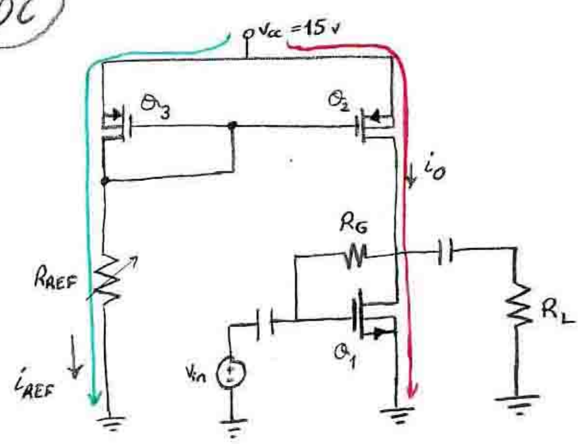
CMOS Common-Source Amplifier with an Active Load

DC



$V_{cc} = 15\,V$

$R_L = 100\,k\Omega$

$R_G = 1\,M\Omega$

$K_n = 500\,\mu A/V^2$ ← for nMOS

$K_p = 500\,\mu A/V^2$ ← for two pMOS

$V_{TP} = -1{,}3$

$V_{TN} = 1{,}45$

$\lambda_3 = \lambda_2 = \lambda_1 = 1/100\ V^{-1}$

$I_{REF} = 0{,}6\ mA$

$$I_{REF} = I_{SD_3} + \cancel{I_{G_3}}^{0} + \cancel{I_{G_2}}^{0} \qquad I_{REF} = I_{SD_3} = 0{,}6\,mA$$

$$I_{REF} = 0{,}6 \cdot 10^{-3} A = \frac{K_P}{2} \cdot (V_{GS_3} - V_{TP})^2 = \frac{500 \times 10^{-6}}{2} (V_{GS_3} + 1{,}3)^2 = 0{,}6 \times 10^{-3} A$$

$V_{SD_3} = V_{SG_3}$ sat. condition

$$V_{GS_3}^2 + 2{,}6\,V_{GS_3} - 0{,}71 = 0$$

$$V_{GS_{3_1}} = 0{,}249\,V$$

$$V_{GS_{3_2}} = -2{,}849\,V \Rightarrow \boxed{V_{SG_3} = 2{,}849\,V}$$

* $V_{CC} = V_{SD_3} + I_{SD_3} \cdot R_{REF}$

$V_{CC} = V_{SG_3} + I_{SD_3} \cdot R_{REF}$

$15 = 2{,}849 + 0{,}6 \times 10^{-3} \cdot R_{REF}$

$\boxed{R_{REF} = 20{,}252\ k\Omega}$

Q point for Q_3 is $(0{,}6\,mA,\ 2{,}849\,V)$

* $V_{CC} = V_{SD_2} + V_{DS_1}$

$V_{CC} = V_{SD_2} + \cancel{I_{G_1}}^{0} \cdot R_G + V_{GS_1}$

$V_{GS_1} = V_{CC} - V_{SD_2}$

$$I_0 = I_{DS_1} = \frac{K_n}{2} (V_{GS_1} - V_{TN})^2\ A$$

$$I_0 = 250 \times 10^{-6} (V_{CC} - V_{SD_2} - V_{TN})^2\ A$$

$$\boxed{I_0 = 250 \times 10^{-6} (13{,}55 - V_{SD_2})^2\ A \qquad I_0 = \frac{1 + \lambda V_{SD_2}}{1 + \lambda V_{SD_3}}}$$

