EE 330 HW 8 Solutions

Spring 2024

Problem 1

Both M1 and M2 are in Saturation as $V_{GS} = V_{DS}$

$\Rightarrow I_{D1} = I_{D2}$

$$\Rightarrow I_{D2} = \frac{100 \times 10^{-6}}{2} \times \frac{4}{2} \times (5 - V_{out} - 0.75)^2$$

$$\Rightarrow I_{D1} = \frac{100 \times 10^{-6}}{2} \times \frac{5}{2} \times (V_{out} - 0 - 0.75)^2$$

$$\Rightarrow 100 \times 10^{-6} (4.25 - V_{out})^2 = 1.25 \times 10^{-4} (V_{out} - 0.75)^2$$

$$\Rightarrow (4.25 - V_{out})^2 = 1.25 (V_{out} - 0.75)^2$$

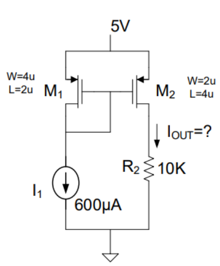
$$0.25 V_{out}^2 + 6.625 V_{out} - 17.36 = 0$$

$$V_{out} = 2.4_V, \quad -28.9_V$$

$\Rightarrow V_{out} = -28.9_V$ puts M_1 in cutt off

Thus, $V_{out} = 2.4_V$

Problem 2

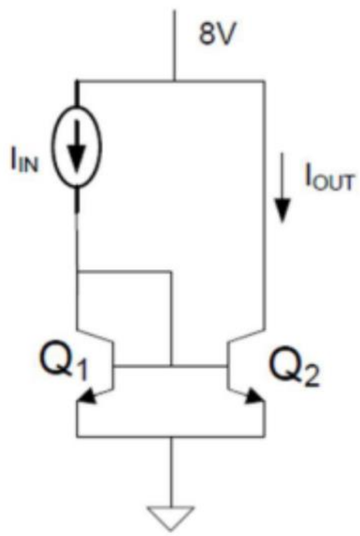


$$I_{D1} = \frac{\mu_p C_{OX} W_1}{2L_1}\left(V_{GS1} - V_{THp}\right)^2$$

$$I_{D2} = \frac{\mu_p C_{OX} W_2}{2L_2}\left(V_{GS2} - V_{THp}\right)^2$$

Since V_{GS1}=V_{GS2}, taking the ratio I_{D2}/I_{D1}, we obtain $\frac{I_{D2}}{I_{D1}} = \frac{W_2}{L_2}\frac{L_1}{W_1} = \frac{1}{4}$ so I_{D2}=150uA

Problem 3



Since VBE1=VBE2, can write the two equations

$$I_{IN} = I_{C1} + I_{B1} + I_{B2} = J_S A_{E1} e^{\frac{nV_{BE1}}{V_t}} + J_S \frac{A_{E1}}{\beta_n} e^{\frac{nV_{BE1}}{V_t}} + J_S \frac{A_{E2}}{\beta_n} e^{\frac{nV_{BE1}}{V_t}}$$

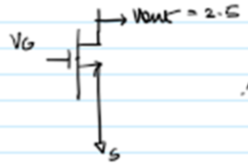
$$I_{OUT} = I_{C2} = J_S A_{E2} e^{\frac{nV_{BE1}}{V_t}}$$

Taking the ratio, the JS and exponential terms cancel and we obtain

$$\frac{I_{OUT}}{I_{IN}} = \frac{A_{E2}}{A_{E1} + \frac{A_{E1}}{\beta_n} + \frac{A_{E2}}{\beta_n}} = \frac{600}{100 + \frac{100+600}{100}} = 5.61$$

Since IIN=1mA, it follows tkhat IOUT=5.61mA

Problem 4.



