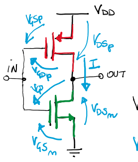
Inverter CMOS

Wednesday, March 17, 2021 10:35 AM

CARATTERISTICA DI TRASFERIMENTO STATICA - INVERTER CMOS



pMOS $\begin{cases} V_{DS_p} = OUT - V_{DD} \\ V_{GS_p} = IN - V_{DD} \end{cases}$ $I = -I_D$

nMOS $\begin{cases} V_{DS_n} = OUT \\ V_{GS_n} = IN \end{cases}$ $I = I_D$

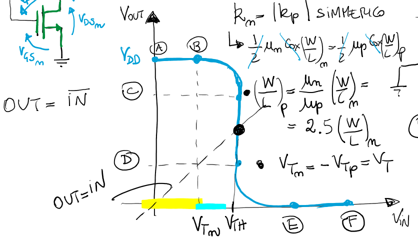
INVERTER SIMMETRICO

$k_n = |k_p|$ $\rightarrow \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_n = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_p$

$\left(\frac{W}{L}\right)_p = \frac{\mu_n}{\mu_p}\left(\frac{W}{L}\right)_n = 2.5\left(\frac{W}{L}\right)_n$

$V_{Tn} = -V_{Tp} = V_T$

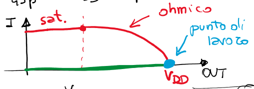
OUT = $\overline{IN}$

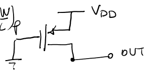


Ⓐ $V_{IN} = 0$ $V_{GS_n} = 0 < V_{Tn}$

nMOS off

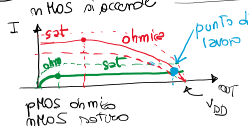
$V_{GS_p} = -V_{DD} < V_{Tp}$ pMOS on





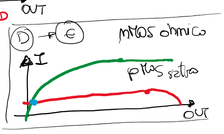
Ⓑ $V_{IN} > V_{Tn}$

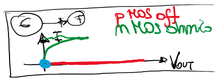
nMOS si accende



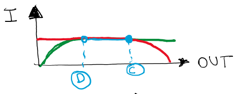
pMOS ohmico

nMOS saturo





Ⓒ e Ⓓ nMOS e pMOS in saturazione



$I_{D_{n\,sat}} = |I_{D_p}|_{sat}$

$k_n (V_{GS_n} - V_{Tn})^2 = |k_p| (V_{GS_p} - V_{Tp})^2$ (>0, <0)

Se inverter simmetrico posso semplificare $k_n = |k_p|$

$[IN - V_{Tn}]^2 = [(IN - V_{DD}) - V_{Tp}]^2$

$IN - V_{Tn} = V_{DD} - IN + V_{Tp} \Rightarrow 2IN = V_{DD} \Rightarrow$ $\boxed{IN = \frac{V_{DD}}{2}}$

SOGLIA LOGICA DI COMMUTAZIONE

se inverter non simmetrico

$k_n [IN - V_{Tn}]^2 = |k_p| [IN - V_{DD} - V_{Tp}]^2$

$\sqrt{k_n}(IN - V_{Tn}) = \sqrt{|k_p|}\,[V_{DD} - IN + V_{Tp}]$

$[\sqrt{k_n} + \sqrt{|k_p|}]\,IN = \sqrt{|k_p|}\,V_{DD} + \sqrt{|k_p|}\,V_{Tp} + \sqrt{k_n}\,V_{Tn}$

$IN = \frac{\sqrt{|k_p|}\,V_{DD} + \sqrt{|k_p|}\,V_{Tp} + \sqrt{k_n}\,V_{Tn}}{\sqrt{k_n} + \sqrt{|k_p|}} \rightarrow \frac{V_{DD}}{2}$ inverter simmetrico

pMOS $V_{GD_p} \geq V_{Tp}$ cond. di saturazione

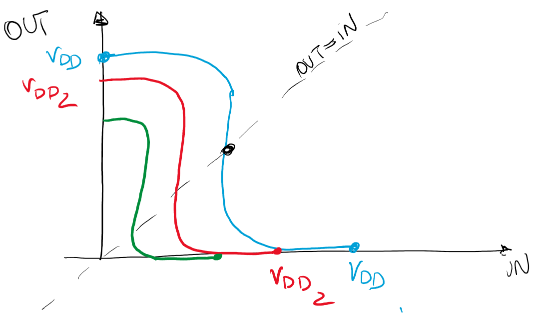
$IN - OUT = V_{Tp} = -V_T$ Ⓒ

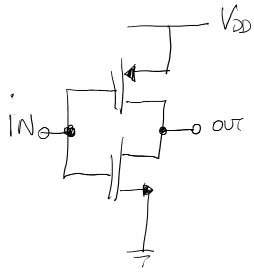
$OUT = \frac{V_{DD}}{2} + V_T$

nMOS $V_{GD_n} \leq V_{Tn} \Rightarrow IN - OUT = V_{Tn} \Rightarrow$ confine della zona di saturazione per nMOS

