Santa Clara University

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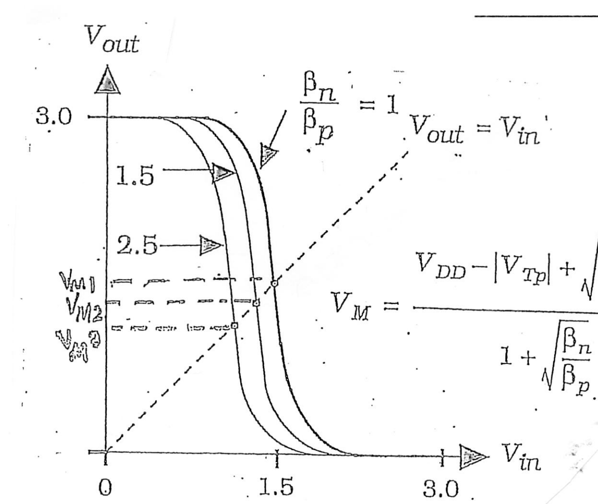
ELEN 153 **Problem Set #2** **Due: 10-8-2020, Thursday, 12:00 pm**
Fall 2020

1. A CMOS asymmetrical inverter using power supply of 4.5 V and Channel length = 45 nm is built in a process with the following specification:
   nFET : Process transconductance = 163 ($\mu A/V^2$) ; Threshold voltage = 0.57 V ; Width = 8 μm
   pFET : Process transconductance = 74 ($\mu A/V^2$) ; Threshold voltage = - 0.63 V ; Width = 12 μm

   a) Calculate Device transconductances of the nFET and the pFET.
   b) Estimate the Midpoint voltage V_M of the inverter.

2. a) Find the ratio of device transconductances of nFET and pFET needed to obtain a CMOS inverter midpoint voltage to be 2.68 V. The inverter uses a power supply of 5.0 V with nFET Threshold voltage = 0.58 V and pFET Threshold voltage = - 0.62 V.

   b) In a CMOS process, the Gate oxide thickness and the Channel length of both the nFET and the pFET are kept same. What would be the relative width sizes of the nFET and pFET in the inverter in 2a) if the electron mobility in the nFET and hole mobility in the pFET are related by $\mu_n = 3.47\ \mu_p$?



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

Dependence of V_M on the device ratio

$V_{DD} = 3\ V$ $V_{Tp} = -0.7V$ $V_{Tn} = +0.7\ V$

Daren Liu (1)

1) a) $\beta_n = k_n'\left(\frac{W}{L}\right)$

$L = 45\,nm = 45 \cdot 10^{-9}$

$W = 8\,\mu m = 8 \cdot 10^{-6}$

$\beta_n = (163)\left(\frac{8 \cdot 10^{-6}\,m}{45 \cdot 10^{-9}\,m}\right) = 28.98\ \frac{mA}{V^2}$

$\beta_p = (74)\left(\frac{12 \cdot 10^{-6}\,m}{45 \cdot 10^{-9}\,m}\right) = 19.73\ \frac{mA}{V^2}$

b) $V_m = \dfrac{V_{DD} - |V_{Tp}| + \sqrt{\frac{\beta_n}{\beta_p}}\,V_{Tn}}{1 + \sqrt{\frac{\beta_n}{\beta_p}}}$ $\qquad V_{DD} = 4.5\,V$

$= \dfrac{4.5 - (0.63) + \sqrt{\frac{28.98}{19.73}}\,0.57}{1 + \sqrt{\frac{28.98}{19.73}}} = 2.06\,V$

2) a) $V_{DD} = 5.0\,V \quad V_{Tn} = 0.58\,V \quad V_{Tp} = -0.62 \quad V_m = 2.68\,V$

$\left(1 + \sqrt{\frac{\beta_n}{\beta_p}}\right)V_m = V_{DD} - |V_{Tp}| + \sqrt{\frac{\beta_n}{\beta_p}}\,V_{Tn}$

$V_m + V_m\sqrt{\frac{\beta_n}{\beta_p}} - \sqrt{\frac{\beta_n}{\beta_p}}\,V_{Tn} = V_{DD} - |V_{Tp}|$

$\sqrt{\frac{\beta_n}{\beta_p}}\left(V_m - V_{Tn}\right) = V_{DD} - |V_{Tp}| - V_m$

$\sqrt{\frac{\beta_n}{\beta_p}} = \dfrac{V_{DD} - |V_{Tp}| - V_m}{V_m - V_{Tn}}$

$\frac{\beta_n}{\beta_p} = \left(\dfrac{V_{DD} - |V_{Tp}| - V_m}{V_m - V_{Tn}}\right)^2 = \left(\dfrac{5 - 0.62 - 2.68}{2.68 - 0.58}\right)^2 = 0.655$

b) $\frac{\beta_n}{\beta_p} = \dfrac{\mu_n C_{ox}\left(\frac{W_n}{L}\right)}{\mu_p C_{ox}\left(\frac{W_p}{L}\right)} = \dfrac{3.47\cancel{\mu_p}\,(W_n)}{\cancel{\mu_p}\,(W_p)} = \dfrac{3.47\,(W_n)}{W_p}$

$0.655 = \dfrac{3.47 W_n}{W_p} \qquad 0.655\,W_p = 3.47 W_n$

$W_p = 5.300\,W_n$