EE204 Autumn 2023

Tutorial I

Date 17 Aug 2023

Q1) The circuit in Fig. 1 utilizes an ideal op-amp.

(a) Find I_1, I_2, I_3, I_L, and Vx.

(b) If V_o is not to be lower than -13 V, find the maximum allowed value for RL.

(c) If RL is varied in the range 100Ω to 1 kΩ, what is the corresponding change in I_L And in VO?

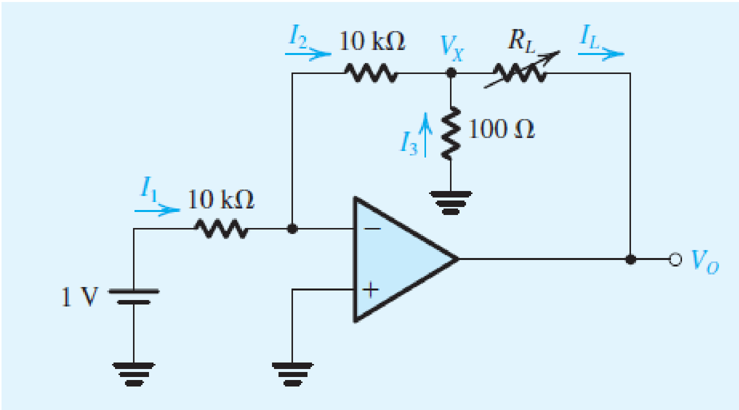


Figure 1

Q2) The circuit in Fig. 2 utilizes an ideal op-amp. Determine expression for v_0 in terms of v_1, v_2, v_3.

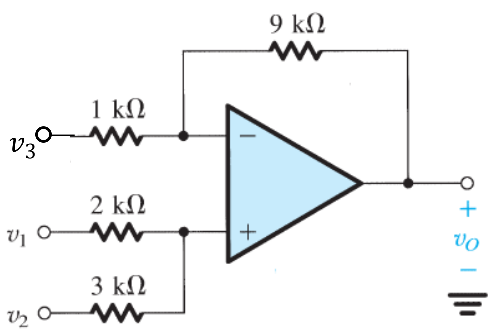


Figure 2

Q3) Consider a CMOS process for which $Lmin$ = 0.25 µm, tox= 6 nm, μ_n= 350 cm^2/V.s, and V_t= 0.5 V.

(a) Find Cox.

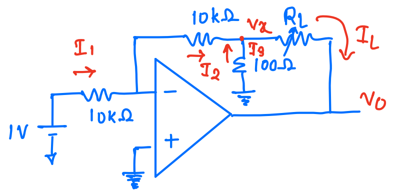
(b) For an NMOS transistor with W/L = 20 µm/0.25 µm, calculate the values of V_{OV} , V_{GS}, and V_{DSmin} needed to operate the transistor in the saturation region with a dc current I_D = 0.5 mA.

(c) For an NMOS transistor with L = 0.25 µm, calculate the W/L ratio needed to operate the transistor in the saturation region with a dc current I_D = 0.3 mA and V_{GS} = 0.8V.

Solution

Q1)

a)



$I_1 = \frac{1V}{10k\Omega}$ (virtual ground)

$= 0.1mA$

$I_1 = I_2 = 0.1mA$

$V_x = -I_2 \cdot 10k\Omega = -1V$

$I_3 = -\left(\frac{-1V}{100}\right) = 10mA$

$\therefore I_L = I_3 + I_2 = 10mA + 0.1mA = 10.1mA$

b) $V_o > -13V$

$V_o = V_x - I_L \cdot R_L$

$-13V = -1 - 10.1mA \times R_{L_{max}}$

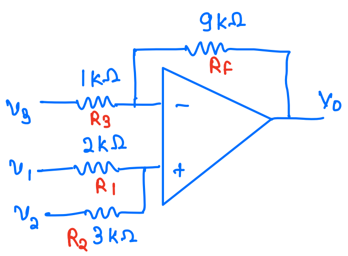
$\therefore R_{L_{max}} = 1.19k\Omega$

c) If R_L changes from 100Ω to $1k\Omega$, I_L will not change

$V_o = -1 - 10.1mA \times 0.1k = -2.01V$ when $R = 100\Omega$

$V_o = -1 - 10.1mA \times 1k = -11.1V$ when $R = 1k\Omega$

Q2)



$$V_o = \left(1 + \frac{R_F}{R_3}\right)\left[\left(\frac{R_2}{R_1+R_2}\right)V_1 + \left(\frac{R_1}{R_1+R_2}\right)V_2\right] - \frac{R_F}{R_1} \cdot v_3$$

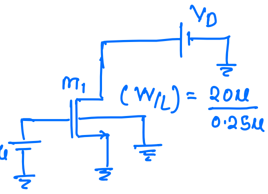
$$= (1+9)\left[\frac{3}{5}V_1 + \frac{2}{5}V_2\right] - 9V_3$$

$$V_o = 6V_1 + 4V_2 - 9V_3$$

Q3) We have $C_{ox} = 8.6\ fF/(\mu V)^2$ for $t_{ox} = 4\,nm$

a) Hence for $t_{ox} = 6\,nm$ $C_{ox} = 5.73\ fF/(\mu V)^2$

$\mu_n \cdot C_{ox} = 350\ cm^2/V \cdot s \times 5.73\ fF/(\mu V)^2 = 200.5\ \frac{\mu A}{V^2} \approx 200\,\mu A/V^2$



b) if M_1 is in Saturation region then

$$I_D = \frac{\mu_n C_{ox}}{2} \times \left(\frac{W}{L}\right)\left[V_{GS} - V_T\right]^2$$

$$0.5\,mA = \frac{200\mu}{2} \times \frac{20\mu}{0.25\mu}\left(V_{GS} - 0.5\right)^2$$

$V_{GS} = 0.75V$

$V_{ov} = V_{GS} - V_T = V_{GST}$

$= 0.75 - 0.5 = 0.25V$

$V_{DS_{min}} = V_{ov} = 0.25V$

c) $I_D = 0.3\,mA = \frac{200\mu}{2} \times \left(\frac{W}{L}\right)\left[0.8 - 0.5\right]^2$

$0.3m = 100\,\mu A \left(\frac{W}{L}\right)(0.3)^2$

$\frac{W}{L} = 33.33$