Kuwait University
2020

ELECTRONICS III

PSEUDO-NMOS Logic Circuits

Chapter 15 - Part (1)

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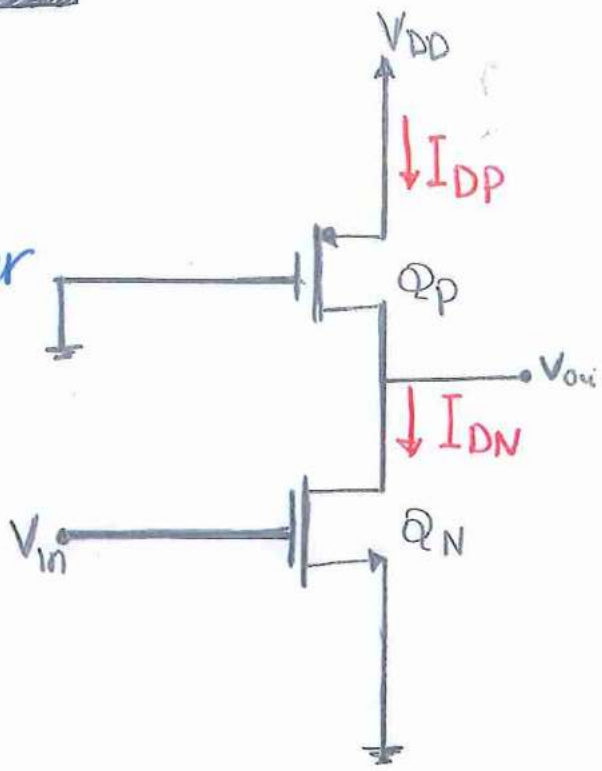
4 The Pseudo-NMOS inverter:

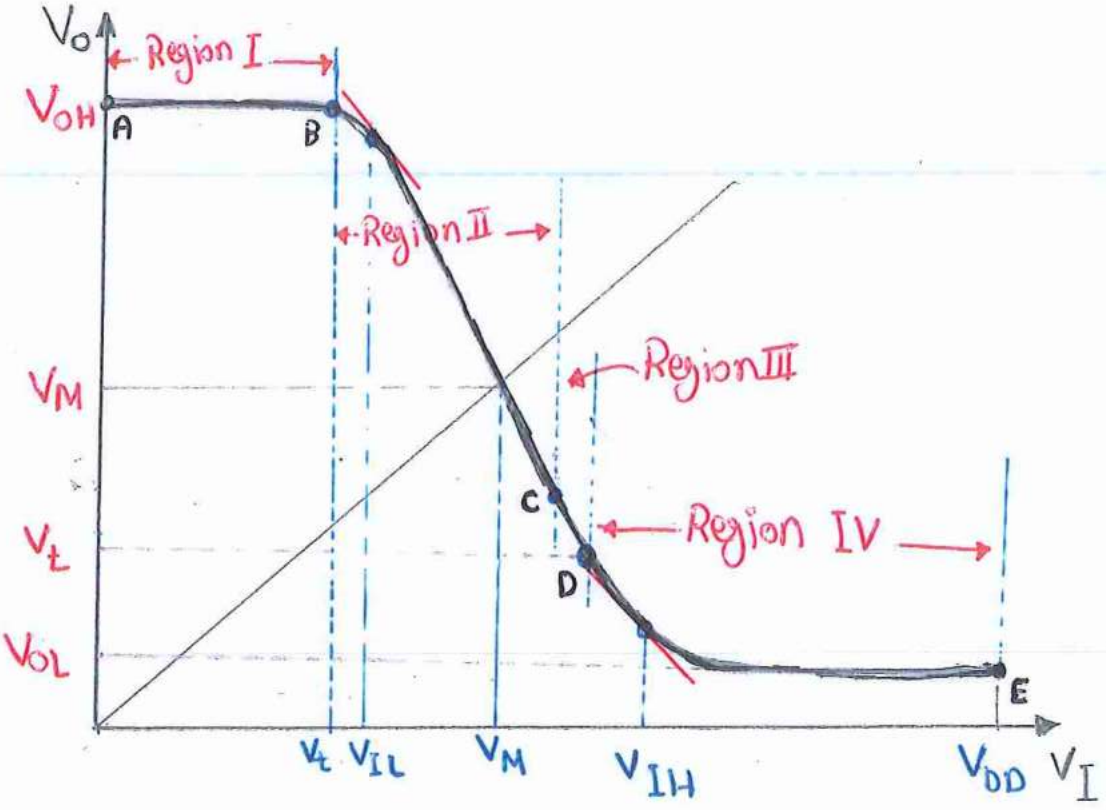


It has the advantage of being compatible with CMOS:

(1) Faster

(2) simple

The Voltage Transfer Charcteristic (VTC):



Region	segment on VTC	Q_N	Q_p	Condition
Region I	A to B	off	Triode	$V_I < V_t$
Region II	B to C	Saturation	Triode	$V_o \geq V_i - V_t$
Region III	C to D	Triode	Triode	$V_t \leq V_o \leq V_I - V_t$
Region IV	D to E	Triode	Saturation	$V_o \leq V_t$

- In pseudo-NMOS inverter the Q_p always ON and Q_N can be off.