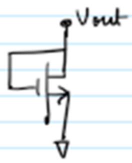
Assume NMOS in saturation

$\therefore V_{ds} = V_{gs} - V_{Tn}$ $\{$let $V_{Tn} = 0.75\}$

$V_{out} = V_G - 0.75$

$V_G = 2.5 + 0.75 = 3.25 \geq V_T$

But we only have 5V supply



Lets make $V_g = V_{out}$

For saturation

$V_{ds} \geq V_{gs} - V_{Tn}$

$V_{out} \geq V_{out} - V_{Tn}$ (which is valid)

let's provide another NMOS

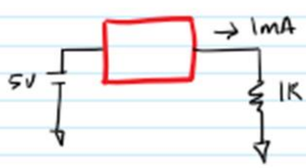
current through M2

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W_2}{L_2} (5 - 2.5 - 0.75)^2 = \frac{\mu_n C_{ox}}{2} \times \frac{W_1}{L_1} (2.5 - 0.75)^2$$

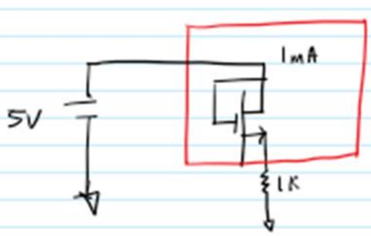
$$\frac{W_2}{L_2} = \frac{W_1}{L_1}$$

Let L1=L2=2u and W1=W2=4u

Problem 5.



$V_{out} = 1mA \times 1K = 1V$

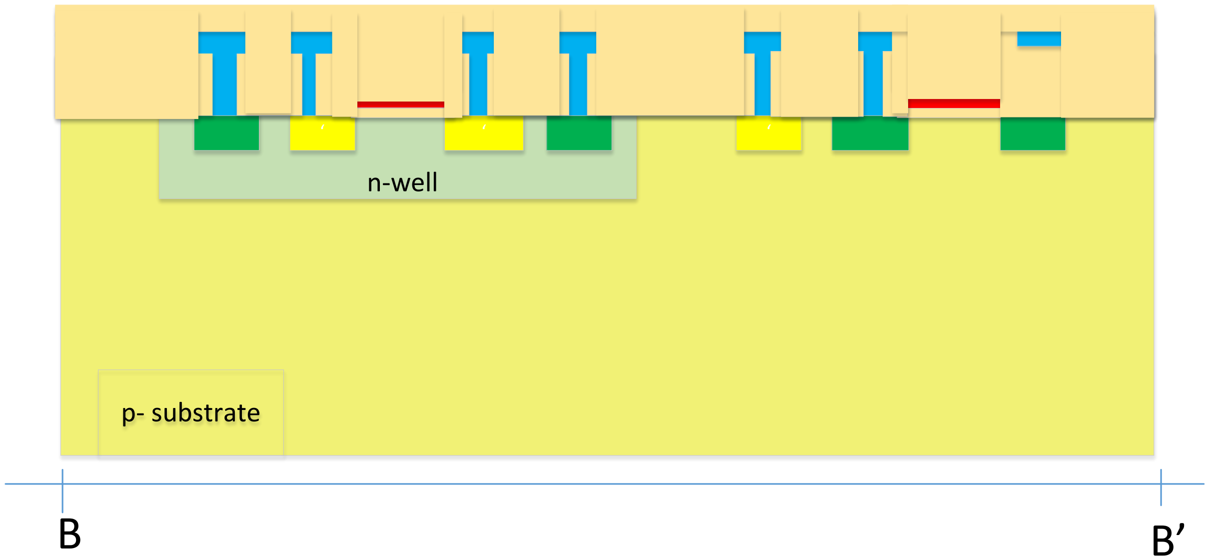


$$I_{D1} = \frac{\mu_n C_{ox}}{2} \frac{W_1}{L_1} (5-1-.75)^2 = 1 \times 10^{-3}$$

