Homework No. 4 – Solutions

Problem 1 – P4.2

Problem should refer to Figure P4.1

a. Resistive load

$$V_{OH} = V_{DD}$$

$$V_{OL} = \frac{V_{DD}}{1 + kR_L\left(V_{DD} - V_T\right)} = \frac{V_{DD}}{1 + \mu_N C_{OX} \frac{W}{L} R_L\left(V_{DD} - V_T\right)}$$
$$= \frac{1.2}{1 + \left(260\right)\left(10^{-6}\right)\left(\frac{1}{0.1}\right)\left(10\times10^{3}\right)\left(1.2 - 0.4\right)} = 0.055\text{V}$$

b. Saturated-enhancement load

$$V_{OH} = V_{DD} - V_T = V_{DD} - \left(V_{T0} + \gamma\left(\sqrt{V_{SB} + 2\left|\phi_f\right|} - \sqrt{2\left|\phi_f\right|}\right)\right)$$
$$= V_{DD} - V_{T0} - \gamma\sqrt{V_{OH} + 2\left|\phi_f\right|} + \gamma\sqrt{2\left|\phi_f\right|}$$
$$= 1.2 - 0.4 - 0.2\sqrt{V_{OH} + 0.88} + 0.2\sqrt{0.88}$$
$$= 0.988 - 0.2\sqrt{V_{OH} + 0.88}$$

Iterate to produce:

$$V_{OH} = 0.733\text{V}$$

To compute V_{OL} we can ignore body effect and equate currents:

$$\therefore \frac{W_I}{L_I}\frac{\mu_N}{\left(1 + \frac{V_{OL}}{E_{CN}L_I}\right)}\left[\left(V_{DD} - V_{TI}\right)V_{OL} - \frac{V_{OL}^{\ 2}}{2}\right] = \frac{W_L v_{sat}(V_{DD} - V_{OL} - V_{TL})^2}{(V_{DD} - V_{OL} - V_{TL}) + E_{CN}L_L}$$

$$\therefore \frac{1.2}{0.1}\frac{(270\, cm^2/V-s)}{\left(1 + \frac{V_{OL}}{0.6}\right)}\left[\left(1.2 - 0.4\right)V_{OL} - \frac{V_{OL}^{\ 2}}{2}\right] = \frac{(0.2\mu m)(8\times10^6 cm/s)(1.2 - V_{OL} - 0.4)^2}{(1.2 - V_{OL} - 0.4) + 0.6}$$

Solve for $V_{OL} \approx 0.03V$

c. Linear-enhancement load

$$V_{OH} = V_{GG} - V_T = V_{DD} - \left(V_{T0} + \gamma\left(\sqrt{V_{SB} + 2|\phi_f|} - \sqrt{2|\phi_f|}\right)\right)$$
$$= V_{GG} - V_{T0} - \gamma\sqrt{V_{OH} + 2|\phi_f|} + \gamma\sqrt{2|\phi_f|}$$
$$= 1.6 - 0.4 - 0.2\sqrt{V_{OH} + 0.88} + 0.2\sqrt{0.88}$$
$$= 1.388 - 0.2\sqrt{V_{OH} + 0.88}$$

Iterate to produce:

$$V_{OH} = 1.11\text{V}$$

This tells us that V_{GG} should have been above 1.6V (closer to 1.7 V).

To compute V_{OL} we can ignore body effect and equate currents. Note that the load is saturated even though we call it a linear-enhancement load. The driver is also saturated due to the device sizes used.

$$\therefore \frac{W_I v_{sat}(V_{DD} - V_{TI})^2}{(V_{DD} - V_{TI}) + E_{CN}L_I} = \frac{W_L v_{sat}(V_{GG} - V_{OL} - V_{TL})^2}{(V_{GG} - V_{OL} - V_{TL}) + E_{CN}L_L}$$

$$\therefore \frac{(0.1\mu m)(8\times10^6 cm/s)(1.2 - 0.4)^2}{(1.2 - 0.4) + 0.6} = \frac{(0.1\mu m)(8\times10^6 cm/s)(1.6 - V_{OL} - 0.4)^2}{(1.6 - V_{OL} - 0.4) + 0.6}$$

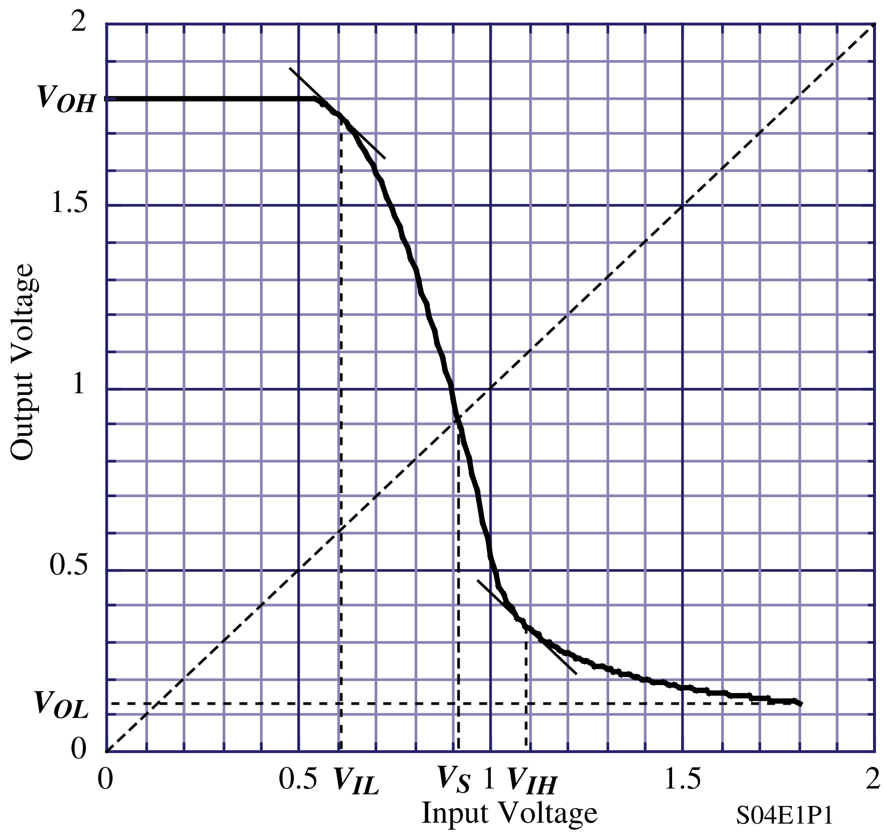
Solve for $V_{OL} \approx 0.69\text{V}$

d. CMOS

$$V_{OH} = V_{DD} \qquad V_{OL} = 0\text{V}$$

Problem 4

From the voltage transfer function curve shown, numerically identify, V_{OH}, V_{OL}, V_{IL}, V_{IH}, and V_S. From these values, find the value of NM_H and NM_L.



From the curve we get the following numerical values.

V_{OH} = 1.8V, V_{OL} = 0.13V, V_{IL} = 0.6V, V_{IH} = 1.08V, and V_S = 0.92V

The noise margins are,

$$NM_H = V_{OH} - V_{IH} = 1.80 - 1.08 = 0.72\text{V}$$

and

$$NM_H = V_{IL} - V_{OL} = 0.60 - 0.13 = 0.47\text{V}$$