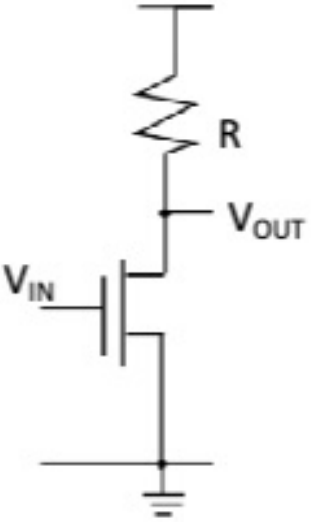


This circuit can work as an inverter if the value of resistance, R is chosen appropriately. Assume that the R_{ON} of the transistor is 1K Ohm and the R_{OFF} of the transistor is 10 M Ohm.

Determine the range of values of R, such that the V_{OUT} swings from at least 0.05 to 0.95 of V_{DD}, when the V_{IN} is V_{DD} and 0 respectively. In other words, when $V_{IN} = 0$, $V_{OUT} > 0.95\ V_{DD}$ and when $V_{IN} = V_{DD}$, $V_{OUT} < 0.05\ V_{DD}$.

When $V_{in} = 0$, $V_{out} > .95\,V_{DD}$

$$\Rightarrow V_{out} = \frac{1}{1+R/R_{off}} V_{DD} \Rightarrow \frac{1}{1+R/R_{OFF}} > .95 \Rightarrow 1 + \frac{-1}{.95} > R/10M$$

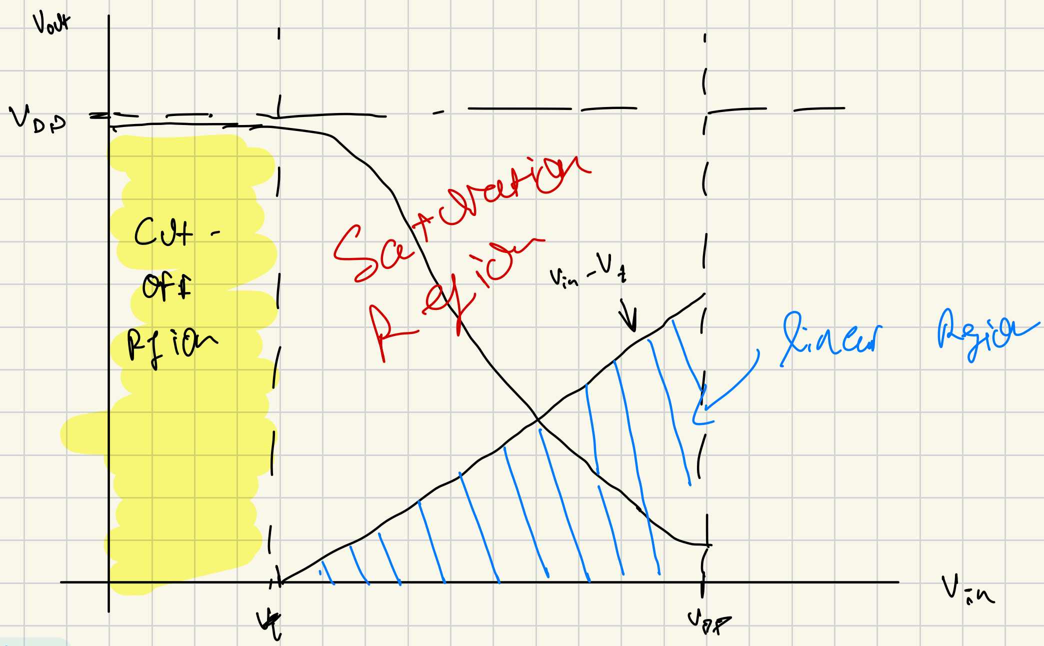
$$10M + -10.526M > R \Rightarrow R < .526 M\Omega$$

When $V_{in} = V_{DD}$, $V_{out} < .05\,V_{DD}$

$$\Rightarrow \frac{1}{1+R/R_{on}} < .05 \Rightarrow 20 < 1 + \frac{R}{1e3} \Rightarrow R > 19e3$$

$$\boxed{19\,k\Omega < R < 526\,k\Omega}$$

2. For the modified inverter shown in Problem 1, qualitatively draw the voltage transfer characteristics and show the regions of operation of the NMOS device. Follow the same procedure that we discussed in the class for CMOS inverters.



