Homework 8 Solutions

EE 330: FALL 2024

Problem 1

$$I_D = \mu_n C_{ox} \frac{W}{2 \cdot L}(V_{gs} - V_T)^2 \quad \text{and} \quad I_{D1} = I_{D2}$$

$$I_D = \mu_n C_{ox} \frac{W_1}{2 \cdot L_1}((V_{out} - 0) - V_{Tn})^2 = \mu_n C_{ox} \frac{W_2}{2 \cdot L_2}((V_{DD} - V_{out}) - V_{Tn})^2$$

$$\frac{5\mu}{2\mu}(V_{out} - 0.4)^2 = \frac{4\mu}{2\mu}(1.8 - V_{out} - 0.4)^2$$

$$\frac{V_{out}^2}{2} + 3.6 * V_{out} - 3.52 = 0$$

$$\text{Quadratic Formula: } V_{out} = 0.872 \text{ or } -8.07\, V$$

$$\mathbf{V_{out} = 872\, mV}$$

Problem 2

$$I_D = \mu_n C_{ox} \frac{W}{2 \cdot L}(V_{gs} - V_T)^2$$

$$I_{D1} = 600\, \mu A \quad \text{and} \quad V_{gs1} = V_{gs2}$$

$$\text{All parameters same expect } \frac{W}{L}$$

$$\frac{I_{D1}}{I_{D2}} = \frac{W_1/L_1}{W_2/L_2}$$

$$I_{D2} = I_{D2} \cdot \frac{W_2/L_2}{W_1/L_1} = 600\, \mu A \cdot \frac{2\mu/4\mu}{4\mu/2\mu} = 600\, \mu A \cdot \frac{1}{4}$$

$$\mathbf{I_{out} = 150\, \mu A}$$

Problem 3

$$I_C = J_s A_E e^{\frac{V_{BE}}{V_t}}$$

$$I_{IN} = 1\, mA \quad \text{and} \quad V_{BE1} = V_{BE2}$$

$$I_{IN} = I_{C1} + I_{B1} + I_{B2} = (J_s A_{E1} + \frac{J_s A_{E1}}{\beta} + \frac{J_s A_{E2}}{\beta}) \cdot e^{\frac{V_{BE}}{V_t}}$$

$$\frac{I_{C2}}{I_{IN}} = \frac{J_s A_{E2}}{J_s A_{E1} + \frac{J_s A_{E1}}{\beta} + \frac{J_s A_{E2}}{\beta}}$$

$$I_{C2} = \frac{600}{100 + \frac{100}{100} + \frac{600}{100}} \cdot 1\, mA$$

$$\mathbf{I_{D2} = 5.61\, mA}$$

Problem 4

Using a NMOS and a PMOS in a diode configuration.

$$I_D = \mu_n C_{ox} \frac{W_1}{2 \cdot L_2} (V_{out} - V_T)^2$$

$$I_D = \mu_p C_{ox} \frac{W_2}{2 \cdot L_2} ((V_{DD} - V_{out}) - V_{Tn})^2$$

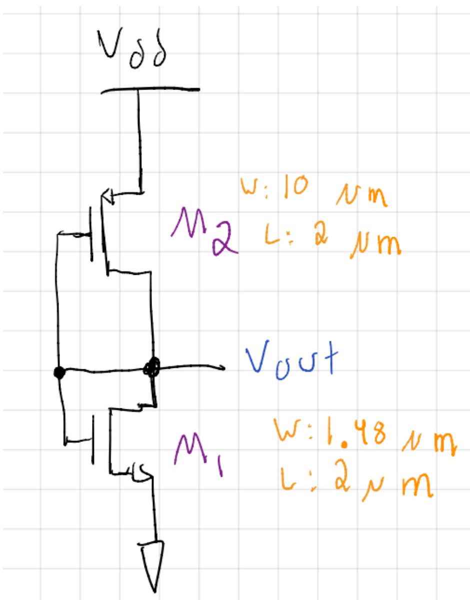
$$\mu_n C_{ox} \frac{W_1}{2 \cdot L_1} (V_{out} - V_T)^2 = \mu_p C_{ox} \frac{W_2}{2 \cdot L_2} ((1.8 - V_{out}) - V_T)^2$$

$$\frac{W_1}{L_1} (1 - 0.4)^2 = \frac{1}{3} \frac{W_2}{L_2} (1.8 - 1 - 0.4)^2$$

$$\frac{W_1}{L_1} = \frac{0.4^2}{3 \cdot 0.6^2} \frac{W_2}{L_2}$$

$$\text{Let } L_1 = 2\,\mu m, \quad L_2 = 2\,\mu m, \quad \& \quad W_2 = 10\,\mu m$$

$$\text{then:} \quad W_1 = \frac{27}{25} W_2 = 1.48\,\mu m$$



Problem 5

Using a PMOS in a diode configuration.