solve these two equation

$V_{SD_2} = 11{,}93\,V$

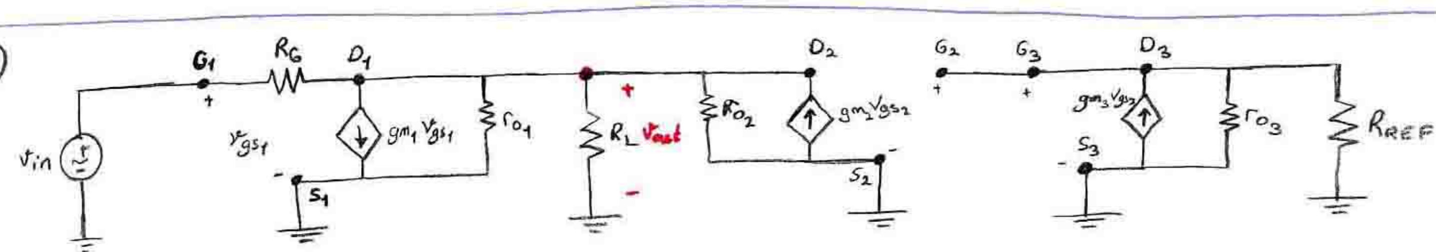
$I_0 = 0{,}656\,mA$

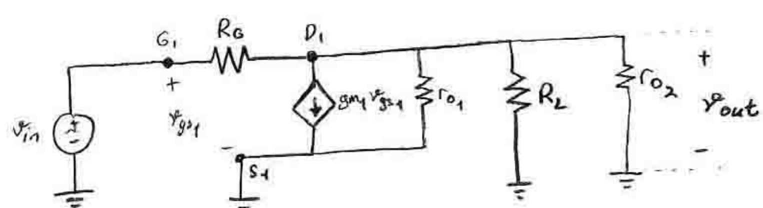
then; Q points for Q_1 and Q_2 are

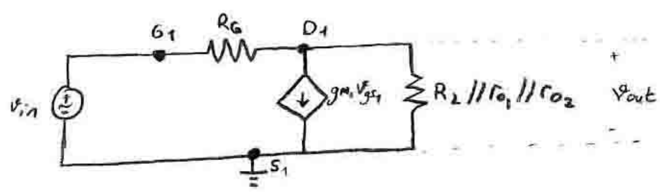
$Q_1\ (0{,}656\,mA,\ 3{,}07\,V)$

$Q_2\ (0{,}656\,mA,\ 11{,}93\,V)$

AC







$v_{in} = v_{gs_1}$

$$g_{m_1} = \sqrt{2 K_n I_{DS_1}} = 0{,}81\ mS$$

$$r_{o_1} = \frac{1/\lambda + V_{DS_1}}{I_{DS_1}} = 157{,}12\ k\Omega$$

$$r_{o_2} = \frac{1/\lambda + V_{SD_2}}{I_{SD_2}} = 170{,}62\ k\Omega$$

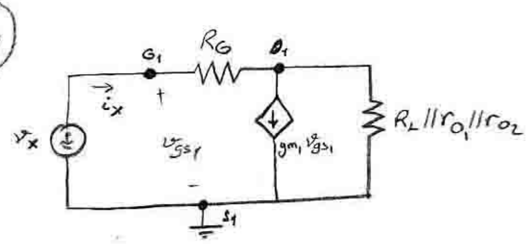
gain

$$AV = \frac{v_{out}}{v_{in}}$$ overall gain (R_L included)

$$\frac{v_{out} - v_{in}}{1 \times 10^6} + g_{m_1} v_{gs_1} + \frac{v_{out}}{R_L // r_{o_2} // r_{o_1}} = 0 \qquad R_L // r_{o_1} // r_{o_2} = 44,993\ k\Omega$$

$$AV = \frac{v_{out}}{v_{in}} = -g_{m_1} \times \frac{1 \times 10^6 \cdot 44,993 \times 10^3}{1 \times 10^6 + 44,993 \times 10^3} = \boxed{-34,991 = AV_{overall}}$$

input impedance



$$v_x = v_{gs_1}$$

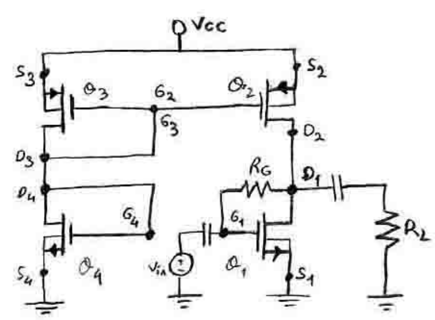
$$v_x = i_x R_G + (i_x - g_{m_1} v_{gs_1}) (R_L // r_{o_1} // r_{o_2})$$

