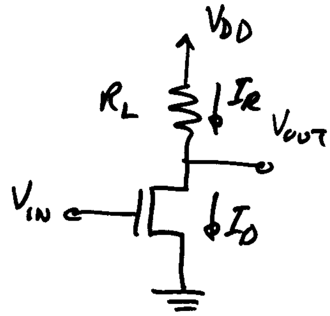
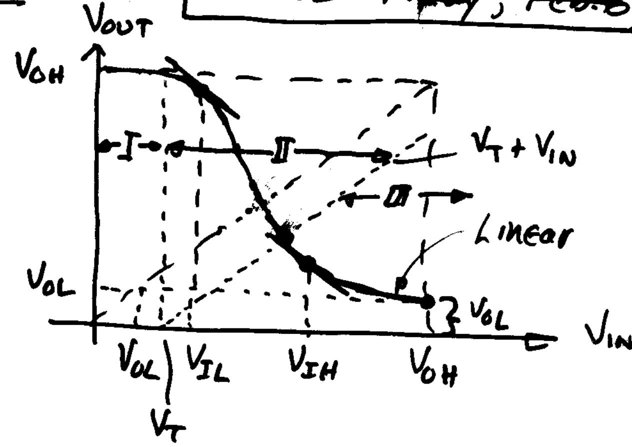
Resistor Load Inverter

Exam 1 ~~Friday~~, ~~Feb. 6~~ Monday, Feb. 9



$\Rightarrow$



I. Cutoff
II - Saturation
III - Linear

1.) $\underline{V_{OH} = V_{DD}}$ if $V_{IN} < V_T$ (cutoff)

2.) $V_{OL} = ?$ → MOSFET is linear

$$I_R = \frac{V_{DD} - V_{OL}}{R_L} \qquad I_D(\text{linear}) = \frac{1}{2}\frac{W_N}{L_N}\left(\frac{\mu_n C_{ox}}{1 + \frac{V_{OL}}{E_C L_N}}\right)\left[2(V_{OH} - V_T)V_{OL} - V_{OL}^2\right]$$

Assume that $\frac{V_{OL}}{E_C L_N} < 1$ → $I_D(\text{linear}) = \frac{k}{2}\left[2(\overset{V_{DD}}{V_{OH}} - V_T)V_{OL} - V_{OL}^2\right]$

Quadratic -

$$V_{OL}^2 - 2\left(\frac{1}{kR_L} + V_{DD} - V_T\right)V_{OL} + \frac{2V_{DD}}{kR_L} = 0$$

Or assume $V_{OL} < 1$ so that $V_{OL}^2 \approx 0$

$$\underline{V_{OL} \approx \frac{V_{DD}}{1 + kR_L(V_{DD} - V_T)}}$$

3.) $V_{IL} = ?$

Assumptions: MOSFET in saturation and $v_{IN}-V_T$ small

$$I_R = I_D \rightarrow \frac{V_{DD}-v_{OUT}}{R_L} = \frac{W v_{sat} C_{ox}(v_{IN}-V_T)^2}{\underbrace{(v_{IN}-V_T)}_{\rightarrow 0}+E_cL} \approx \frac{W v_{sat} C_{ox}(v_{IN}-V_T)^2}{E_cL}$$

Recall, $v_{sat} = \frac{\mu E_c}{2}$

$$\frac{V_{DD}-v_{OUT}}{R_L} = \frac{\mu C_{ox}}{2}\frac{W}{L}(v_{IN}-V_T)^2 = \frac{k}{2}(v_{IN}-V_T)^2$$

$$\frac{d}{dv_{IN}} \rightarrow -\frac{1}{R_L}\frac{dv_{out}}{dv_{IN}} = k(v_{IN}-V_T)$$

Setting $\frac{dv_{out}}{dv_{IN}} = -1 \rightarrow \frac{1}{R_L} = k(v_{IN}-V_T) = k(V_{IL}-V_T)$

$$V_{IL} = V_T + \frac{1}{kR_L}$$

$$\overline{\cancel{\frac{A}{V^2}}\ \cancel{\frac{V}{A}}}$$

$$NM_L = V_{IL} - V_{OL} = V_T + \frac{1}{kR_L} - \frac{V_{DD}}{1+kR_L(V_{DD}-V_T)}$$

4.) $V_{IH} = ?$

Assume: MOSFET is linear and $v_{OUT} < E_cL$

$$\frac{V_{DD}-v_{OUT}}{R_L} = \frac{W}{L}\frac{\mu C_{ox}}{1+\frac{v_{OUT}}{E_cL}}\left[(v_{IN}-V_T)v_{OUT} - \frac{v_{OUT}^2}{2}\right]$$

$$\frac{V_{DD}-v_{OUT}}{R_L} = k\left[(v_{IN}-V_T)v_{OUT} - \frac{v_{OUT}^2}{2}\right]$$

Take the partial derivative w.r.t. v_{IN}

$$k\left[(v_{IN}-V_T)\underbrace{\frac{dv_{OUT}}{dv_{IN}}}_{=-1} + v_{OUT} - v_{OUT}\underbrace{\frac{dv_{OUT}}{dv_{IN}}}_{=-1}\right] = -\underbrace{\frac{dv_{OUT}}{dv_{IN}}}_{=-1}\frac{1}{R_L}$$

$$k\left[-(V_{IN}-V_T)+2V_{OUT}\right]\overset{?}{=}\frac{1}{R_L}$$

$$\frac{V_{DD}-V_{OUT}}{R_L}=k\left[(V_{IN}-V_T)V_{OUT}-\frac{V_{OUT}^2}{2}\right]$$

$$V_{IH}=V_T+\sqrt{\frac{8V_{DD}}{3kR_L}}-\frac{1}{kR_L}$$

$$\therefore\ NM_H=V_{OH}-V_{IH}=V_{DD}-V_T-\sqrt{\frac{8V_{DD}}{3kR_L}}+\frac{1}{kR_L}$$

Example 4.2

Find NM_L and NM_H if $k'=430\frac{\mu A}{V^2}$, $V_T=0.4V$, $\frac{W}{L}=2$, $V_{DD}=1.2V$ and $R_L=20k\Omega$.

