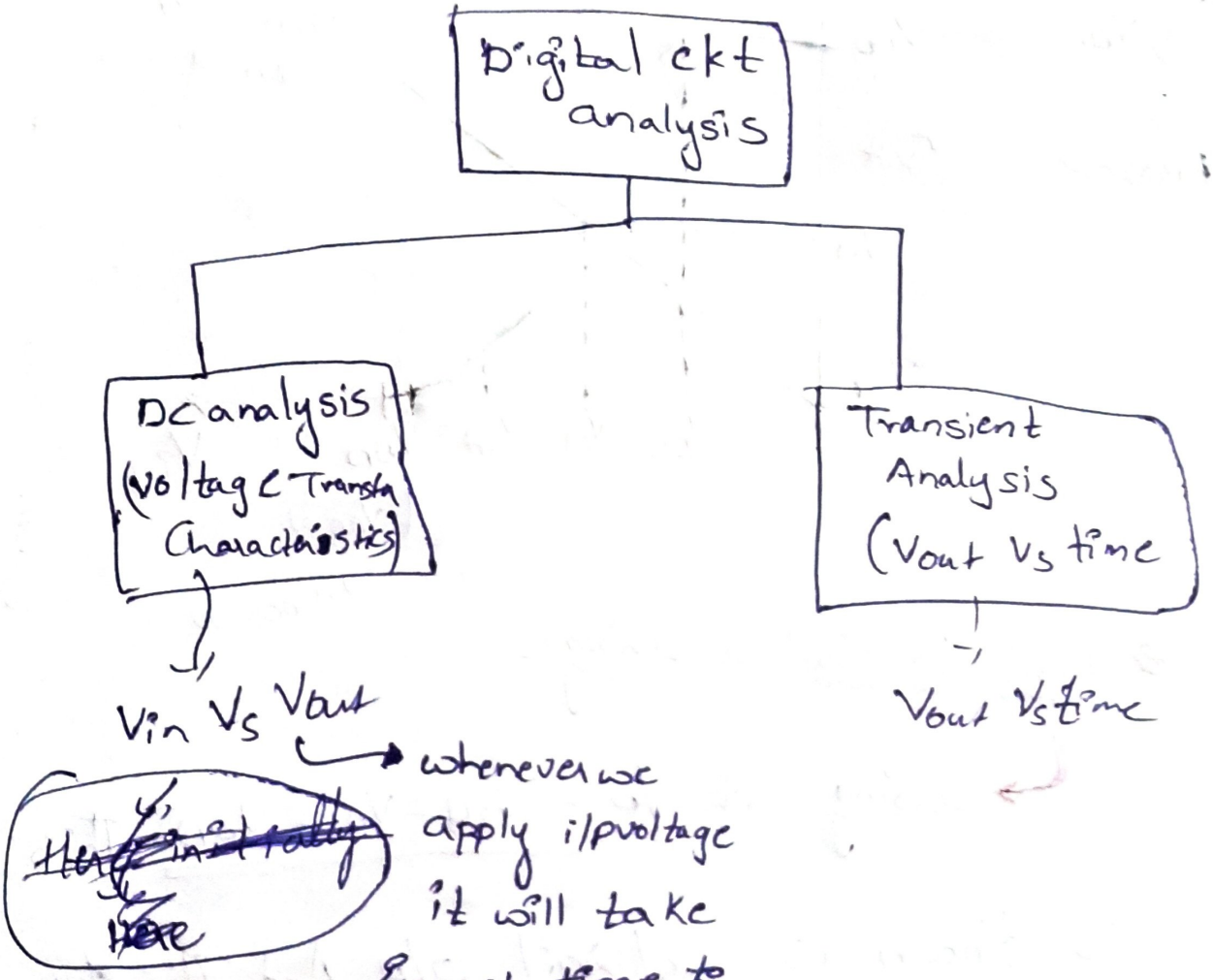
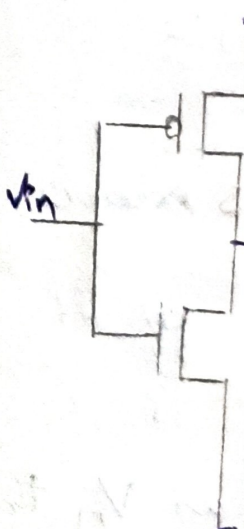
Dc characteristics of CMOS Inverter:



i) CMOS Inverter:-



when $v_{in}=0$; nmos OFF, PMOS ON

$V_{out} = V_{DD} = V_{OH}$ at high i/p

o/p voltage

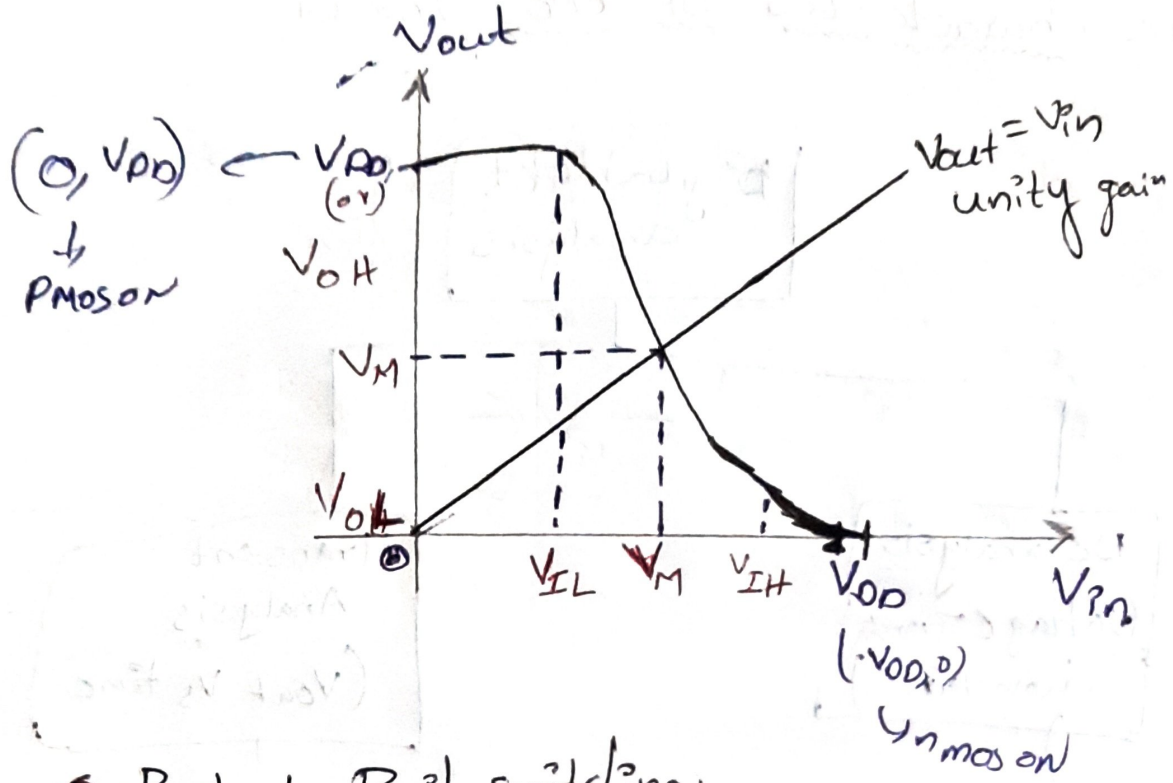
$(V_{in}, V_{out}) = (0, V_{DD})$

when $V_{in}=V_{DD}$, nmos ON, PMOS OFF

$V_{out} = 0 = V_{OL}$ at Low i/p

o/p voltage

$(V_{in}, V_{out}) = (V_{DD}, 0)$



- Rail to Rail switching :-

  ↳ Swing at o/p = $V_{OH} = V_{OL} = V_{DD}$. This is known as Full rail o/p. And this type of switching is known as Rail to Rail switching.