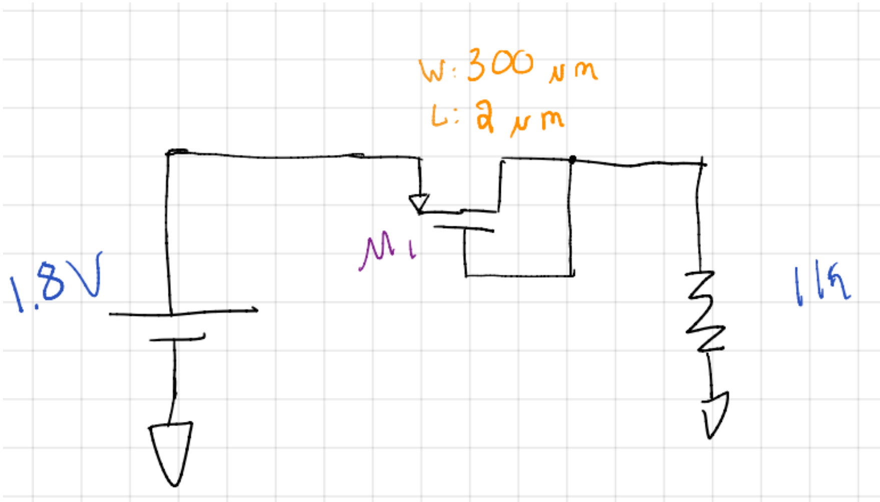
$$I_D = \mu_p C_{ox} \frac{W}{2 \cdot L} ((V_{DD} - V_{out}) - V_{Tn})^2$$