- For NMOS:

  (1) In Sat: $V_{DS} > V_{GS} - V_t$

  $\therefore V_o > V_{in} - V_t$

$$\therefore I_{DN} = \frac{1}{2} K_n' \left(\frac{W}{L}\right) (V_{in} - V_t)^2$$

(2) in Linear Region:

$$V_{DS} < V_{GS} - V_t$$

$$\therefore I_{DN} = K_n' \left(\frac{W}{L}\right) \left[(V_{in} - V_t) V_o - \frac{V_o^2}{2} \right]$$

$$\begin{bmatrix} V_{DS} = V_o \\ V_{GS} = V_{in} \end{bmatrix}$$

For PMOS:

(1) in Sat:

$$I_{DP} = \frac{1}{2} K_p' \left(\frac{W}{L}\right) (V_{DD} - V_{tp})^2$$

$$\begin{bmatrix} V_o = V_D \\ V_{DD} = V_S \\ \therefore V_{SD} = V_{DD} - V_o \\ V_{SG} = V_{DD} \end{bmatrix}$$

(2) in Linear:

$$I_{DP} = K_p' \left(\frac{W}{L}\right) \left[(V_{DD} - V_{tp})(V_{DD} - V_o) - \frac{(V_{DD} - V_o)^2}{2} \right]$$

operation Region in Pseudo:

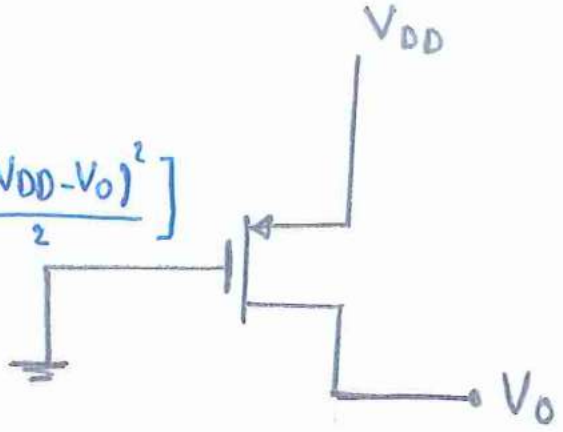
* $V_{tn} = -V_{tp} = V_t$
* $K_R = \frac{K_n}{K_p} = \frac{K_n' \left(\frac{W}{L}\right)}{K_p' \left(\frac{W}{L}\right)}$

1 Region I:

$$V_{in} < V_t$$

Q_N is off , $I_{DN} = 0$

Q_P is ON (Triode)



$$I_{DP} = K_P\left[(V_{DD}-V_t)(V_{DD}-V_o) - \frac{(V_{DD}-V_o)^2}{2}\right]$$

$$\boxed{V_o = V_{DD} = V_{OH}}$$

2 Region II:

Q_N is sat. , $I_{DN} = \frac{1}{2}K_n(V_I - V_t)^2$

Q_P is Triode , $I_{DP} = K_P\left[(V_{DD}-V_t)(V_{DD}-V_o) - \frac{(V_{DD}-V_o)^2}{2}\right]$

$$I_{DN(sat)} = I_{DP(Linear)}$$

$$\frac{1}{2}K_n(V_I - V_t)^2 = K_P\left[(V_{DD}-V_t)(V_{DD}-V_o) - \frac{(V_{DD}-V_o)^2}{2}\right]$$

$$\therefore V_o = V_t + \sqrt{(V_{DD}-V_t)^2 - K_R(V_I - V_t)^2}$$

a to find V_{IL} :

Take $\frac{dV_o}{dV_I} = -1 \Big|_{V_I = V_{IL}}$

$$\therefore \frac{dV_o}{dV_i} = 0 + \frac{1}{2}\left[(V_{DD}-V_t)^2 - K_R(V_{in}-V_t)^2\right]^{-1/2} * (-2K_R(V_{IL}-V_t))$$

$$\therefore -1 = \left[(V_{DD}-V_t)^2 - K_R(V_{IL}-V_t)^2\right]^{-1/2} * (-K_R)(V_{IL}-V_t)$$

$$\therefore V_{IL} = V_t + \frac{V_{DD}-V_t}{\sqrt{K_R(K_R+1)}}$$

b The Threshold Voltage (V_M): is defination by The value of V_I for wheh equal V_o or slop = 1.

