EE204 : Analog Circuits
Dept of Electrical Engineering
IIT Bombay
Autumn Semester 2023

Tutorial-2

1. Figure 1 shows an op amp that is ideal except for having a finite open-loop gain and is used to realize an inverting amplifier whose gain has a magnitude $G = \frac{R_2}{R_1}$(ideal closed loop gain). To compensate for the gain reduction due to the finite A_V, a resistor R_c is shunted across R_1. Find the value of R_c in terms of R_2,R_1 and G such that obtained closed loop gain is equal to ideal closed loop gain.

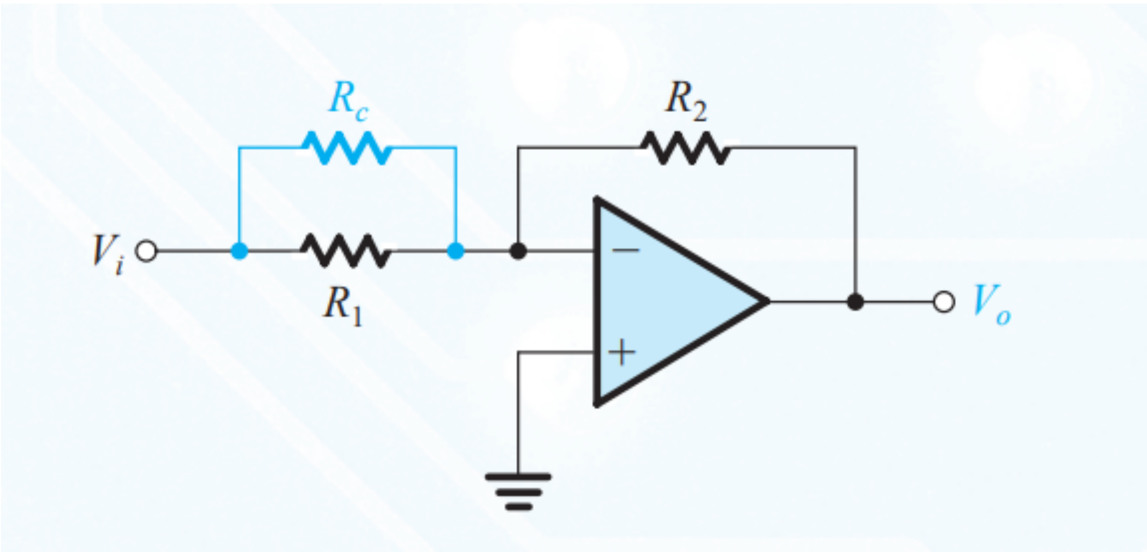
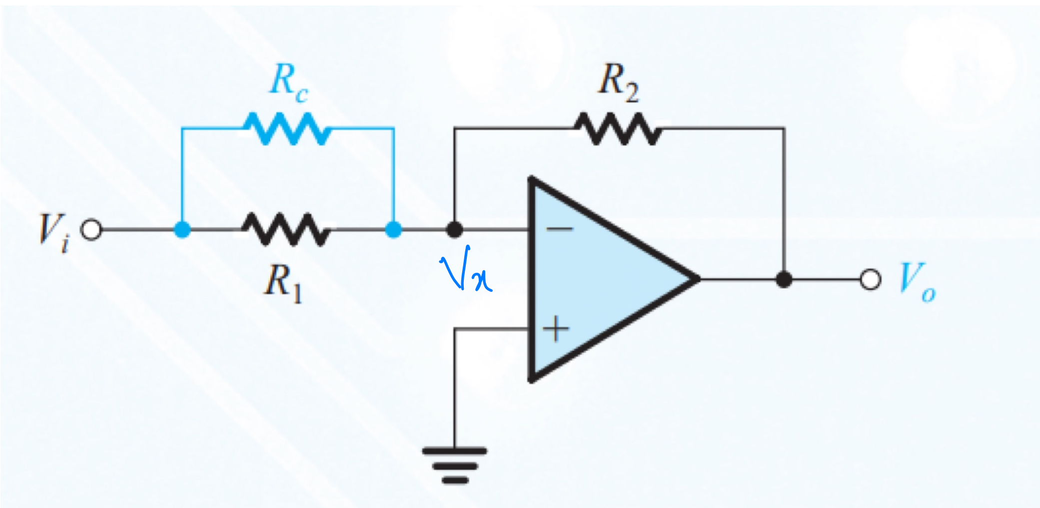


