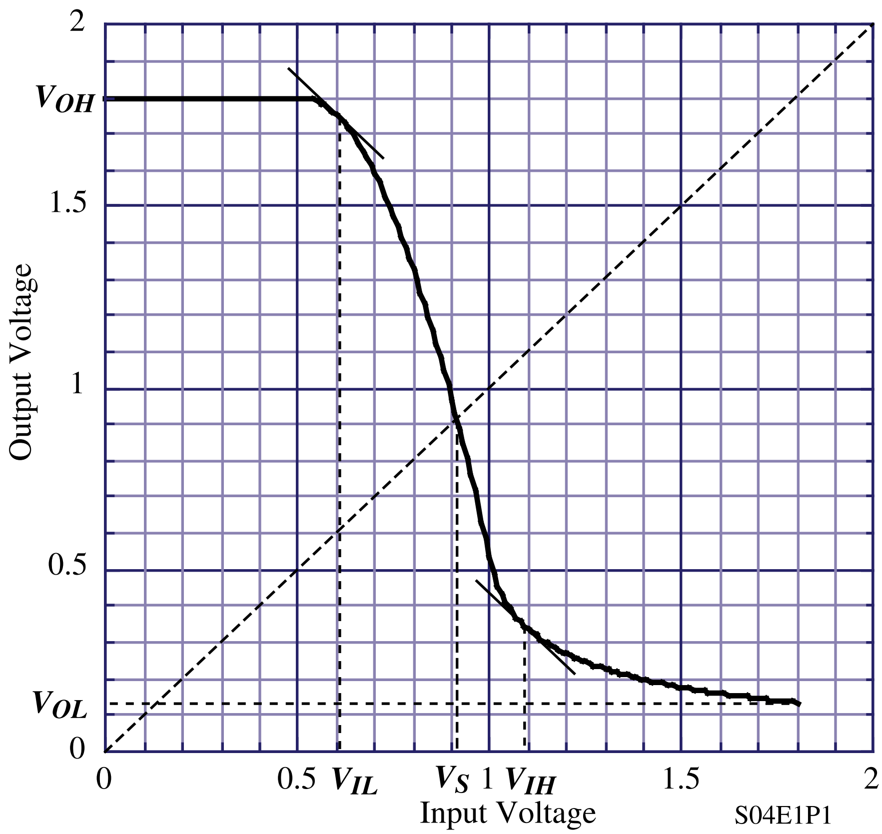
EXAMINATION NO. 1 - SOLUTIONS

(Average score = 78.4/100)

Problem 1 - (25 points)

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,

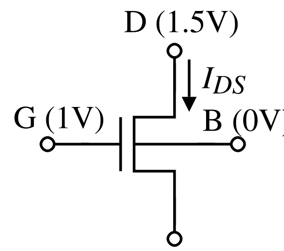
$$NM_H = V_{OH} - V_{IH} = 1.80 - 1.08 = 0.72\text{V}$$

and

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

Problem 2 – (25 points)

Solve for the dc value of the drain current, I_{DS}, for the NMOS transistor shown assuming 0.18μm CMOS technology. The W and L for this transistor are given in Problem 3.



S04E1P2

Solution

Check for saturation.

$$V_{DS}(\text{sat}) = \frac{(V_{GS} - V_T)E_cL}{(V_{GS} - V_T) + E_cL} = \frac{(1\text{-}0.5)(1.2)}{(1\text{-}0.5) + 1.2} = 0.353\text{V}$$

$V_{DS} = 1.5\text{V} \Rightarrow$ NMOS in saturation

$$\therefore\ I_{DS} = Wv_{sat}C_{ox}\frac{(V_{GS} - V_T)^2}{(V_{GS} - V_T) + E_cL})$$

$W = 0.6\text{x}10^{-4}$ cm

$$v_{sat} = \frac{\mu_e E_c}{2} = \frac{270\ (\text{cm}^2/\text{V}\cdot\text{s})\ 6\text{x}10^4(\text{V/cm})}{2} = 8.1\text{x}10^6\ \text{cm/sec}$$