3. (a) Consider a CMOS process where $\mu_p = 0.5\ \mu_n$. The threshold voltages are given by V_{tn} = 200mV and V_{tp} = -150mV. Assume that the operating supply voltage V_{DD} = 1.0V. Assume that the PMOS and the NMOS devices have the same length and C_{ox}. Find the ratio of the width of the PMOS to the width of the NMOS when the trip point of the inverter is:

a. V_M = 750 mV (inverter-1)

b. V_M = 300 mV (inverter-2)

Such inverters where the V_M are not at 0.5 V_{DD} are called *skewed inverters*.

1

$\mu_p = .5\mu_n$ $\quad V_{Tn} = 200mV \quad V_{DD} = 1V$

$V_{Tp} = -150mV$

a) Trip point is when output changes from .05 VDD to .95 VDD

$V_M = 750mV$. Given that $V_M = \dfrac{V_{DD} + V_{TP} + \sqrt{\frac{\beta_n}{\beta_p}}\, V_{Tn}}{1 + \sqrt{\beta_n/\beta_p}} = 1.15 + \sqrt{}$

$$\frac{\beta_n}{\beta_p} = \frac{\cancel{\mu_n}\left(\frac{W_n}{\cancel{L}}\right)\cancel{C_{ox}}}{\cancel{\mu_p}\left(\frac{W_p}{\cancel{L}}\right)\cancel{C_{ox}}} = \frac{\beta_n}{\beta_p} = \frac{2W_n}{W_p}$$

$.5\mu_n$

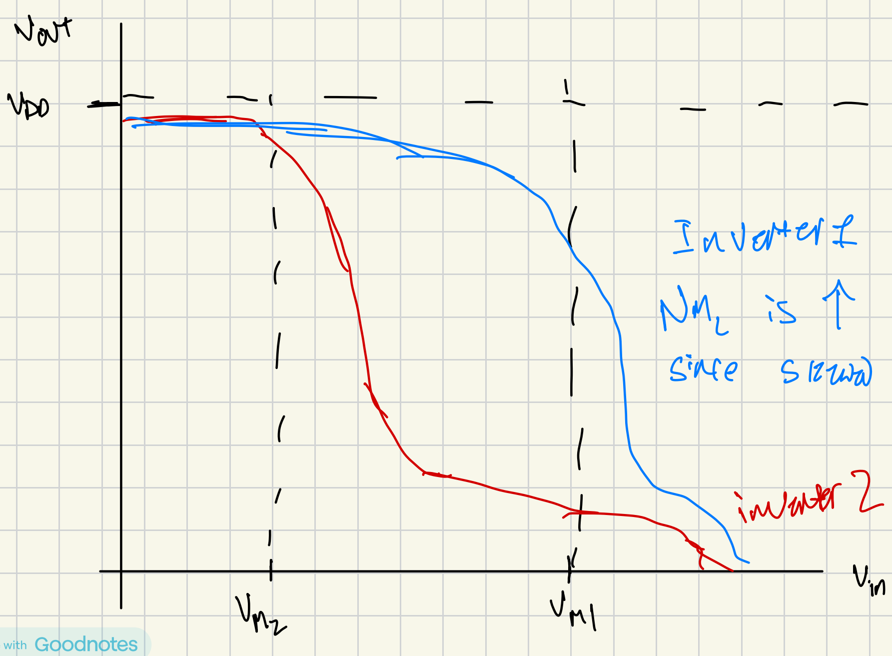
$.75 + .45\sqrt{\beta_n/\beta_p} = 1 + .150 + \sqrt{\beta_n/\beta_p}\,(.2)$

