R_{eq_{PU\,50\%}} \cdot C_L \cdot \ln(2) = 26{,}142 \cdot 10^3 \cdot 52{,}9 \cdot 10^{-15} \cdot 0{,}6931 =$$

$$= 958{,}49\ ps$$

NAND CMOS



A	B	OUT
0	0	1
0	1	1
1	0	1
1	1	0

$$S_{PD} = \frac{S_N}{2}$$

$$t_f = \frac{2\,C_L}{\beta'_m\, S_{PD}} \cdot F_m = \frac{4\,C_L}{\beta'_m\, S_m} \cdot F_m$$

- tempo di salita:

(a) A, B: ~~00~~ 11 $\longrightarrow$ 01 / 10

$$t_r = \frac{2\,C_L}{\beta'_p\, S_p} F_p \qquad \text{(caso peggiore)}$$

A, B: 11 $\longrightarrow$ 00 entrambi i pMOS accesi

$S_{PU} = 2\,S_p$

$$t_r = \frac{2\,C_L}{\beta'_p\, 2S_p} F_p = \frac{C_L}{\beta'_p\, S_p} F_p$$

Se vogliamo $t_f = t_{r\ peggiore}$

$$\frac{4 C_L}{\beta'_m S_m} F_m = \frac{2 C_L}{\beta'_p S_p} F_p$$

$$\frac{S_m}{S_p} = 2 \frac{\beta'_p}{\beta'_m} \cdot \frac{F_m}{F_p} = 2 \cdot \frac{1}{2} \cdot 1 = 1$$

- TECNOLOGIA A $\quad C_L = 120\,fF$

- $S_m = 4 \quad S_p = 4$

$$t_{f\,gox} = \frac{C_L}{\beta'_m} F_{m\,gox} = \frac{120 \cdot 10^{-15}}{100 \cdot 10^{-6}} \cdot 0{,}6212 = 745{,}44\ ps$$

$$t_{r\,gox\ peggiore} = 745{,}44\ ps$$

- $t_{f\,sox} = \frac{120 \cdot 10^{-15}}{100 \cdot 10^{-6}} \cdot 0{,}2509 = 301\ ps$

$$t_{r\,sox\ peggiore} = 301\ ps$$

- $S_m = 1 \quad S_p = 4$

$$t_{r\,gox\ peggiore} = 745{,}44\ ps$$

$$t_{f\,gox} = 4 \cdot t_{r\,gox\ peggiore} = 2{,}98\ ms$$

$$t_{r\,sox\ peggiore} = 301\ ps$$

$$t_{f\,sox} = 4\ t_{r\,sox\ peggiore} = 1{,}204\ ms$$

- $S_m = 4 \quad S_p = 1$

$t_{f\,90\%} = 745,44$ ps

$t_{r\,90\%\ peggiore} = 4 \cdot t_{f\,90\%} = 2,98$ ns

$t_{f\,50\%} = 301$ ps

$t_{r\,50\%\ peggiore} = 4\, t_{f\,50\%} = 1,204$ ns

- TECNOLOGIA B $C_L = 52,9\ fF$

- $S_n = 4 \quad S_p = 4$

$$t_{fgox} = \frac{4 \cdot 52,9 \cdot 10^{-15}}{200 \cdot 10^{-6} \cdot 4} \cdot 2,203 = 582,7 \text{ ps}$$

$t_{rgox\ peggiore} = 582,7$ ps

$$t_{fsox} = \frac{4 \cdot 52,9 \cdot 10^{-15}}{200 \cdot 10^{-6} \cdot 4} \cdot 0,906 = 239,6 \text{ ps}$$

$t_{rsox\ peggiore} = 239,6$ ps

- $S_n = 1 \quad S_p = 4$

$t_{rgox\ peggiore} = 582,7$ ps

$t_{fgox} = 4 \cdot t_{rgox\ peggiore} = 2,33$ ns

$t_{rsox\ peggiore} = 239,6$ ps

$t_{fsox} = 4 \cdot t_{rsox\ peggiore} = 958,4$ ps

- $S_n = 4 \quad S_p = 1$

$t_{fgox} = 582,7$ ps

$t_{rgox\ peggiore} = 4\, t_{fgox} = 2,33$ ns

$t_{fsox} = 239,6$ ps

$t_{rsox\ peggiore} = 4\, t_{fsox} = 958,4$ ps

METODO DELLA RESISTENZA EQUIVALENTE

A) TECNOLOGIA A $\quad C_L = 120\ fF \quad S_n = 1 \quad t_{f,90\%} = ?$

$$S_{PD} = \frac{S_n}{2} = 0,5$$

$$R_{eq\ 90\%}^{PD} = \frac{R_{n\,eq\ 90\%\ ,\ S=1}}{S_{PD}} = 10,79\ k\Omega$$

$$t_{f\,90\%} = R_{eq\ 90\%\ PD} \cdot C_L \ln(10) = 10,79 \cdot 10^3 \cdot 120 \cdot 10^{-15} \cdot 2,3025 =$$

$$= 2,98\ ns$$

B) TECNOLOGIA B $\quad C_L = 52,9\ fF \quad S_p = 4 \quad t_{r\,50\%\ peggiore} = ?$

$$S_{PU} = S_p = 4$$

$$R_{eq\ 50\%\ PU} = \frac{R_{p\,eq\ 50\%\ ,\ S=1}}{S_{PU}} = 6,5355\ k\Omega$$

$$t_{r\,50\%\ peggiore} = R_{eq\ 50\%\ PU} \cdot C_L \cdot \ln(2) = 6,5355 \cdot 10^3 \cdot 52,9 \cdot 10^{-15} \cdot 0,6931 =$$

$$= 239,6\ ps$$