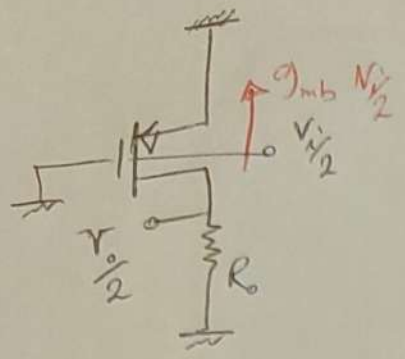
① Half-circuit differential equivalent:



$$\frac{V_o}{2} = -R_o\left(g_{mb}\frac{V_i}{2}\right)$$

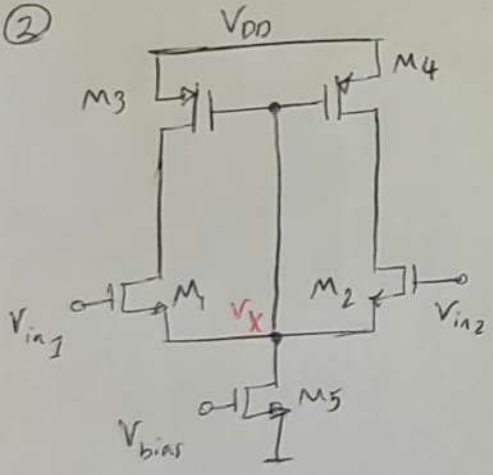
$$\Rightarrow \frac{V_o}{V_i} = -g_{mb}R_o$$

$$I_{D0} = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_0 (V_{SG_0} - |V_{th1}|) = \frac{1}{2}\times 0.1\frac{mA}{V^2}\times 40\times\underbrace{(3-1.4-0.6)}_{1}^{2} = 2\,mA$$

$$I_{D1} = \frac{I_{D0}}{2} = 1mA\,,\quad g_{m_1} = \sqrt{2\times\mu_p C_{ox}\left(\frac{W}{L}\right)_1 I_{D_1}} = \sqrt{2\times 0.1\times 20\times 1mA} = 2m\mho$$

$$g_{mb_1} = \eta\, g_{m_1} = 0.2\times 2m\mho = 0.4m\mho \quad\Rightarrow \frac{V_o}{V_i} = -0.4m\mho\times 1k = \boxed{-0.4}$$

②



when operating in deep triode:

$$R_{ON} = \frac{1}{\mu_p C_{ox}\left(\frac{W}{L}\right)(V_{SG} - |V_{th}|)}$$

$$\frac{W}{L} = \frac{7lm}{0.35lm} = 20$$

$$2k = \frac{1}{0.1\times 20\times(V_{SG_3} - 0.6)} \Rightarrow V_{SG_3} = 0.6 + \frac{1}{0.1\times 20\times 2} = 0.85\,V$$

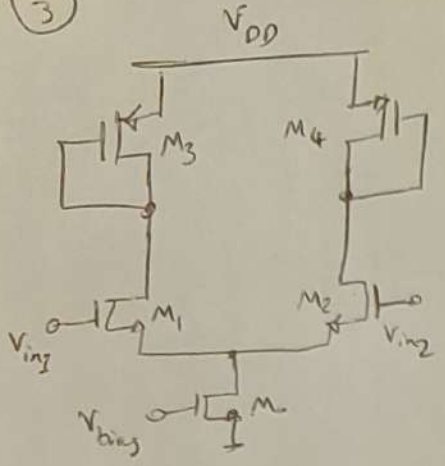
$$\Rightarrow V_X = V_{DD} - V_{SG_3} = 3 - 0.85 = 2.15V$$

$$I_5 = 40\mu A \Rightarrow I_1 = 20\mu A \qquad I_1 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 V_{eff_1}^2 \Rightarrow V_{eff_1} = \sqrt{\frac{2\times 0.02}{0.2\times 20}} = 0.1$$

$$\Rightarrow V_{GS_1} = V_{eff_1} + V_{th} = 0.1 + 0.5 = 0.6 \qquad V_{DC_{in}} = V_X + V_{GS_1} = 2.15 + 0.6 = \boxed{2.75V}$$

$$g_1 = \frac{2I_1}{V_{eff}} = \frac{2\times 0.02}{0.1} = 0.4m\mho \qquad A_V = -g_1 R_{ON_3} = -0.4m\times 2k = \boxed{-0.8}$$