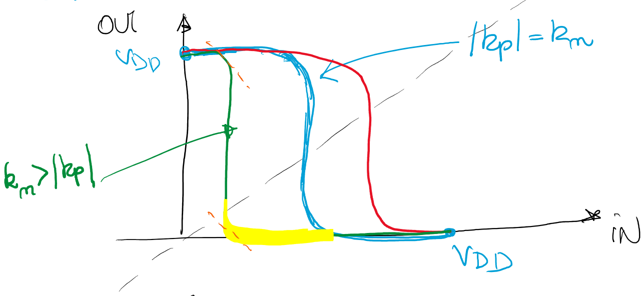
$OUT = \frac{V_{DD}}{2} - V_{Tn} = \frac{V_{DD}}{2} - V_T$ Ⓓ

EFFETTO DELLA TENSIONE DI ALIMENTAZIONE E DEL K DEI TRANSISTORI





EFFETTO DEL K DEI TRANSISTORI



AREA MINIMA

$\left(\frac{W}{L}\right)_n = 1 = \left(\frac{W}{L}\right)_p$

$\rightarrow k_n > |k_p|$

alla soglia logica nMOS, pMOS } saturi

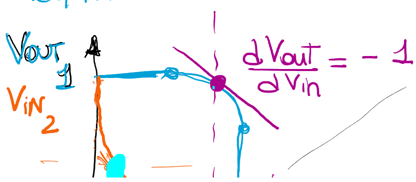
se $k_n > |k_p|$

$\rightarrow (V_{GS_n} - V_{Tn})^2 < (V_{GS_p} - V_{Tp})^2$

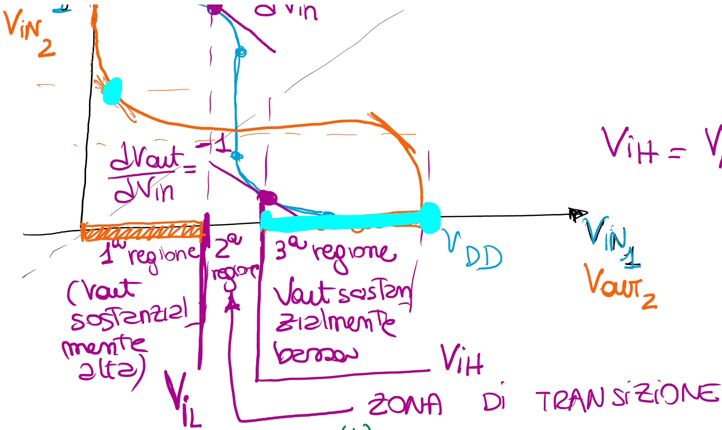
$I_{D_{n\,sat}} = |I_{D_{p\,sat}}|$

$k_n (V_{GS_n} - V_{Tn})^2 = |k_p| (V_{GS_p} - V_{Tp})^2$

MARGINI DI RUMORE (NOISE MARGINS)

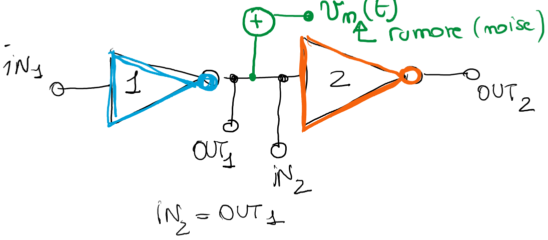


$V_{IL} = V_{IN_{LOW}}$ = max V_{in} che fornisce in uscita una tensione interpretata come livello logico alto



in uscita una tensione interpretata come livello logico alto

$V_{iH} = V_{IN_{HIGH}}$ = min V_{in} che fornisce una tensione di uscita interpretata come livello logico basso



$OUT_2 = \overline{IN_2} = \overline{OUT_1} = IN_1$

nella realtà può essere che

$IN_2 \neq OUT_1$

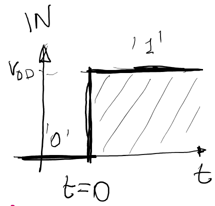
$IN_2 = OUT_1 + v_n(t)$

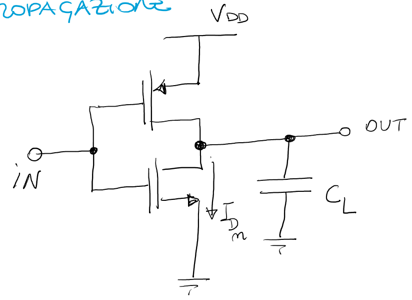
$NM_{LOW} = V_{iL} - 0 = V_{iL}$ (noise margin low)

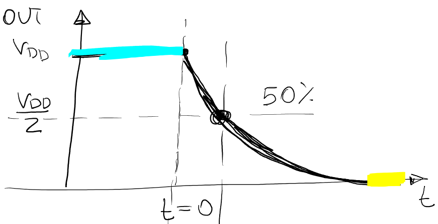
$NM_{HIGH} = V_{DD} - V_{iH}$ (noise margin high)

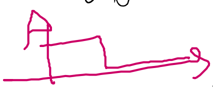
COMPORTAMENTO DINAMICO DELL'INVERTER CMOS