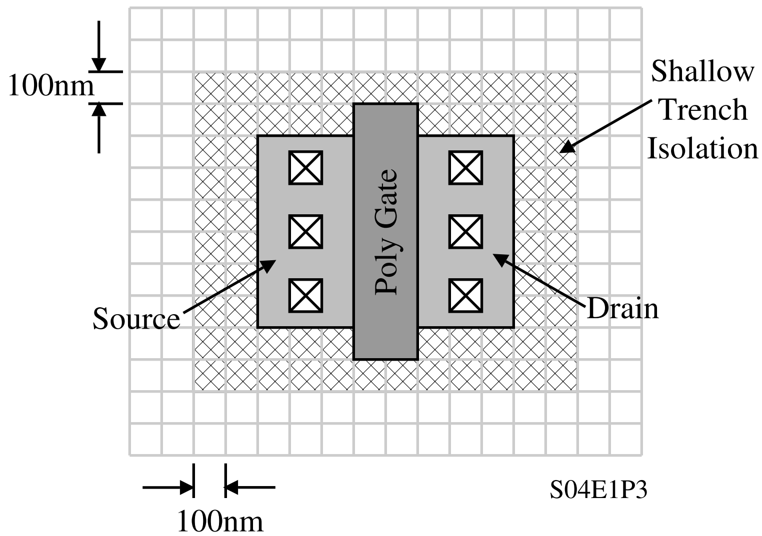
$$C_{ox} = \frac{\varepsilon_r(\varepsilon_o)}{t_{ox}} = \frac{4\cdot 8.85\text{x}10^{-14}\ (\text{F/cm})}{35\text{x}10^{-8}\ \text{cm}} = 1.01\text{x}10^{-6}\ \text{F/cm}^2$$

$$\therefore\quad I_{DS} = (0.6\text{x}10^{-4}\text{cm})(\ 8.1\text{x}10^6\ \text{cm/sec})(\ 1.01\text{x}10^{-6}\ \text{F/cm}^2)\left(\frac{0.5^2}{0.5 + 1.2}\right)(\text{V})$$

$= \underline{\underline{72.18\ \mu\text{A}}}$

Problem 3 – (25 points)

Given the layout for the NMOS transistor of Problem 2, find the value of C_{gs}, C_{gd}, C_{gb}, C_{db}, and C_{sb} assuming that the junction depth of the source-drain diffusions is x_j = 50 nm, m = 0.5 and the lateral diffusion is 10nm.



S04E1P3

Solution

From Problem 2, we know that the NMOS transistor is in saturation. To make the calculations, we will need C_g and C_{ov}. They are calculated as follows,

$$C_g = C_{ox}\cdot W\cdot L = 1.01\text{x}10^{-6}\ (\text{F/cm2})\cdot 0.6\text{x}10^{-4}(\text{cm})\cdot 0.2\text{x}10^{-4}(\text{cm}) = 1.212\text{x}10^{-15}\ \text{F}$$

(C_{ox} was calculated in Problem 2)

$$C_{ol} = C_{ox}\cdot LD = 1.01\text{x}10^{-6}\ (\text{F/cm2})\cdot 10\text{x}10^{-7}(\text{cm}) = 1.01\text{x}10^{-12}\ \text{F/cm}$$

$$\therefore\ C_{gs} = C_{ol}\cdot W + 0.667C_g = (1.01\text{x}10^{-12})(0.6\text{x}10^{-4}) + (0.667)(1.212) = (0.061+0.808)\text{fF}$$