$V_{OH}=V_{DD}=\underline{1.2V}$ $k=k'\frac{W}{L}=430\frac{\mu A}{V^2}\times 2=860\frac{\mu A}{V^2}$

$$V_{OL}\approx\frac{V_{DD}}{1+kR_L(V_{DD}-V_T)}=\frac{1.2}{1+(.860)(20)(1.2-0.4)}=\underline{0.081V}$$

$$V_{IL}=V_T+\frac{1}{kR_L}=0.4+\frac{1}{(0.860)(20)}=\underline{0.46V}$$

$$V_{IH}=+V_T+\sqrt{\frac{8V_{DD}}{3kR_L}}+\frac{1}{kR_L}=+0.4+\sqrt{\frac{8(1.2)}{3(.86)(20)}}+\frac{1}{(0.86)(20)}$$

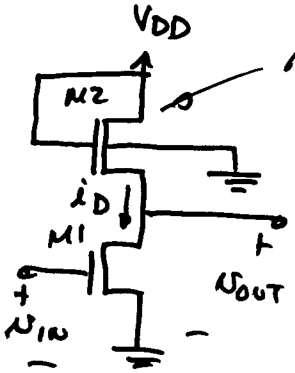
$V_{IH}=\underline{0.773V}$

$NM_L=V_{IL}-V_{OL}=0.46-0.081=\underline{0.38V}$

$NM_H=V_{OH}-V_{IH}=1.2-0.773=\underline{0.43V}$

ACTIVE LOAD INVERTERS

Saturated Enhancement Load Inverter

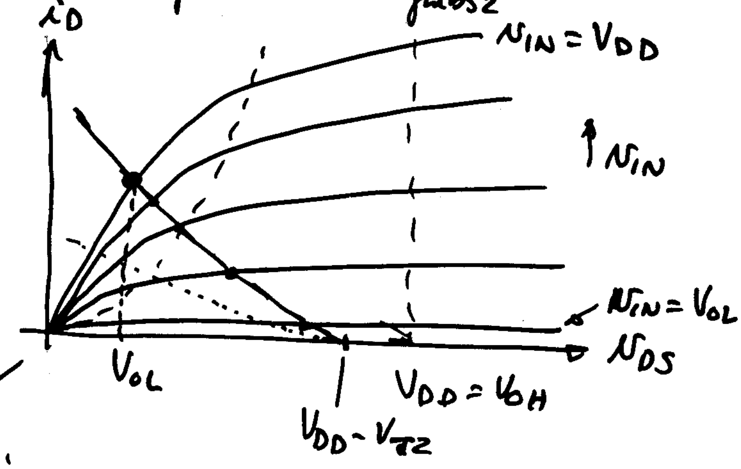


Always saturated ($v_{DS} \geq v_{GS} - V_T$)

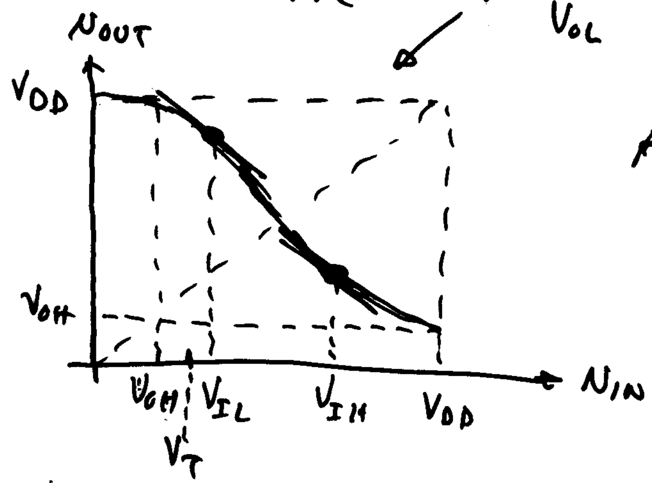
$v_D - v_S \geq v_G - v_S - V_T$

($v_{DG} \geq -V_T$)

$$\text{"}R_L\text{"} = \frac{1}{g_{m2}} \,\|\, r_{ds2} \,\|\, \frac{1}{g_{mbs2}}$$

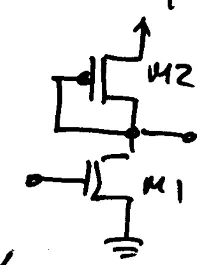


VTC

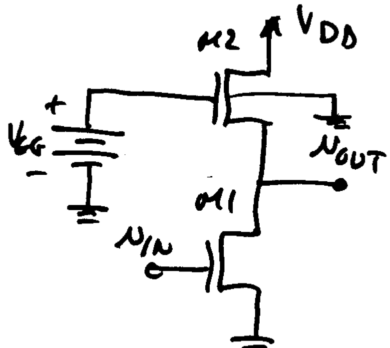


Problem: $V_{T2} = f(v_{OUT})$

"CMOS Equivalent"



Linear Enhancement Load Inverter



More gain

Disadvantages:

1. Must provide V_{GG}.
2. More chip area rqd.
3. More power dissipation