$$V_o = V_{in} = V_M$$

$$\therefore V_M = V_t + \frac{V_{DD}-V_t}{\sqrt{K_R+1}}$$

$$V_M = V_t + \sqrt{(V_{DD}-V_t)^2 - K_R(V_M-V_t)^2}$$

$$\therefore (V_M-V_t)^2 = (V_{DD}-V_t)^2 - K_R(V_M-V_t)^2$$

$$\therefore (V_M-V_t)^2[1+K_R] = (V_{DD}-V_t)^2 \quad \sqrt{\ }$$

$$\therefore V_M - V_t = \frac{V_{DD}-V_t}{\sqrt{1+K_R}}$$

3 Region III :

It's a short segment which has no importance

Q_N is Triode

Q_P is Triode

and $V_o = V_t$

4 Region IV :

Q_N is Triode , $I_{DN} = K_n \left[(V_{in} - V_t) V_o - \frac{V_o^2}{2} \right]$

Q_P is Sat. , $I_{DP} = \frac{1}{2} K_P [V_{DD} - V_t]^2$

$$I_{DN\,(Triode)} = I_{DP\,(Sat.)}$$

$$\therefore K_n \left[(V_{in} - V_t) V_o - \frac{V_o^2}{2} \right] = \frac{1}{2} K_P (V_{DD} - V_t)^2$$

$$\therefore V_o = (V_{in} - V_t) - \sqrt{(V_I - V_t)^2 - \left(\frac{1}{KR}\right)(V_{DD} - V_t)^2}$$

a to find V_{IH} :

$$\frac{dV_o}{dV_{in}} = (1 - 0) - \frac{1}{2} \left[(V_{IH} - V_t)^2 - \left(\frac{1}{KR}\right)(V_{DD} - V_t)^2 \right]^{-1/2} * 2 (V_{IH} - V_t)$$

$$-1 = 1 - \frac{1}{2}\left[(V_{IH}-V_t)^2 - \left(\frac{1}{K_R}\right)(V_{DD}-V_t)^2\right]^{-\frac{1}{2}} * 2(V_{IH}-V_t)$$

$$\boxed{V_{IH} = V_t + \frac{2}{\sqrt{3K_R}}(V_{DD}-V_t)}$$

- to Find V_{OL} : (we put $V_{in} = V_{DD}$)

$$\therefore V_O = (V_{in}-V_t) - \sqrt{(V_I-V_t)^2 - \left(\frac{1}{\gamma}\right)(V_{DD}-V_t)^2}$$

$$\therefore V_{OL} = (V_{DD}-V_t) - \sqrt{(V_{DD}-V_t)^2 - \frac{1}{\gamma}(V_{DD}-V_t)^2}$$

$$\boxed{V_{OL} = (V_{DD}-V_t)\left[1 - \sqrt{1 - \frac{1}{K_R}}\right]}$$

- If the term $\frac{1}{K_R} \ll 1$:

$$\therefore V_{OL} = (V_{DD}-V_t)\left[1 - \sqrt{1}\right]$$

$$\therefore \boxed{V_{OL} = 0}$$

- Static current:

9 Low State : $V_{in} = V_{DD}$ & $V_O = V_{OL}$

$$I_{DN\,(Triode)} = I_{Dp\,(sat.)}$$

$$\therefore I_{Static} = \frac{1}{2} K_p (V_{DD} - V_t)^2$$

$$\therefore P_{Static} = I_{Static} * V_{DD}$$

b High State :

$$V_{in} = 0 \quad \& \quad V_o = V_{DD}$$

Q_N is off

Q_p is Triode

$$\therefore I_{DN} = I_{DP} = 0$$

$$\therefore I_{Static} = 0 \qquad \therefore P_{Static} = 0$$

Dynamic operation :

We will use The average current Method

$$t_{PLH} = \frac{\alpha_p C}{K_p V_{DD}}$$

$$\& \quad \alpha_p = \frac{2}{\left[\frac{7}{4} - 3\left(\frac{V_t}{V_{DD}}\right) + \left(\frac{V_t}{V_{DD}}\right)^2\right]}$$

$$t_{PHL} = \frac{\alpha_n C}{K_n V_{DD}}$$

$$\alpha_n = \frac{2}{\left[1 + \frac{3}{4}\left(1 - \frac{1}{K_R}\right) - \left(3 - \frac{1}{K_R}\right)\left(\frac{V_t}{V_{DD}}\right) + \left(\frac{V_t}{V_{DD}}\right)^2\right]}$$