Figure 1: Circuit for Q1

Soln



$$\frac{V_i - V_n}{R_1 \| R_c} = \frac{V_n - V_o}{R_2}$$

$$V_o = -A_V V_n$$

$$\frac{V_i + \frac{V_o}{A_V}}{R_1 \| R_c} = \frac{-\left(\frac{V_o}{A_V} + V_o\right)}{R_2}$$

$$R_2 V_i + \frac{R_2}{A_V} V_o = -(R_1 \| R_c)\left(\frac{V_o}{A_V} + V_o\right)$$

$$R_2 V_i = -\left(\frac{R_1 \| R_c}{A_V} V_o + R_1 \| R_c V_o + \frac{R_2}{A_V} V_o\right)$$

$$\frac{V_o}{V_i} = \frac{-R_2}{\frac{R_1 \| R_c}{A_V} + R_1 \| R_c + \frac{R_2}{A_V}}$$

$$\frac{V_o}{V_i} = \frac{-R_2}{\frac{R_1 R_c}{R_1 + R_c}\left(\frac{1}{A_V} + 1\right) + \frac{R_2}{A_V}}$$

$$= \frac{-R_2}{R_1} \cdot \frac{1}{\frac{R_c}{R_1 + R_c}\left(\frac{1}{A_V} + 1\right) + \frac{G}{A_V}}$$

$$\frac{R_c}{R_1 + R_c} \frac{(1 + A_V)}{A_V} + \frac{G}{A_V} = 1$$

$$A_V = \frac{R_c}{R_1 + R_c}(1 + A_V) + G$$

$$A_V R_1 + \cancel{A_V R_c} = R_c + \cancel{R_c A_V} + G R_1 + G R_c$$

$$(A_V - G) R_1 = R_c (1 + G)$$

$$R_1 = \frac{R_c (G + 1)}{A_V - G}$$

2. The MOSFET in Figure 2 has $V_t = 0.5$ V, $\mu_n C_{ox} = 400 \frac{\mu A}{V^2}$ and λ=0. Find the required values of W/L and of R so that when $V_i = V_{DD} = +1.8$ V, effective channel resistance(r_{DS}) = 50Ω , and V_0 =50 mV.

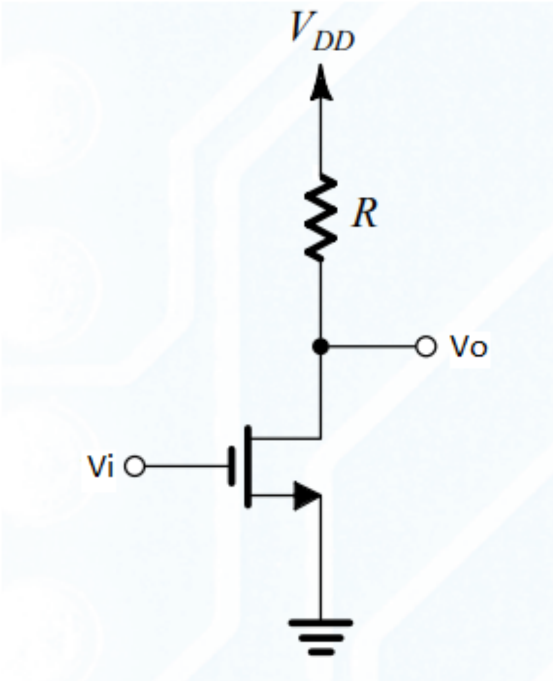


Figure 2: Circuit for Q2

Soln

Given $V_0 = 50mV$; $r_{DS} = 50\Omega$; $V_{GS} = 1.8V$

as V_{DS} is very low

$$I_D = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T) V_{DS}$$

$$\frac{1}{r_{DS}} = g_{ds} = \frac{\delta I_D}{\delta V_{DS}} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)$$

$$I_D = \frac{V_0}{r_{DS}} = 1mA$$

$$1mA = 400 \frac{\mu A}{V^2} \frac{W}{L} (1.8 - 0.5)\ 50mV$$

$$\boxed{\frac{W}{L} = 38.46}$$

$V_0 = V_{DD} - I_D R$

$50mV = 1.8 - (1mA)R$

$$\boxed{R = 1.75K\Omega}$$

3. For the devices in the circuits of Fig, $|V_t|$=0.5 V, $\lambda = 0$, $\mu_n C_{ox} = 40 \frac{\mu A}{V^2}$, L = 1 μm, and W =10 μm. Find V_2 and I_2. How do these values change if Q3 and Q4 are made to have W = 100 μm?