  (operating point at which $V_{out} = V_{in} = V_M$)

  Significance of V_M (Mid point Voltage) :-

  ↳ If operating point (Vout) is above the V_M then it is logic "1" or if the operating point (Vout) is less than V_M then it is logic "0"

Operating regions for nmos and Pmos:

$V_{in} = V_{out} = V_m$

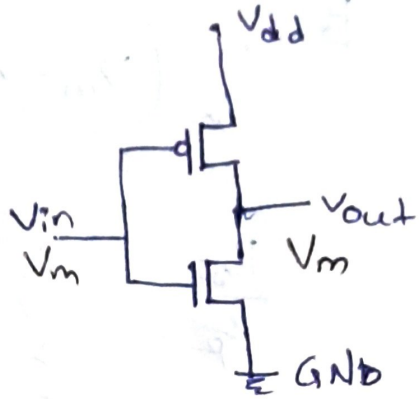
for saturation:-(nmos)

$V_{DS} \geq V_{GS} - V_T$

$\therefore V_m \geq V_m - V_T$

$\Downarrow$

True



$\therefore$ Nmos is in Saturation

(Pmos) :-

$V_{SD} \geq V_{SG} = |V_T|$ $\quad V_S = V_{dd}$

~~$V_{dd} - V_{in} \geq V_{dd} - V_{in}$~~ $\quad V_d = V_{out}$

$V_{dd} - V_{out} \geq V_{dd} - V_{in} - |V_T|$

$\Rightarrow V_{dd} - V_m \geq V_{dd} - V_m - V_T$

$\Downarrow$

True.

$\therefore$ Pmos is in Saturation

Current is same from source (Pmos) to GND.

for, nmos $\quad I = \frac{\beta_n}{2}(V_{GS} - V_{Tn})^2 = \frac{\beta_n}{2}(V_m - V_{Tn})^2$ ①

for, Pmos $\quad I = \frac{\beta_p}{2}(V_{SG} - V_{TP})^2 = \frac{\beta_p}{2}(V_{dd} - V_m - |V_{TP}|)^2$ ②

Equating ① & ②

$$\frac{\beta_n}{2}(V_m - V_{Tn})^2 = \frac{\beta_p}{2}(V_{DD} - V_M - |V_{TP}|)^2$$

$$\frac{\beta_n}{\beta_p} = \frac{(V_{DD} - V_M - |V_{TP}|)^2}{(V_M - V_{Tn})^2}$$

$$V_M = \frac{V_{DD} - |V_{TP}| + \sqrt{\frac{\beta_n}{\beta_p}}\, V_{Tn}}{1 + \sqrt{\frac{\beta_n}{\beta_p}}}$$

If $\beta_n = \beta_p$ & $V_{Tn} = |V_{TP}|$

then $V_M = \frac{V_{DD}}{2}$

To make $\beta_n = \beta_p$

$\left(\frac{W}{L}\right)$ → aspect ratio.

$$\beta_n = \mu_n C_{ox} \frac{W}{L} \qquad \beta_p = \mu_p C_{ox} \frac{W}{L}$$

~~but mobility of electrons are high than mobility of holes~~

but mobility of electrons are high than mobility of holes. So, width of pmos should be higher to make equal to n_mos.

∴ pmos ↑ than nmos.

Q) $k_n' = 100$; $V_{Tn} = 0.70V$; $k_p' = 42$; $V_{Tp} = -0.80$ and power supply of $V_{DD} = 3.3V$ is used. Find the V_M if $(W/L)_n = 10$ & $(W/L)_p = 14$

Sol:-

$$\frac{\beta_n}{\beta_p} = \frac{k_n'(W/L)_n}{k_p'(W/L)_p} = \frac{100(10)}{42(14)}$$

$$= \frac{1000}{588} = 0.1698$$

$$V_M = \frac{V_{DD} - |V_{TP}| + \sqrt{\frac{\beta_n}{\beta_p}} V_{Tn}}{1 + \sqrt{\frac{\beta_n}{\beta_p}}} = \frac{3.3 - 0.8 + (0.412)(0.7)}{1 + 0.412}$$

$$V_M = \frac{3.3 - 0.8 + (1.304)(0.7)}{1 + 1.304}$$

$$V_M = 1.481$$