- where $K_R = \frac{K_n}{K_p}$ and If K_R Large, so we can say $\alpha_n = \alpha_p$

- $t_p = \frac{1}{2}\left[t_{PHL} + t_{PLH}\right]$

Example:

consider a pseudo-NMOS inverter fabricated in a 0,25 μm CMOS technology, $\mu_n C_{ox} = 115\ \mu A/V^2$, $\mu_p C_{ox} = 30\ \mu A/V^2$, $V_{tn} = -V_{tp} = 0,5$ and $V_{DD} = 2,5V$ and $\left(\frac{W}{L}\right)_n = \frac{0,375}{0,25}$ ⇒ $r = 9$

Find:

(a) V_{OH}, V_{OL}, V_{IL}, V_{IH}, V_M, NM_H and NM_L

(b) $\left(\frac{W}{L}\right)_p$

(c) I_{state} and P_D

(d) t_{PLH}, t_{PHL} and t_p when $C = 7fF$.

(a) * $V_{OH} = V_{DD} = 2,5$

* $V_{OL} = (V_{DD} - V_t)\left[1 - \sqrt{1 - \frac{1}{r}}\right]$

∴ $V_{OL} = (2,5-0,5)\left[1 - \sqrt{1 - \frac{1}{9}}\right] = 0,11$ Volt

* $V_{IH} = V_t + \frac{2}{\sqrt{3*r}}(V_{DD} - V_t)$

$V_{IH} = 0,5 + \frac{2}{\sqrt{3*9}}(2,5-0,5) = 1,27V$

* $V_M = V_t + \frac{V_{DD} - V_t}{\sqrt{r+1}}$

∴ $V_M = 0,5 + \frac{2,5-0,5}{\sqrt{9+1}} = 1,13$ Volt

* $NM_H = V_{OH} - V_{IH} = 2,5 - 1,27 = 1,23$ Volt

* $NM_L = V_{IL} - V_{OL} = 0,71 - 0,11 = 0,6$ Volt

(b) $\frac{K_n}{K_p} = 9$

∴ $\frac{\mu_n C_{ox} * (\frac{W}{L})_n}{\mu_p C_{ox} * (\frac{W}{L})_p} = 9$

$$\frac{115 * \frac{0,375}{0,25}}{30 * \left(\frac{W}{L}\right)_p} = 9$$

$$\therefore \left(W/L\right)_p = 0,64$$

(c)

$$I_{static} = \frac{1}{2} K_p \left(V_{DD} - V_t\right)^2$$

$$= 0,5 * 30 * 0,64 \left(2,5 - 0,9\right)^2$$

$$= 38,4 \ \mu A$$

$$P_D = I_{static} * V_{DD} = 38,4 * 2,5 = 96 \ \mu W$$

(d)

$$* \ \alpha_p = \frac{2}{\left[\frac{7}{4} - 3\left(\frac{V_t}{V_{DD}}\right) + \left(\frac{V_t}{V_{DD}}\right)^2\right.} = 1,68$$

$$\therefore t_{PLH} = \frac{\alpha_p * C}{K_p * V_{DD}}$$

$$= \frac{1,68 * 7 * 10^{-15}}{30 * 10^{-6} * 0,64 * 2,5} = 0,25 \ ns$$

$$* \ \alpha_n = \frac{2}{\left[1 + \frac{3}{4}\left(1 - \frac{1}{\gamma}\right) - \left(3 - \frac{1}{\gamma}\right)\left(\frac{V_t}{V_{DD}}\right) + \left(\frac{V_t}{V_{DD}}\right)^2\right]} = 1,54$$

$$t_{PHL} = \frac{\alpha_n C}{K_n V_{DD}} = 0,03 \ ns \quad \Phi \quad t_p = 0,14 \ ns$$

Example:

use PSEuDo implement to Design

(a) NOR Gate (4 input)

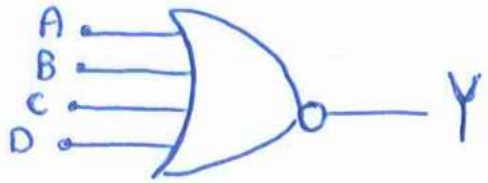
(b) NAND Gate (4input)