$$1\,mA = \frac{250\mu}{3} \cdot \frac{W}{2 \cdot L} (1.8 - 1 - 0.4)^2$$

$$\frac{W}{L} = \frac{1m}{\frac{250\mu}{3 \cdot 2} \cdot (0.4)^2}$$

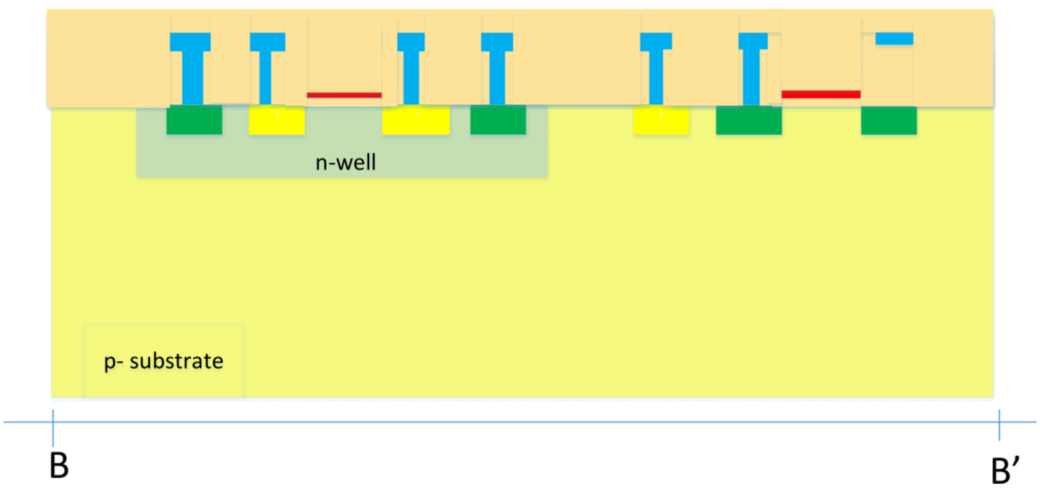
$$\text{Let } L = 2\,\mu m$$

$$\text{then:} \quad W = \frac{1}{6.67m} L = 300\,\mu m$$



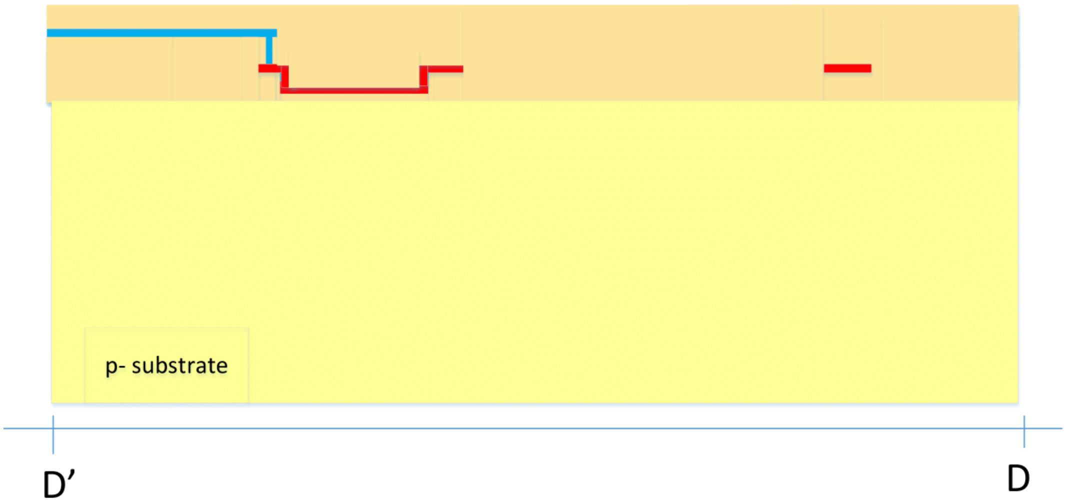
Problem 6

BB' Cross Section



Problem 7

DD' Cross Section



Problem 8

a)

$$I_B = \frac{10\,V - 0.6\,V}{600\,k\Omega} = 15.67\,\mu A$$
$$I_C = \beta I_B = 100 \cdot 15.67\,\mu A = 1.57\,mA$$
$$V_{out} = Vdd - I_C \cdot R = 10\,V - 1.57\,mA \cdot 2.5\,k\Omega$$
$$\mathbf{V_{out} = 6.08\,V}$$

b)

$$V_{out} = Vdd - \beta I_B \cdot R = 10\,V - (50 \cdot 15.67\,\mu A) \cdot 2.5\,k\Omega$$
$$\mathbf{V_{out} = 8.04\,V}$$

c)

$$I_C = J_s A_E e^{\frac{V_{BE}}{V_t}} \qquad I_B = \frac{J_s A_E}{\beta} e^{\frac{V_{BE}}{V_t}}$$

Looking at the equations describing the behavior of a BJT in a forward-active region, we can predict that the voltage across the base-emitter junction (V_{BE}) would slightly increase, resulting in a small decrease in the current through both the base and collector. This would increase V_{out} slightly.

d)

A similar change would take place if you decrease the charge density. A small increase in the base-emitter voltage (V_{BE}) and a small decrease in current through the BJT, resulting in a small increase to the V_{out}.

Problem 9

Ideal op-amp so no current at input so $V_1 = V_p = V_n = 2\,V$

$$I_{M1} = \frac{1.8\,V - 1\,V}{10\,k\Omega} = 80\,\mu A$$

$$I_{M1} = 80\,\mu A = \mu_n C_{ox} \frac{W\mu}{2 \cdot L\mu}(V_2 - V_T)^2$$

$$80\,\mu A = 250\mu \cdot \frac{10\mu}{2 \cdot 2\mu}(V_2 - 0.4)^2$$

$$\mathbf{V_1 = 1\,V} \qquad \mathbf{V_2 = 436\,mV}$$

Problem 10

Requirements for Saturation: $V_{gs} > V_T$ & $V_{ds} > V_{gs} - V_T$

$$Vgs = 0 - (-0.6\,V) = 0.6\,V$$

$$Vds = (1.2 - I_{M1} \cdot R_1) - (-0.6) = 1.8 - I_{M1} \cdot R_1$$

$$I_{M1} = 250\,\mu \cdot \frac{6\mu m}{2 \cdot 3\mu m}(0.6 - 0.4)^2 = 10\,\mu A$$

$$\text{so} \quad 1.8\,V - 10\,\mu A \cdot R_1 > 0.6\,V - 0.4\,V$$

$$R_1 < \frac{1.6\,V}{10\,\mu A}$$

$$\mathbf{R_1 < 160\,k\Omega}$$