TEMPO DI PROPAGAZIONE









tempo di propagazione alto - basso

t_{PHL}

RITARDO DI PROPAGAZIONE

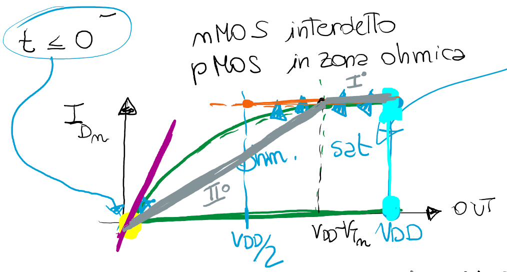
$$\tau = \frac{t_{PHL} + t_{PLH}}{2}$$

$t \leq 0^-$

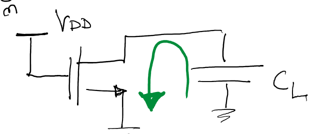
nMOS interdetto
pMOS in zona ohmica

$t = 0^+$

pMOS off
nMOS si accende con una $V_{GS_n} = V_{DD}$ in saturazione



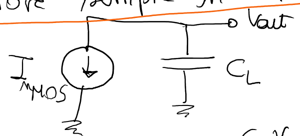
$t \geq 0^+$



MODELLIZZAZIONE PER IL CALCOLO DEL TEMPO DI PROPAGAZIONE:

1) transistore sempre in saturazione. (approx per difetto ← dei tempi)

Approx. satura



$$I_{nMOS} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_n (V_{GS} - V_{Tn})^2$$

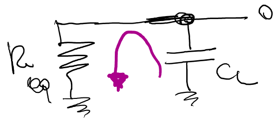
$$t_{PHL} = \frac{Q_{50\%}}{I_{nMOS_{sat}}} = \frac{C_L V_{DD} - C_L V_{DD}/2}{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_n (V_{GS}-V_{Tn})^2} = \frac{C_L V_{DD}/2}{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_n (V_{GS}-V_{Tn})^2}$$

2) transistore modellizzato con R_{DSon} (approx. per difetto ← sui tempi)

$\tau = C_L R_{eq} = C_L = R_{DSon}$

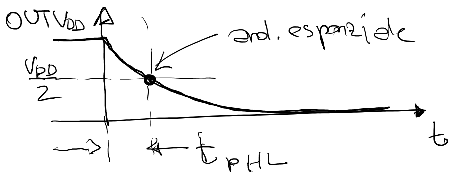
② transistore modellizzato con R_{dson} (appross. per difetto)

approx. ohmica



$\tau = C_L R_{eq} = C_L = R_{dson}$

$R_{eq} = R_{dson} = \frac{\partial V_{DS}}{\partial I_D}\Big|_{ohmica,\ V_{DS}=0} = \frac{1}{2 k_n (V_{GS}-V_{Tn})}$



$V_{OUT}(t) = V_{DD} \exp(-t/\tau)$

$V_{out}(t_{pHL}) = \frac{V_{DD}}{2}$

$\frac{V_{DD}}{2} = V_{DD} \exp\left(-\frac{t_{pHL}}{\tau}\right)$

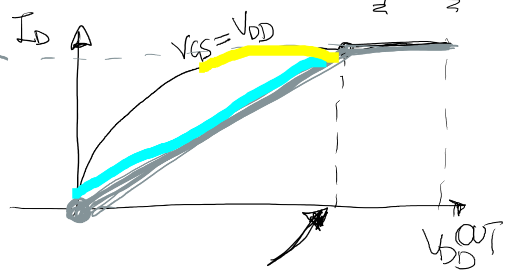
$\ln\frac{1}{2} = -\frac{t_{pHL}}{\tau}$

$$\boxed{t_{pHL} = \ln 2\ \tau = 0.69\ \tau}$$

③ modello più raffinato

approx per eccesso (modello misto)

$t_{pHL} = t_{psat} + t_{pohm}$



$t_{psat} = \frac{Q_{V_{DD}-V_{Tn}}}{I_{Dsat}} =$

$= \frac{C_L V_{DD} - C_L (V_{DD}-V_{Tn})}{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{DD}-V_{Tn})^2} = \frac{C_L V_{Tn}}{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{DD}-V_{Tn})^2}$

tpohm

$R_{eq} = \frac{V_{DD}-V_{Tn}}{I_{Dsat}}$

$\tau = C_L R_{eq}$

$$\begin{cases} V_{out}(t) = (V_{DD}-V_{Tn}) \exp(-t/\tau) \\ V_{out}(t_{psat}) = \frac{(V_{DD}-V_{Tn})}{2} \end{cases}$$

$\frac{V_{DD}}{2} = (V_{DD}-V_{Tn}) \exp\left(-\frac{t_{psat}}{\tau}\right)$

$t_{pohm} = \tau \ln \frac{V_{DD}-V_{Tn}}{\frac{V_{DD}}{2}}$

$$\boxed{t_{pHL} = t_{psat} + t_{pohm}}$$