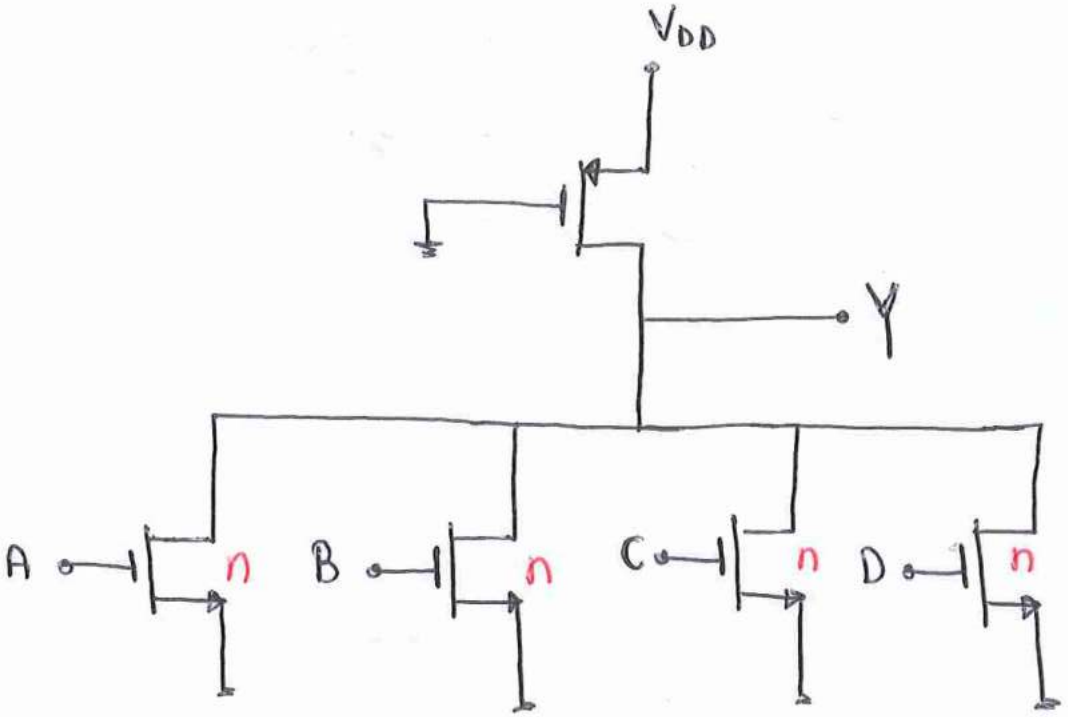
(c) $\bar{Y} = AB\bar{C} + CDE + \bar{C}\bar{D}\bar{E}$

(a)

$$Y = \overline{A+B+C+D}$$

$$\bar{Y} = A+B+C+D$$

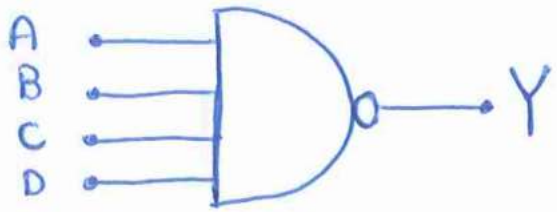


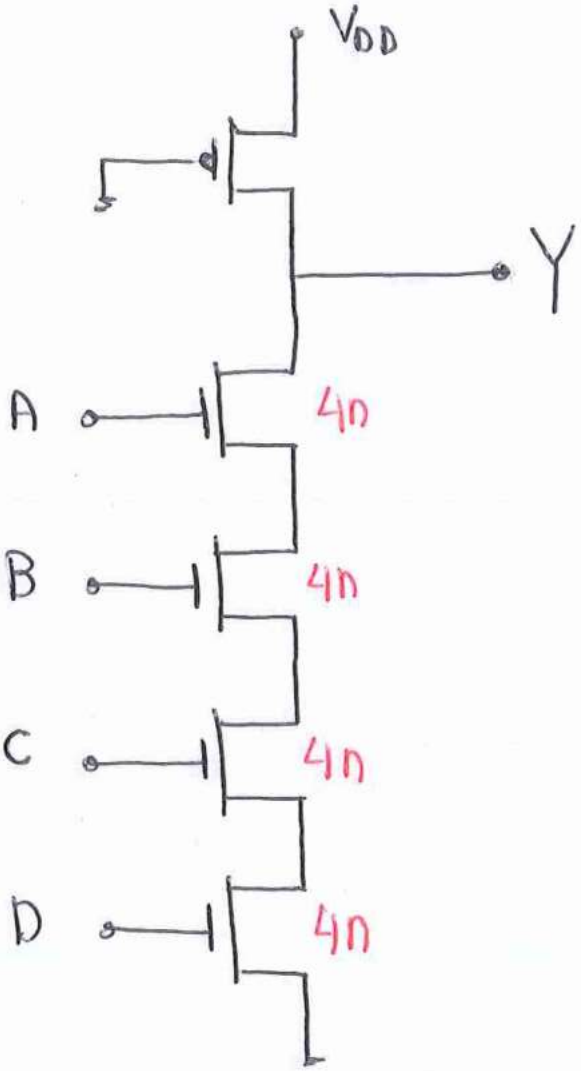


(b)

