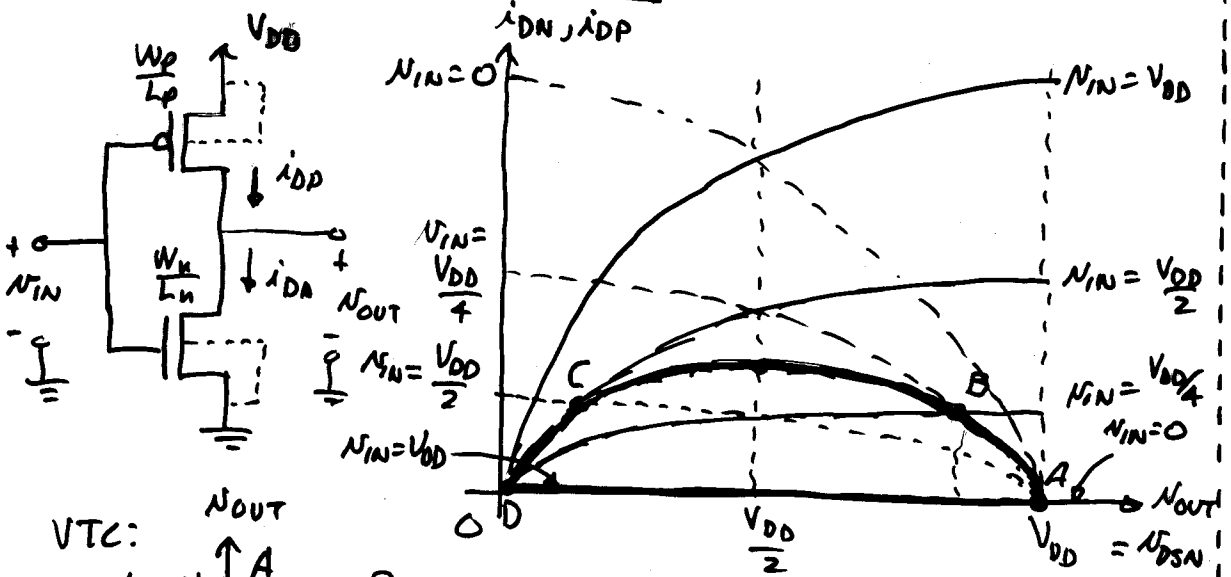
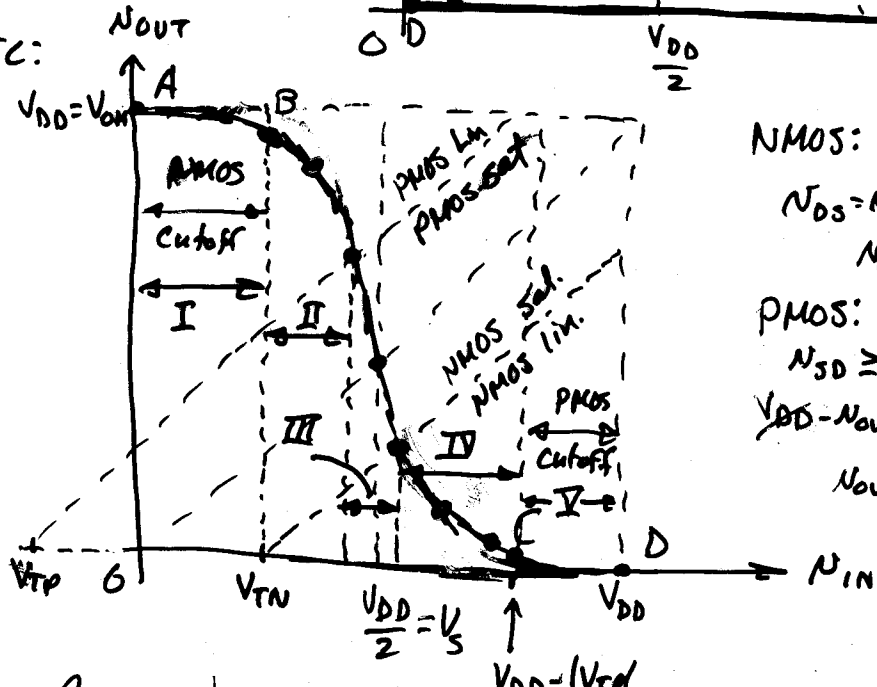
Review Session on Sunday, Feb. 8, 4-5pm (341)

CMOS INVERTERS

DC Analysis of CMOS Inverter



VTC:



NMOS:

$v_{DS}=v_{OUT} \geq v_{GS}-V_{TN}$

$v_{OUT}=v_{IN}-V_{TN}$

PMOS:

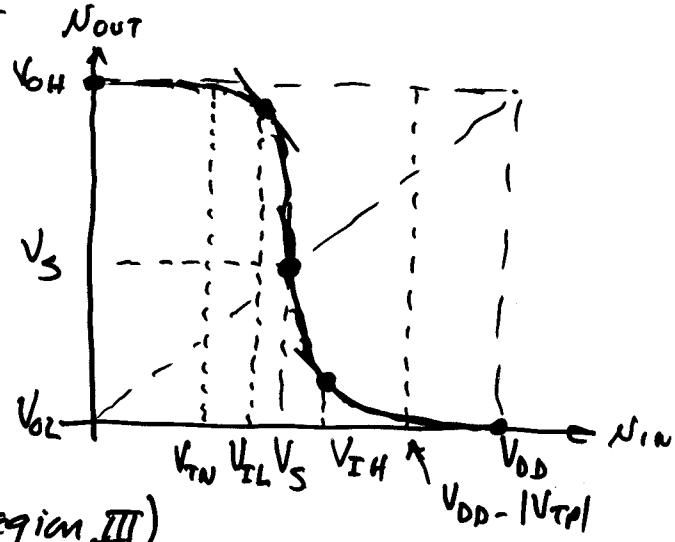
$v_{SD} \geq v_{SG}-|V_{TP}|$

$V_{DD}-v_{OUT} \geq V_{DD}-v_{IN}-|V_{TP}|$

$v_{OUT} \leq v_{IN}+|V_{TP}|$

Region	NMOS	PMOS
I	OFF	LIN
II	SAT	LIN
III	SAT	SAT
IV	LIN	SAT
V	LIN	OFF

VTC Again –



Find V_S (Region III)

$$i_{DP}(sat.) = i_{DN}(sat.)$$

$$\frac{W_P N_{sat.} C_{ox} (V_{DD} - V_{IN} - |V_{TP}|)^2}{(V_{DD} - V_{IN} - |V_{TP}|) + E_{CP} L_P} = \frac{W_N N_{sat.} C_{ox} (V_{IN} - V_{TN})^2}{(V_{IN} - V_{TN}) + E_{CN} L_N}$$

Let $V_{IN} = V_S$ and solve.

Note that $V_S \approx \frac{V_{DD}}{2}$, then $\left(\frac{V_{DD}}{2} - V_{TN}\right) < E_{CN} L_N$

and $\left(\frac{V_{DD}}{2} - |V_{TP}|\right) < E_{CP} L_P$

$$\frac{W_P N_{sat} C_{ox}}{E_{CP} L_P} (V_{DD} - V_S - |V_{TP}|)^2 = \frac{W_N N_{sat.} C_{ox}}{E_{CN} L_P} (V_S - V_{TN})^2$$

$\left(N_{sat} = \frac{\mu E_C}{2}\right)$

Take the square root of both to get

$$(V_S - V_{TN}) \sqrt{\frac{E_{CP} W_N}{E_{CN} W_P}} = V_{DD} - V_S - |V_{TP}| \quad \text{where } L_N = L_P$$

$$X = \sqrt{\frac{E_{CP} W_N}{E_{CN} W_P}} = \sqrt{\frac{\mu_N W_N}{\mu_P W_P}}$$

Question?

$N_{sat}(n) = N_{sat}(p)$

$$V_S = \frac{V_{DD} - |V_{TP}| + X V_{TN}}{1 + X}$$

V_{IL} (Region II)

$$I_{DN}(\text{sat.}) = I_{DP}(\text{lin.})$$

$$\frac{W_n N_{sat.} C_{ox} (N_{IN} - V_{TN})^2}{(N_{IN} - V_{TN}) + E_{cn} L_n} = \frac{W_p}{L_p} \frac{\mu_p C_{ox}}{\left(1 + \frac{V_{DD} - N_{OUT}}{E_{cp} L_p}\right)} \left[(V_{DD} - N_{IN} - |V_{TP}|)(V_{DD} - N_{OUT}) - \frac{(V_{DD} - N_{OUT})^2}{2} \right]$$

Assumptions:

$$N_{IN} - V_{TN} \approx 0 \quad \text{and} \quad N_{OUT} \approx V_{DD} \rightarrow \frac{V_{DD} - N_{OUT}}{E_{cp} L_p} \approx 0$$

$$\frac{W_n N_{sat.} C_{ox} (N_{IN} - V_{TN})^2}{E_{cn} L_n} \approx \frac{W_p}{L_p} \mu_p C_{ox} \left[(V_{DD} - N_{IN} - |V_{TP}|)(V_{DD} - N_{OUT}) - \frac{(V_{DD} - N_{OUT})^2}{2} \right]$$

$$N_{sat} = \frac{\mu E_{cn}}{2}$$

(1) $$\frac{W_n}{L_n} \frac{\mu_n}{2} C_{ox} (N_{IN} - V_{TN})^2 = \frac{W_p}{L_p} \mu_p C_{ox} \left[(V_{DD} - N_{IN} - |V_{TP}|)(V_{DD} - N_{OUT}) - \frac{(V_{DD} - N_{OUT})^2}{2} \right]$$

To be continued