Problem 1 - (10 points)

A top view of a MOS transistor is shown. (a) Identify the type of transistor (NMOS or PMOS) and its value of W and L.

(b.) Draw the cross-section A-A' approximately to scale.

(c) Assume that dc voltage of terminal 1 is 5V, terminal 2 is 3V and terminal 3 is 0V. Find the numerical value of the capacitance between terminals 1 and 2, 2 and 3, and 1 and 3. Assume that the dc value of the output voltage is 2.5V and that the voltage dependence for pn junction capacitances is for both transistors is -0.5 (this is called MJ in SPICE).

Solution

(a.) This transistor is an NMOS transistor with the drain as terminal 1, the gate as terminal 2, and the bulk and source connected together to terminal 3. The $W = 13\mu m$ and $L = 2\mu m$.

(b.) The approximate cross-section is shown (vertical scale is magnified by 4 times).

(c.) With $V_{DS} = 5V$, $V_{GS} = 3V$ and $V_{T} = 0.75V$, the transistor is in saturation. Therefore, the capacitors are:

$$C_{12} = C_{GD} = LD(NMOS) x W x C_{ox}$$

$$= 0.45\mu m \cdot 13\mu m \cdot 0.7fF/\mu m^2 = 4.095fF$$

$$C_{23} = C_{GS} = LD(NMOS) x W x C_{ox} + 0.67(W x L) x C_{ox} = 4.095fF + 12.133fF$$

$$= 16.228fF$$

$C_{13}$ requires the area of the drain (AD) and the perimeter of the drain (PD). These values are AD = 13\mu m x 5\mu m = 65\mu m^2 and PD = 2(5+13) = 36\mu m.

$$C_{13} = CBD = \frac{[AD \cdot 0.33fF/m^2 + PD \cdot 0.9fF/\mu m]}{\sqrt{1 + \frac{5}{0.6}}} = \frac{[65\mu m^2 \cdot 0.33fF/m^2 + 36\mu m \cdot 0.9fF/\mu m]}{\sqrt{1 + \frac{5}{0.6}}}$$

$$= 17.63fF$$
Problem 2 - (10 points)

Find the numerical values of $I_1$, $I_2$, $V_D$, $V_E$, and $V_C$ to within ±5% accuracy.

**Solution**

First find $I_1$. This is done by solving the equations

$$I_1 = \frac{K'W}{2L} (V_{GS4} - V_T)^2$$

and

$$5V = I_1 100k\Omega + V_{GS4}$$

Solving quadratically gives

$$V_{GS4}^2 - V_{GS4} \left(2V_T - \frac{1}{12}\right) + \left(V_T^2 - \frac{5}{12}\right) = 0$$

$$V_{GS}^2 - 1.41667V_{GS} + 0.145833 = 0$$

This gives $V_{GS} = 0.708335 \pm 0.5965 = 1.305V$ \[ \therefore V_D = -2.5 + 1.305 = -1.195V \]

This value of $V_{GS}$ gives $I_1 = \frac{5-1.195}{100k\Omega} = 36.95\mu A$

Neglecting the lambda effects, let $I_2 = 10I_1 = 369.5\mu A$

The base-emitter voltage of Q1 is found as

$$V_E = V_{BE1} = -V_T \ln \left(\frac{I_2}{I_S}\right) = -0.026 \ln \left(\frac{369.5\mu A}{10fA}\right) = -0.633V$$

Finally, the value of $V_{GS2} = \sqrt{\frac{2I_2}{K'W_2/L_2}} + V_T = \sqrt{\frac{2\cdot369.5}{800}} + 0.75 = 1.711V$

$\therefore V_C = 2.5V - 1.711V = +0.7889V$
Problem 3

C1 = 1.1950K, 14.939
C2 = 10.635, 11.920
dif = 1.1844K, 3.0192
Problem 4

\( I_C := 0.5 \times 10^{-3} \quad \beta := 150 \)

\( r_\pi := \frac{\beta}{I_C} V_T \)

\( r_\pi = 7.8 \times 10^3 \)

\( A_1 := \frac{-\beta R_C}{r_\pi} \)

\( A_1 = -192.308 \)

\( A_{DM} := A_1 \frac{r_\pi}{r_\pi + R_B} \)

\( A_{DM} = -138.889 \)

\( f_{3dB} := \frac{1}{2 \pi \cdot 2 R_C C} \)

\( f_{3dB} = 7.958 \times 10^4 \)

\( R_C := 10 \times 10^3 \quad R_E := 100 \times 10^3 \quad V_T := 0.026 \)

\( R_B := 3 \times 10^3 \quad C := 100 \times 10^{-12} \)

\( A_2 := \frac{-\beta R_C}{r_\pi + (\beta + 1) \cdot 2 R_E} \)

\( A_2 = -0.05 \)

\( A_{CM} := A_2 \frac{r_\pi + (\beta + 1) \cdot 2 R_E}{r_\pi + (\beta + 1) \cdot 2 R_E + R_B} \)

\( A_{CM} = -0.05 \)
Problem 5
Draw the electrical schematic using the proper symbols for the transistors. Identify on your schematic the terminals which are +5V, ground, input, and output. Label the transistors on the layout as M1, M2, etc. and determine their W/L values. Assume each square in the layout is 1 micron by 1 micron. Find the area in square microns and periphery in microns for the source and drain of each transistor.

\[ W_1 \times L_1 = 10 \]
\[ W_2 \times L_2 = 20 \]

\[ A_{S1} = A_{D1} = 20 \times 4 = 80 \mu \text{m}^2 \]
\[ P_{S1} = P_{D1} = 4 + 4 + 20 + 20 = 48 \mu \text{m}^2 \]

\[ A_{S2} = 2A_{S1} = 160 \mu \text{m}^2 \]
\[ A_{D2} = A_{D1} = 80 \mu \text{m}^2 \]
\[ P_{S2} = 2P_{S1} = 96 \mu \text{m}^2 \]
\[ P_{D2} = P_{D1} = 48 \mu \text{m}^2 \]