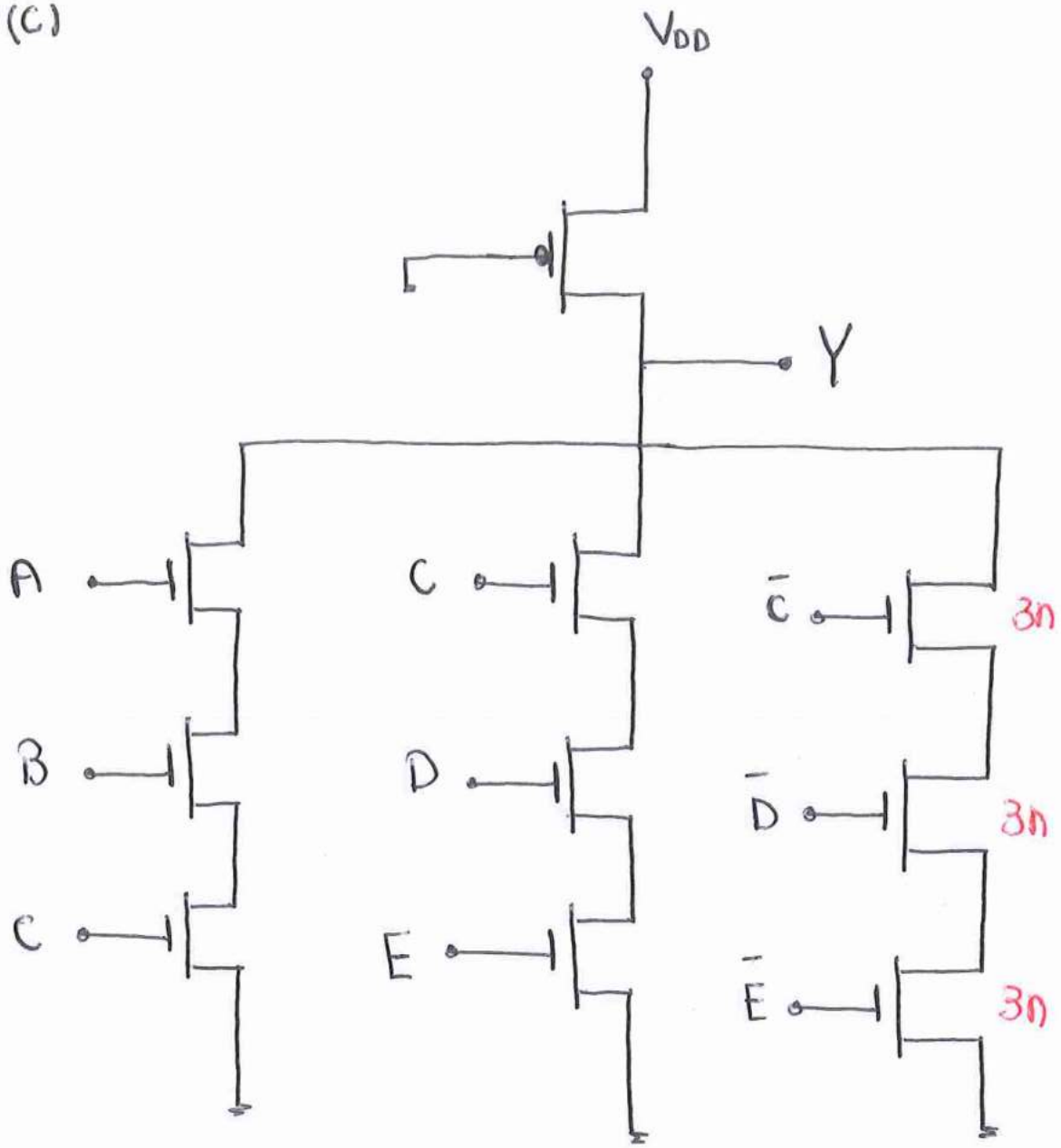
$$Y = \overline{ABCD}$$

$$\bar{Y} = ABCD$$





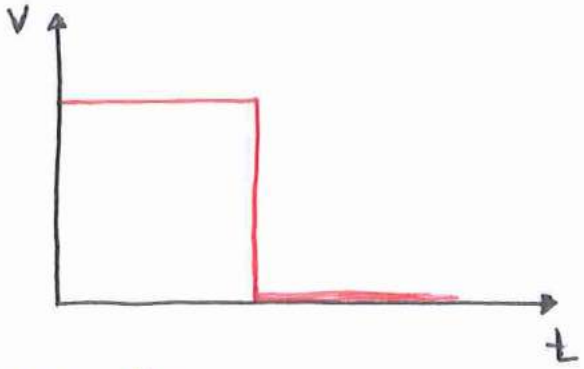
(C)