(3)



$P = 3mW \Rightarrow I_{DC} = \frac{P}{V_{DD}} = \frac{3mW}{3} = 1mA$

$V_{eff_0} = V_{GS_0} - V_{th_N} \Rightarrow V_{bias} = V_{eff_0} + V_{th} = 0.2 + 0.5 = 0.7V$

$I_0 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_0 V_{eff_0}^2 \Rightarrow \left(\frac{W}{L_0}\right) = \frac{2 \times 1mA}{1mA \times 0.04} = 50$

$\Rightarrow W_0 = 50 \times L = 50 \times 0.4\mu m = 20\mu m$

$V_{oDC} = 1.5 \Rightarrow V_{SG_{3,4}} = 3 - 1.5 = 1.5V \qquad I_{3,4} = 0.5mA$

$\left(\frac{W}{L}\right)_{3,4} = \frac{2 \times 0.5mA}{0.25mA \times (1.5-0.5)^2} = 4 \Rightarrow W_{3,4} = 4 \times 0.4\mu m = 1.6\mu m$

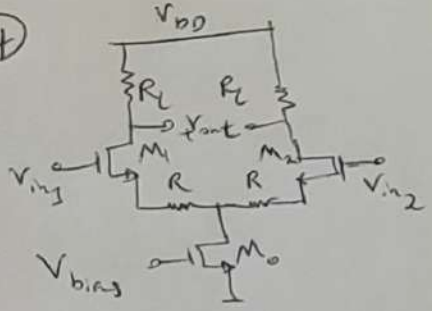
$|A_v| = 40 \Rightarrow A_v = -\frac{g_1}{g_3} = -40 \Rightarrow \frac{\sqrt{2 \times 1mA \times \left(\frac{W}{L}\right)_1 \times I_1}}{\sqrt{2 \times 0.25mA \times \left(\frac{W}{L}\right)_3 \times I_3}} = 40 \Rightarrow \sqrt{\frac{\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_3}} = 20$

$\Rightarrow \left(\frac{W}{L}\right)_{1,2} = 400 \times 4 = 1600 \Rightarrow W_{1,2} = 1600 \times 0.4 = 640\mu m$

minimum input CM level: $V_{GS_1} + V_{eff_0} = 0.5 + \sqrt{\frac{2 \times 0.5mA}{1mA \times 1600}} + 0.2 = 0.725$

maximum input CM level: $V_{DS_1} \geq V_{G_1} - V_{th} \Rightarrow V_{G_{1max}} = V_{D_1} + V_{th} = 1.5 + 0.5 = 2V$

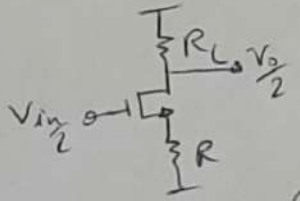
(4)



$I_0 = \frac{1}{2} \times 1mA \times (V_{bias} - V_{th})^2 \times \left(\frac{W}{L}\right)_0 = \frac{1}{2} \times 1mA \times 32 \times (0.75-0.5)^2 = 1mA$

$\Rightarrow I_1 = I_2 = 0.5mA$

Half-circuit to find differential gain:



$A_V = \frac{V_o/2}{V_{in}/2} = \frac{V_o}{V_{in}} = \frac{-R_L}{R + 1/g_1} = -4$

$g_1 = \sqrt{2 \times \mu_n C_{ox} \times \left(\frac{W}{L}\right)_1 \times I_{D_1}} = \sqrt{2 \times 1mA \times 16 \times 0.5m} = 4mv$

$\Rightarrow \frac{R_L}{100 + \frac{1}{4m}} = 4 \Rightarrow R_L = 4(100+250) = 1.4K\Omega$

maximum input CM level: $V_{D_1} \geq V_{G_1} - V_{th} \Rightarrow V_{G_1} \leq V_{DD} - I_1 R_L + V_{th} = 3 - 0.7 + 0.5 = 2.8V$

minimum input CM level: $V_{GS_1} + I_1 R + V_{eff_0} = \sqrt{\frac{2 \times 0.5}{1mA \times 16}} + 0.5 + 0.5 \times 0.1 + 0.25 = 1.05V$