$$v_x (37,44\ k\Omega) = i_x (1044,993\ k\Omega)$$

$$\boxed{\frac{v_x}{i_x} = R_{in} = 27,91\ k\Omega}$$

Let's replace R_{REF} with NMOS transistor

DC



Q_1 and Q_4 are nMOS
Q_2 and Q_3 are pMOS
} assume all transistor in sat. region

$$-V_{CC} + V_{SD_3} + V_{DS_4} = 0 \qquad -V_{CC} + V_{SD_2} + V_{DS_1} = 0$$

$$V_{SD_3} + V_{DS_4} = 15 \qquad V_{SD_2} + V_{DS_1} = 15$$

$$i_{SD_3} = i_{DS_4} \qquad i_{SD_2} = i_{DS_1}$$

$$V_{SD_3} = V_{SG_3} \ \& \ V_{GS_4} = V_{DS_4}$$

$$I_{DS_1} = \frac{K_n}{2} (V_{GS_1} - V_{TN_1})^2$$

$$I_{SD_2} = \frac{K_P}{2} (V_{GS_2} - V_{TP_2})^2$$

$$\rightarrow I_{DS_1} = I_{DS_2} \Rightarrow (V_{GS_1} - V_{TN_1})^2 = (V_{GS_2} - V_{TP_2})^2$$

$$I_{SD_3} = \frac{K_P}{2} (V_{GS_3} - V_{TP_3})^2$$

$$I_{DS_4} = \frac{K_n}{2} (V_{GS_4} - V_{TN_4})^2$$

$$\rightarrow I_{DS_3} = I_{DS_4} \Rightarrow (V_{GS_3} - V_{TP_3})^2 = (V_{GS_4} - V_{TN_4})^2$$

$$\boxed{I_{DS_1} = I_{DS_2} = I_{DS_3} = I_{DS_4}}$$

$$I_{DS_3} = \frac{K_P}{2} (\underbrace{V_{GS_3}}_{V_{DS_3}} - V_{TP})^2 = \frac{K_n}{2} (\underbrace{V_{GS_4}}_{V_{DS_4}} - V_{TN_4})^2 = I_{DS_4}$$

$V_{TP} = -1,3 \quad V_{TN} = 1,45 \quad K_P = K_n = 500 \times 10^{-6}$

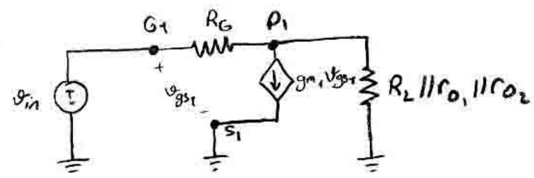
$$V_{DS_3} = 15 - V_{DS_4}$$

$$\cancel{\frac{K_P}{2}} (15 - V_{DS_4} - V_{TP})^2 = \cancel{\frac{K_n}{2}} (V_{DS_4} - V_{TN_4})^2 \Rightarrow V_{DS_4} = 8,875\ V \quad I_{DS_4} = \frac{K_n}{2} (\underbrace{V_{GS_4}}_{V_{DS_4}} - V_{TN})^2 = 13,78\ mA$$

all Q points are the same

$$Q_1 \Leftrightarrow Q_2 \Leftrightarrow Q_3 \Leftrightarrow Q_4 \Rightarrow Q(13,78\ mA,\ 8,875\ V)$$

AC



$v_{in} = v_{gs1}$

$g_{m1} = \sqrt{2 \cdot K_n I_{DS_1}} = 3{,}71 \text{ mS}$

$r_{o1} = \dfrac{1/\lambda + V_{DS1}}{I_{DS1}} = 7{,}9 \text{ k}\Omega$

$r_{o2} = \dfrac{1/\lambda + V_{SD2}}{I_{SD2}} = 7{,}9 \text{ k}\Omega$

$R_L // r_{o2} // r_{o1} = 3{,}8 \text{ k}\Omega$

gain

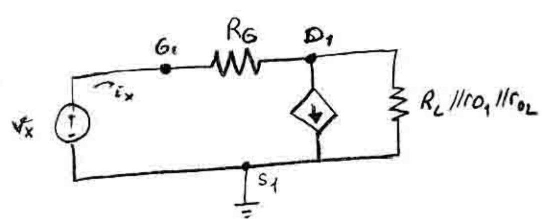
$AV = \dfrac{v_{out}}{v_{in}}$

$AV = -g_{m1} \cdot \dfrac{R_G \cdot R_L // r_{o2} // r_{o1}}{R_G + R_L // r_{o2} // r_{o1}}$

$AV = -3{,}71 \times 10^{-3} \dfrac{1 \times 10^6 \cdot 3800}{1 \times 10^6 + 3800}$

$\boxed{AV = -14{,}05}$

input impedance



$v_x = v_{in}$

$v_x = i_x \cdot R_G + (i_x - g_{m1} v_{gs1})(R_L // r_{o2} // r_{o1})$

$\boxed{R_{in} = \dfrac{v_x}{i_x} = 66{,}48 \text{ k}\Omega}$