Note That:

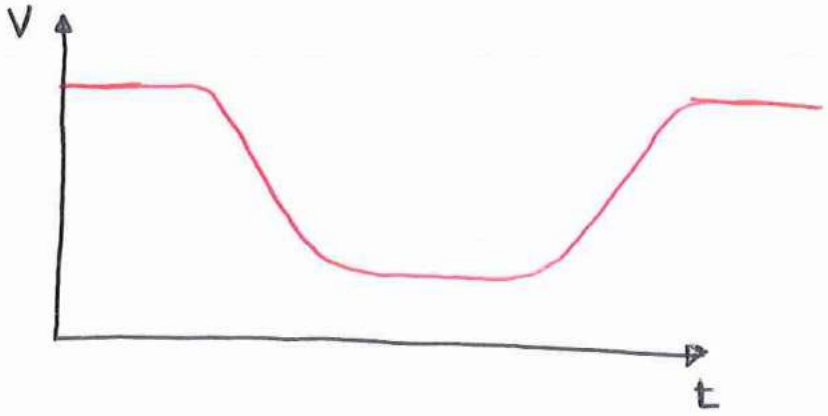
- For $K_R = \frac{K_n}{K_P}$ High: * (Low V_{OL} & Wide NM_L)
  - * Large gate for $(\frac{W}{L})_P$
  - * Large area and current of NMOS
  - * Large static current and P_D
  - * Low t_P
- For $K_R = \frac{K_n}{K_P}$ Small: * (Large V_{OL} & Small NM_L)
  - * Small area and capacitance
  - * Small $(\frac{W}{L})_P$
  - * Small I_{static} and P_D
  - * Long t_{PLH}
- K_R between 4 and 10

In Ideal inverter:



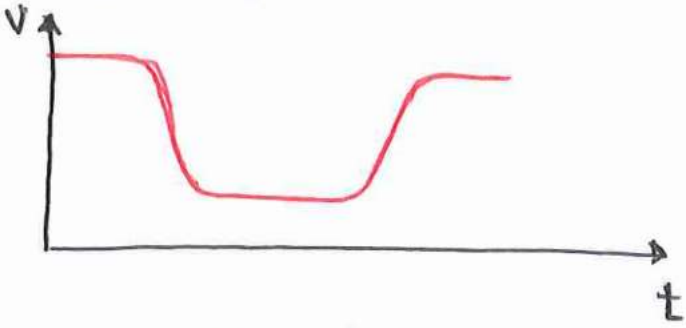
$t_{PHL} = t_{PLH} = 0$

In CMOS inverter:



$P_{static} = 0$

In Pesudue inverter:



$P_{static} \neq 0$ ∴ $t_{PHL}{}_{Pesude} < t_{PHL}{}_{CMOS}$

Example:

In pseudo NMos inverter $L = 0,25\ \mu m$ technology

$V_{DD} = 2,5$, $V_t = 0,4V$, $\mu_n C_{ox} = 4\mu_p C_{ox} = 100\ \mu A/V^2$

$(\frac{W}{L})_n = \frac{0,375}{0,25}$ and $V_{OL} = 0,1\ V$

(a) Find L_p, W_p.

$$V_{OL} = (V_{DD} - V_t)\left[1 - \sqrt{1 - \frac{1}{K_R}}\right]$$

$$0,1 = (2,5 - 0,4)\left[1 - \sqrt{1 - \frac{1}{K_R}}\right]$$

$$\therefore K_R = 10,756 = \frac{\mu_n C_{ox} (\frac{W}{L})_n}{\mu_p C_{ox} (\frac{W}{L})_p}$$

$$\therefore 10,756 = \frac{4\ (\frac{0,375}{0,25})}{(\frac{W}{L})_p}$$

$$\therefore (\frac{W}{L})_p = 0,557 < 1$$

$$\therefore W_p < L_p$$

$$\therefore L_p \neq L_{p_{min}}$$

$\therefore W_P = L_{P_{min}} = 0,25\ \mu m$

$\therefore L_P = \frac{0,25}{0,557} = 0,448\ \mu m$

$\therefore \left(\frac{W}{L}\right)_P = \frac{0,25\ \mu m}{0,448\ \mu m}$

If $\left(\frac{W}{L}\right) > 1$

$\therefore \left(\frac{W}{L}\right)_P = 2,5$

$W_P = 2,5\ L_P$

$\therefore L_P = L_{min} = 0,25$

$\therefore W_P = 0,625$

$\therefore \left(\frac{W}{L}\right)_P = \frac{0,625}{0,25}$

(b) find Power in Low and high state.