$$= \underline{\underline{0.868\ \text{fF}}}$$

$$C_{gd} = 0.061\text{fF} \approx \underline{\underline{0}}$$

$$C_{gb} = \underline{\underline{0}}$$

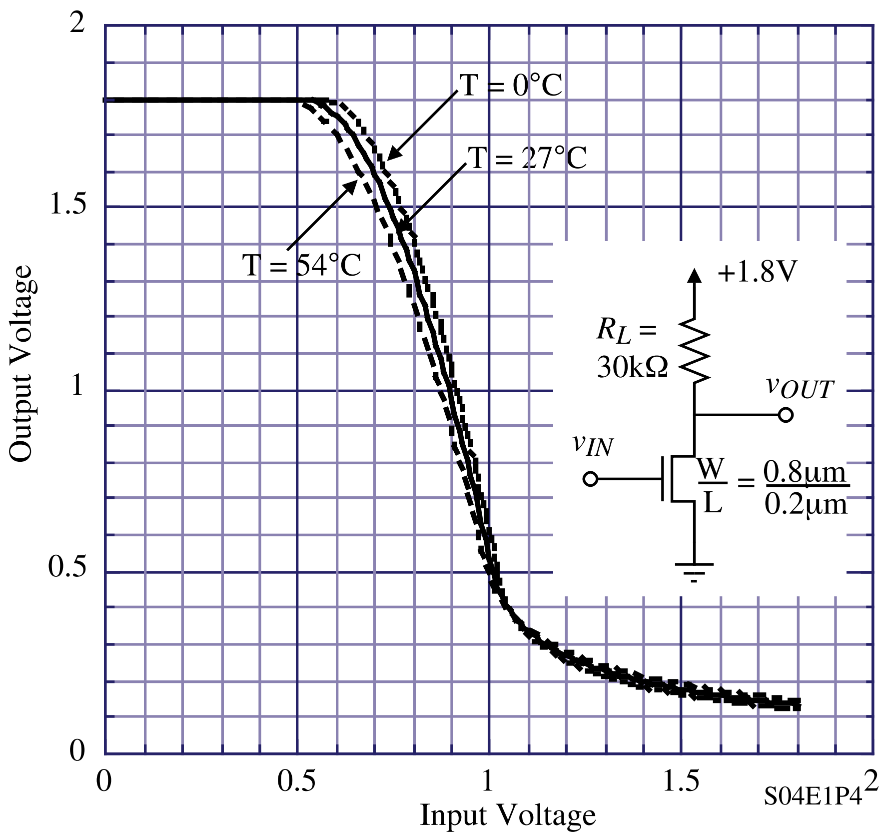
$$C_J = \frac{C_{jb}\,(A_b+A_{sw})}{\left(1\ -\ \frac{V_j}{\phi_B}\right)} = \frac{C_{j0}\,(A_b+A_{sw})}{\left(1\ -\ \frac{V_j}{\phi_B}\right)}$$

$$C_{bd} = \frac{1.6\text{fF}/\mu\text{m}^2[(0.3)(0.6)+(0.05)(0.6)]}{\sqrt{1\ +\ \frac{1.5}{0.9}}} = \underline{\underline{0.206\ \text{fF}}}$$

$$C_{bs} = \frac{1.6\text{fF}/\mu\text{m}^2[(0.3)(0.6)+(0.05)(0.6)]}{\sqrt{1\ +\ 0}} = \underline{\underline{0.336\ \text{fF}}}$$

Problem 4 – (25 points)

A voltage transfer curve of the circuit shown is given for T = 0°C, 27°C, and 54°C. The solid curve corresponds to T = 27°C. Identify which of the two dashed curves corresponds to T = 0°C and T = 54°C? Justify your reason (for full credit) using the relationships for the temperature dependence of the mobility and threshold voltage given in the text. Assume that the resistor, R_L, has no temperature dependence and the technology is 0.18μm CMOS.



Assume the transistor is in saturation which might correspond for example to a value of v_{IN} = 0.8V. Therefore, assume that v_{IN} is fixed at a constant value such as 0.8V.

The output voltage can be found as

$$v_{OUT}(T) = 1.8 - I_D R_L = 1.8\text{–}30\text{k}\Omega\left[\frac{W\mu_e(T)E_C C_{ox}[V_{IN}\text{-}V_T(T)]^2}{2[(V_{IN}\text{-}V_T(T)) + E_C L]}\right]$$

$$\approx 1.8\text{–}30\text{k}\Omega\left[\frac{W\mu_e(T)C_{ox}[V_{IN}\text{-}V_T(T)]^2}{2L}\right], \text{ where } \frac{\mu_e(27°\text{C})C_{ox}W}{2L} = 0.54\text{mA/V}^2$$

assuming 0.18μm CMOS technology. Assuming also that V_{IN} = 0.8V,

$$v_{OUT}(T) = 1.8 - 16.2\left(\frac{T}{T_o}\right)^{-1.5}[0.8\text{–}0.5+0.002(T\text{-}T_o)]^2 = 1.8\text{–}16.2\left(\frac{T}{T_o}\right)^{-1.5}[0.3+0.002(T\text{-}T_o)]^2$$

For $T = T_o$ = 27°C we get, v_{OUT}(27°C) = 1.8 – 16.2(0.09) = 1.8-1.45 = 0.342V

For $T = T_o$ = 0°C we get, v_{OUT}(0°C) = 1.8 – 16.2(1.15)$(0.3\text{-}0.054)^2$ = 1.8-1.13 = 0.67V

For $T = T_o$ = 54°C we get, v_{OUT}(54°C) = 1.8 – 16.2(0.78)$(0.3+0.054)^2$ = 1.8-1.58 = 0.22V

(Unfortunately I used the wrong mobility on the curves so that the values don't correspond but the trend is correct.)