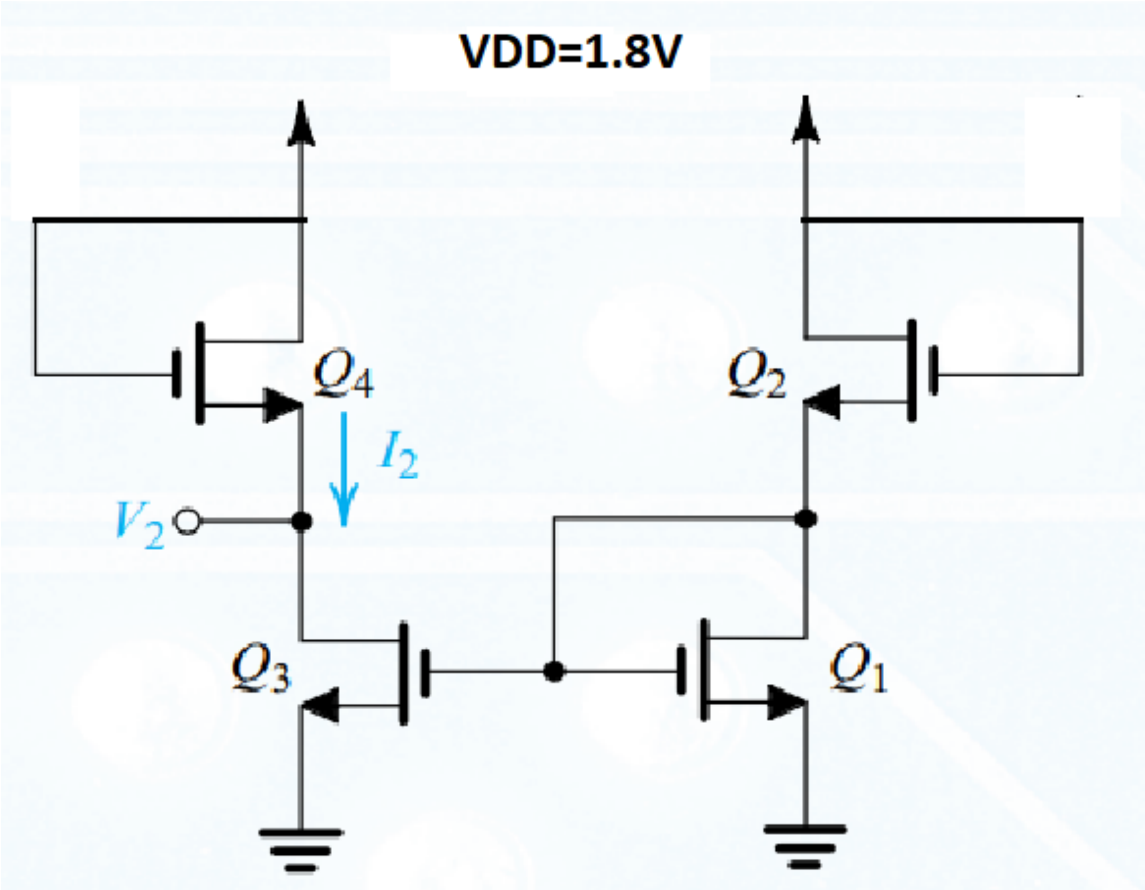


Figure 3: Circuit for Q1

μm.

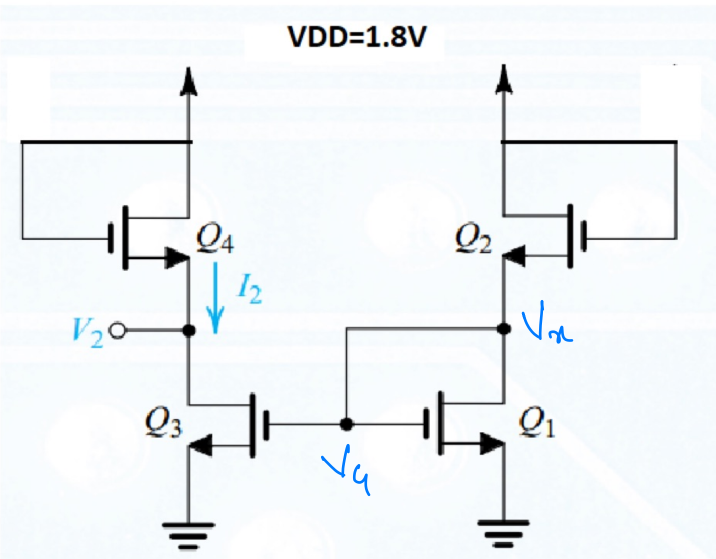


Figure 3: Circuit for Q1

Equating currents in Q_2 and Q_1

$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{DD}-V_x-V_t)^2$$

$$= \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_x-V_t)^2$$

$$V_{DD}-V_x-V_t = V_x-V_t$$

$$V_x = \frac{V_{DD}}{2} = 0.9$$

So $V_4 = 0.9$

As Q_4 has to pass same current as Q_3

$$(V_{GS})_{Q_4} = (V_{GS})_{Q_3}$$

$$V_{DD} - V_2 = V_G$$

$$\boxed{V_2 = V_{DD} - V_G = 0.9}$$

$$I_2 = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2$$

$$= \frac{1}{2} \, 40 \frac{\mu A}{V^2} \, 10 \, (0.9 - 0.5)^2$$

$$\boxed{I_2 = 32 \mu A}$$

If Q_3 and Q_4 W changes to $100 \mu m$

then I_2 increases by 10 times

$$\boxed{I_2 = 320 \mu A}$$