in High state:

$V_{in} = 0$

$Q_n \longrightarrow$ off $\quad I_{DN} = 0$

$\therefore P_{static} = 0$

In Low State:

$$I_{DN_{triode}} = I_{DP\ sat.}$$

$$I_{DP_{Sat}} = \frac{1}{2} K_P (V_{DD} - V_t)^2$$

$$= \frac{1}{2} * \frac{100}{4} \left(\frac{0,25}{0,498}\right)(2,5 - 0,4)^2$$

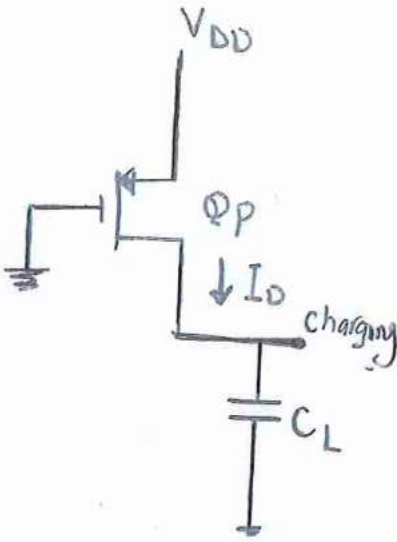
$$= 30,7617\ \mu A$$

$$P_{Stat.} = V_{DD} * I_{Stat}$$

$$\approx 77\ \mu W$$

Dynamic operation (Propagation Delay): (charging)

(a) Low to High t_{PLH}:



V_{in} = Low Q_N off

and C_L charging Through Q_P

* $I_p(0)$ In Saturation

$V_{SG} = V_{DD}$ & $V_{SD} = V_{DD}$

* $I_p(t_{PLH})$ in Linear

$V_{SG} = V_{DD}$ & $V_{SD} = \frac{V_{DD}}{2}$

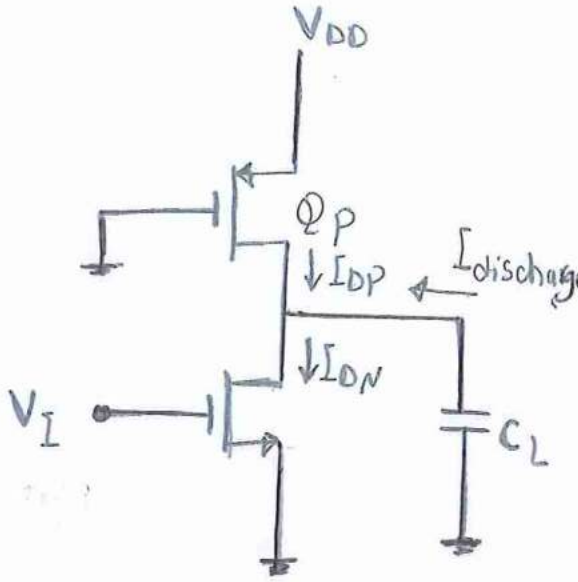
∴ Average current charging

* $I_{ave} = \frac{I_p(0) + I_p(t_{PLH})}{2}$

* $t_{PLH} = \frac{C_L * (V_{DD} - \frac{V_{DD}}{2})}{I_{ave}}$

$$t_{PLH} = \frac{C_L * (\frac{V_{DD}}{2})}{I_{ave}}$$

b High to Low (t_{PHL}):



Q_N & Q_P are ON

$$I_{Discharge} = I_{DN} - I_{DP}$$

$$I_{Discharge}(0) = I_{DN}(0) - I_{DP}(0)$$

$$I_{Discharge}(t_{PHL}) = I_{DN}(t_{PHL}) - I_{DP}(t_{PHL})$$

at $t=0$: ($V_O = V_{DD}$)

$Q_N \longrightarrow$ Sat.

$Q_P \longrightarrow$ Linear

at $t = t_{PHL}$: ($V_O = \frac{V_{DD}}{2}$)

$Q_N \longrightarrow$ Linear

$Q_P \longrightarrow$ Linear

* $t_{PLH} > t_{PHL} \longrightarrow K_n > K_p$