$.55\sqrt{\beta_n/\beta_p} = .85 - .75 \Rightarrow \left(\frac{.1}{.55}\right)^2 = \frac{\beta_n}{\beta_p}$

$\frac{W_n}{W_p} = \frac{1}{2}\left(\frac{10^2}{5.5^2}\right) \Rightarrow \boxed{\frac{W_p}{W_n} = \frac{605}{100} = .605}$

b) $.1\sqrt{\beta_n/\beta_p} = .85 - .3 \Rightarrow \frac{.55}{.1} = \sqrt{\beta_n/\beta_p} = (5.5)^2 = \frac{2W_n}{W_p} \Rightarrow \boxed{\frac{W_n}{W_p} = \frac{1}{60.5}}$

(b) Draw the VTC of these two inverters. Your diagram should be qualitative, and you can assume that the inverters have high gain during the transition. State whether inverter-1 has higher NM_L or higher NM_H. State whether inverter-2 has higher NM_L or higher NM_H. Explain your answer.



This is because inverter 1 is skewed to switch @ a higher input voltage as compared to inverter 2.

Inverter 1

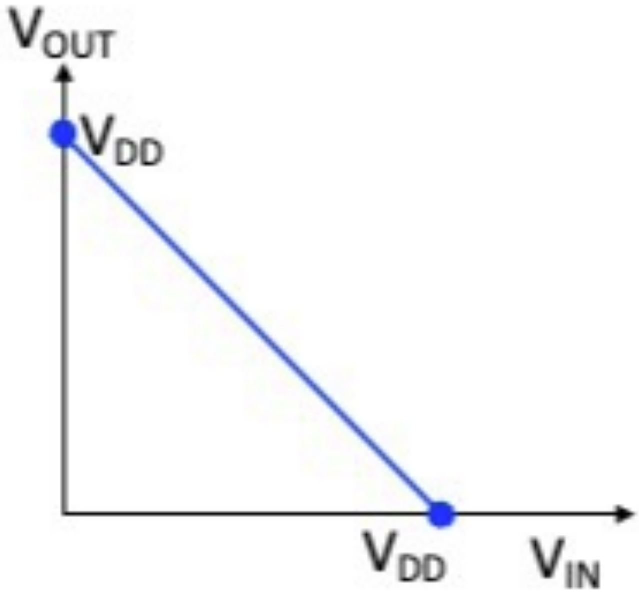
NM_L is ↑

since skewed past $\frac{V_{DD}}{2} < .75 \Rightarrow .5 < .75$

inverter 2 NMH higher

$\Rightarrow \frac{V_{DD}}{2} = .5 > .3$

4. Consider a hypothetical inverter with a VTC as shown below.



a. Determine the V_{OL}, V_{OH}, V_{IL} and V_{IH} of this inverter.

b. Determine NM_H and NM_L of the inverter

c. Will this inverter have regenerative properties? Explain your answer.

a) $V_{IL} = 0 \Rightarrow V_{OUT} = V_{DD}$ $\quad$ $V_{OH} = V_{DD} \Rightarrow V_{in} = 0$

$V_{IH} = V_{DD} \Rightarrow V_{OUT} = 0$ $\quad$ $V_{IH} = 0 \Rightarrow V_{in} = V_{DD}$

b) $NM_H = V_{OH} - V_{IH} = V_{DD} - V_{DD} = 0$

$NM_L = V_{OL} - V_{IL} = 0 - 0 = 0$

c) Regenerative properties are qualities such that an input signal which is noisy can be correctly interpreted through the inverter and produce a clean output. in our case, any noise in the input will produce undefined behavior of the inverter $\Rightarrow$ NO Regen. properties. Since this graph is lined, any changes will be propagated in a chain of inverters.

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