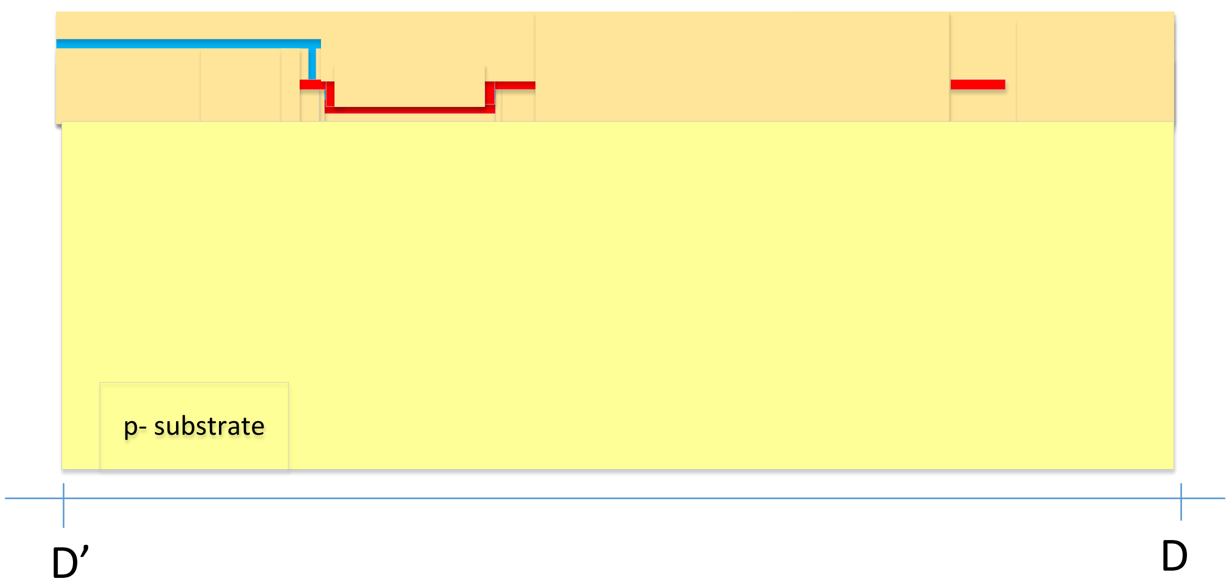
$$\frac{W_1}{L_1} = \frac{1 \times 10^{-3}}{50 \times 10^{-6} \times 10.6} = 1.9$$

$W = 3.8\ \mu m$ $L = 2\mu m$

Problem 6



Problem 7



Problem 8

a) Assuming VBE=0.6V, we obtain $I_B = \frac{9.4V}{600K}$. Thus $I_C = \beta I_B = 100\frac{9.4}{600K} = 1.57mA$ and thus $V_{OUT} = 10 - I_C \bullet 2.5K = 6.1V$

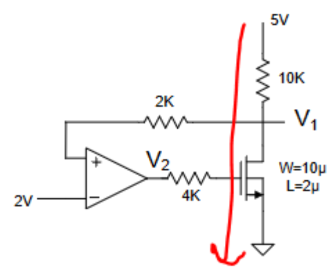
b) Replacing the β=100 with β=50 in part a) we obtain IC=0.78mA and VOUT=8.04V

c) The solution is independent of AE so the outputs will not change significantly

d) The solution is also independend of JS so the outputs will not change significantly

Problem 9

With the op amp being ideal, we can assume that there is no current flowing into either device input. This means that there is no current flowing through the 2kΩ or the 4kΩ resistor and thus **V1=2V**.



Since V1=2V, is follows that ID=$\frac{5v-2v}{10000\Omega} = 0.3mA$. Since the MOSFET is operating in saturation, it thus follows that

$$I_{DS} = \frac{\mu C_{ox} W}{2L}(V_{GS} - V_T)^2$$

$$0.3mA = \frac{\left(100\frac{\mu A}{V^2}\right)(10\mu m)}{2(2\mu m)}(V_{GS} - 0.75V)^2$$

$$1.09545V = V_{GS} - 0.75V$$

This gives us a V_{GS} = **V_2 = 1.84545V**. Note this solution satisfies both requirements for saturation ($V_{GS} \geq V_T$, $V_{DS} \geq V_{GS} - V_T$).

Problem 10.

To keep M1 in saturation (since VGS>VTH), must have VDS>VGS-VTH. Substituting values into this equation we obtain $4V - I_D R - -2V \geq 2V - 0.5V$. This can be expressed as $R \leq \frac{4.5V}{I_D}$. It remains to find ID. But $I_D = \frac{u_n C_{OX} W}{2L}(V_{GS} - V_{TH})^2$. Substituting in the model parameters given with VGS=2V, obtain ID=0.1875mA. Thus $R \leq \frac{4.5V}{0.1875mA} = 24K\Omega$