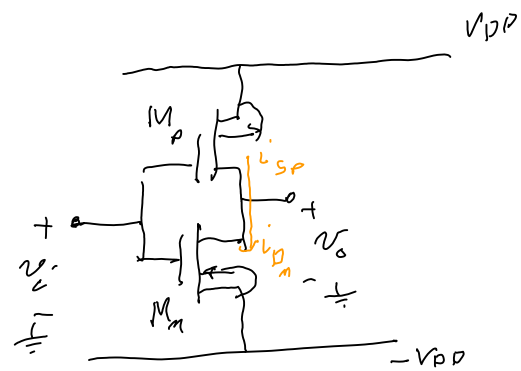
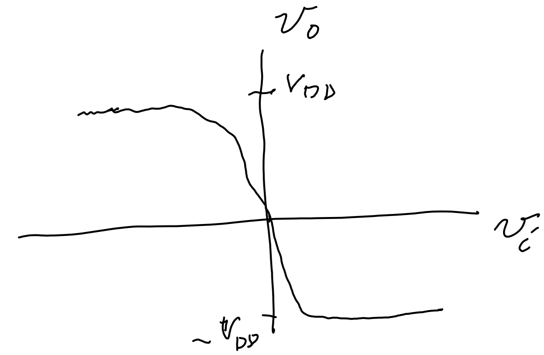
Note Title 3/28/2019

ENEE303
03/28/19

Inverter





with no load

$i_{S_p} = i_{D_n}$

$$i_{S_p} = \frac{KP_p}{2}\left(\frac{W}{L}\right)_p \left(v_{SG_p} - |V_{TO_p}|\right)^2 \left(1 + \lambda_p v_{SD_p}\right)$$

$$i_{D_n} = \frac{KP_n}{2}\left(\frac{W}{L}\right)_n \left(v_{GS_n} - V_{TO_n}\right)^2 \left(1 + \lambda_n v_{DS_n}\right)$$

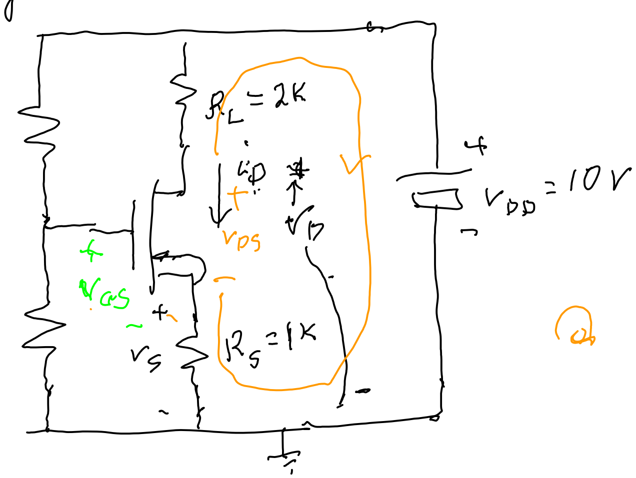
Note that M_p & M_n are in saturation @ bias ($v_i = v_o = 0$)

as $v_{GS_n} = V_{DD}$, $v_{DS} = V_{DD}$ $\quad V_{DD} = v_{DS}$ so $v_{GS} - V_{TO} = V_{DD} - V_{TO}$, $V_{TO} > 0$ if enhancement mode transistors

$\therefore$ $v_{DS} > v_{GS} - V_{TO}$ @ origin gives a formula for $W_p = L_p \left(\frac{KP_n}{KP_p}\right)\left(\frac{W}{L}\right)_n \frac{(V_{DD} - V_{TO_n})^2 (1+\lambda_n V_{DD})}{(V_{DD} - |V_{TO_p}|)^2 (1+\lambda_p V_{DD})}$

if M_p ⇒ exact complement of M_n then $W_p = W_n$

Bias & small signal



$5V = \frac{V_{DD}}{2} = V_G$ $\quad R_B = R_A$

if in saturation

$i_D = I_D \times 10^{-3}$

$R_S = r_S \times 10^3$, $R_L = r_L \times 10^3$

(a) $V_{DS} = V_{DD} - i_D R_L - i_D \cdot R_S = V_{DD} - (r_S + r_L) I_D$

$V_{GS} = \frac{V_{DD}}{2} - r_S I_D = 5 - 1 \cdot I_D$; $V_{DS} = 10 - (3) I_D$

assume $\frac{KP}{2}\frac{W}{L} = 5 \times 10^{-3} \frac{A}{V^2}$

$V_{TO} = 1V$

$i_D = 10^{-3} I_D = \frac{KP}{2}\frac{W}{L}(V_{GS} - V_{TO})^2 \Rightarrow I_D = \frac{\left(\frac{KP}{2}\frac{W}{L}\right)}{10^{-3}} \cdot (V_{GS} - V_{TO})^2$

$V_{GS} = 5 - I_D \Rightarrow I_D = 5(5 - I_D - 1)^2$

$$I_D = 5(4 - I_D)^2 \Rightarrow \frac{I_D}{5} = 16 - 8I_D + I_D^2 \Rightarrow I_D^2 - \left(8 + \frac{1}{5}\right)I_D + 16 = 0$$

$$I_D = -\left(-\frac{41}{5}\right) \pm \frac{1}{2}\left(\sqrt{\left(\frac{41}{5}\right)^2 - 4(16)}\right) = \frac{41}{5}\left(1 \pm \sqrt{1 - \frac{4 \times 16 \times 25}{(41)^2}}\right) \approx \frac{41}{5}\left(1 \pm \left[1 - \frac{1}{2}\left(\frac{4 \times 16 \times 25}{41^2}\right)\right]\right)$$

$$= + \text{sign} \quad \frac{41}{5}\left(2 - \frac{1}{2}\left(\frac{4 \times 16 \times 25}{41^2}\right)\right) \approx \frac{41}{5}\left(2 - \frac{1}{2}\right) = \frac{40}{5} \times \frac{3}{2} = 4 \times 3 = 12$$

$$- \text{sign} = \frac{41}{5}\left(\frac{1}{2} \cdot \left(\frac{4 \times 16 \times 25}{41^2}\right)\right) = \frac{41}{5} \cdot \frac{1}{4} = 2$$

$$\approx \frac{\overset{8}{\cancel{4 \times 16}} \times 25}{\cancel{2} \times \underset{10}{\cancel{40}} \times 40} = \frac{8 \times 5}{2 \times 40} = \frac{20}{40} = \frac{1}{2}$$

saturation

$$V_{DS} = 10 - (3) \cdot I_D > V_{GS} - V_{TO} = 5 - I_D - 1 = 4 - I_D \Rightarrow 10 - 3I_D > 4 - I_D$$

$$6 > 4I_D \Rightarrow I_D < 3/2 = 1.5$$

$\therefore$ must use the $-$ sign $\Rightarrow I_D \approx 2$

$\therefore V_{GS} = 5 - I_D = 3V$; $V_{DS} = 4V$ & $V_{DS} > V_{GS} - V_{TO}$

$$Q = i_D = 2\,\text{ma}, \quad V_{DS} = 4V, \quad V_{GS} = 3V$$